Presentation online at:
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Climate Change Impacts to the Colorado River

Water Resources Review Committee

Colorado General Assembly
Denver, CO
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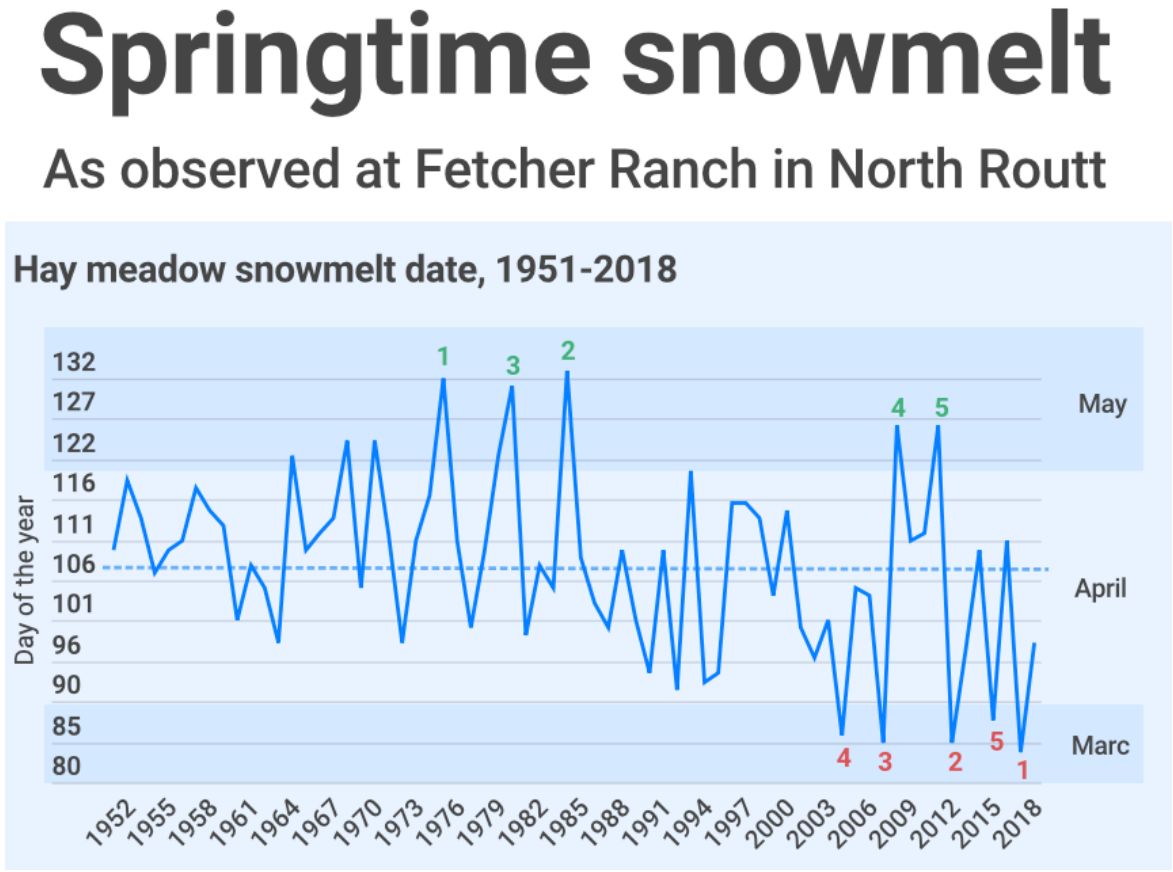
Take Home Points

- Climate Change is a real and serious threat
- Growing sense of urgency from the scientific community
- Climate Change will impact water supplies and demands
- Climate change is already impacting the Colorado River
- As climate change continues in the 21st century….
  - It will get much warmer
  - Precipitation changes are less certain
  - Flow reductions are likely
  - ‘Aridification’ likely
  - Expect ‘weather whiplash’
- Prepare for a future we can not fully foresee



Trend to Earlier Melt but with ‘Weather Whiplash’

Human-caused climate change is universally accepted by the climate science community

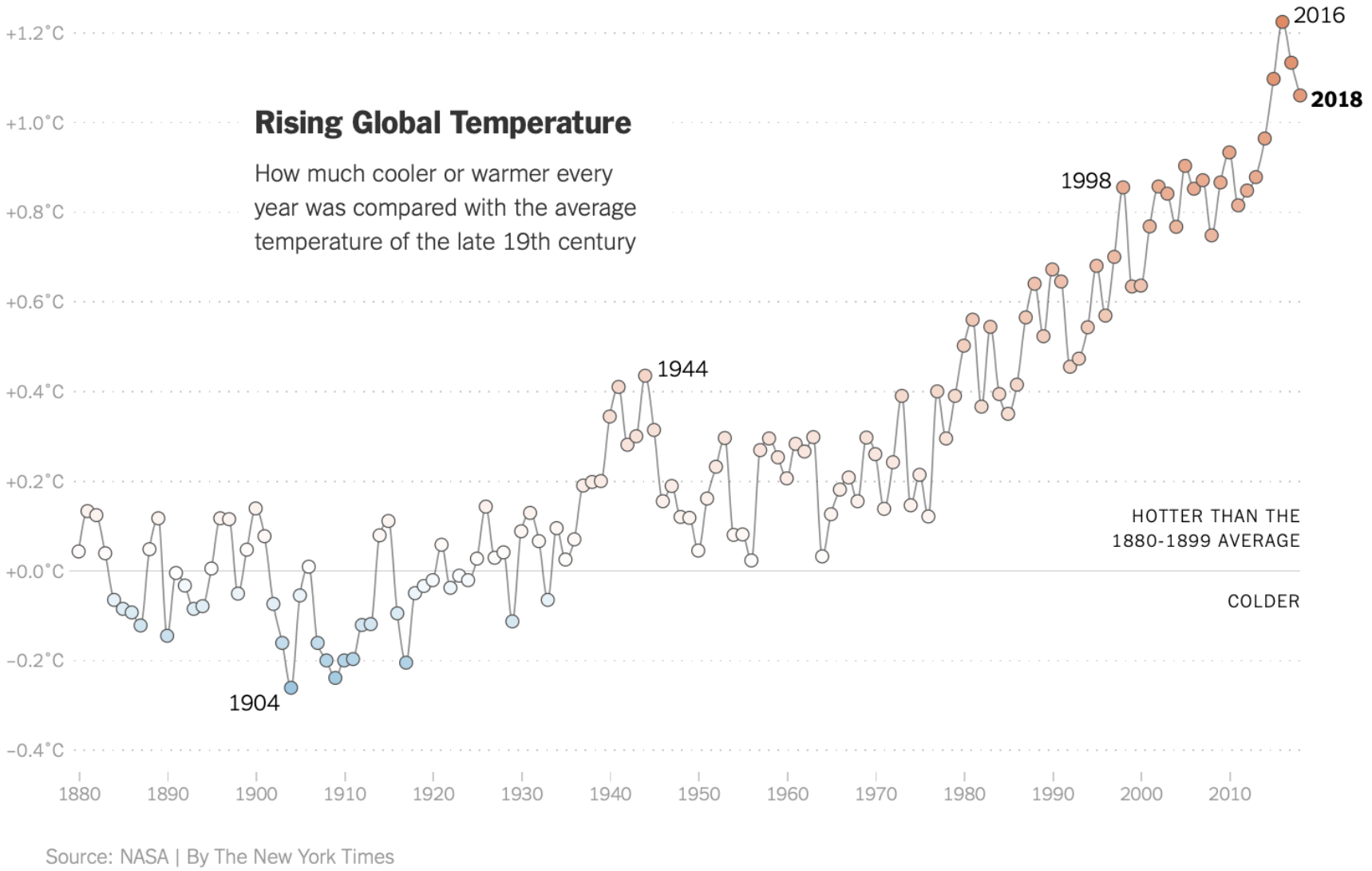
(and by Shell and Exxon-Mobil)

5 Key Climate Concepts in 10 Words

18 of the 19 Hottest Years have occurred since 2001

It's Official: 2018 Was the Fourth-Warmest Year on Record

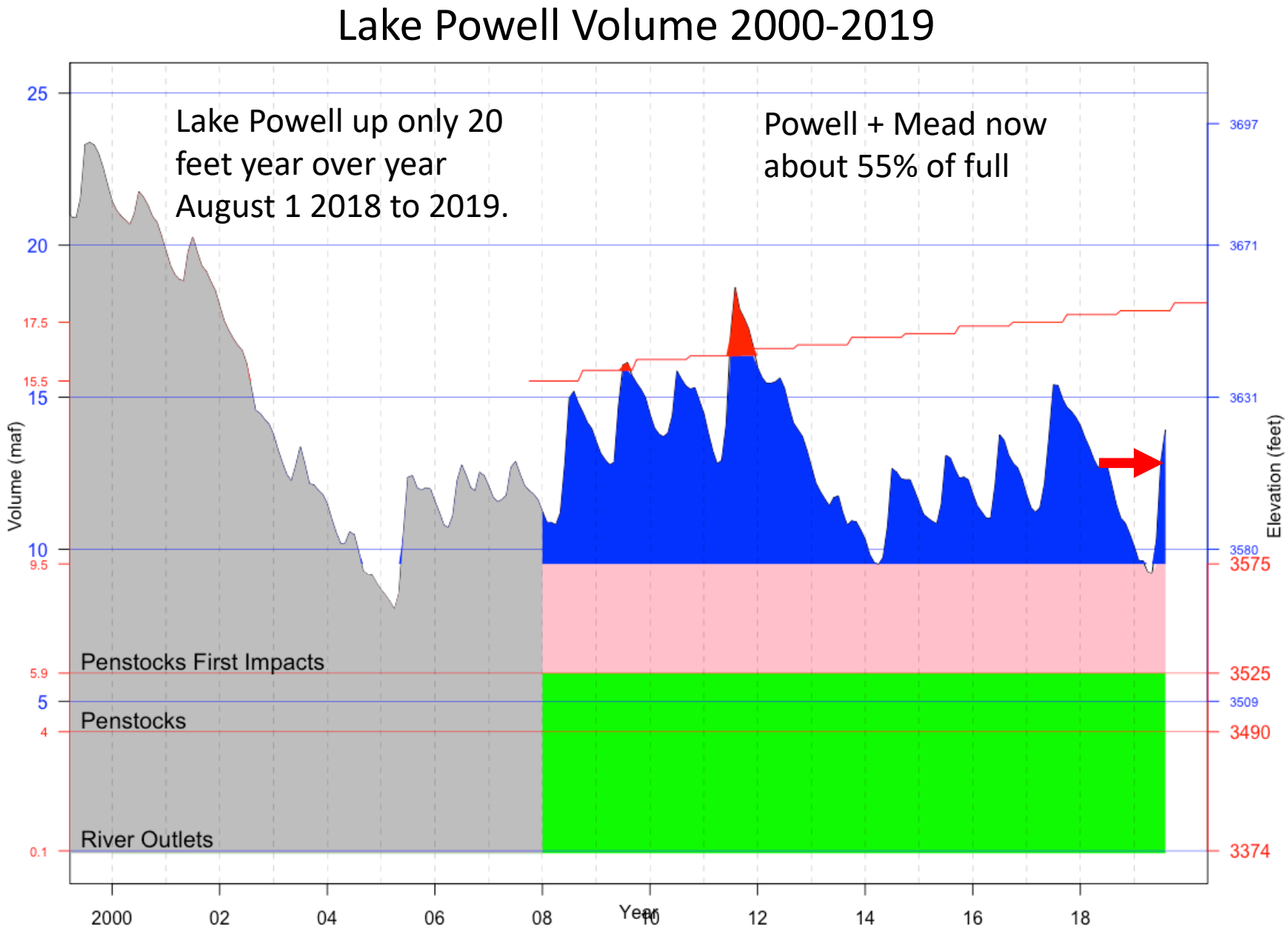
By JOHN SCHWARTZ and NADJA POPOVICH FEB. 6, 2019



Source: NASA | By The New York Times

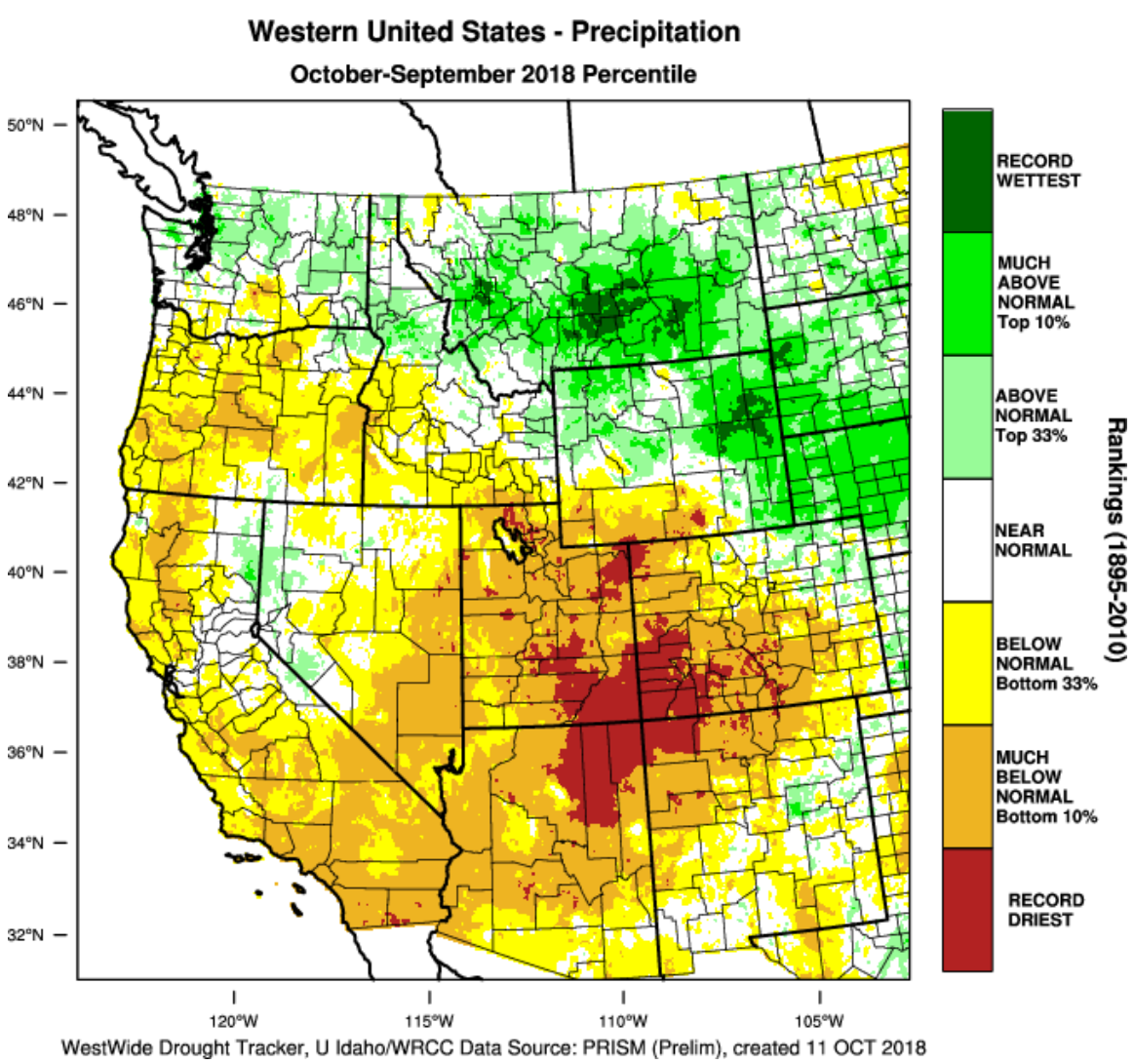
2018-2019 was a big water year but…

- Not as big as 2011
  - More like 2005
  - 10% less than 2011
- Only 1 year after record warm and dry 2017-2018
- Unlikely to be our future
- “Weather Whiplash” Example
- Note: we can and do still set cold records now at 1:2 cold:warm ratio

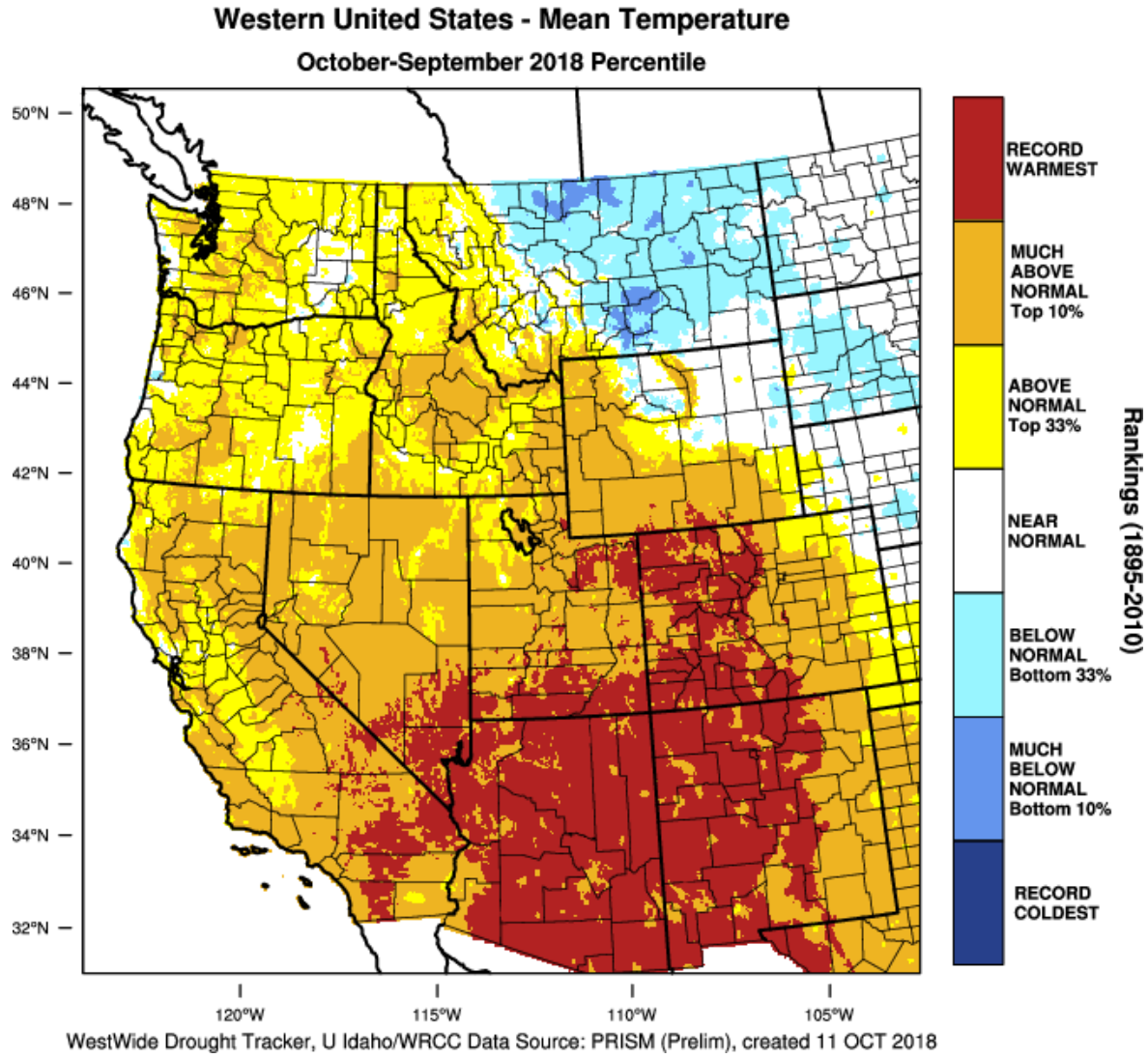


2018 was Record Warm and Dry in Large Parts of the Southwest

Lowest Precipitation on Record 4 Corners Area

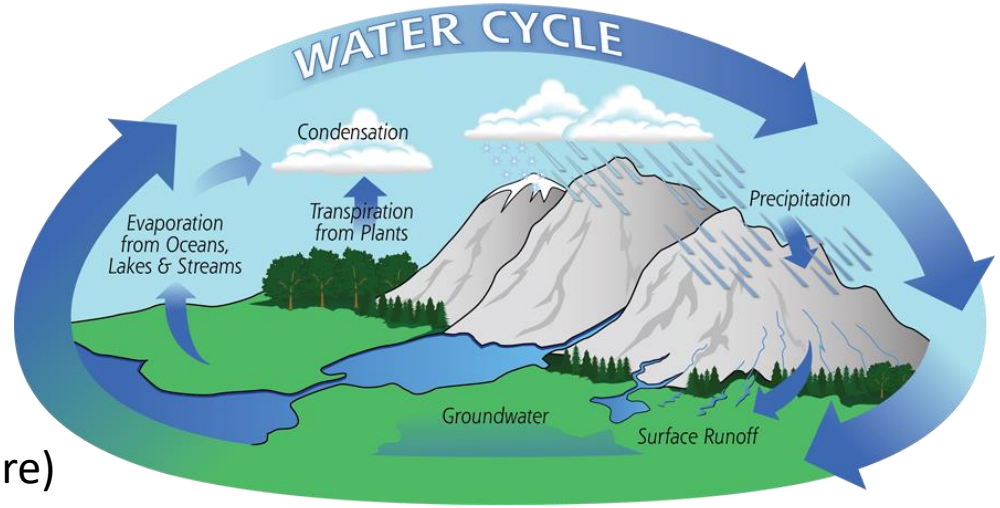


Warmest Temps on Record in parts of NV, AZ,UT,CO,NM



Climate Change affects all aspects of the Heat-Driven Water Cycle

- Location of Precipitation (less to south, more to north)
- Timing of Precipitation (when in the year)
- Type of Precipitation (more rain, less snow)
- Intensity of Precipitation (more when it does precipitate)
- Frequency of Precipitation
  - (more dry days, potential for longer droughts)
- Evaporation / Sublimation from soils, waterbodies and snowpacks (more)
- Plant water use (more)
- Thirstier Atmosphere (wants to hold more water)
- Snow melt and Runoff Dates (earlier)
- Annual Pattern of Runoff (slightly more winter, more spring, less late summer)
- Quality of Water, too (warmer, harmful algal blooms)

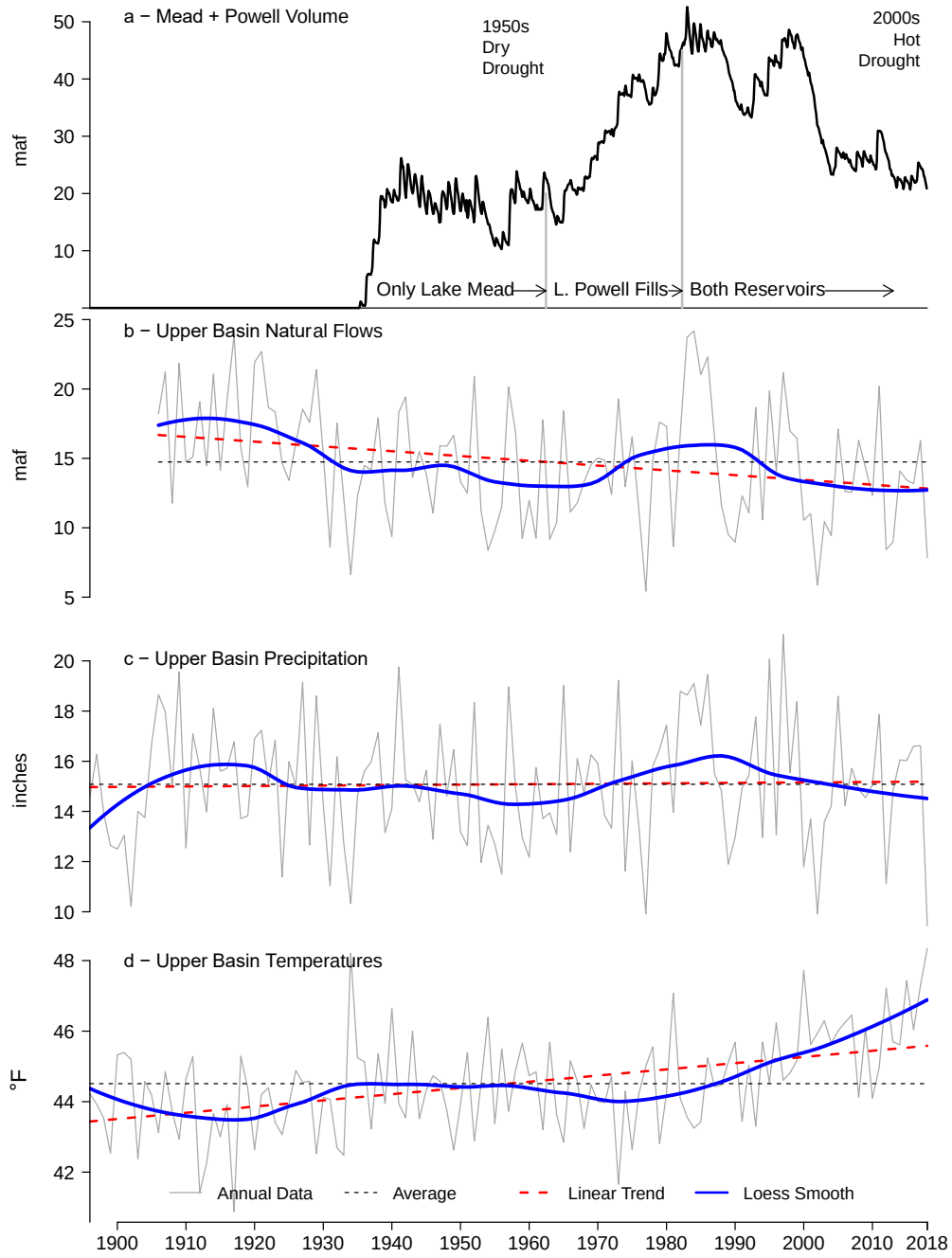


- Climate change also impacts fires (more), dust on snow, (more), and human water demands (higher) which in turn impact water supply and water demand

- Past Statistics on supply and demand are less and less applicable for management

Climate Change is already impacting the Colorado River

- Flow reductions due to higher temperatures
  - Woodhouse et al, 2016 showed declining CRB runoff efficiency in late 20th and early 21st century because of higher temperatures
  - Udall and Overpeck 2017 showed 1/3 of recent CRB decline due to higher temperatures
- Earlier Runoff
  - Lukas et al 2014 showed 2 to 4 weeks earlier runoff across Colorado
- Less Snowpack
  - Mote et al, 2018 showed ~ 10% declines Apr 1 since 1950
- Perhaps changes in Precipitation
  - Dueling scientific papers on this topic

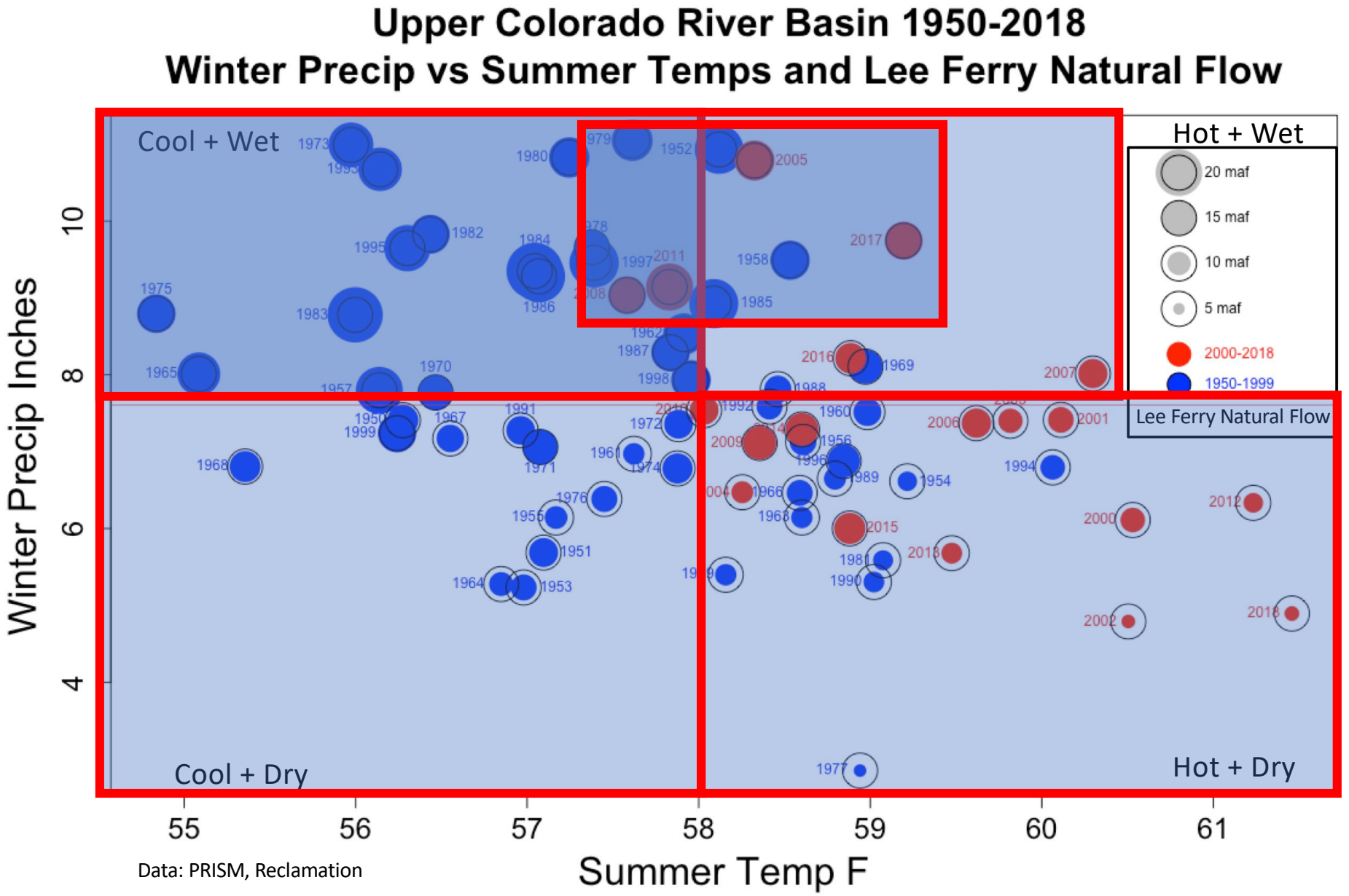


Red = 2000 and after,
19 years total

Blue = 1950 to 1999,
50 years total

Size of the Dot
Proportional to
the annual flow

- Since 2000 (19 years)
  - only 2 years (~10%) cooler than summer average.
  - Only 6 years (~30%) greater than average winter precipitation.
  - 13 years (~70%) both hot and dry.
  - Only 4 (~20%) years flows > average.



Data: PRISM, Reclamation

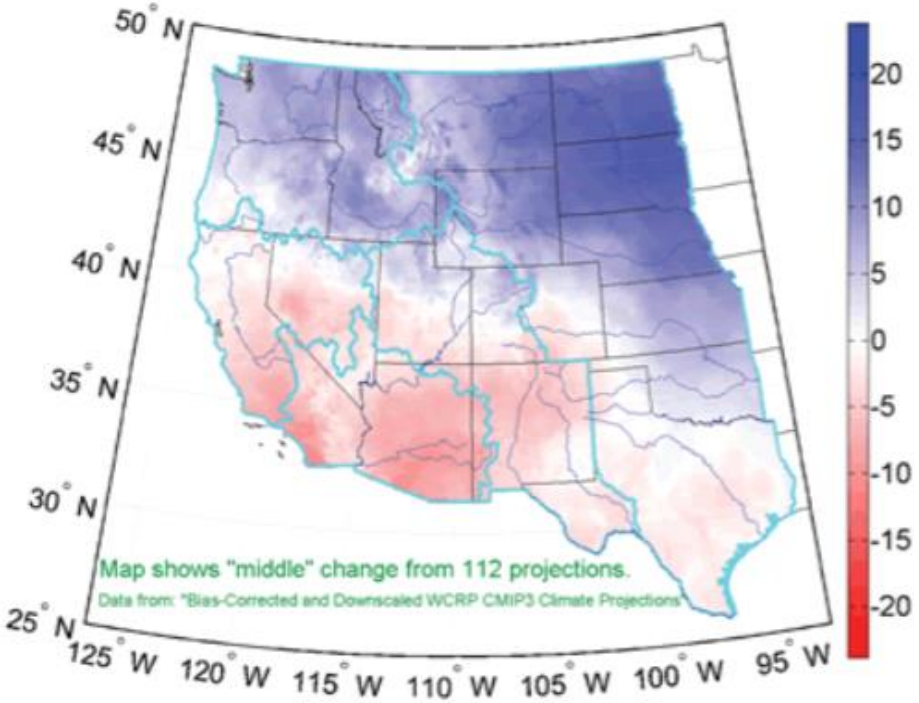
Brad Udall, Colorado State University

December 9, 2018

Climate Change will increasingly impact CRB as 21st century unfolds

- Temperatures will become much warmer
  - Mid-Century: 2.5 to 6.5 °F
  - End-Century: 5.5 to 9.0 °F
  - If 2F Denver = Pueblo, if 4F Denver = Lamar, if 6F Denver = Albuquerque
  - 2018 record warmth will be 'cool' compared to normal mid to late century temps
- Precipitation changes much less certain
  - North-South Wet-Dry Gradient likely – risk for S. Colorado
- Colorado River Flow Reductions
  - Given no precipitation change, Udall and Overpeck projected declines up to 20% by mid- and up to 35% by end-century due to higher temperatures
  - Other Colorado rivers will be similarly impacted
- Higher Water Demands
  - Both nature and human
- Earlier and Earlier Runoff
  - Less April 1 snowpack
- Potential for multi-decadal 'mega-droughts'
  - Cook et al suggest 90% change of megadrought vs 10% in 20th century
- Overall drying trend ('Aridification') in the basin
  - "Hot and Dry" Quadrant from Previous Slide

Future Precipitation Projection



Conclusions

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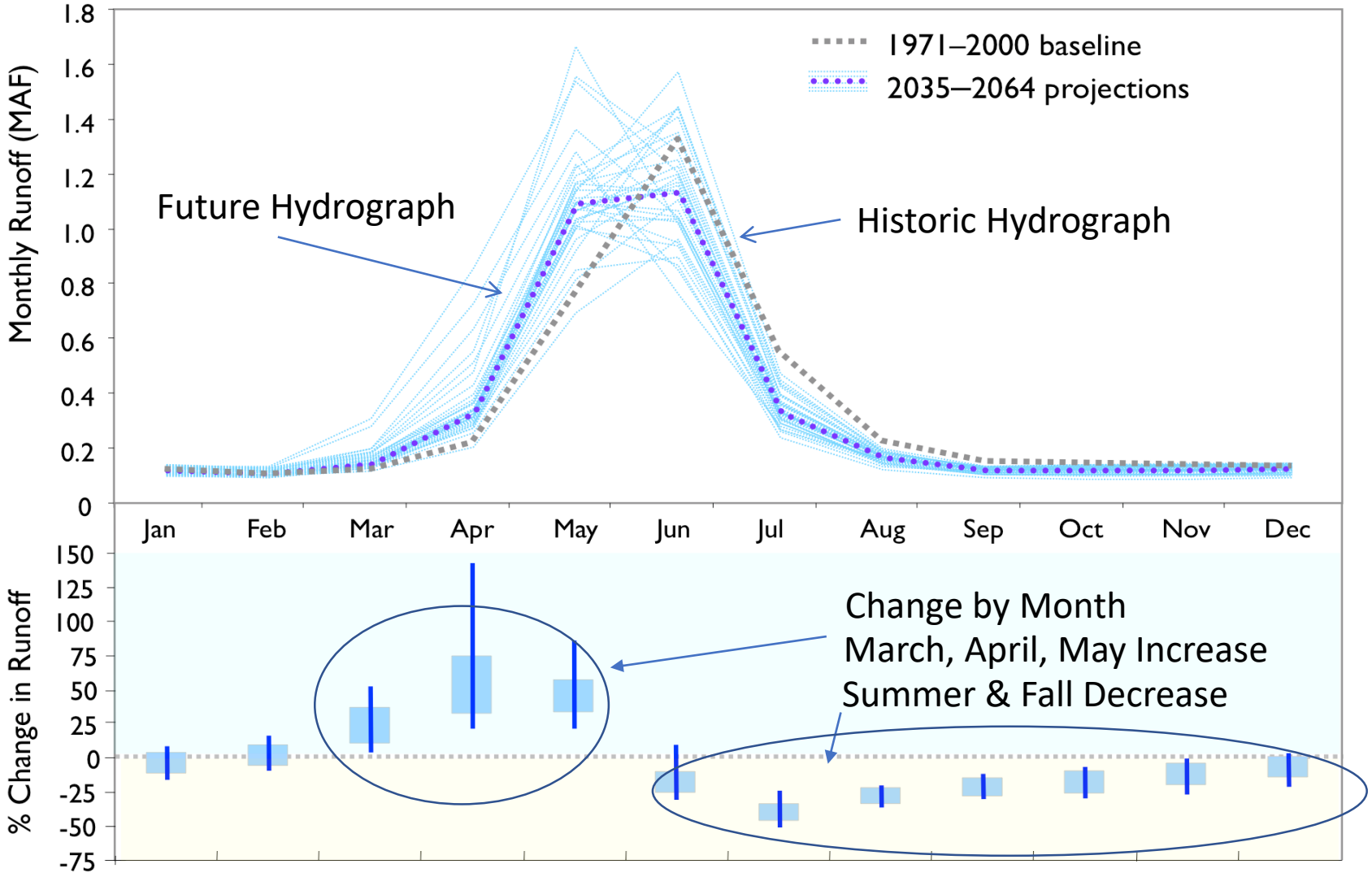
- Human-caused climate change is real, and serious threat to society
- Climate change impacts all aspects of the water cycle
- Climate change is already impacting the Colorado River
  - Definitely temperature-induced reductions, maybe precipitation declines
- Climate change will get much worse as the 21st century proceeds
  - Greater temperature-induced flow reductions than currently
  - Little overall precipitation change within CRB but a N-S gradient likely
  - Aridification trend overall with ‘weather-whiplash’
- Must be prepared for a future we can not fully foresee
  - Maximum flexibility needed to avoid worst case outcomes

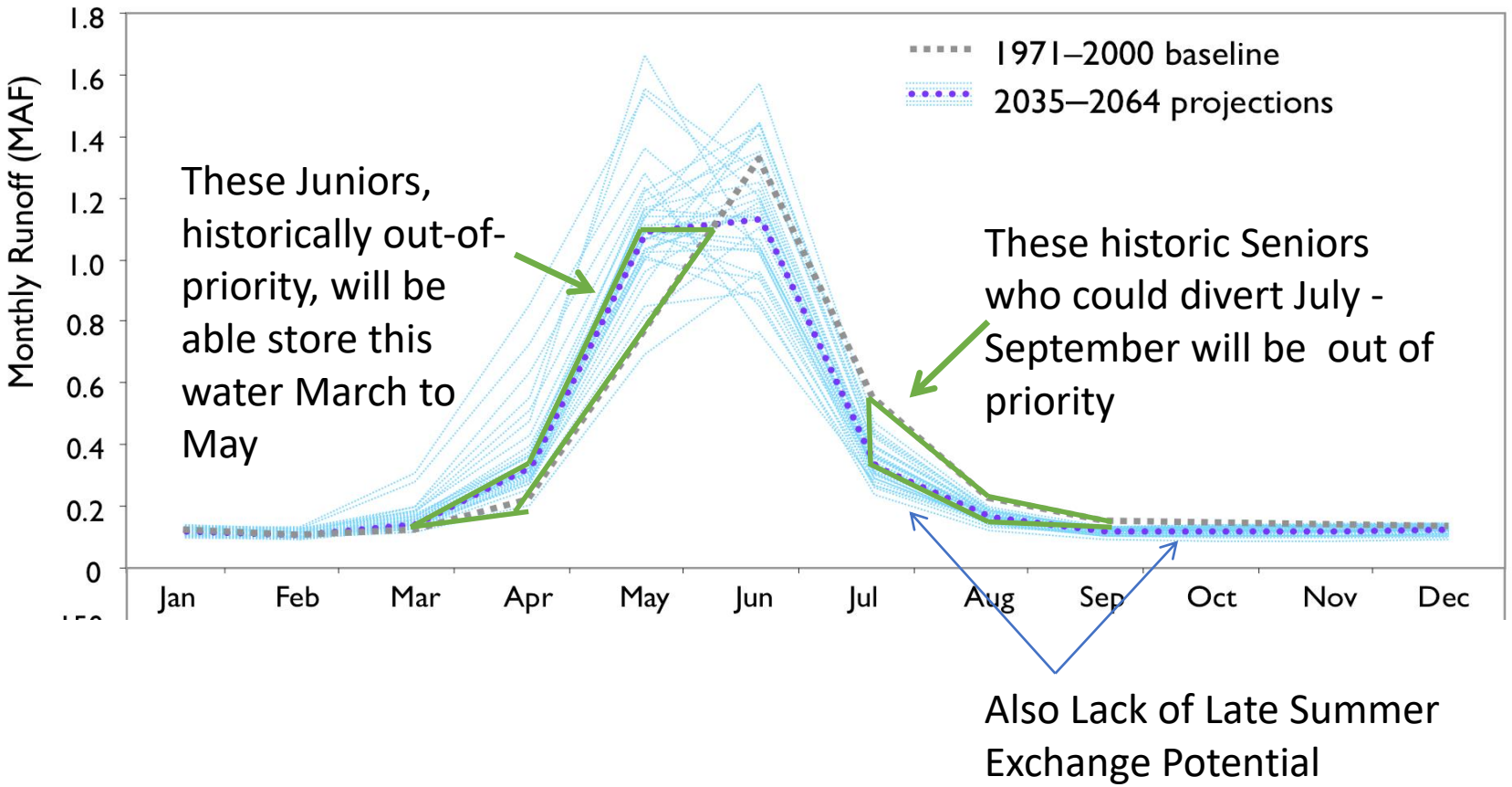
Sample Shifted Hydrograph in the Future

Take Home Point:

More Runoff Earlier in Spring
Less Runoff in Summer / Fall



Shifting Hydrograph will create winners and losers in Prior Appropriation.



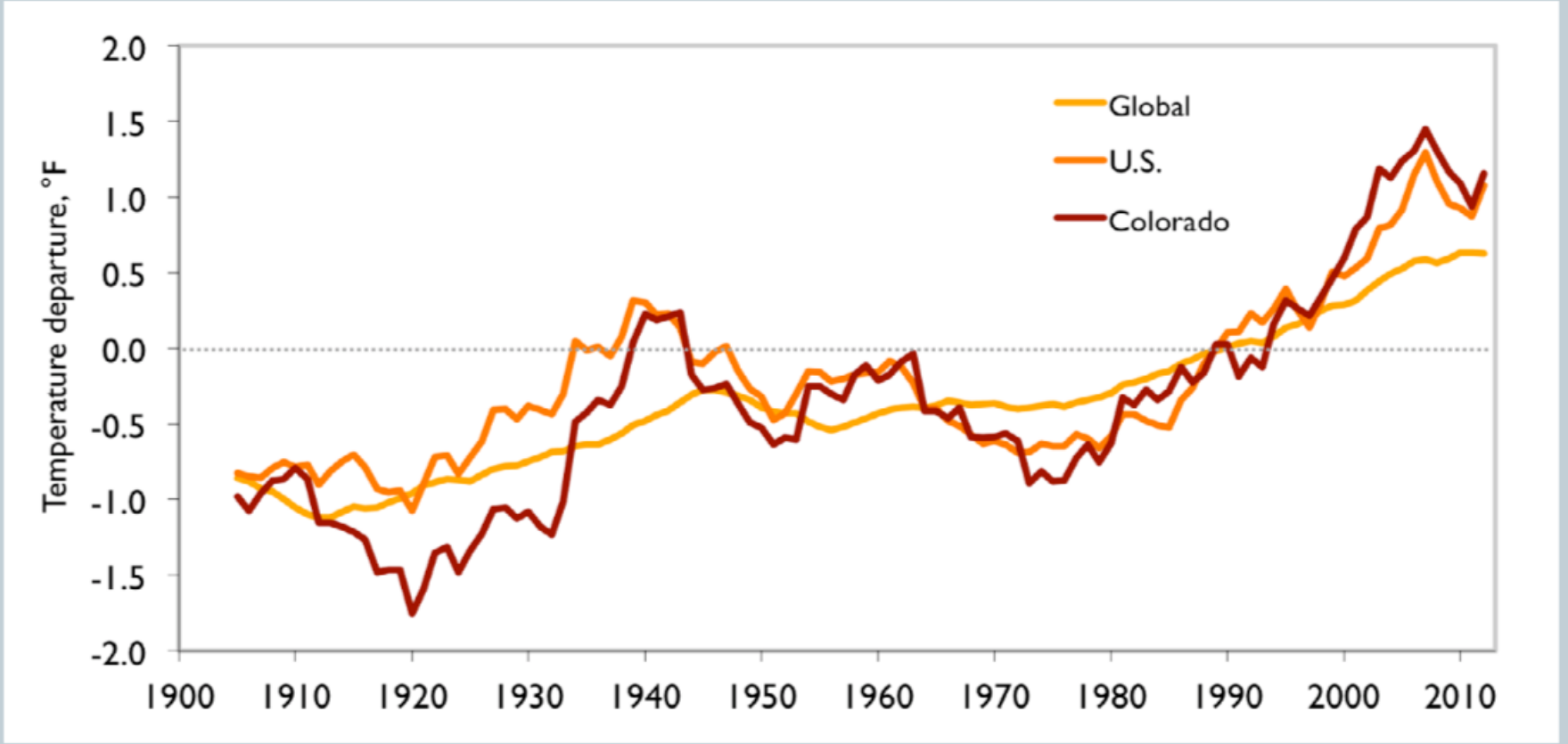
Reference: Stratus Study of Boulder, Colorado Water Rights

Take Home:

Colorado matches US and Global trend, but with greater warming

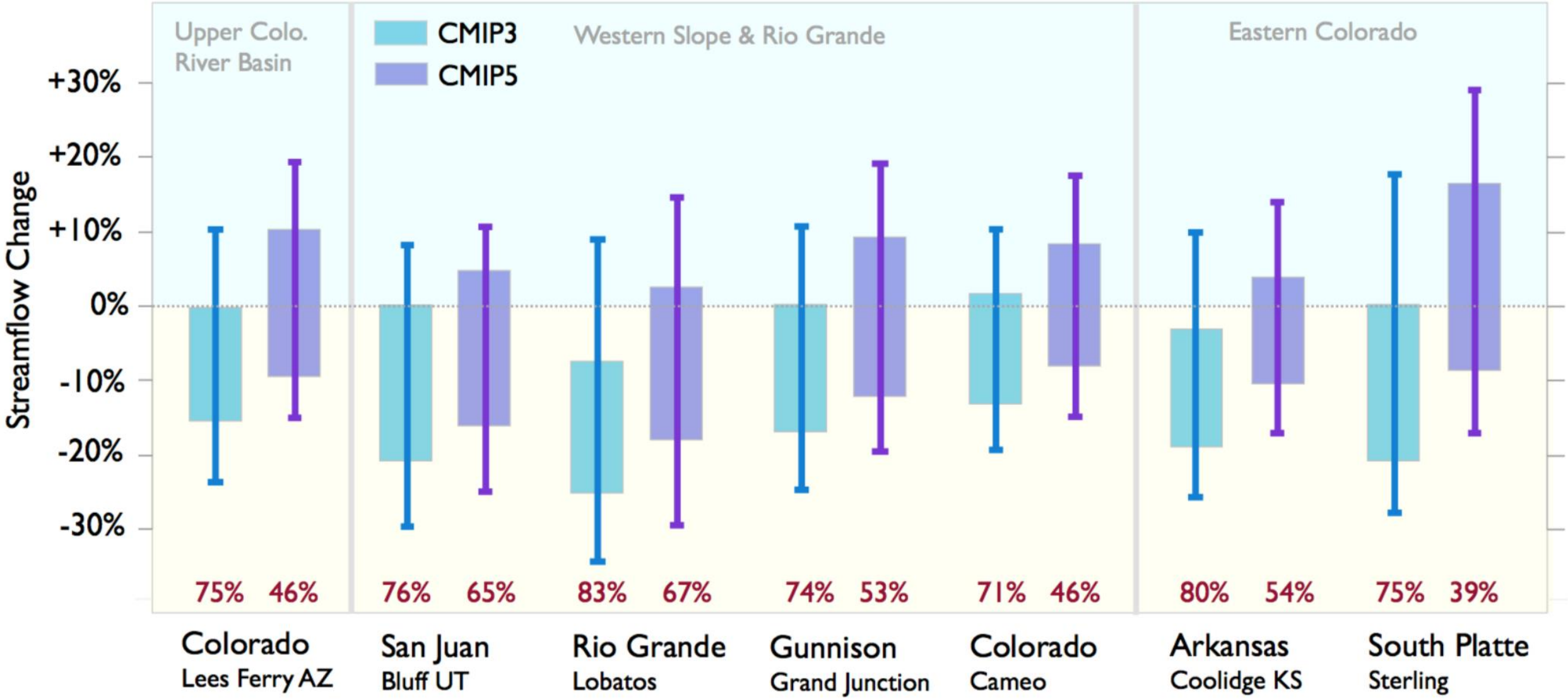
Note: missing very warm post-2012 years

Figure 1-1. Colorado, U.S, and Global Temperatures, 1895–2012



Source: Climate Change in Colorado

Mid-Century Streamflow Projections for Colorado Rivers

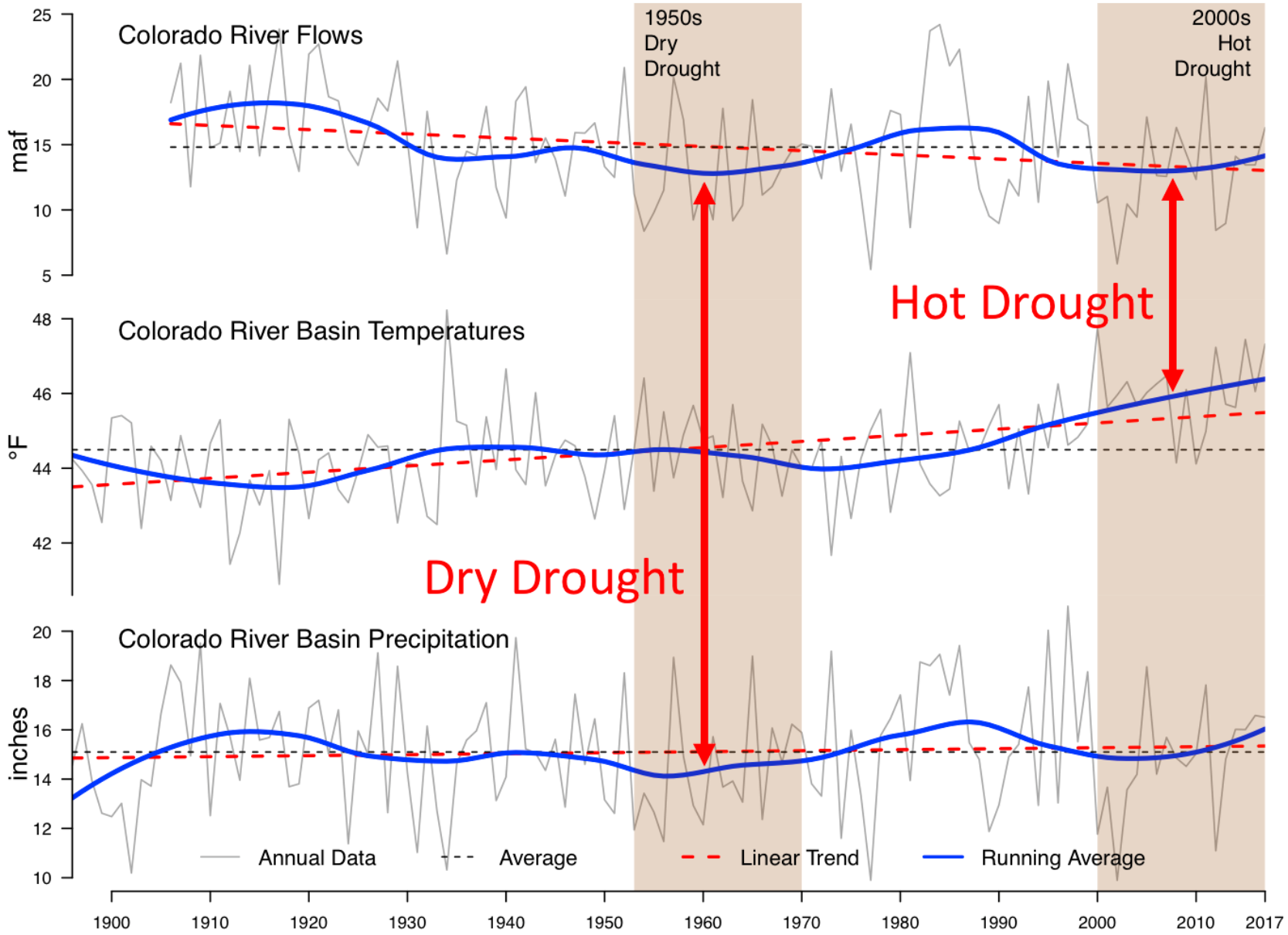


Source: Climate Change in Colorado, 2014

The twenty-first century Colorado River hot drought and implications for the future - 2017

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

- Since 2000, about 17% / year decline
- Precipitation declines only partially explain flow loss
  - ~ 2/3rd of the loss
- Temperature increases explain the remainder
  - ~ 1/3rd of the loss
- Why?
  - More Evaporation
  - Thirstier Atmosphere
- Temperature-Induced Losses
  - Now = ~6%
  - 2050 = ~20%
  - 2100 = ~35%

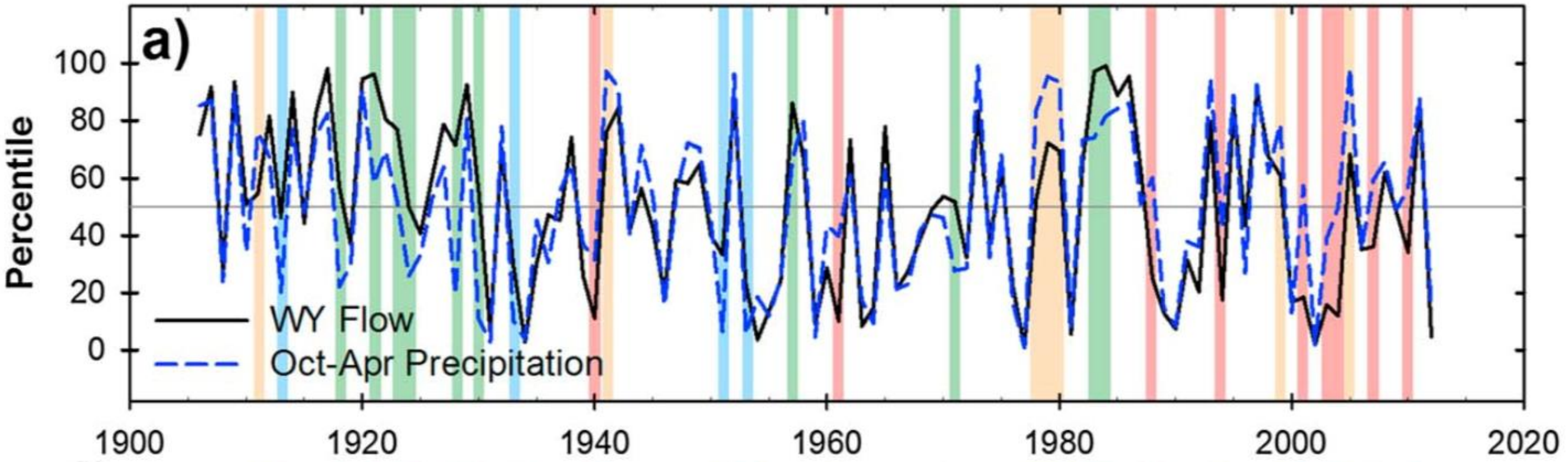


Udall and Overpeck, WRR, 2017

Increasing influence of air temperature on upper Colorado River streamflow - 2016

Connie A. Woodhouse[1,2], Gregory T. Pederson[3], Kiyomi Morino[2], Stephanie A. McAfee[4], and Gregory J. McCabe[5]

- Temperature can be a major flow driver (normally we just think about precipitation)
- Since 1988 flows have been less than expected given winter precipitation
- Warm temperatures exacerbated modest precipitation deficits in the Millennium Drought



Green + Blue = High Runoff Efficiency

Orange + Pink = Low Runoff Efficiency

On the causes of declining Colorado River streamflows

Mu Xiao, Bradley Udall, Dennis P. Lettenmaier

First published: 30 August 2018 | https://doi.org/10.1029/2018WR023153

Model-based Study using Historical Data

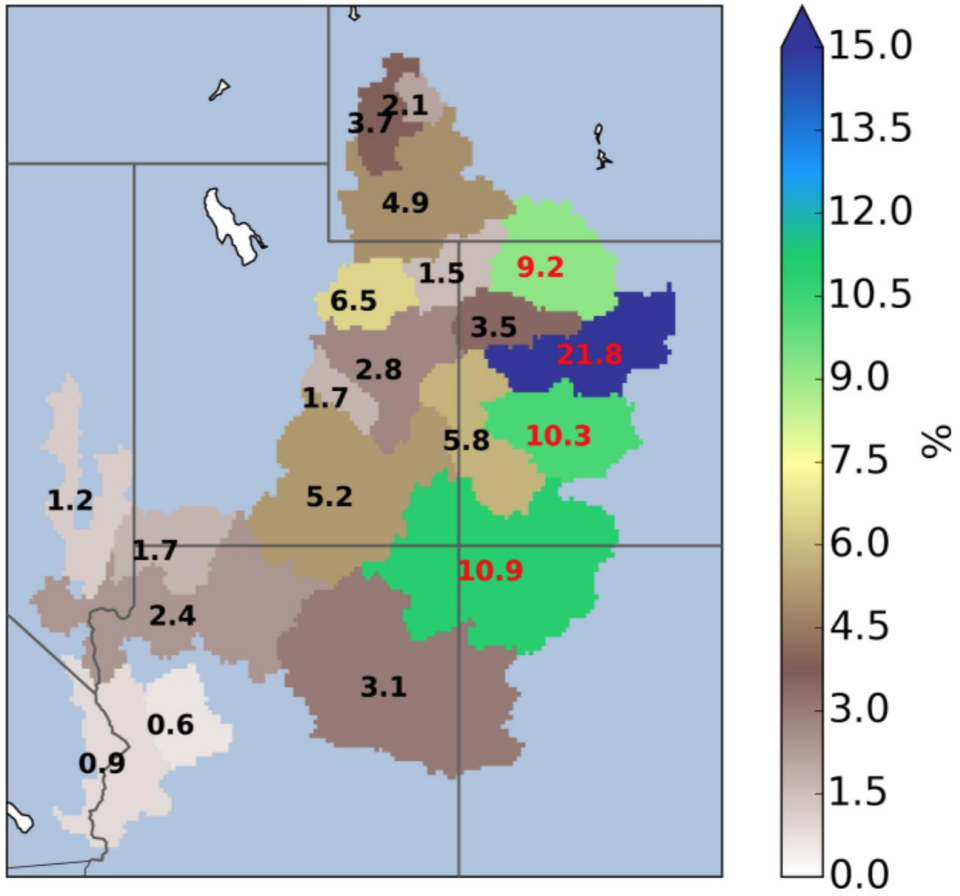
- Long-term Trend Analysis (-16.5% Decline)
- Temperature De-trend Model Experiment
- 1950s vs 2000s Drought Analysis

Findings

~50% of Decline due to Higher Temperatures

~50% of Decline due to Changing Precipitation Patterns

Note: 50% is at upper end of Udall and Overpeck findings



4 Key Basins (Green + Blue) produce ~55% of all runoff

Water Resources Research
AN AGU JOURNAL
Research Article