Past, Present, Future of the Colorado River: Climate, Management, and Policy Challenges

Renewable Natural Resources Foundation
March 9, 2021

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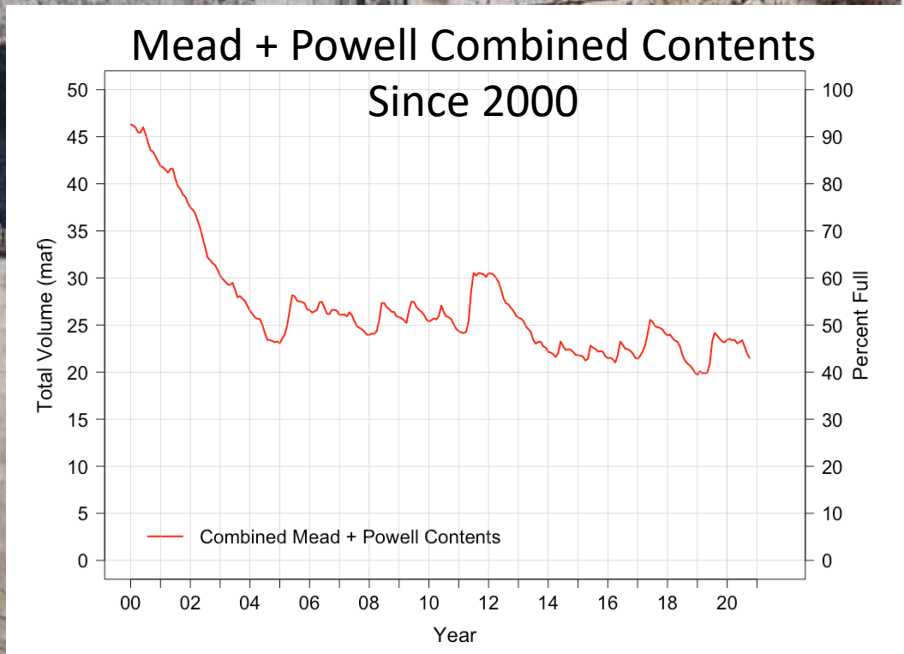
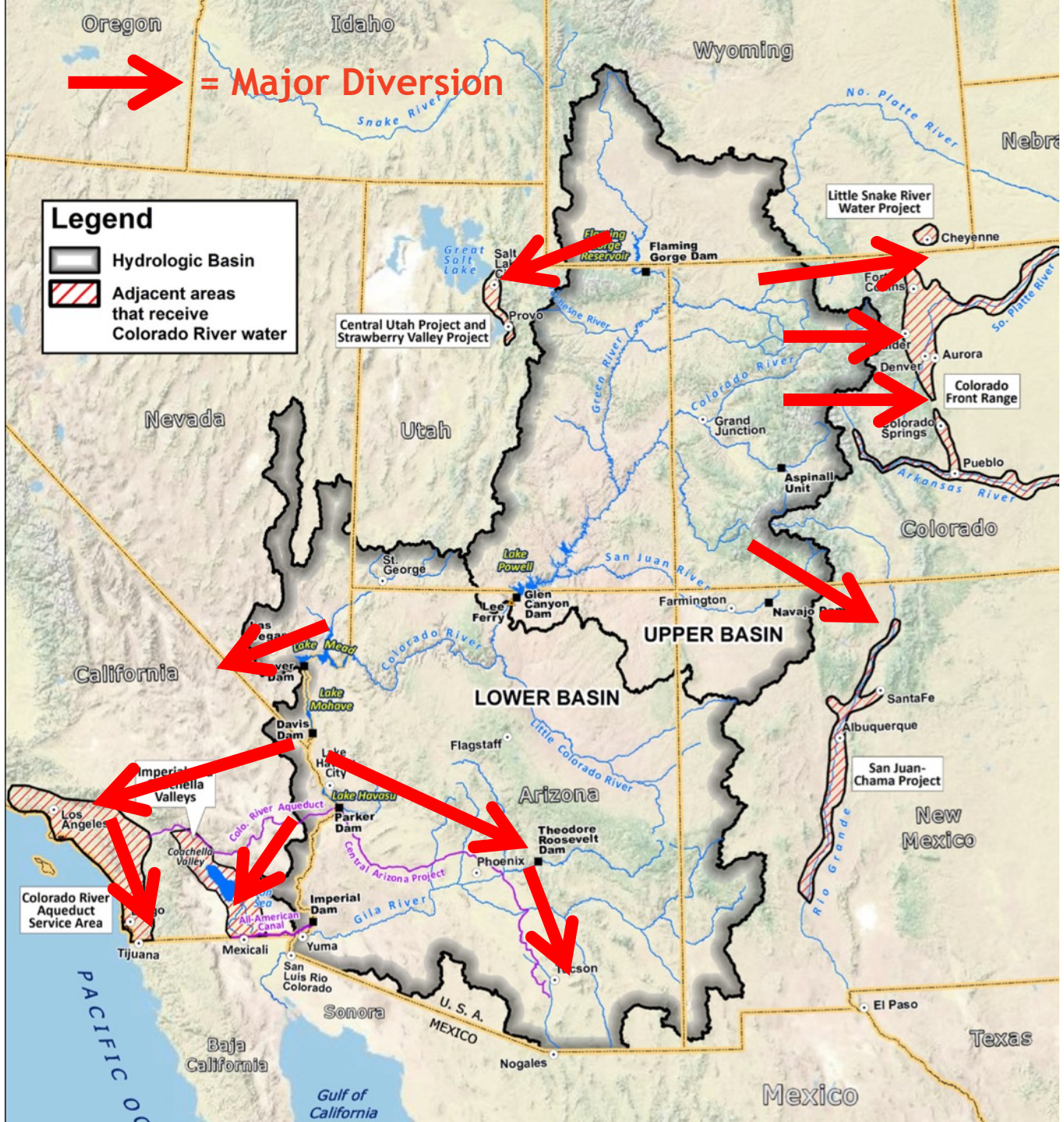
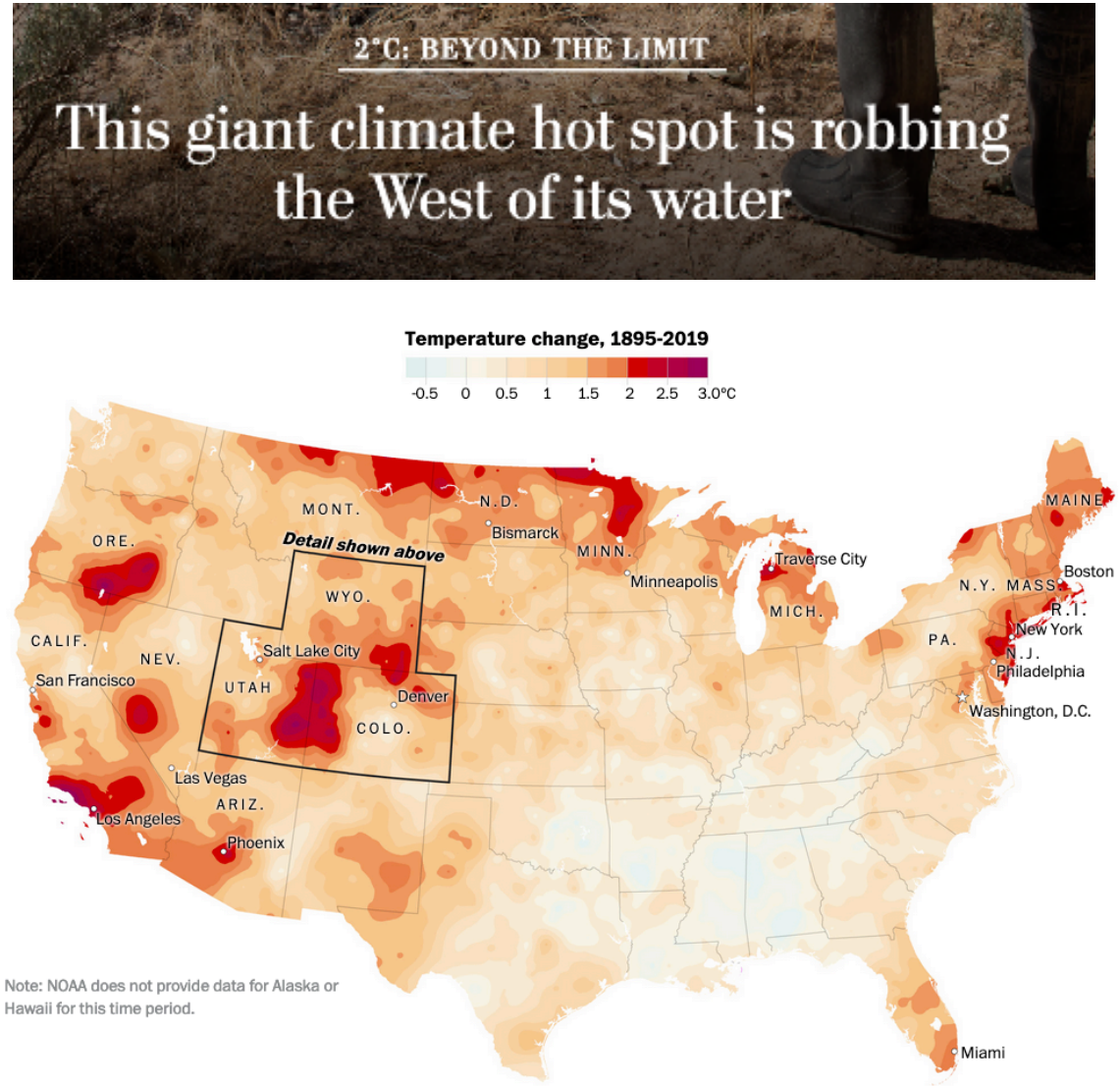


Colorado River

- 7 States, 2 Nations, 29 Tribes
- 8% of area of the Lower 48
- Annual Flow ~14.75 MAF
  = Hudson River
- Worst drought in gaged record started 2000 ~12.4 MAF/yr
  = ~18% decline annually
- 40 M People
- All of the Major Cities in SW US
- 4.5m Irrigated Acres
- Fully Allocated in 1922
- Complex Use Agreements
- Withdrawals equaled Supplies ~2000
- New Projects still contemplated
- No longer reaches the ocean



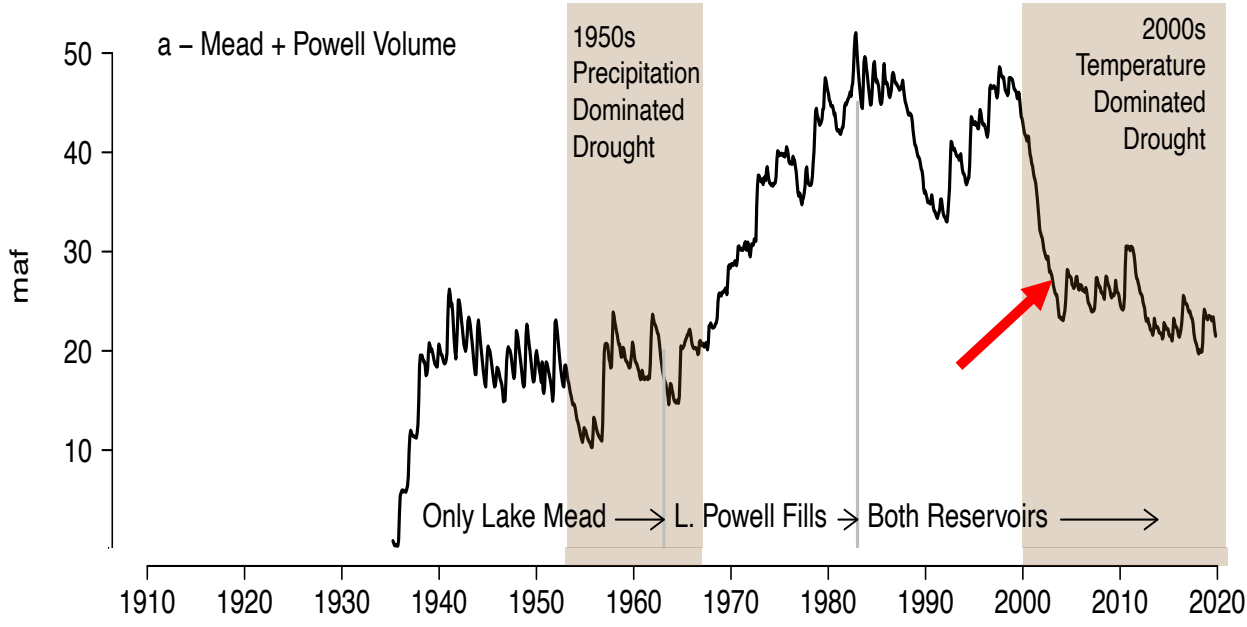
- Talk Overview
  - Basin Overview
  - Management since 2007
    - Interim Guidelines
    - Drought Contingency Plan
  - Science of Climate Change
  - Alternative Management Paper
  - Process and Solutions for New 2026 Agreement



The Washington Post

2007 Interim Guidelines

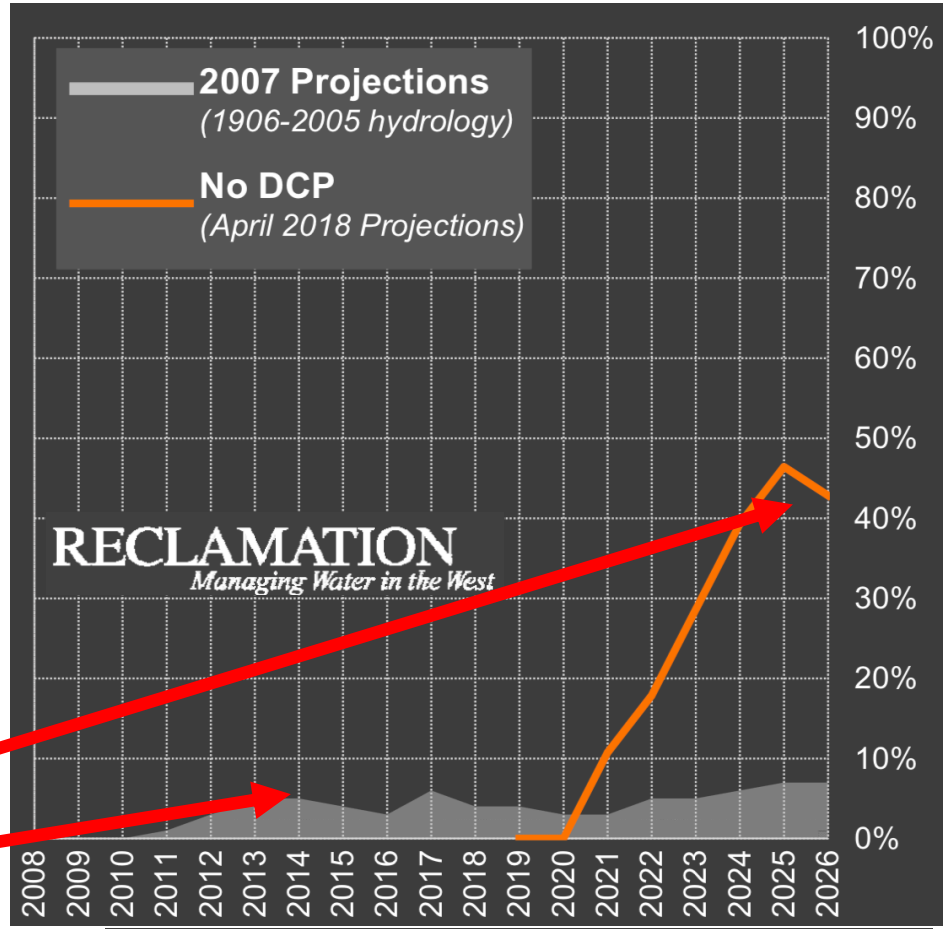
- Came out of 2005 Secretarial Ultimatum in face of declining reservoirs
- Record of Decision 2007
  - Last thru 2026
  - Renegotiations to start no later than 12/31/2020
  - Appendix U Document in EIS
- Complicated Rules for Powell & Mead Releases
  - Based solely on Reservoir elevations
  - Solved ~ ½ of 'Structural Deficit'
- Innovations in Reservoir Storage ("ICS")
- Continued Low Flows forced 'Drought Contingency Planning', 2013-2019
  - Short-term solution to Long Term Problem



Updated From Udall & Overpeck, 2017

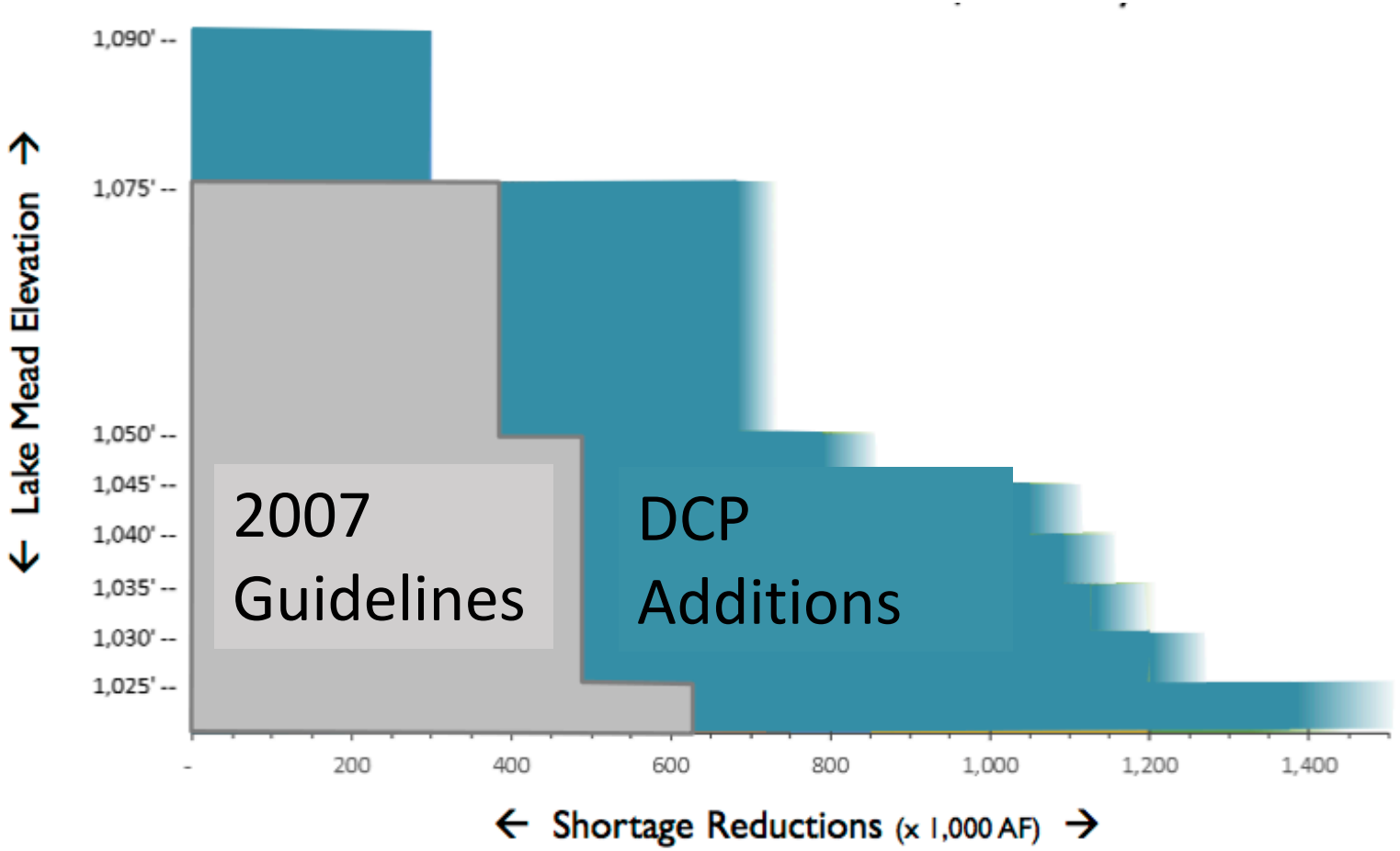
2019 Drought Contingency Plan - DCP

- 2007 'Interim Guidelines' Agreement first step to solving Structural Deficit
  - only dealt with 600 kaf of 1.2 maf deficit
- Intervening years showed not enough to avert catastrophe
  - Dawning realization ~ 2012 that Mead elevation 1075' too low to start shortage, and 600 kaf not enough
  - Also, "re-consult" at 1025' way too late (6 maf in Mead)
  - Much higher risk of low elevations now compared to 2007 (8% vs 45%)
- Series of Agreements
  - AZ, Multi-state, Federal Legislation, Mexico



Risk of Lake Mead < 1,025'

2007 Guidelines Shortage Amounts vs DCP Shortage Amount Additions



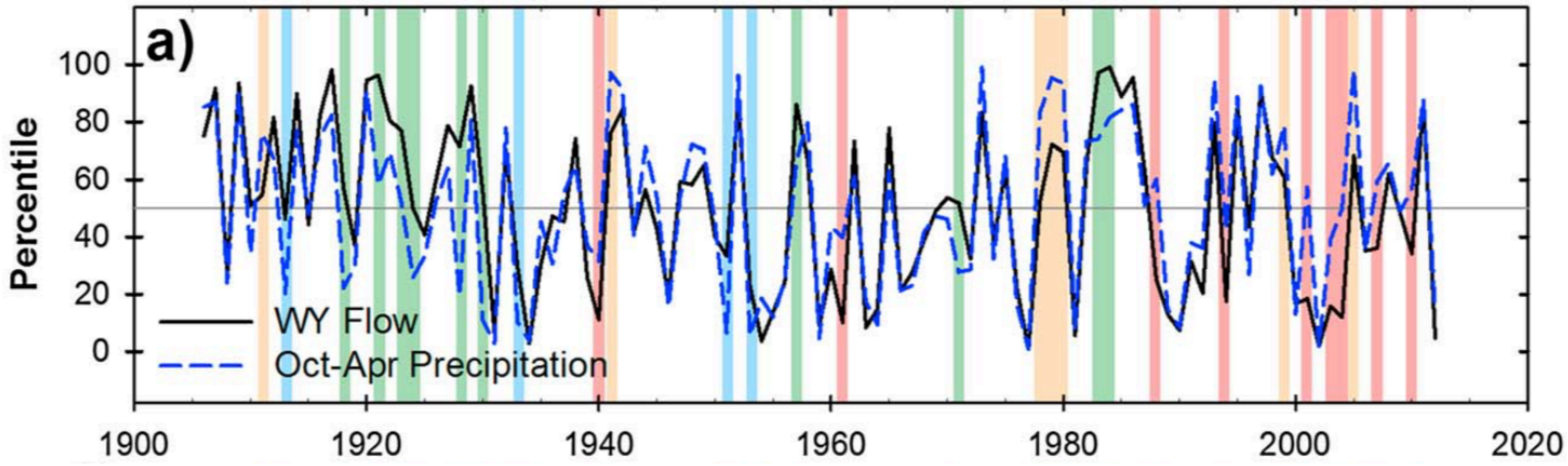
Source: CAP

Increasing influence of air temperature on upper Colorado River streamflow

Geophysical Research Letters, 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

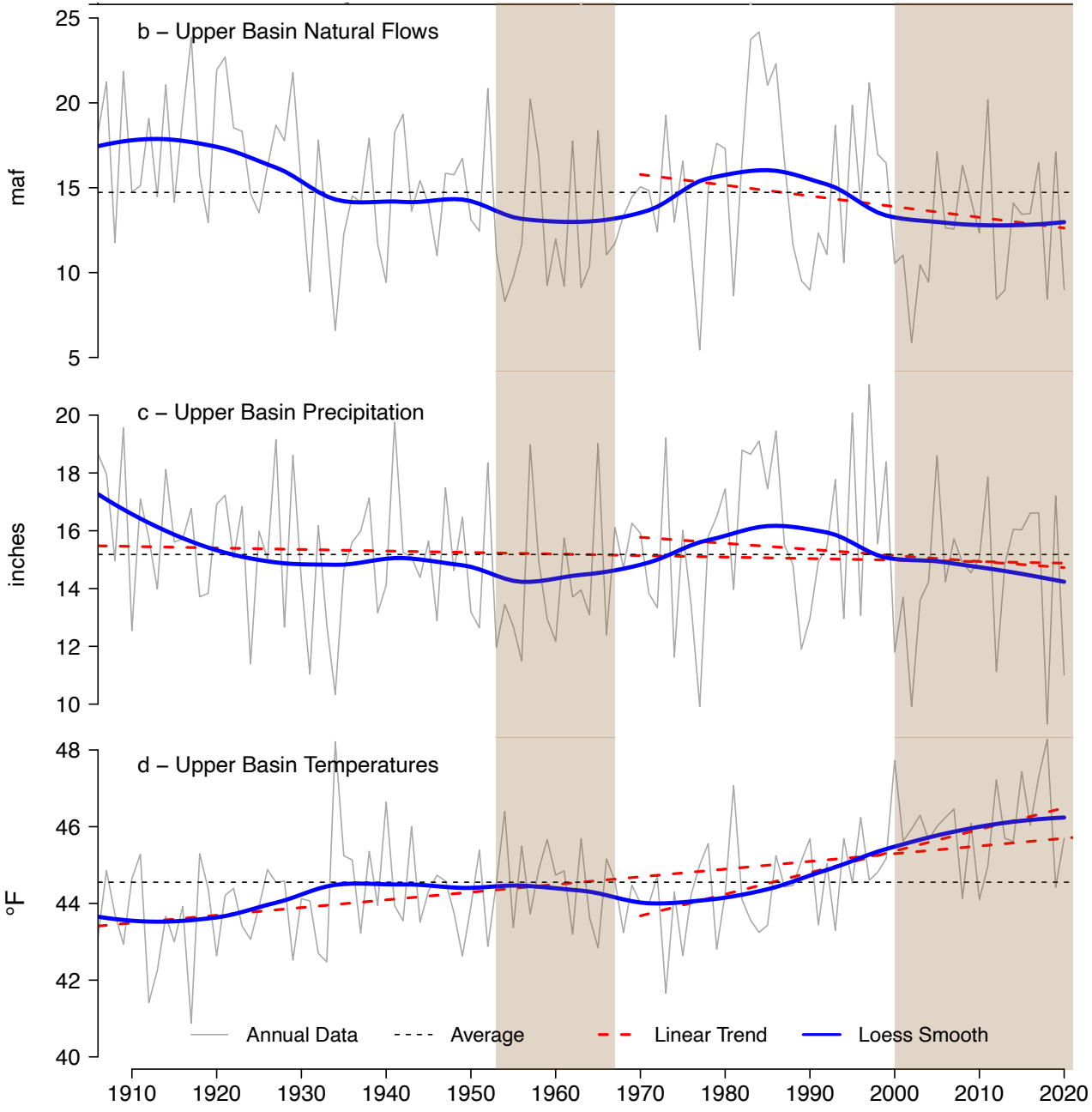


The twenty-first century Colorado River hot drought and implications for the future - 2017

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

Water Resources Research
AN AGU JOURNAL
Research Article

- Precipitation declines only partially explain flow loss
  - ~ 66% of the loss
- Temperature increases explain the remainder
  - ~ 33% of the loss
- Why?
  - More Evaporation
  - Thirstier Atmosphere
- Temperature-Induced Losses
  - Now = ~6% - 10%
  - 2050 = ~20%
  - 2100 = ~35%



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

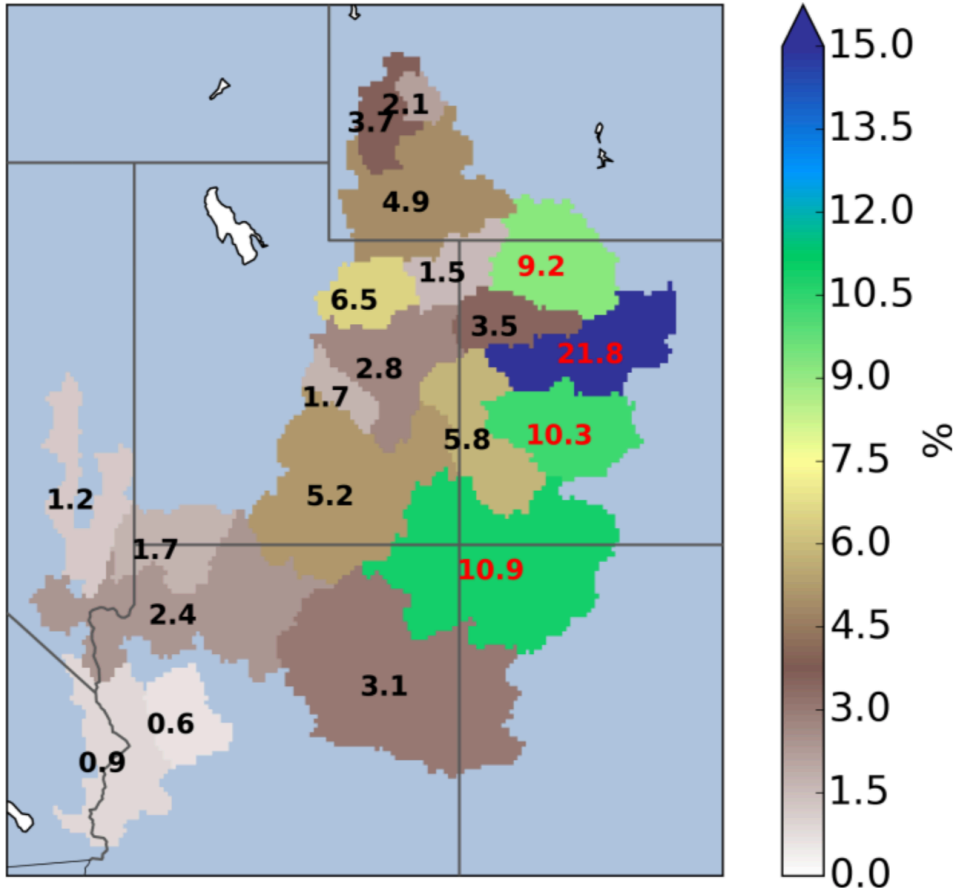
Water Resources Research
AN AGU JOURNAL
Research Article

- Hydrology Model-based Study using Historical Data
  - Run model with and without temperature change

Findings

- ~50% of Decline due to Higher Temperatures
- More Evaporation of all kinds

- ~50% of Decline due to Changing Precip Patterns
- Precipitation shift to less productive basins



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

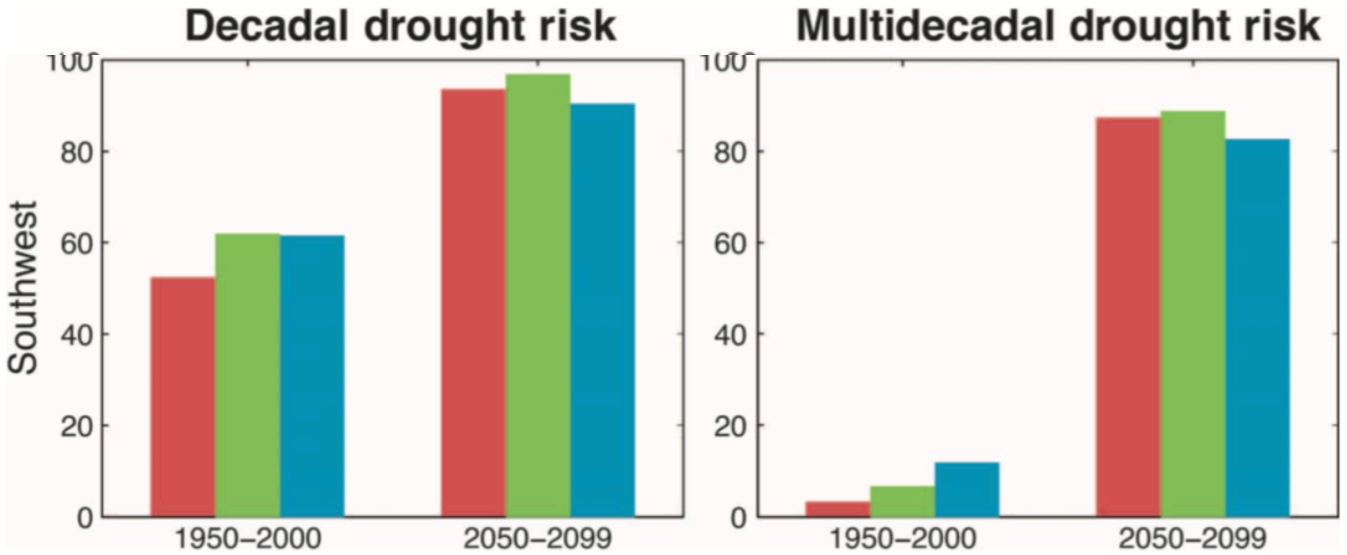
CLIMATOLOGY

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

Other studies have shown 21st Century megadroughts can even occur with increases in precipitation



* Defined as 35 years or more

Science Advances, 2015

Emerging Megadrought

Science, April 2020

DROUGHT

Large contribution from anthropogenic warming to an emerging North American megadrought

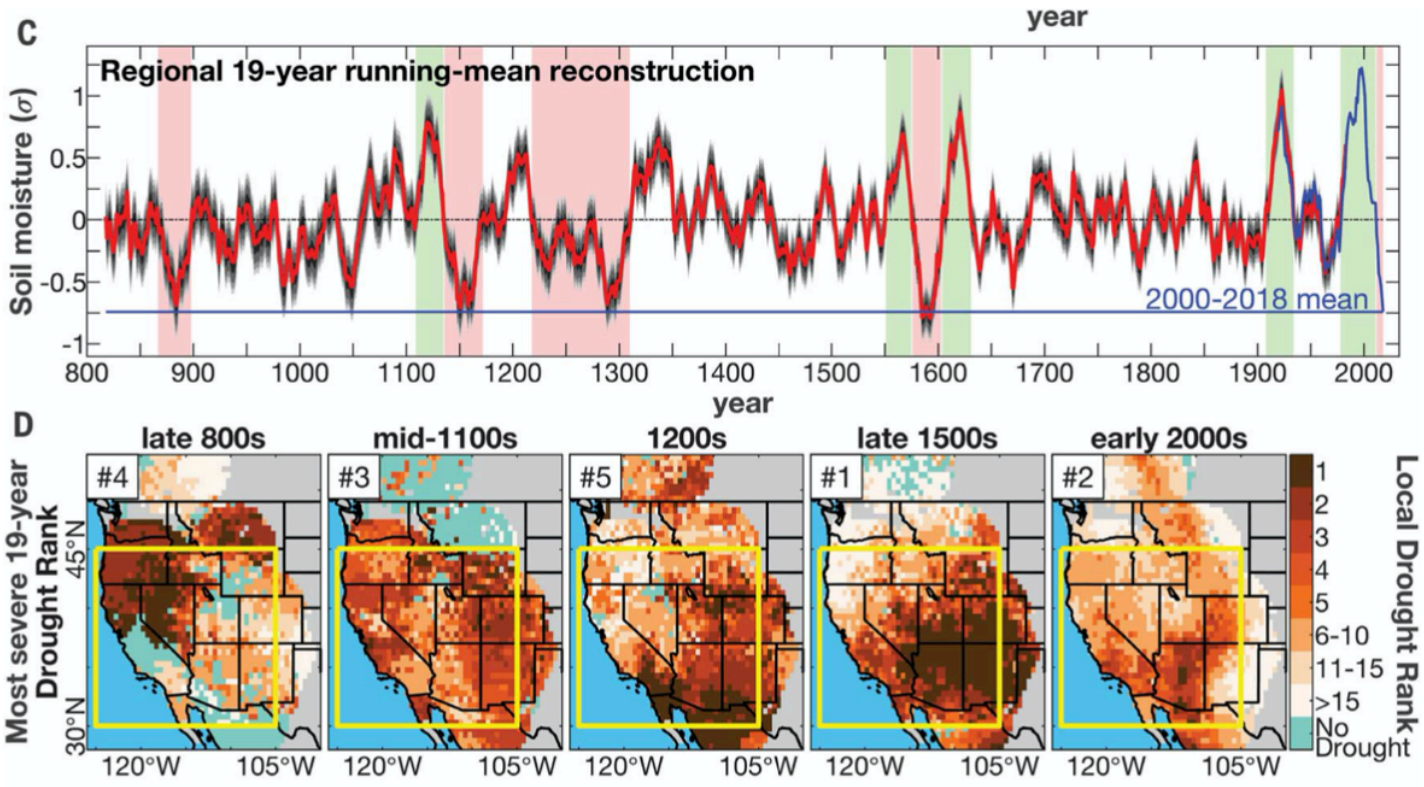
A. Park Williams[1]*, Edward R. Cook[1], Jason E. Smerdon[1], Benjamin I. Cook[1,2], John T. Abatzoglou[3,4], Kasey Bolles[1], Seung H. Baek[1,5], Andrew M. Badger[6,7,8], Ben Livneh[6,9]

2000—2018 2nd Driest 19-year period since 800 AD

Caused by Natural Variability aided by anthropogenic drying

About 50% due to humans

Without anthropogenic drying, would be a moderate drought

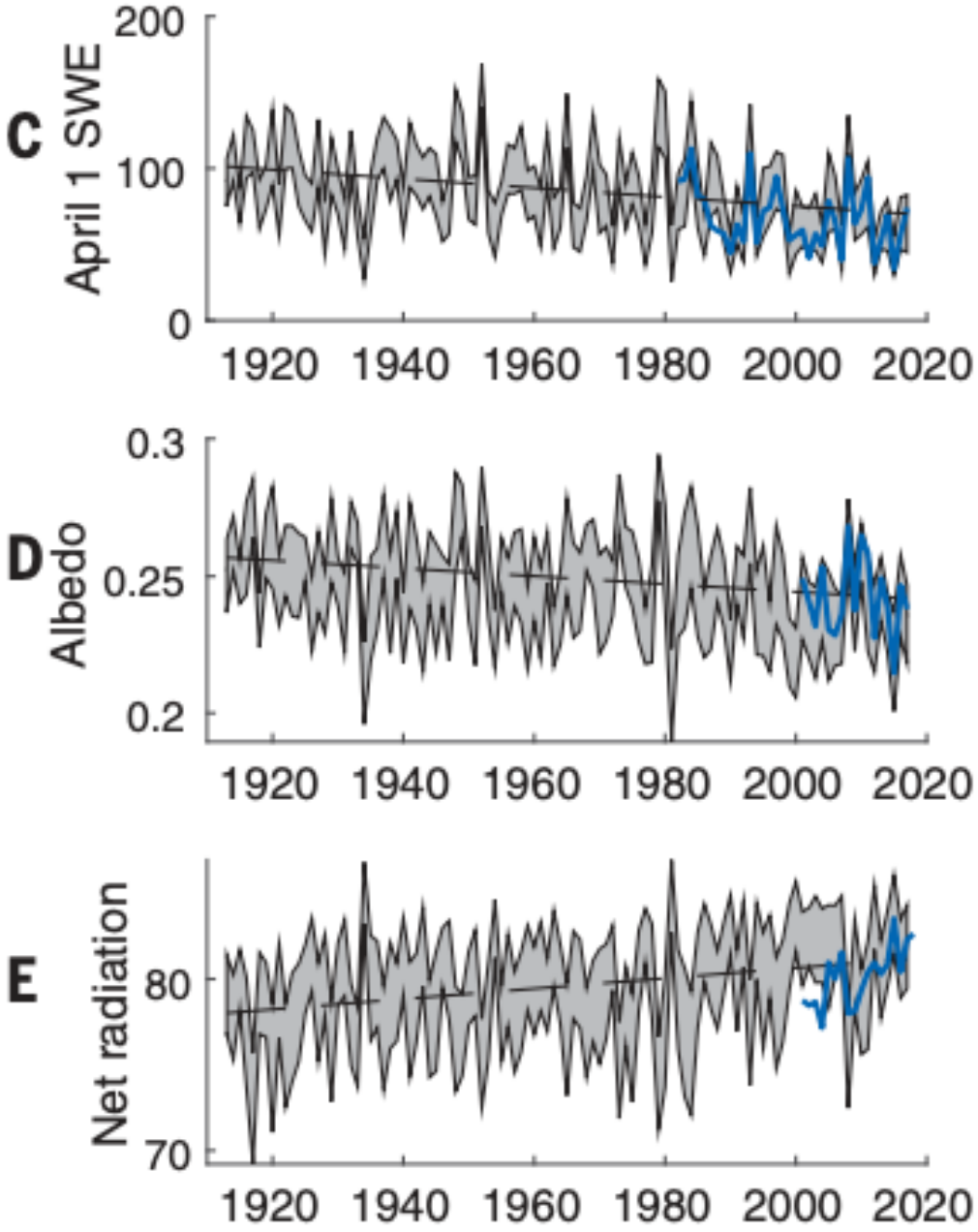


WATER RESOURCES

Colorado River flow dwindles as warming-driven loss of reflective snow energizes evaporation

P. C. D. Milly* and K. A. Dunne

- Attempt to ‘reconcile’ the wide range of CR Temperature Sensitivities
- Answer: -9.3 %/°C !
- Mid-century flow loss (only Temps)
  - -14% to -26% RCP4.5
  - -19% to -31% RCP8.5
- Mid-century flow loss (both Temps & Precip)
  - +5% to -24%
  - +3% to -40%
- Key Finding: As shiny, reflective snow declines, absorbed radiation goes up (2/3 of the cause)



Milly *et al.*, *Science* **367**, 1252–1255 (2020) 13 March 2020

Aridification – not a drought

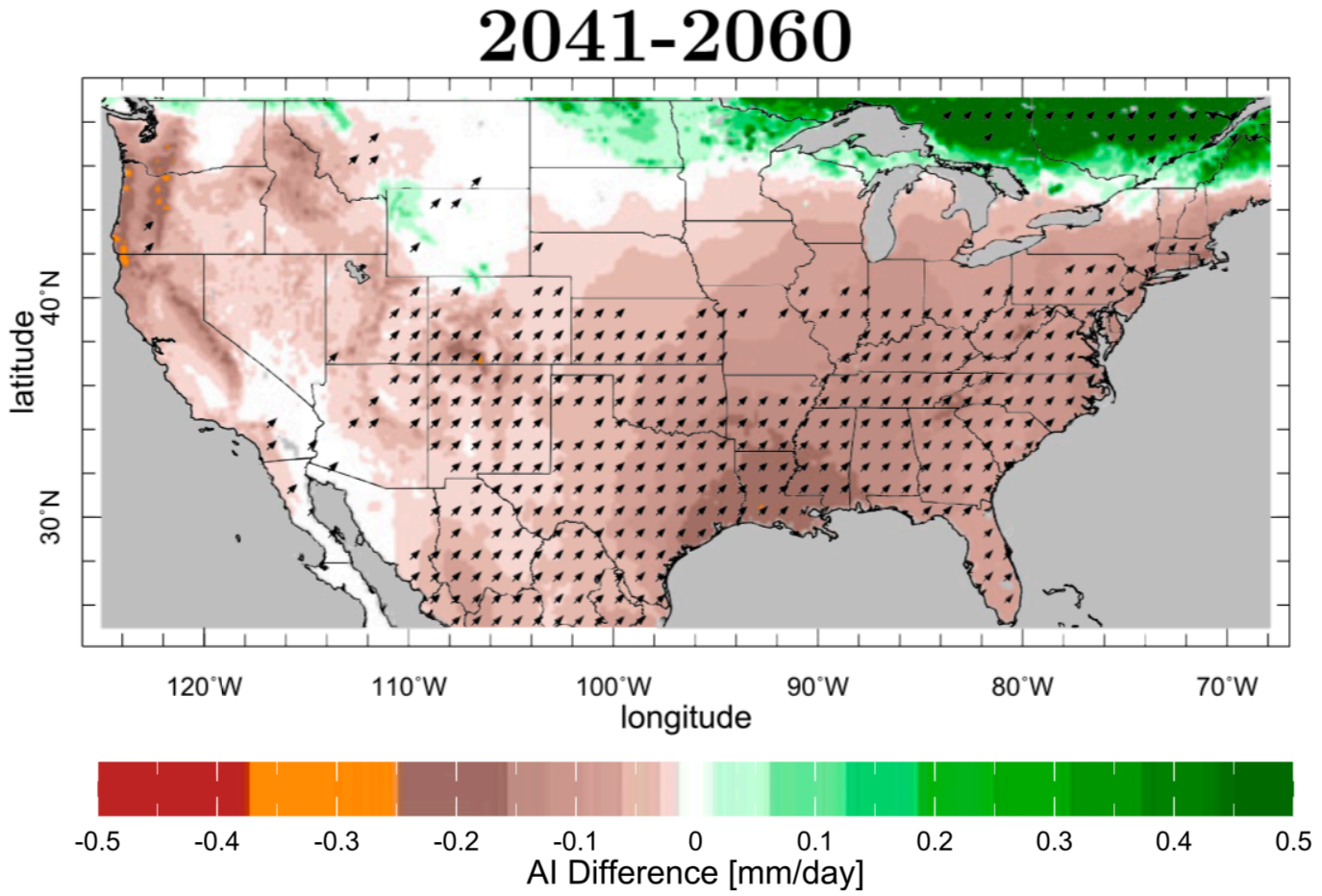
WHEN IS DROUGHT NOT A DROUGHT?

DROUGHT, ARIDIFICATION, AND THE "NEW NORMAL" (March, 2018)

A publication of the Colorado River Research Group
"An independent, scientific voice for the future of the Colorado River"

- Declining Snowpack and earlier runoff
- Higher Temperatures
- Drying Soil
- Thirsty Atmosphere
- Moving storm tracks
- Shorter Winter/Longer Fall
- Megadrought

Aridity Index (P/PET) Changes



Seager et al., 2018

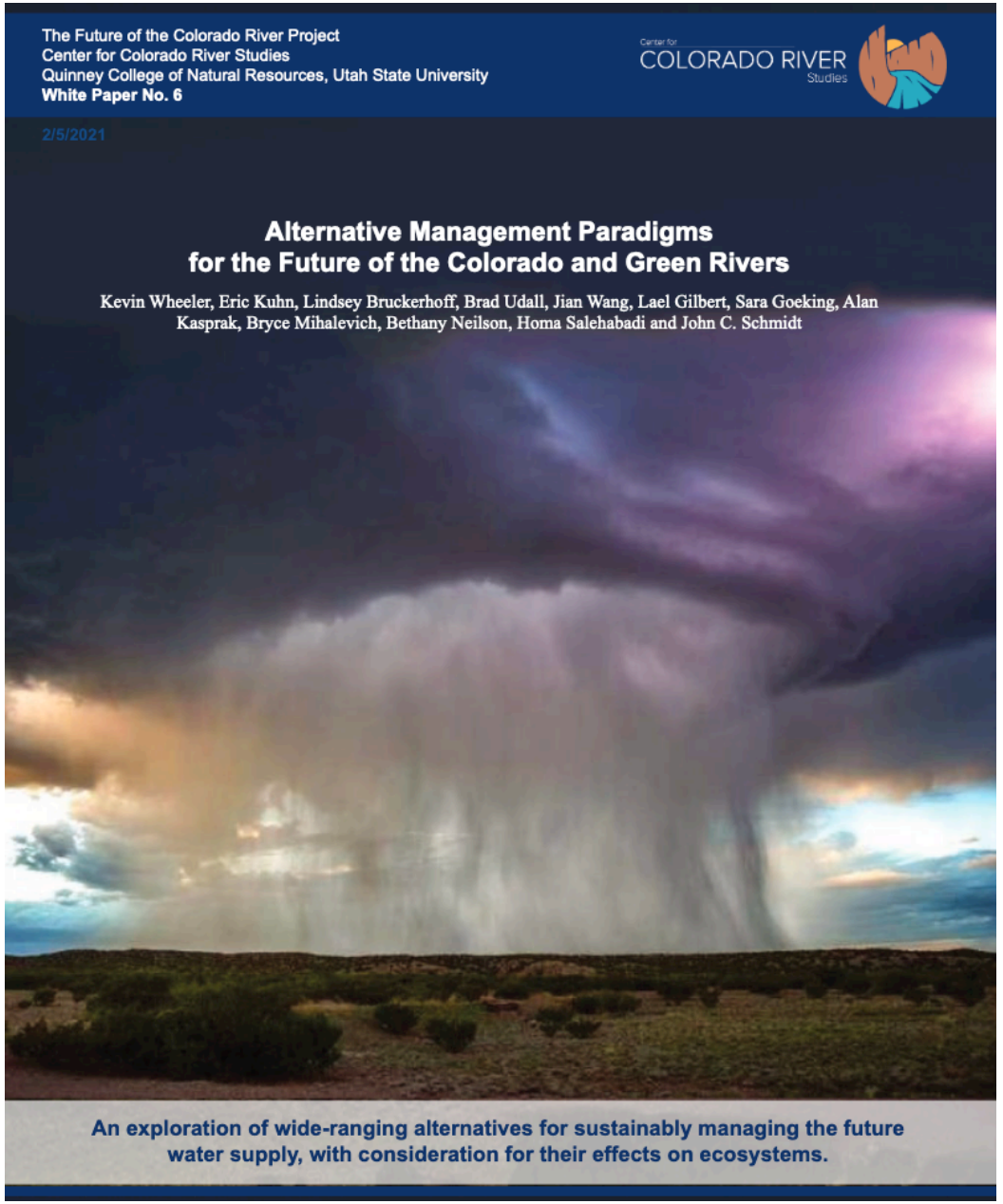
New Study by Futures of the Colorado River Project

Authors:

Kevin Wheeler - Oxford
Jack Schmidt – Utah State University
Plus many others

What:
Exploration of new ways to manage the Colorado River System

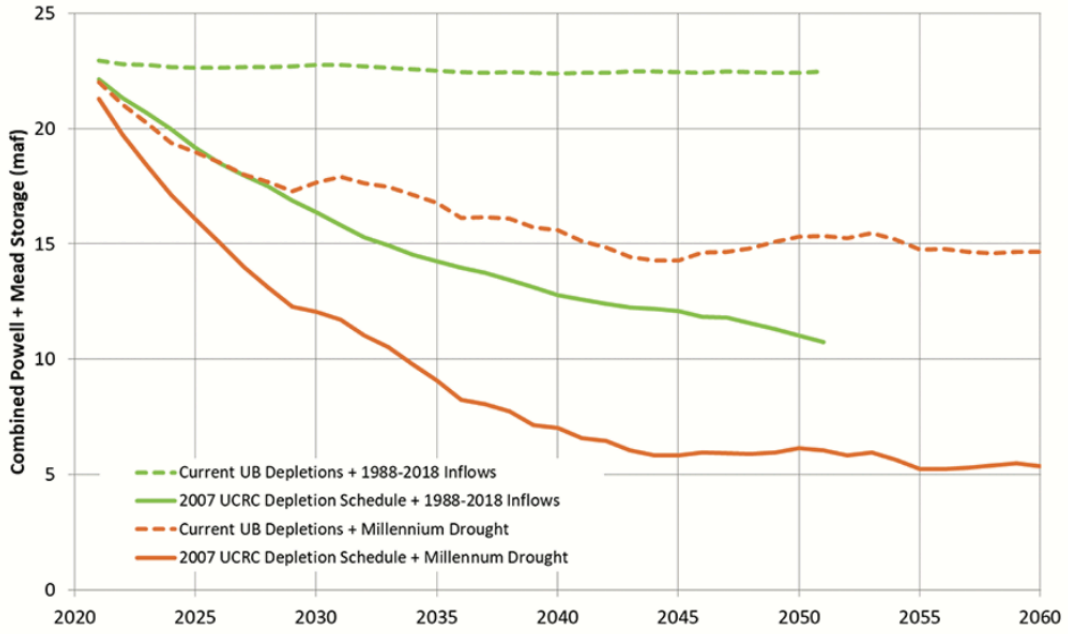
How:
Using the existing management model, different levels of future demands and potential river flows ("hydrologies"), explore reservoir levels, water deliveries and environmental outcomes



Key Findings

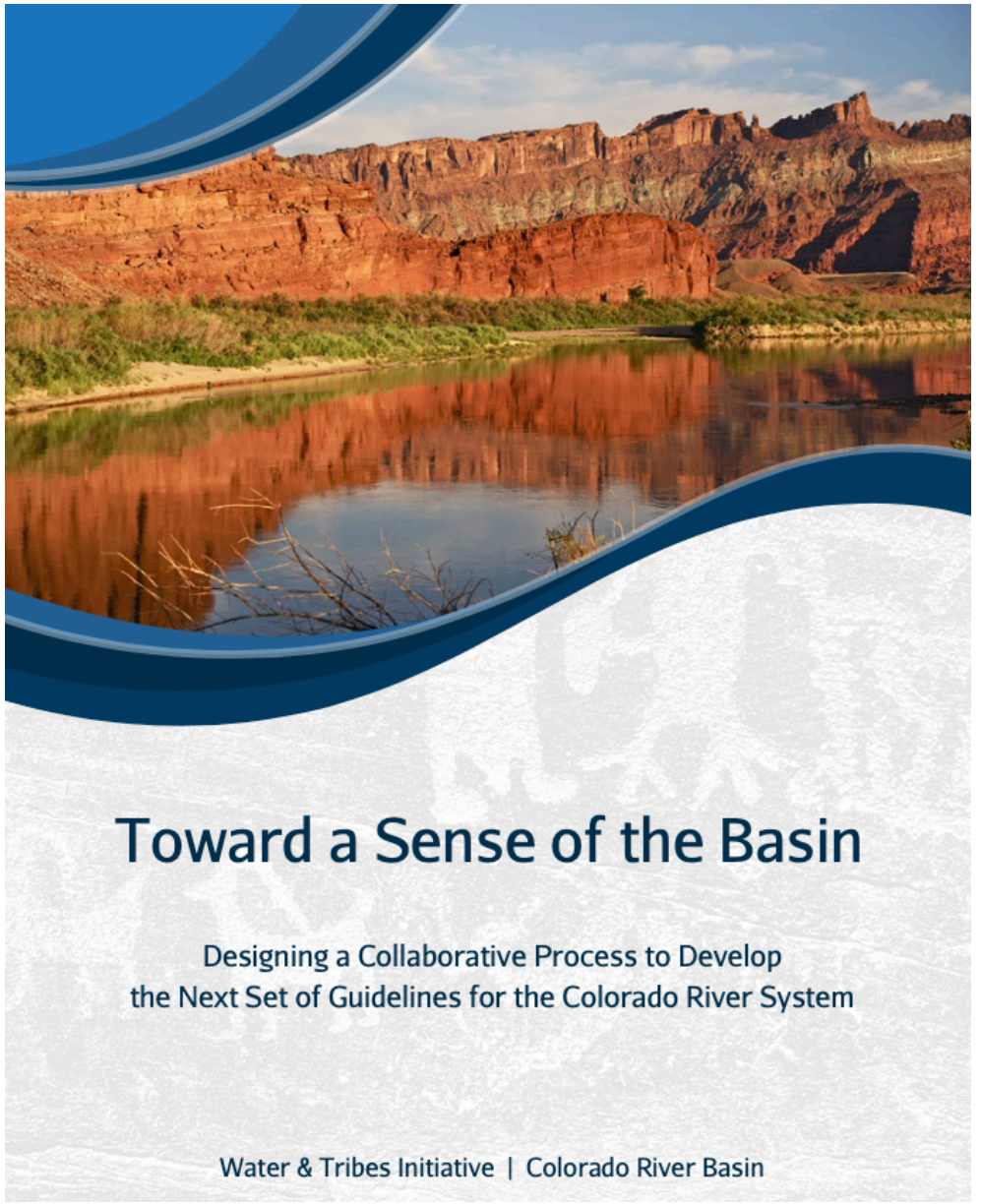
- Tenuous Supply – Demand Balance now
- A gradual and incremental approach won't work
- Upper Colorado River Commission Demands too high
- Combined Powell and Mead Storage should be the management metric
- Changes in Reservoir Operations will not solve the supply-demand imbalance
- Have control over demands but not over hydrology
- Consumptive water uses must be matched to available supplies
  - Requires Upper Basin limitations and substantially larger Lower Basin reductions than are currently envisaged
  - Without demand reductions, high probability of reservoirs falling to 15 maf or less

Combined reservoir storage comparing current depletions and 2007 UCRC Upper Basin depletion schedules under recent hydrologic conditions



Tribal Issues

- 29 Tribes
- Control ~20% of basin water
- Not part of 1922 Compact
- Many rights are unquantified 100+ years after 1908 Winters Doctrine
- Not invited to participate in 2007 process, nor in 2012 Basin Study.
- Needs and Rights ignored for far too long
- Without at least 1 Tribe, DCP would not have happened
- Very Different Individually, but now are engaging collectively



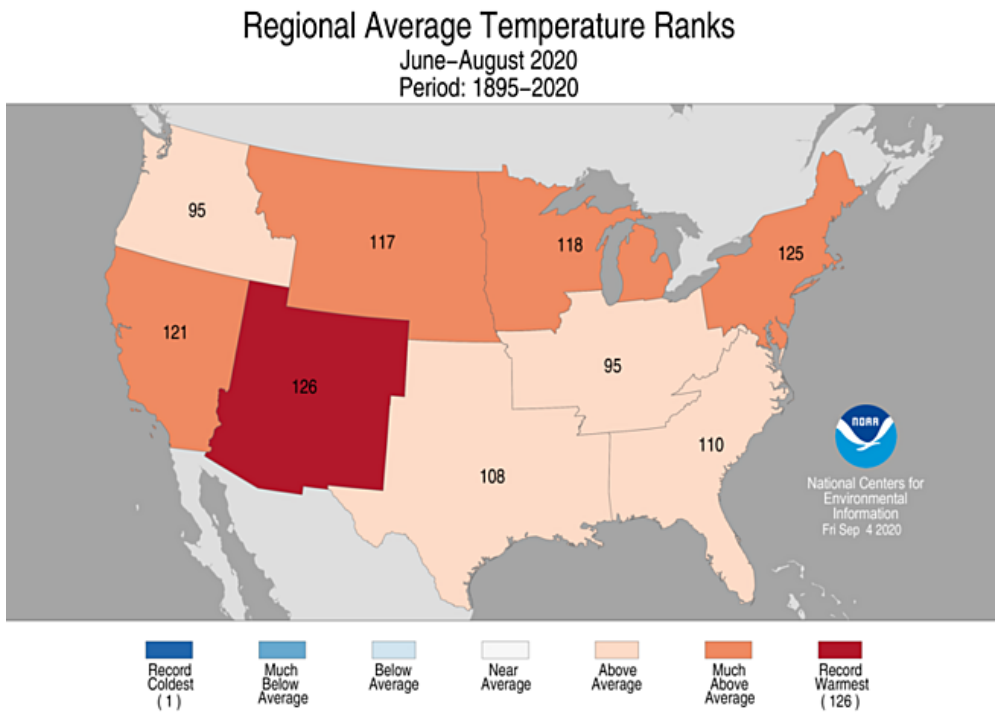
The Next Agreement…

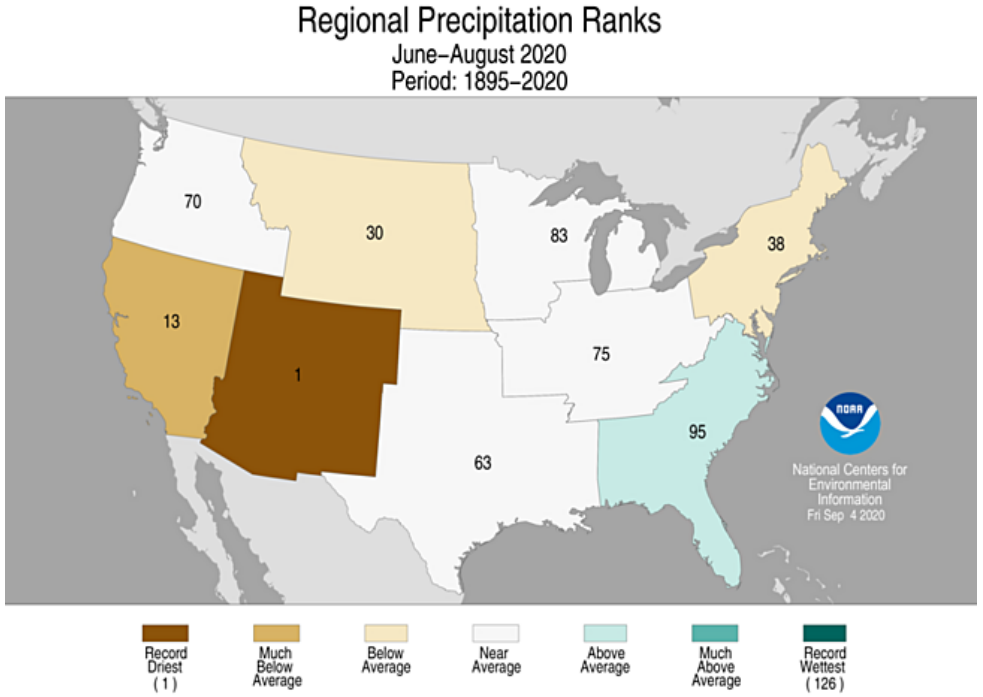
- IG + DCP Agreements in force thru 2026
- Negotiations underway
- Very Difficult Problems
  - Lower Basin Overuse
  - Upper Basin Delivery “Obligation”
  - Upper Basin Desire to Increase Demands
  - Tribal Needs and Equity
  - Declining Flows
- Many Parties
  - 7 states, 29 Tribes, Mexico, Federal Government
- Solutions not at all clear
  - But good working relationships
  - Important Role for Tribes

DCP Signing Ceremony at Hoover Dam

Process Thoughts

- Language is Critical
  - E.g. can't say 'renegotiate the Compact'
- Good Modeling to support
  - Representative Hydrology down to 10 maf/year (last 20 years = 12.4 maf/year)
  - Representative Demands
- Room for behind-the-scenes discussions while also having transparency
- Full EIS with ROD at End





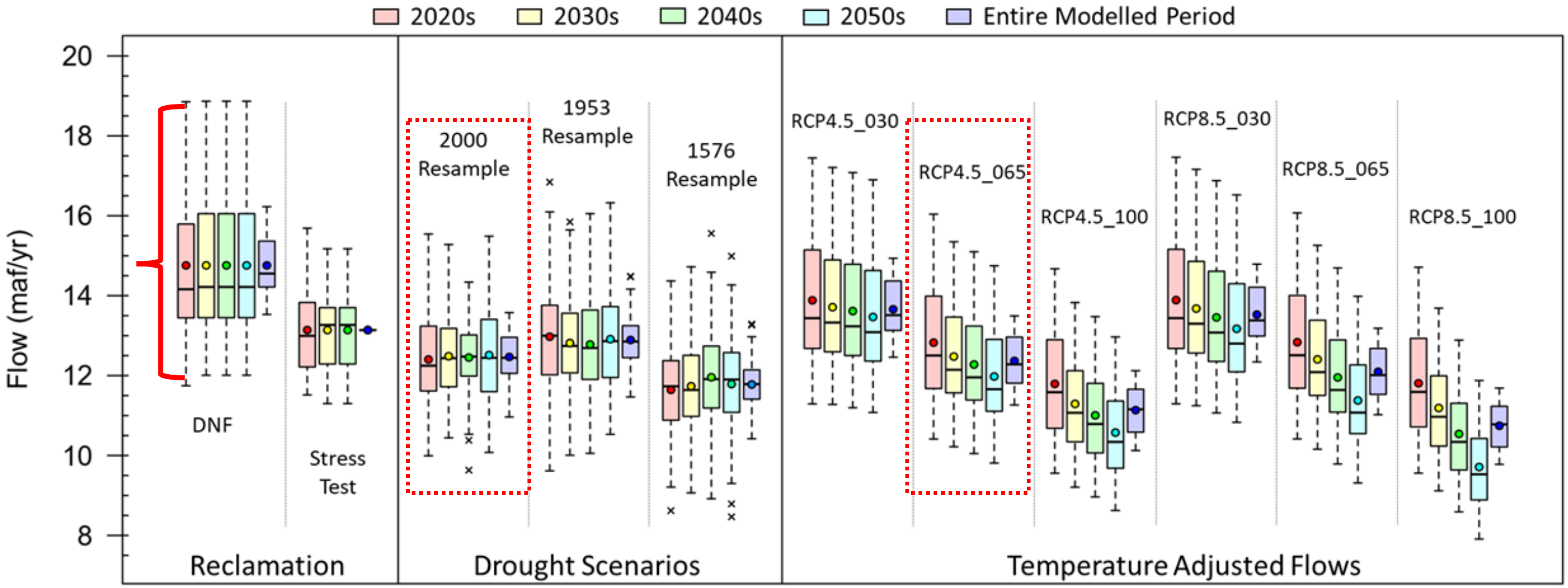
Solution Thoughts

- Political Process informed by Science
- Balancing of Economics, Environment, Societal Values
- “Demand Management”
  - Where possible Voluntary $$ for Water
- Upper Basin Demand Caps / Delivery ”Obligation”
- Lower Basin Demand Cuts
  - Cannot be exclusively on AZ
  - Charge Evaporation to States based on use
- Use Total System Storage for Lower Basin Allocations
- Expansion of Demands = Self-Inflicted Wounds
- Some Adaptive Measures over Time
  - To deal with difficult futures
- Despite all the challenges, I am optimistic


Pine Gulch Fire, 2020


Cameron Peak Fire, 2020

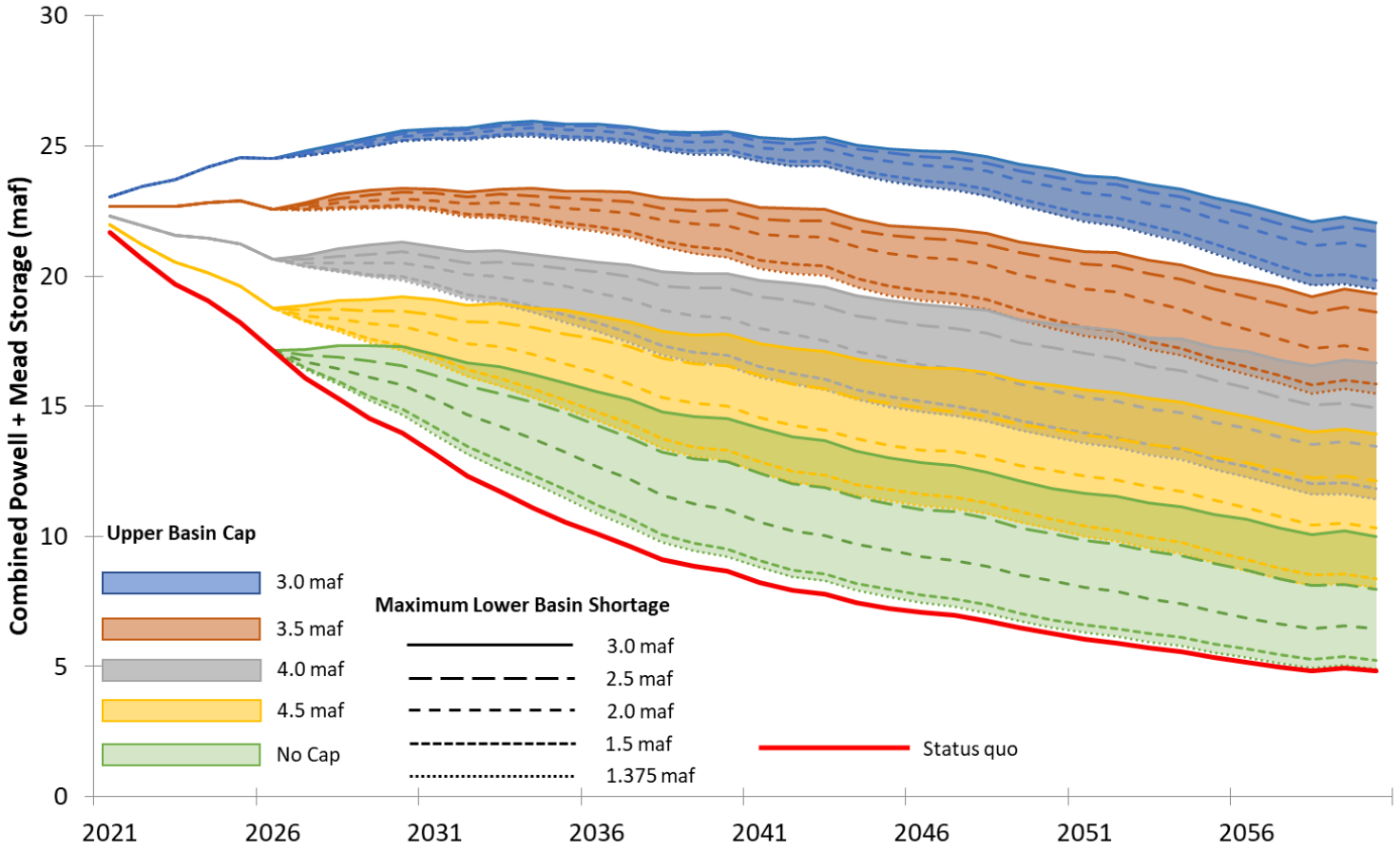
Plausible Hydrologic Futures



So what would it take to actually balance demands to match supplies if dryer conditions prevail?

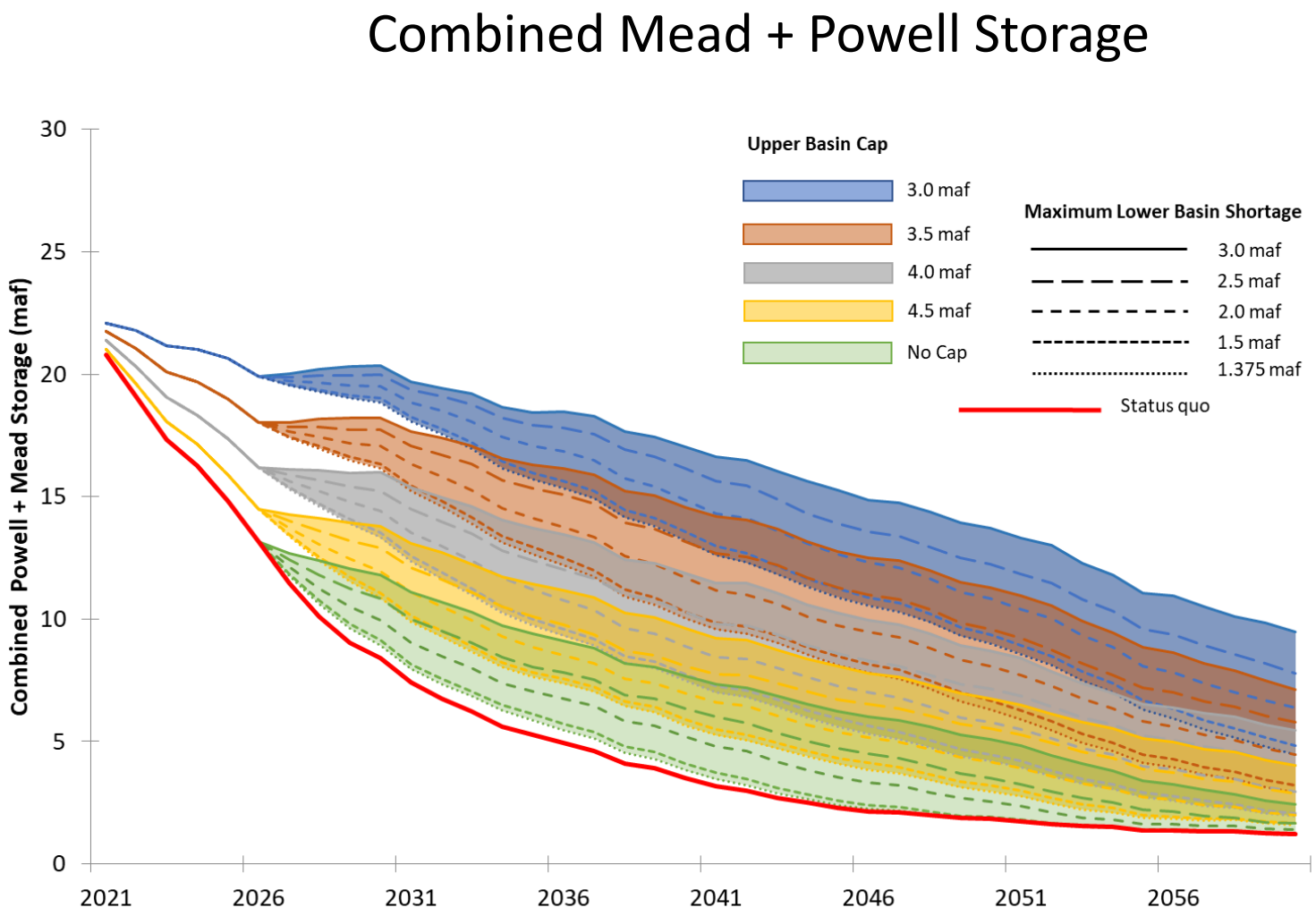
RCP4.5 – 6.5% / Deg C Hydrology

Combined Mead + Powell Storage



So what would it take to actually balance demands to match supplies if dryer conditions prevail?

RCP8.5 – 10% / Deg C Hydrology



State of Colorado Demand Management

Reductions in Consumptive Use for Compact Compliance

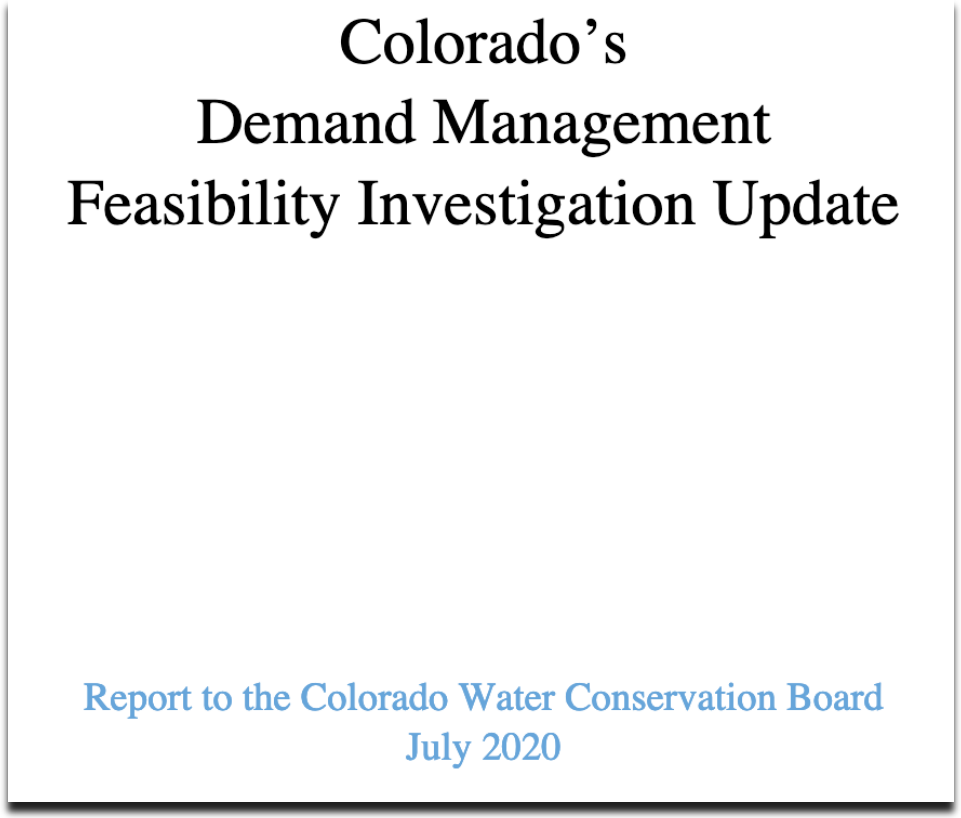
Part of 2019 DCP Agreement

Reductions must be:

- Voluntary
- Temporary
- Compensated

- Complicated !
  - On Farm and Off Farm Impacts
  - Local Economic Impacts

- Federal CRP and Pilot Lease-Fallowing are somewhat similar



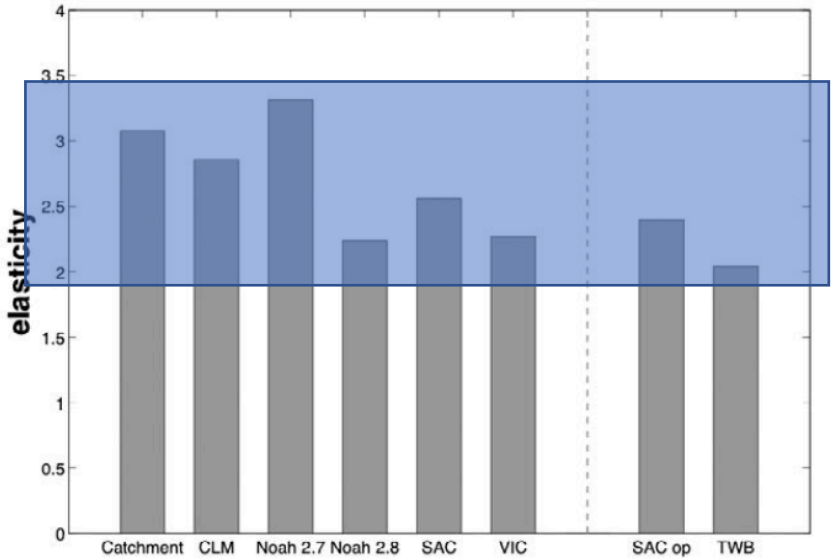
8 Key CRB Climate Change Studies Last 8 Years

- Understanding Uncertainties in Colorado River Streamflows
  - Vano et al., 2014
- The Importance of Warm Season Warming to Western US streamflow changes
  - Das et al., 2011
- Increasing Influence of Air Temperature on Upper Colorado River Streamflow
  - Woodhouse, 2016
- The Colorado River Hot Drought and Implications for the Future
  - Udall & Overpeck, 2017
- On the Causes of Declining Colorado River Flows
  - Xiao, Udall and Lettenmaier, 2018
- Climate-Driven Disturbances in the San Juan River sub-basin of the Colorado River
  - Bennett et al., 2018
- Causes for the Century-Long Decline in Colorado River Flow
  - Hoerling et al., 2019
- Chris Milly new study on Temperature Sensitivity
  - Under Review, 2020

UNDERSTANDING UNCERTAINTIES IN FUTURE COLORADO RIVER STREAMFLOW

BY JULIE A. VANO, BRADLEY UDALL, DANIEL R. CAYAN, JONATHAN T. OVERPECK, LEVI D. BREKKE, TAPASH DAS, HOLLY C. HARTMANN, HUGO G. HIDALGO, MARTIN HOERLING, GREGORY J. MCCABE, KIYOMI MORINO, ROBERT S. WEBB, KEVIN WERNER, AND DENNIS P. LETTENMAIER

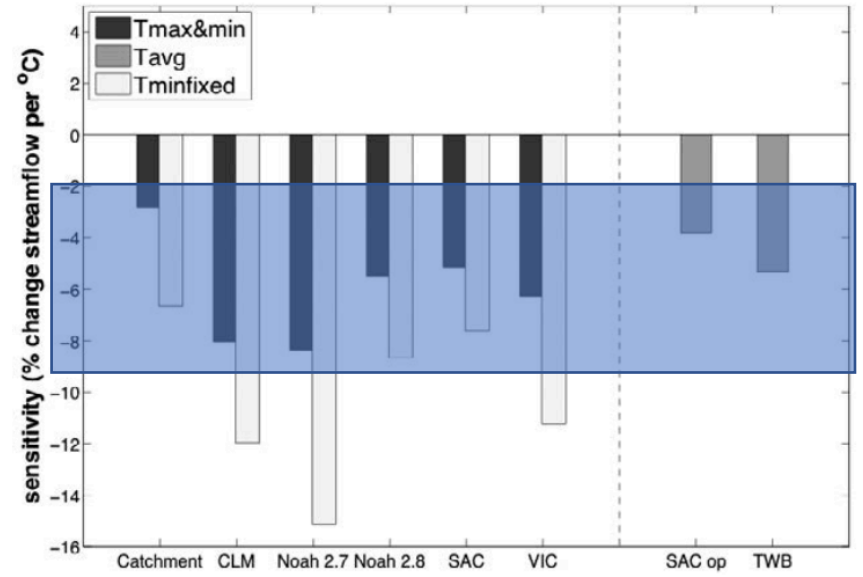
A synthesis of studies on Colorado River streamflow projections that examines methodological and model differences and their implications for water management.



- Introduced 2 key concepts (among many other things)

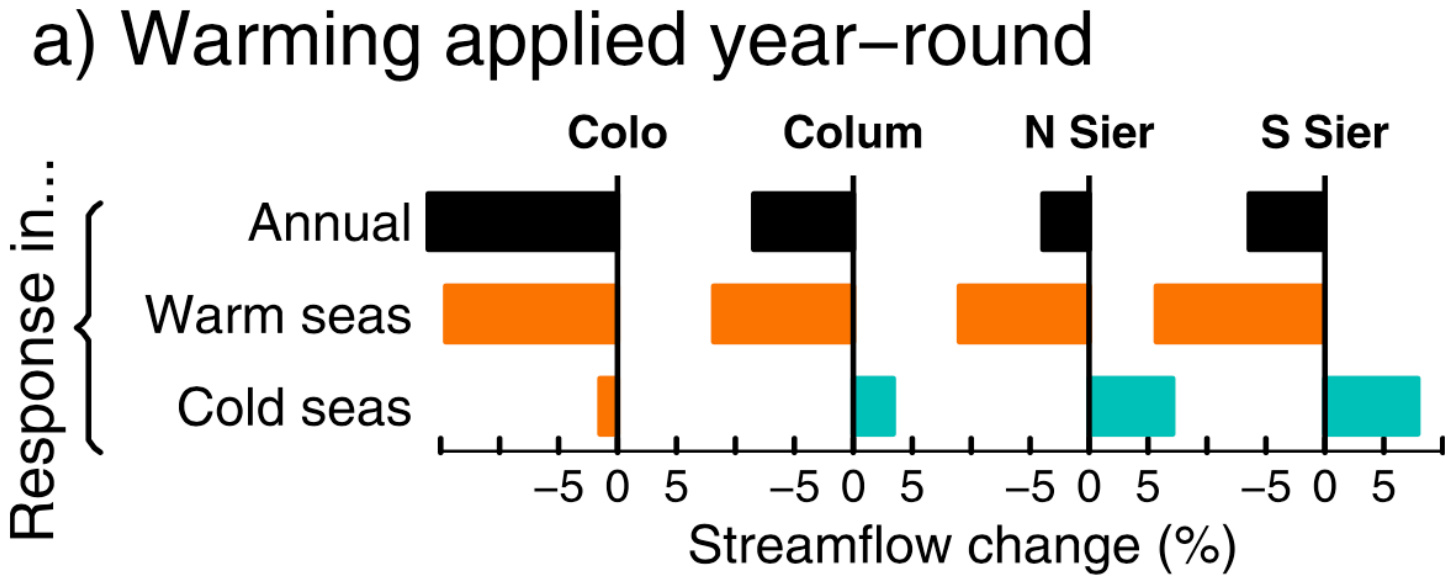
- Precipitation Elasticity
  - Ratio of the change in runoff to a 1% change in precipitation
  - Approximately 2 to 3 (unitless number)
  - 2 means 1% change in precip means 2% change in runoff

- Temperature Sensitivity
  - Reduction in flow (as %) to 1°C temperature rise
  - Approximately -3 % to -10 % / °C
  - Always negative (implies flow loss)
  - With 1°C rise, -5%/C sensitivity means 5% flow loss

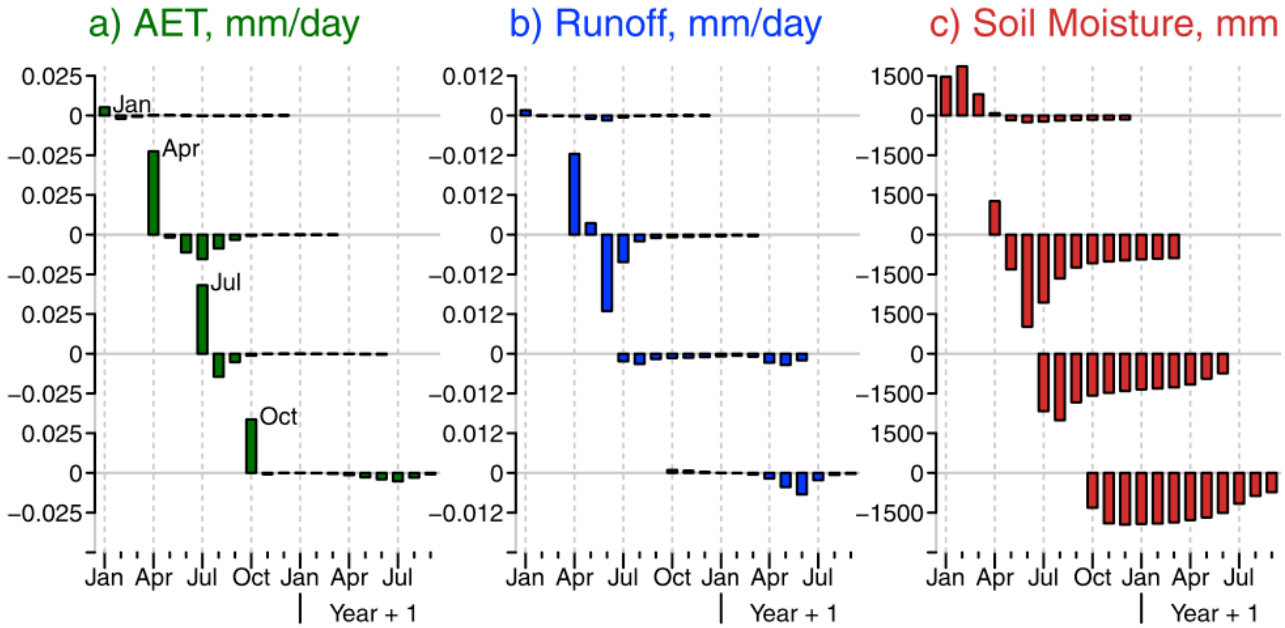


The importance of warm season warming to western U.S. streamflow changes

Tapash Das,[1,2] David W. Pierce,[1] Daniel R. Cayan,[1,3] Julie A. Vano,[4] and Dennis P. Lettenmaier[4]



- Hydrology Model Study over 4 Big Western River Basins
  - Warming applied by single month/season
- CRB most sensitive to annual warming: -16% flow loss with 3C warming (implies ~5%/°C loss)
- Summer Warming most important.
  - Affects flow that summer and following summer via soil moisture deficits.



Causes for the Century-Long Decline in Colorado River Flow

Hoerling, Barsugli, Livneh, Eischeid, Quan, Badger, 2019

Sophisticated Multi-model Multi-Ensemble GCM Effort with and without added greenhouse gasses

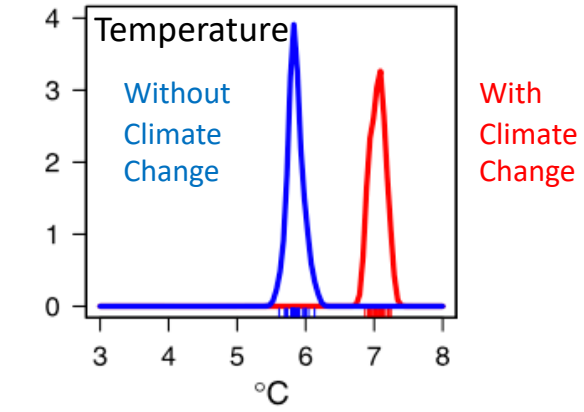
- 20% Flow Decline over last century
- 50% of that due to climate change (i.e. 10% flow loss)
- Climate models show 1.2°C warming and 3% precip decline

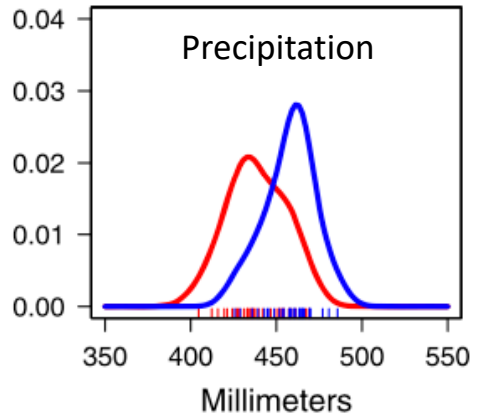
- Precipitation Elasticity of ~ 2
- Temperature Sensitivity of ~ -2.8% to -7% /°C

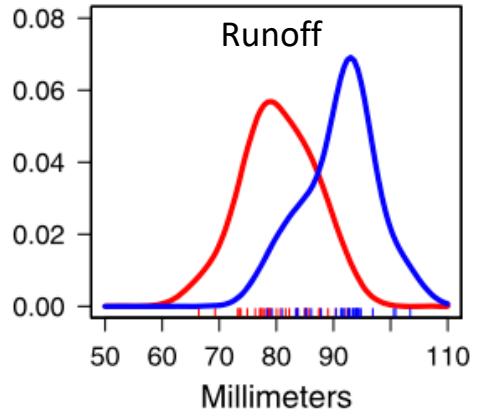
- Warming is 1/3 of the decline (~3 % of flow)
- Precipitation Loss is 2/3 of decline (~7 % of flow)

- What's New:
- 1. Attribution of 1981- 2010 precipitation decline to climate change
- 2. Lower Temperature Sensitivity

Climate Model Results 1981-2010





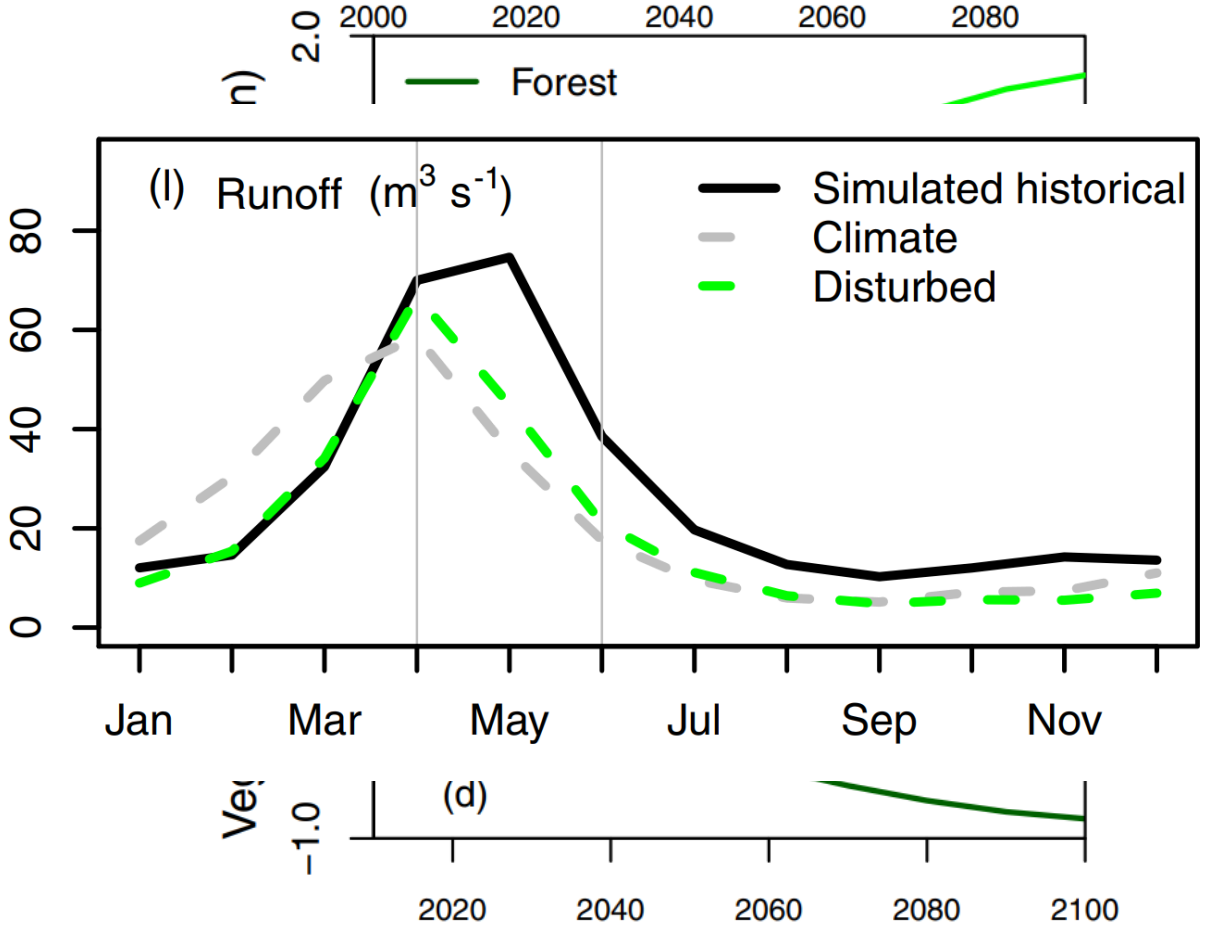


Climate-driven disturbances in the San Juan River sub-basin of the Colorado River

January, 2018

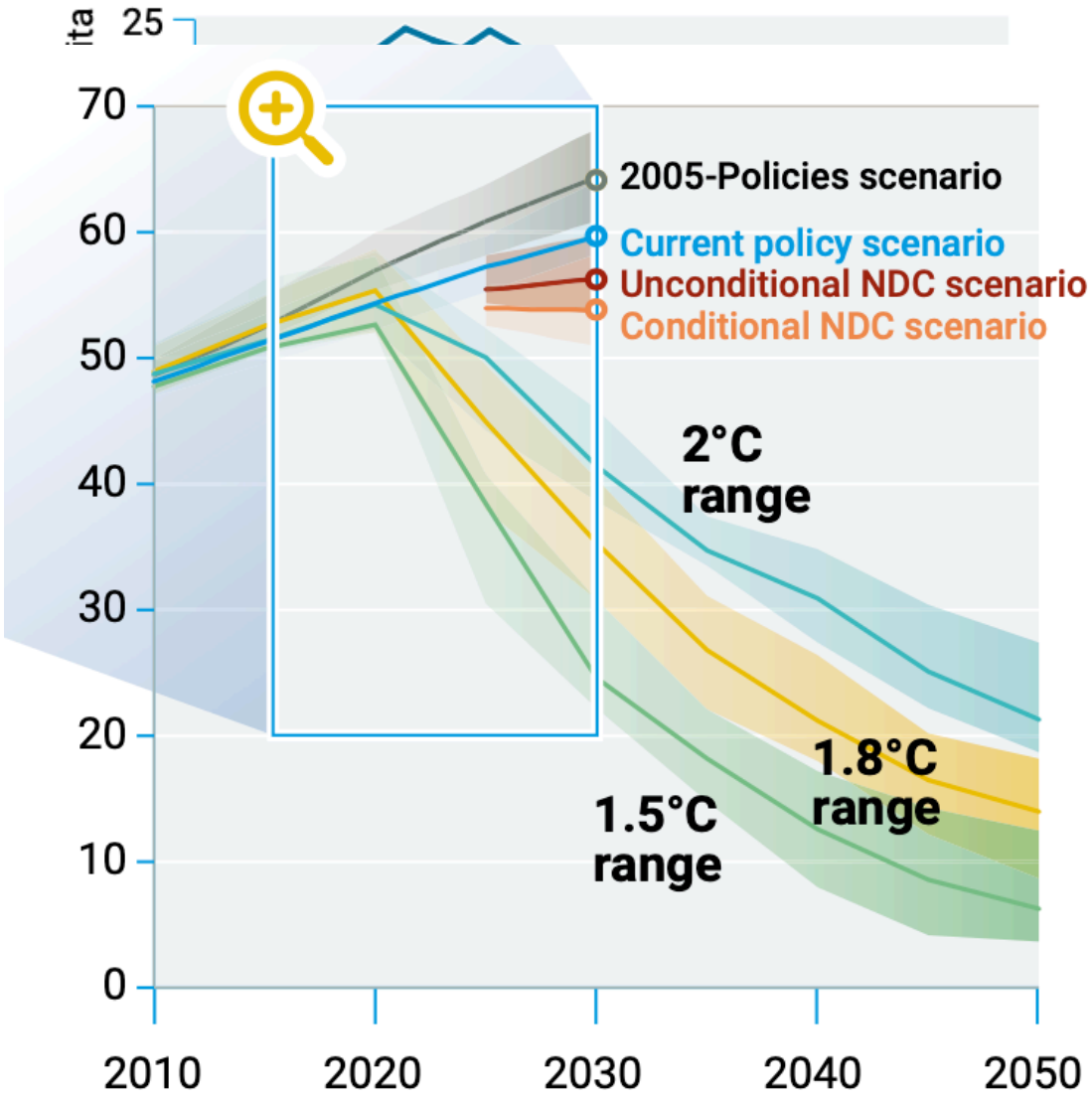
Katrina E. Bennett[1], Theodore J. Bohn[2,3], Kurt Solander[1], Nathan G. McDowell[1,a], Chonggang Xu[1], Enrique Vivoni[3,4], and Richard S. Middleton[1]

- Wildfire, Drought, Pests expected to change forests significantly – lots of shrubs to replace trees
- Few studies quantify both climate change and land cover disturbance
- 'Robustly calibrated' VIC Model
- End-century streamflow is at least 6-11% lower than climate change only



Adapting is not enough

- US now 2nd largest emitter on annual basis
- US largest cumulative emitter by far
- US per capita emissions 2x China, Europe, 4x India
- Emissions continue to rise but solution requires net zero emissions ASAP
- Enormous Gap between 2°C Target and current path (~3.2 °C) (CRB / Land Higher)
- World Leadership Desperately Needed
- Inaction will be increasingly expensive



UN Emissions Gap Report, 2019