Colorado River 21st Century Challenges

GE 592
Professor Jennifer Gimbel
September 12, 2022

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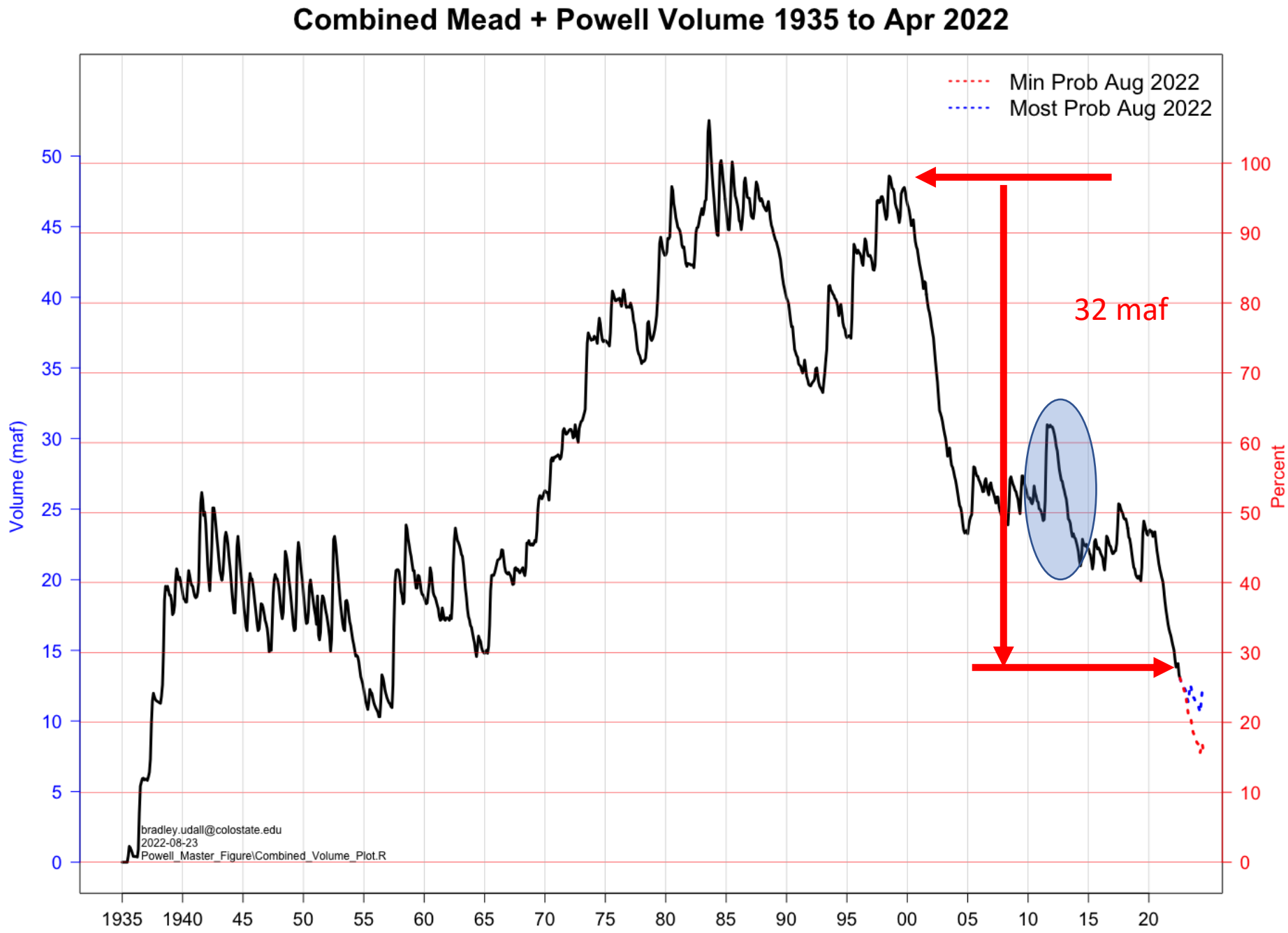
Bullfrog Marina Car Ferry Ramp (closed)
October 2021

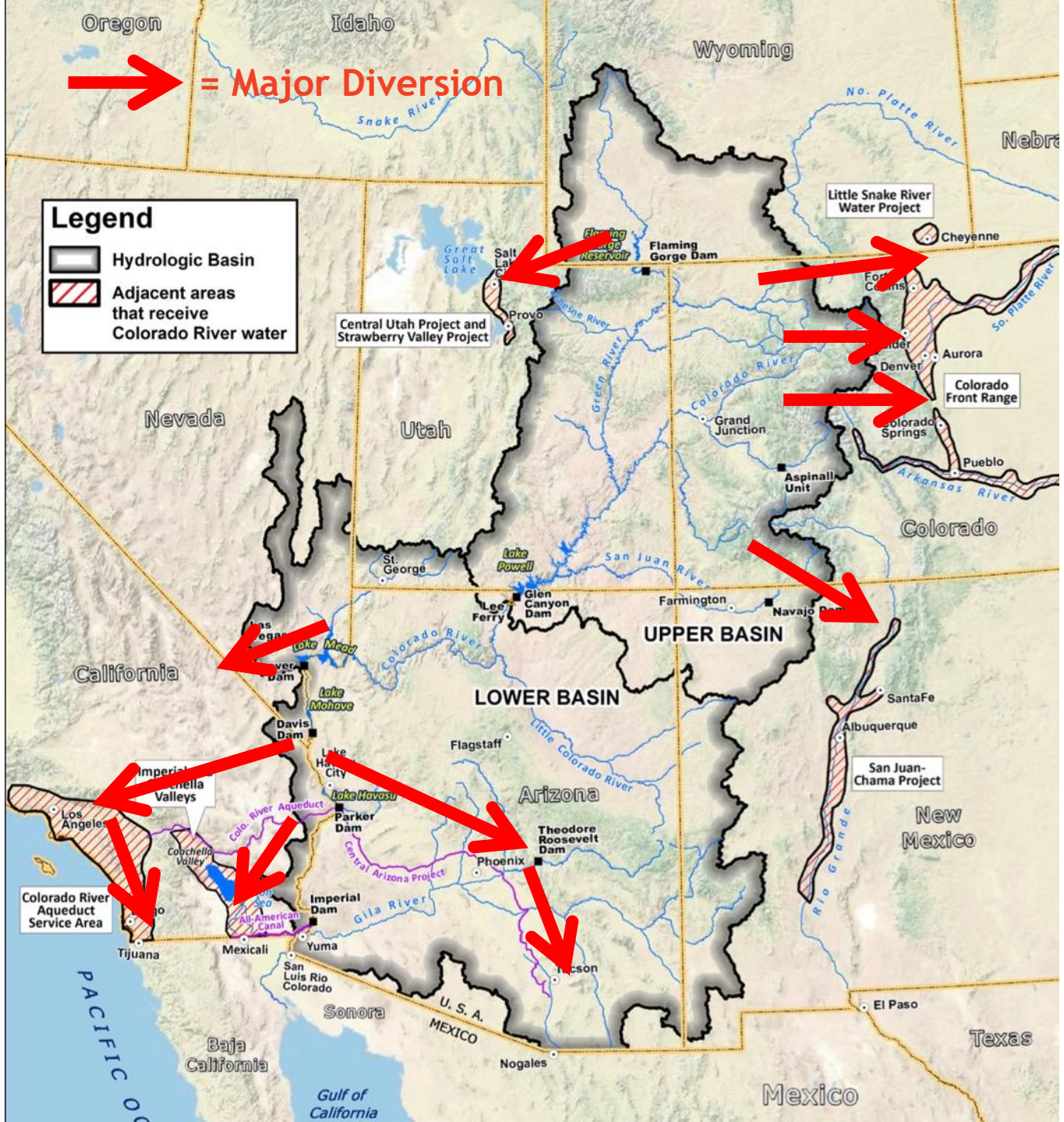
Bullfrog Car Ferry Ramp

- Jan 2000: Powell+Mead 95% Full, 47 MAF
- By April 2022: Powell+Mead less than 30% Full, 15 MAF
- Loss of 32 MAF or 1.4 MAF/Year



Colorado River

- 7 States, 2 Nations, 30 Tribes
- 8% of area of the Lower 48
- Annual Flow ~14.75 MAF
  = Hudson River
- Worst drought in gaged record started 2000 ~12.3 MAF/yr
  = ~19% decline annually
- 40 M People
- All of the Major Cities in SW US
- 4.5m Irrigated Acres
- Fully Allocated in 1922
- Withdrawals equaled Supplies ~2000
- New Projects still contemplated
- No longer reaches the ocean
- Feds Announce 2-4 maf reductions in June 2022 for 2023 and beyond



Lake Mead will fall below 1075’ on January 1, 2022, triggering first-ever ‘Tier 1’ water shortage in Lower Basin…..

circle of blue
where water speaks

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The Colorado River Basin’s Daunting New Math

The basin’s big reservoirs have fallen to uncharted territory. The forecast isn’t any better.

August 13, 2021

The Economist

Menu Weekly edition Search

United States
Aug 21st 2021 edition ›

Low and dry

The American West is drying up

The effects of climate change are being exacerbated by a century of bad policy

August 21, 2021

The Washington Post
Democracy Dies in Darkness

National

First-ever water shortage declared on the Colorado River, triggering water cuts for some states in the West

August 16, 2021

August 21, 2021

Los Angeles Times

CLIMATE & ENVIRONMENT

As drought crisis deepens, government will release less water from Colorado River reservoir

Citing extreme drought, the government has announced reduced water releases from Lake Powell and Glen Canyon Dam by nearly half a million acre-feet.

May 3, 2022

Los Angeles Times

CLIMATE & ENVIRONMENT

As water crisis worsens on Colorado River, an urgent call for Western states to ‘act now’

The federal government is telling seven states to make plans for drastically cutting water use along the Colorado River within two months.

June 20, 2022

Los Angeles Times

CALIFORNIA

They sounded alarms about a coming Colorado River crisis. But warnings went unheeded

Years ago, scientists said climate change would bring a Colorado River crisis. Their warnings, which largely went unheeded, are now playing out.

July 15, 2022

Los Angeles Times

CLIMATE & ENVIRONMENT

Shut out from talks on Colorado River crisis, tribes want inclusion and ‘transformation’

An Indigenous leader says the 30 tribes along the Colorado River need to be included ‘at the decision-making table’ as the West grapples with drought.

July 21, 2022

Los Angeles Times

WORLD & NATION

Today's Headlines: U.S. imposes new restrictions as talks on Colorado River water grow heated

The U.S. Bureau of Reclamation announced new restrictions for Arizona, Nevada and Mexico as the nation's two largest reservoirs hit perilously low levels.

Aug. 17, 2022

Recent Statements from the 3 Lower Basin States

Nevada: “Yet despite the obvious urgency of the situation, the last sixty-two days produced exactly nothing in terms of meaningful collective action to help forestall the looming crisis”.

Arizona: “It is unacceptable for Arizona to carry a disproportionate burden of reductions for the benefit of others who have not contributed.”

Southern California: even though “the Basin States have not yet agreed on a consensus-based solution to address declining reservoir elevations, California will continue implementing additional conservation programs in 2023 that result in meaningful water contributions to the system.”

Overview

- Every Trend in Wrong Direction
- How can 85% Snowpack -> 30% Runoff?
- Recent Scientific Studies
- Not a Drought, Not New Normal
- Worrisome Projections
- What to Plan For?

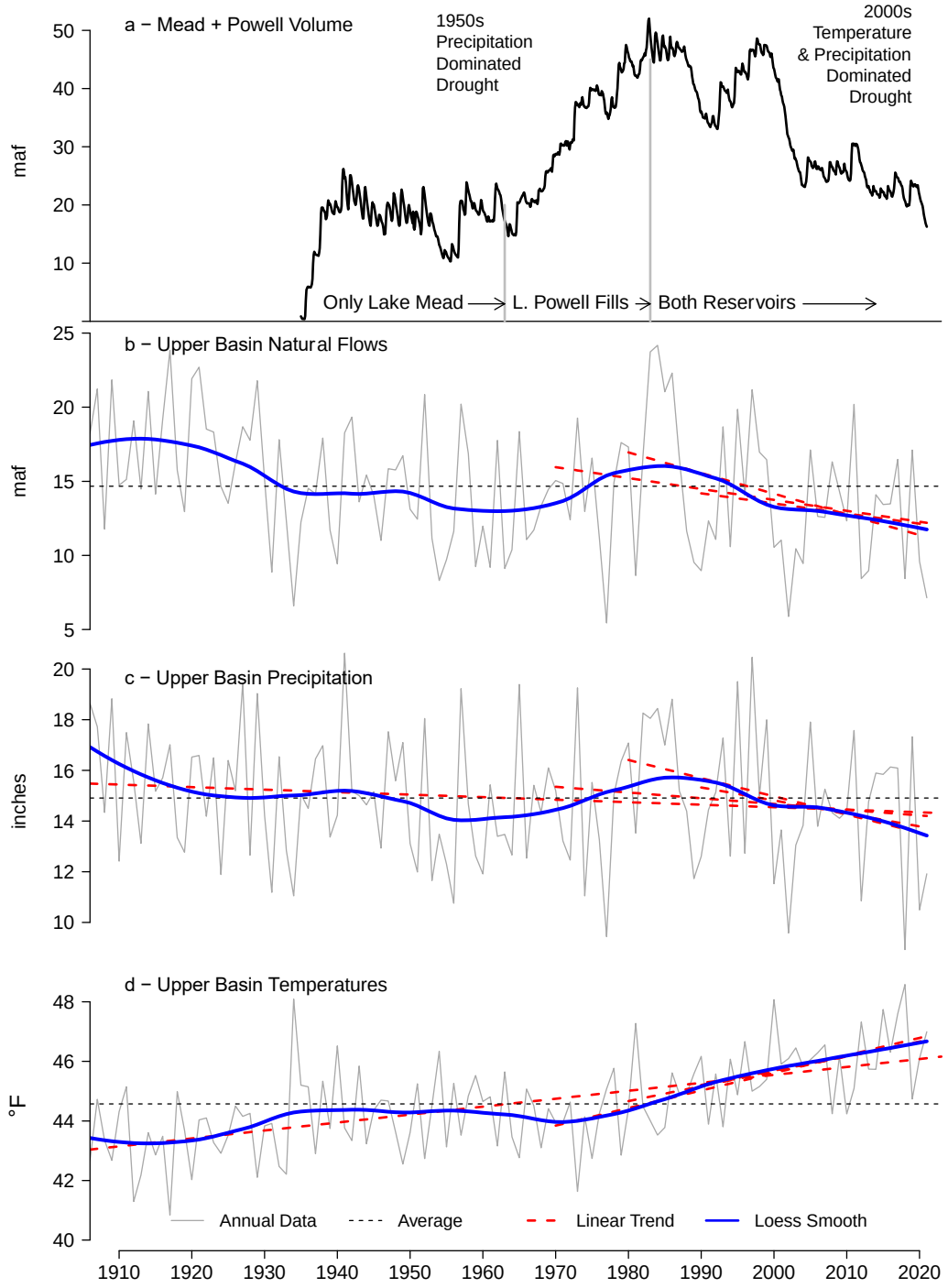
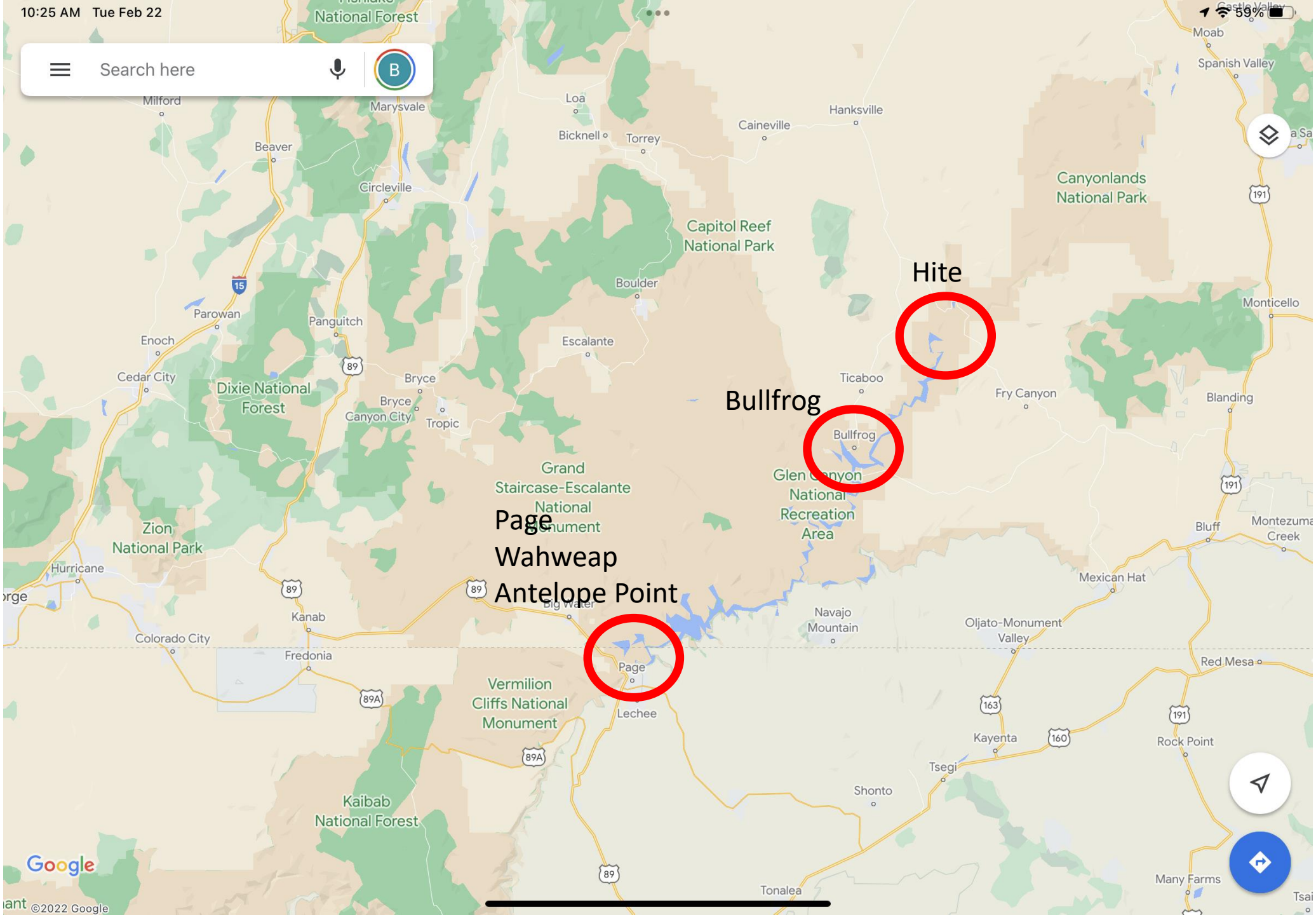


Figure: Udall and Overpeck, 2017 updated through water year 2021.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Glen Canyon National Recreation Area
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Zion National Park
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Hanksville
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Milford
Marysvale
Moab
Spanish Valley
Castle Valley
Montezuma Creek
Red Mesa
Google
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Paired Lake Powell Photos near Hite, UT, 22 Years Apart

Lake Powell ~2000 Full Pool

Lake Powell October 2021 155’ Low


Hite Boat Ramp


ROAD
CLOSED
End of Hite Boat Ramp

Lee Ferry Natural Flow Declines 2000-21

Last 22 Years: How Different from 1906-99?

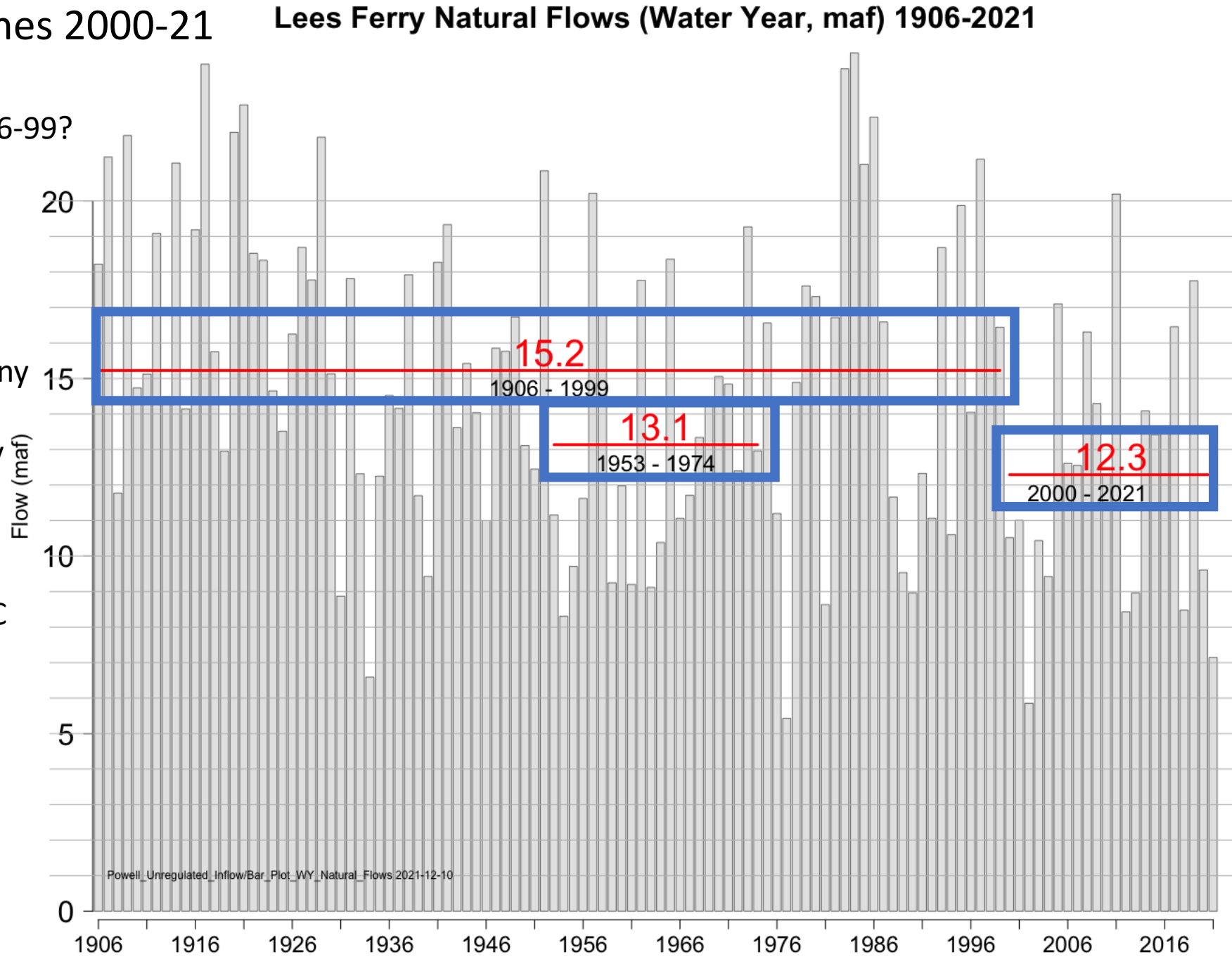
Mean: 15.2 maf vs 12.3 maf (-19%)

High Flow Years (>15 maf): ½ as many

Low Flow Years (<10 maf): 2.5x as many

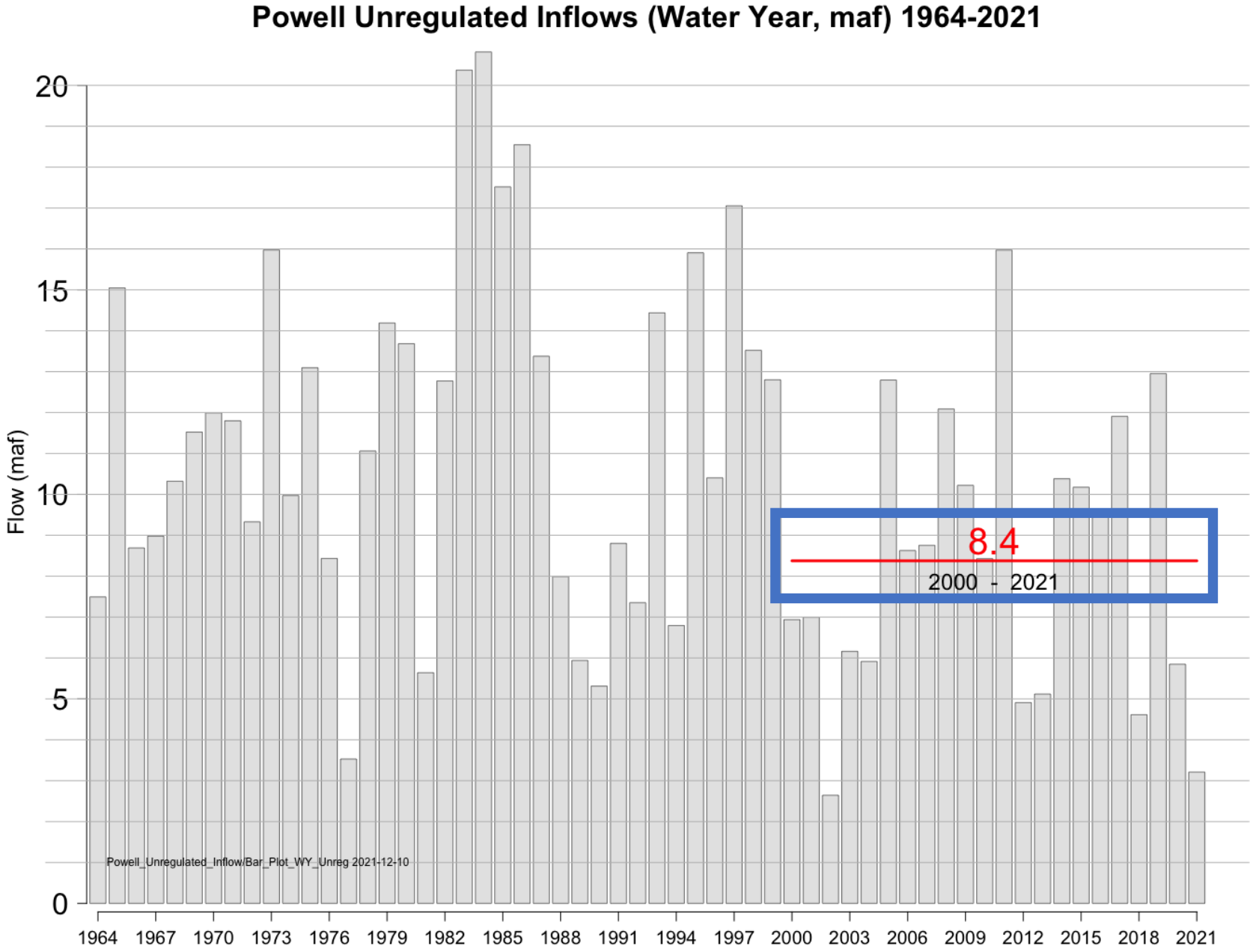
If Worst 22-Year Period in 20th Century had repeated, reservoirs would be 55% full, not 27% full.

Take Home: Last 22 Years has no 20th C Analog. It is completely different.



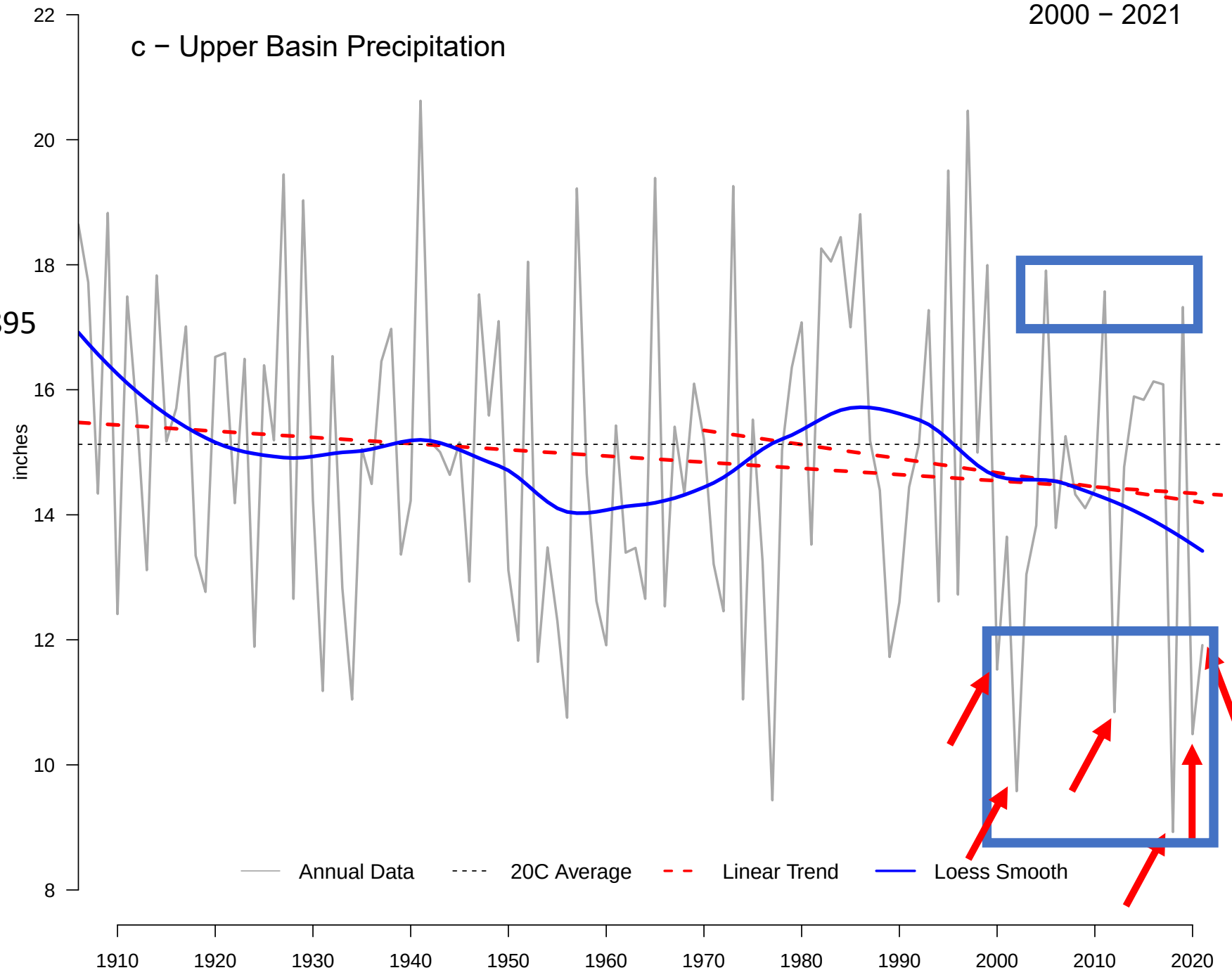
Unregulated Inflows into Powell 2000-2021

- Actual Inflows into Powell with effects of Upstream Reservoir Operations Removed
- If you added Upper Basin Demands to these flows you'd have ~ "Natural Flows"
- 2000-2021 Average is 8.4 maf/year
- Take Home: This is less than the commonly accepted Colorado River Compact amount that is required for delivery to the Lower Basin. Reservoir releases have made up the difference.



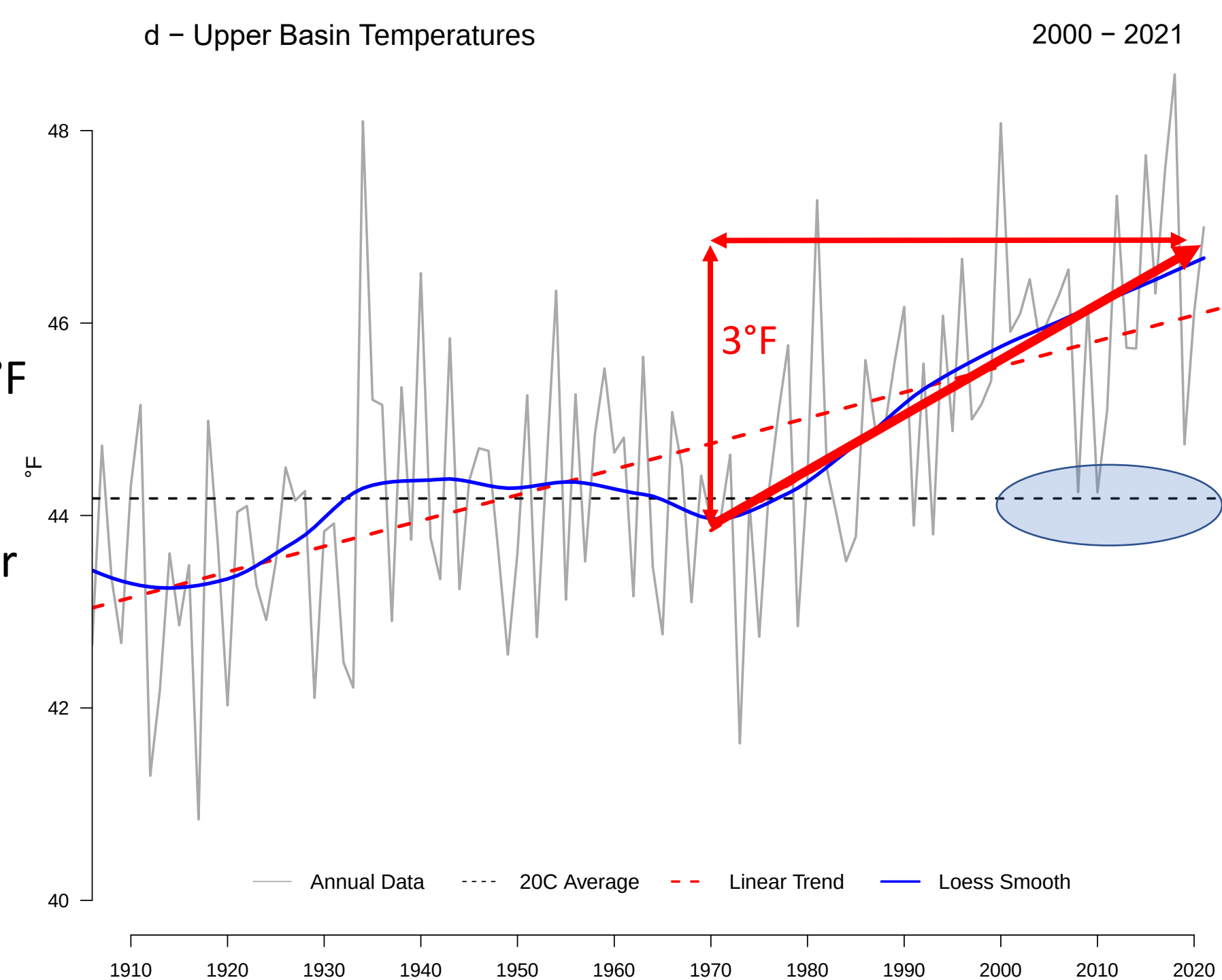
Precipitation Declines 2000-21

- Worst 22-Year Running Average
- Lows are record-setting, numerous
  - 2018 Bottom 10 - Worst since 1895
  - 2020 Bottom 10
  - 2021 Bottom 20
  - 2012 Bottom 10
  - 2002 Bottom 10
  - 2000 Bottom 20
- 1/3 of Years are bottom 20
- Highs are Lower than many 20th Century Highs



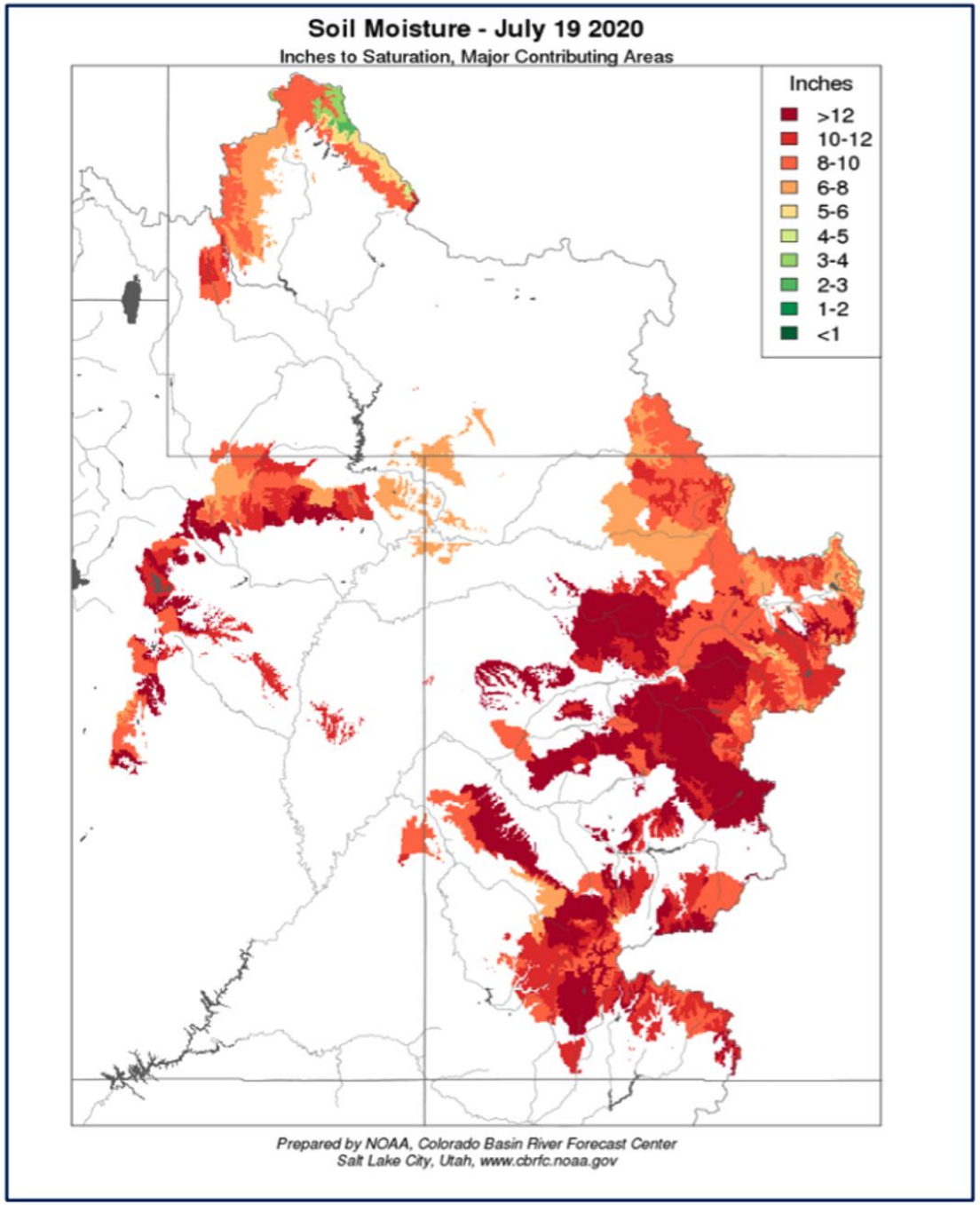
Large Temperature Trends since 1970

- Temperatures up ~ 3°F (1.7°C) since 1970
- Not a single year after 1999 below 20th Century Average

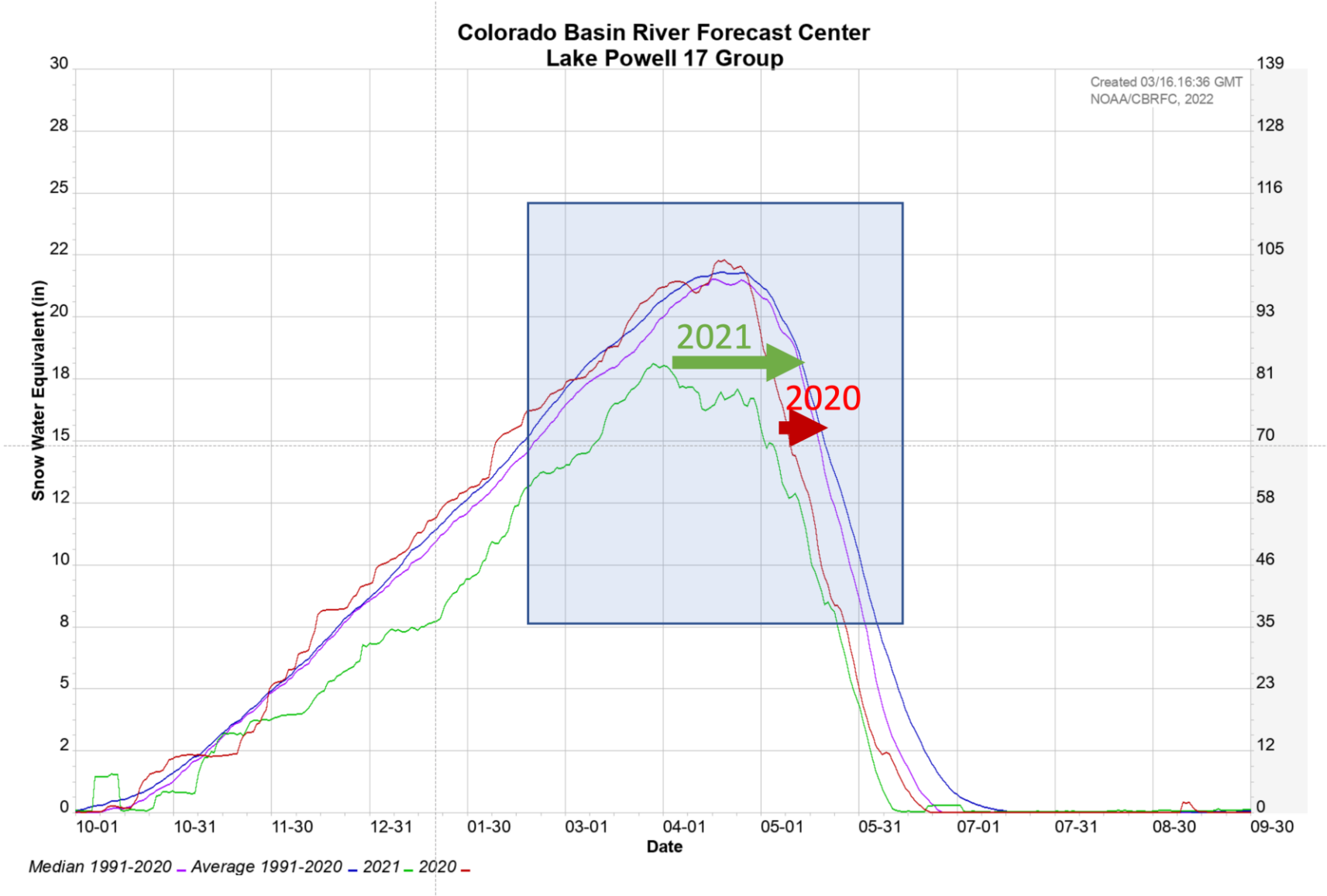


How can 85% April 1 Snowpack -> 30% Runoff?

- 20th C: Only Winter Precipitation Mattered
- But UCRB Precipitation falls evenly every month
- Since 2000 Precipitation Declines:
  - Small Decline Oct-Feb
  - Large Declines Mar+Apr and Jun+Jul+Aug
- March+April declines allows early runoff + early greenup
- Jun+Jul+Aug declines + High Temps dry out soils
- Answer + Insights:
  - Previous Year Dry + Hot Summers along with Early Springs sharply reduce runoff
  - Dry soil moisture serves as a memory from one year to the next
  - Summer Precipitation is important!

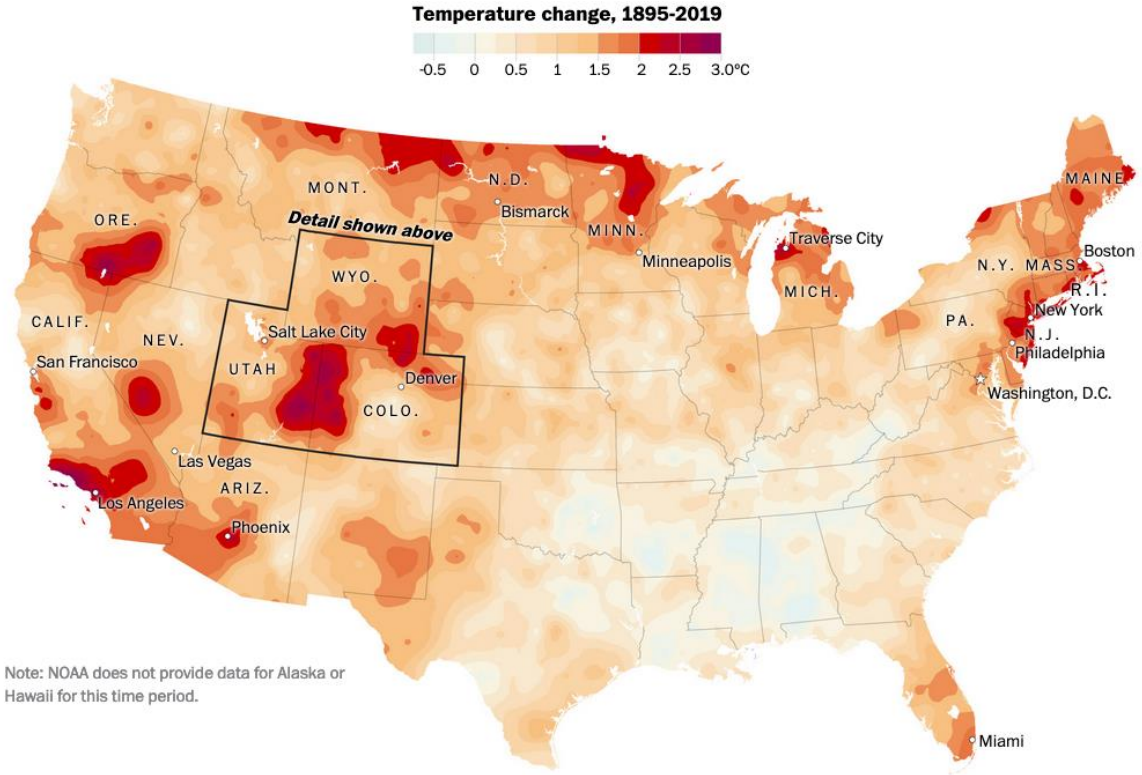


2 to 6 Week Early Runoff Allows earlier Greenup



Why are the 21st Century flows so different?

- 1. Temperature Increases
  - Increased Evaporation / Transpiration
  - Proven Connection to Climate Change (-9% flow loss / 1 °C Increase)
- 2. Precipitation Decreases
  - 2000-21 worst 22-Year Period for Precipitation
  - Summer Precip Declines are critical
  - Hints of Connection to Climate Change
    - Hoerling et al., 2019



The Washington Post

Recent CRB Peer-Reviewed Studies

- Snowpack - 2021
- Groundwater - 2021
- Precipitation Declines are Human Caused - 2019
- Flow Loss is up to -9% / °C Warming - 2020
- Summer Soil Moisture 2nd worst in 1200 Years -2020
- Runoff Efficiency is down since 1988 - 2016
- Up to Half of Flow Loss due to Humans (4 papers)

Water Resources Research

RESEARCH ARTICLE
10.1002/2016WR019638

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

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

Key Points:
- Record Colorado River flow
- by the end of tl
- despite potenti
- precipitation a
- areas
- The largest bas

streamflow

Connie A. Woodhouse, Gregory T. Pederson, Kiyomi Morino, Stephanie A. McAfee, Gregory J. McCabe

Water Resources Research

RESEARCH ARTICLE
10.1029/2018WR023153

On the Causes of Declining Colorado River Streamflows

Mu Xiao[1], Bradley Udall[2], and Dennis P. Lettenmaier[1]

[1]Department of Geography, University of California, Los Angeles, CA, USA, [2]Colorado Water Institute, Colorado State University, Fort Collins, CO, USA

Key Points:
- The naturalized flow of the Colorado River has decreased about 15% over


Lake Powell near Wahweap Marina
Page AZ
Glen Canyon Dam
High Water Mark

‘Aridification’, Not Drought

- Not a Drought and Not a ‘New Normal’
- Declining Snowpacks
- Earlier runoff
- Shorter Winter
- More rain, less snow
- Higher Temperatures: > 3°F
- Drying Soils
- Severe Fires
- Forest Mortality
- Warm Thirsty Atmosphere (holds more moisture)
- Northward moving storm tracks (less certain, but a worry)
- Megadrought

COMMENTARY

Climate change and the aridification of North America

Jonathan T. Overpeck[a,b,1] and Bradley Udall[b,c]

Discussions of droughts and their impacts often center on the lack of precipitation, just as assessments of hydrologic impacts under a changing climate most often focus on how average precipitation in a given locale is likely to change in the future. Within climate science, however, focus has begun to include the growing role warming temperatures are playing as a potent driver of greater aridity: hotter climate extremes; drier soil conditions; more severe drought; and the impacts of hydrologic stress on rivers, forests, agriculture, and other systems. This shift in the hydrologic paradigm is most clear in the American Southwest, where declining flows in the region’s two most important rivers, the Colorado (Fig. 1) and Rio Grande, have been attributed in part to increasing temperatures caused by human activities, most notably the burning of fossil fuels (1–5). Warmer summers are also likely to reduce flows in the Columbia River, as well as in rivers along the Sierra Nevada in California (6). Now, an important study (7) documents how warming is also causing flow declines in the northern Rocky Mountains and in the largest river basin in the United States, the Missouri. This work further highlights the mechanisms behind the temperature-driven river flow declines and places more focus on how anthropogenic climate warming is progressively increasing the risk of hot drought and more arid conditions across an expanding swath of the United States.

The work by Martin et al. (7) on the temperature-driven flow reductions in the Upper Missouri River has broader implications. As they note, many aspects of river management could be increasingly impacted by a more arid river basin, including agricultural water deliveries, river management and navigation, and ecosystem services associated with the river; economies of a large region will likely suffer if the aridification continues. This mirrors the change occurring in the Southwest, where rivers provide the only large sustainable water supply to the region and more than 40 million water users, yet flows have already declined significantly since just the late 20th century (3, 4).

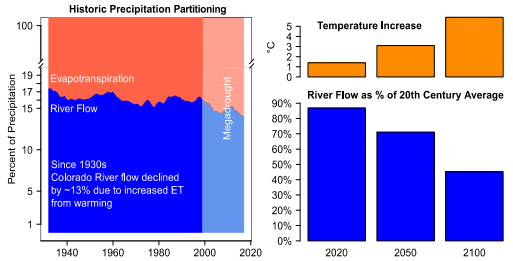


Fig. 1. Climate change is causing the Southwest to aridify. (*Left*) Since the 1930s, increasing temperatures have caused the percentage of precipitation going to evapotranspiration (ET) to increase at the expense of precipitation going to Colorado River flow, resulting in an unprecedented and still ongoing megadrought (shading) starting in 1999 (8). (*Right*) Higher temperatures have already reduced Colorado River flow by 13%, and projected additional warming, assuming continued high emissions of greenhouse gases, will increase ET while reducing river flow even more through the 21st century. Data on *Left* are 20-y running means from ref. 5, and data on *Right* are calculated from Representative Concentration Pathways (RCP) 8.5 multimodel Coupled Model Intercomparison Project–Phase 5 (CMIP5) ensemble temperature increases projected for the Upper Colorado River Basin combined with temperature sensitivity of –9.3%/°C estimated by ref. 5, assuming no change in precipitation.

Across the US West, warming is also contributing to drier soils (8), widespread tree death (9), and more severe wildfires (10). The recent unprecedented drought conditions in California also have been tied to human-caused warming (11). Greater aridity is redefining the West in many ways, and the costs to human and natural systems will only increase as we let the warming continue.

Martin et al. (7) also highlight how increasing temperature-driven aridity is more often framed in the West in terms of episodic drought. Just as in the Southwest, where an unprecedented drought began in 1999 and has continued through 2020 with drier-than-normal soils, reduced river flows, and low levels in major reservoirs, the worst drought of the instrumental era gripped the Upper Missouri River Basin

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Author contributions: J.T.O. and B.U. wrote the paper.
The authors declare no competing interest.
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See companion article, “Increased drought severity tracks warming in the United States’ largest river basin,” 10.1073/pnas.1916208117.
[1]To whom correspondence may be addressed. Email: overpeck@umich.edu.

Projections 1: Reservoirs, Power, UB Water Delivery

- Mead at or below 1020’
  - Problem: 20% full, Rules inadequate
  - When: Greater than 40% chance starting in 2023
- Powell at or below 3525’
  - Problem: Power Generation at Powell at Risk
  - When: Greater than ~40% every year next 5 years
- Compact Delivery Commitment Violation
  - Problem: Non–Depletion Obligation never defined
  - When: Possible by 2025 / 2026

Note:

1. These are not independent events
2. BoR inflows fail to adequately capture 2000-21 risk (~1 maf too high)

Chance of Reaching Critically Low Reservoir Elevations

Comparison of Current (May 2022) and Last Published (February 2022) CRMMS-ESP 5-Year Projections

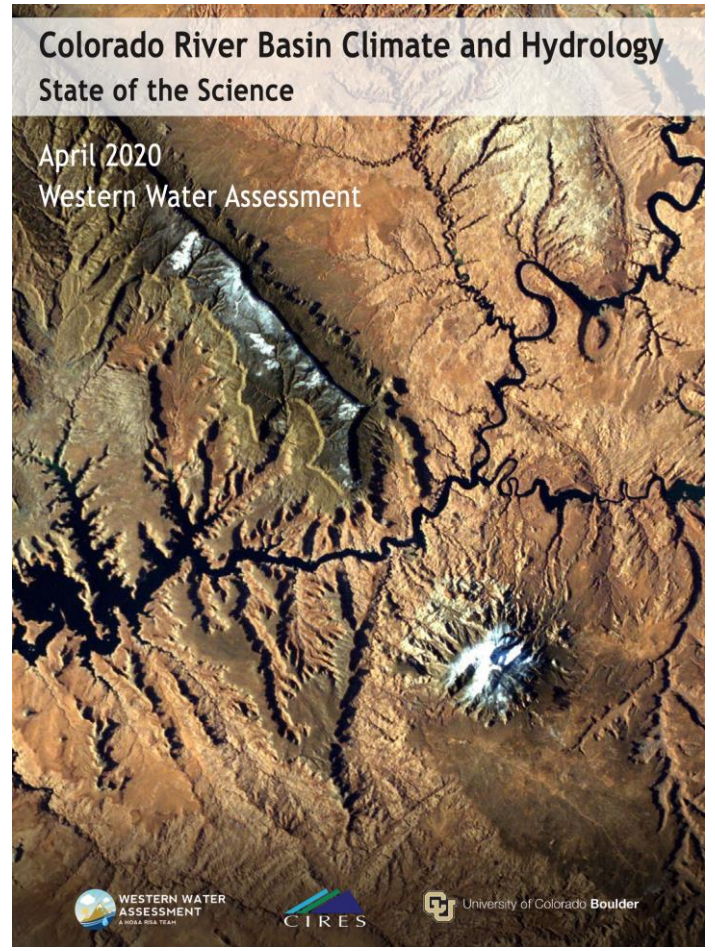
	Run	WY 2022	WY 2023	WY 2024	WY 2025	WY 2026
Lake Powell less than 3,525 feet	February 2022	90%	77%	50%	50%	37%
	May 2022	**100%**	**90%**	**50%**	**37%**	**30%**
	Difference	10%	13%	0%	-13%	-7%
Lake Powell less than 3,490 feet (minimum power pool)	February 2022	N	23%	27%	27%	23%
	May 2022	**N**	**3%**	**23%**	**17%**	**23%**
	Difference	-	-20%	-4%	-10%	0%
Lake Powell less than 3,375 feet (dead pool = 3,370 feet)	February 2022	0%	0%	0%	0%	0%
	May 2022	**0%**	**0%**	**0%**	**0%**	**0%**
	Difference	0%	0%	0%	0%	0%

	Run	2022	2023	2024	2025	2026
Lake Mead less than 1,020 feet	February 2022	0%	0%	20%	33%	37%
	May 2022	**0%**	**40%**	**50%**	**47%**	**50%**
	Difference	0%	40%	30%	14%	13%

Reclamation, 2022

Projections 2: Lee Ferry Flows and Temperatures

- Lee Ferry Flows
  - Udall and Overpeck: up to -30% by Mid-century
  - Milly and Dunne: +5% to -40% by Mid-Century
  - State of Science Report: “strong tendency … towards lower runoff”
- Upper Basin Temperatures
  - Current Trend has another 2°F/1°C rise by 2050
  - Models say almost 5°F/°2.5C possible



What Future to Plan For?

Science, May 28, 2021

- Given…
  - All Trends are in Wrong Direction
  - Climate System is ‘Non-Stationary’
  - ‘Tipping Point’ probabilities are too high
  - We only control demand
  - therefore…
- To avoid Water Management Malpractice…
  - Should anticipate Future Inflows less than last 22 years (12.3 maf)
  - But how much less?
  - “Reasonable Worst Case” Future
- Piecemeal vs Wholistic Planning Options
  - ‘Incrementalism’ unlikely to prepare us
  - Tipping Points indicate lurking Law of the River problems
  - Where are our Delph / Delphina Carpenters?

EDITORIAL

Managing Colorado River risk

In the 1920s, E. C. LaRue, a hydrologist at the United States Geological Survey, did an analysis of the Colorado River Basin that revealed the river could not reliably meet future water demands. No one heeded his warning. One hundred years later, water flow through the Colorado River is down by 20% and the basin’s Lake Powell and Lake Mead—the nation’s two largest reservoirs—are projected to be only 29% full by 2023. This river system, upon which 40 million North Americans in the United States and Mexico depend, is in trouble. But there is an opportunity to manage this crisis. Water allocation agreements from

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driven warming. For every 1°C of warming, researchers expect another 9% decline in the Colorado’s flow. This year’s snowpack was 80% of average but is delivering less than 30% of average river flows. Hot, dry summers bake soils, reducing flows the following year. The Colorado is not unusual. Researchers have identified similar patterns in other North American rivers, as well as in Europe, Asia, Africa, and Australia.

Colorado River water management has a long and uneasy relationship with science. LaRue’s analysis of

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Fortunately, there has since been progress in forging water management plans on the basis of science. For example, the US Bureau of Reclamation has been incorporating climate change into its analyses for more than a decade. Admirably, it overcame some of the political and technical challenges of incorporating the effects of climate change in the water allocation rules adopted in 2019. Models used to support decision-making were adapted to incorporate the 21st-century’s declining flows. Computer simulations showing emptying reservoirs were enough to convince decision-makers of the need to cut back. But have the modelers

real economic, social, and environmental risks of running low on a critical resource upon which 40 million North Americans depend.

The United States and Mexico—not just America’s West and Southwest—can’t afford to get this wrong. There are still political challenges that harken back to the struggles of E. C. LaRue a century ago—namely, as political boosters chose overoptimistic estimates of the river’s flows to make their jobs easier. Climate science indicates that there will likely be less water in the Colorado River than many had hoped. This is inconvenient for 21st-century decision-makers, and overcoming their resistance may be the hardest challenge of all.

–John Fleck and Brad Udall

“…only by planning for even greater declines can we manage the real economic, social, and environmental risks of running low on a critical resource upon which 40 million North Americans depend.”

Take Home Messages

- Every Trend Line Wrong
- Spring Runoff now Influenced by Early Spring Dry, Previous Summer Heat and Dry
- Not a Drought, Not New Normal
- Projections are worrisome
- What to plan for ?
  - More flow declines, but how much?
  - We only control demands
- Two Paths Forward
  - 1. Incrementalism
  - 2. More Wholistic Look at entire Law of the River
- Era of Equitable Shortage Sharing

2026 Renegotiation Considerations

- Open, Inclusive Process
  - Full EIS with Open Tools
- Permanent Structural Deficit Solution Needed
  - Remove 1.2 maf in Lower Basin Demand
  - Charge Evaporation to LB States pro-rata on use
- Plan for Extended Low Flows
  - Give up on providing future flow probabilities from Climate Models
  - Use Stress Test Hydrology PLUS very low flows from warming (10 or 11 maf)
- Revisit Long Standing Assumptions
  - AZ forced to bear full Structural Deficit solution
  - Compact Section III(d) Delivery ”Obligation”
  - Upper Basin allowed to develop to 7.5 maf at own pace promise in 1922
- Reservoir Management
  - use volume + inflows, as triggers
  - Use combined Mead + Powell volumes
- Strict Rules on New Diversions
  - Additional Diversions put existing UB diversions at risk
  - No New Net Demand Increases
  - Very Stringent Rules on when new Demands Allowed to Divert
- Central Arizona Project (CAP) can not be cut to 0
- Outstanding Tribal Claims need to be resolved
- Upper Basin Lake Powell Demand Management Account
  - Free from Lower Basin Control
- Need ways to allow states to contribute without seeming to contribute

Combined Mead + Powell Storage
2000 - 2022