When Hydrology and Management Collide: How Lake Powell got Hammered

Slides at
https://bit.ly/2ITDWf6

Uncertainty: Count on It
Feast or Famine on the Colorado River

Colorado River District Annual Seminar

Colorado Mesa University
Grand Junction, CO
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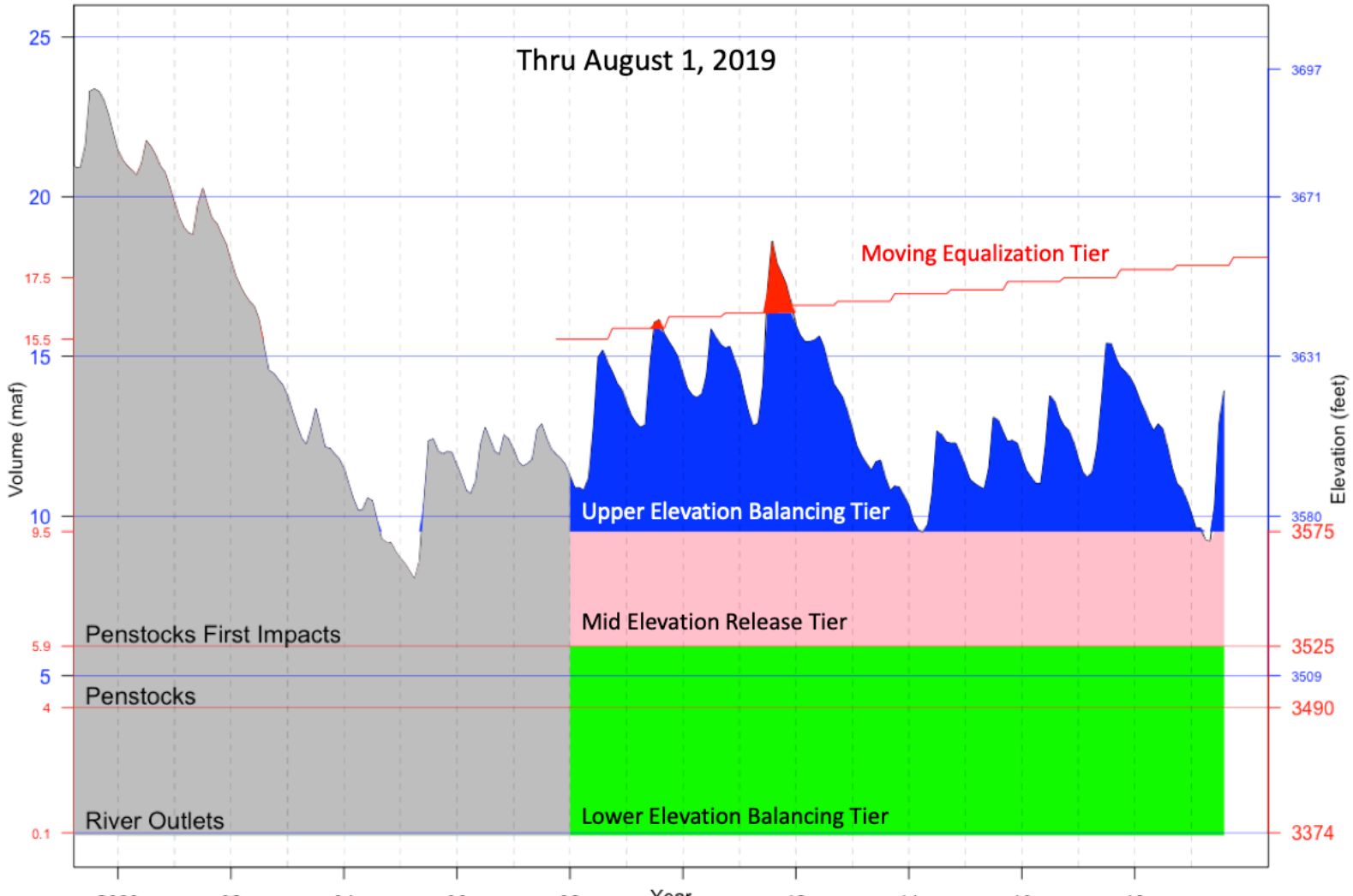
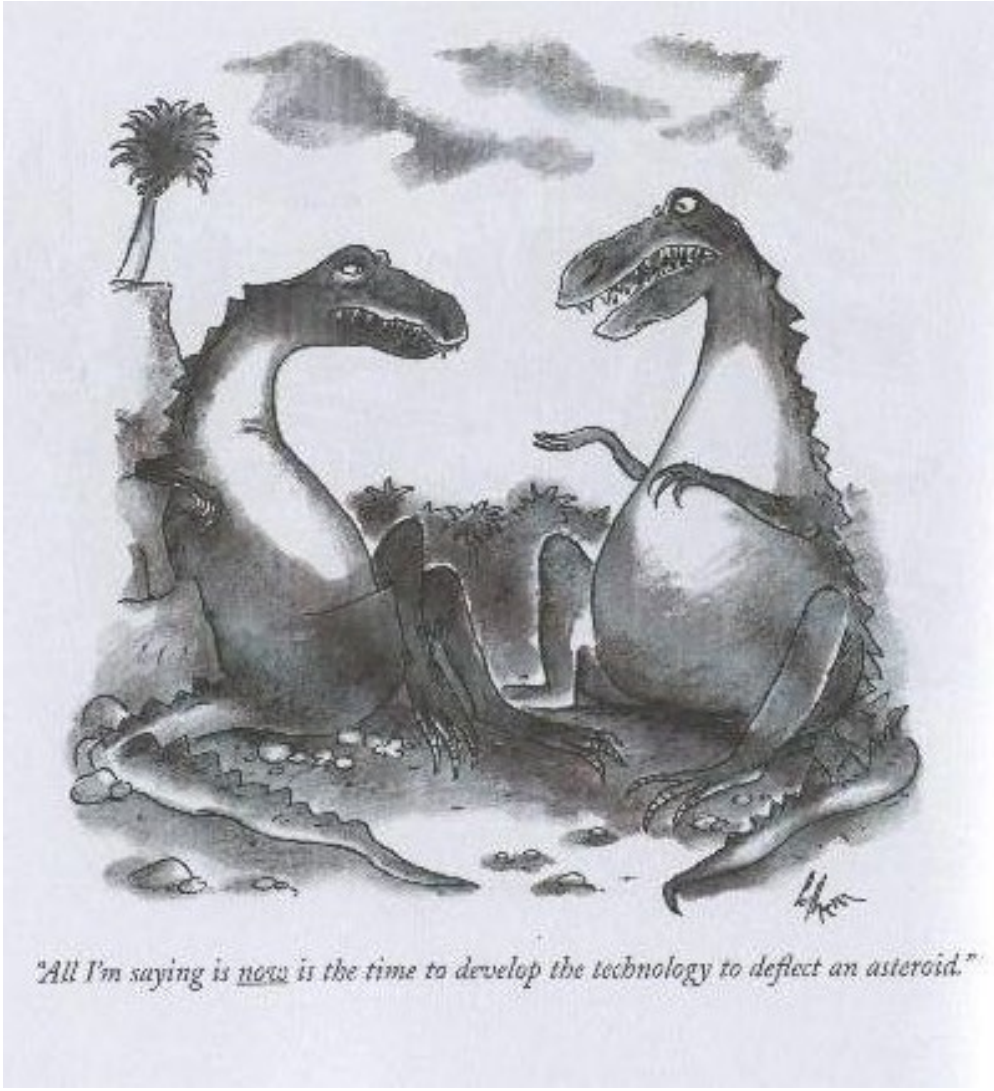
Brad Udall
Senior Scientist/Scholar
Colorado State University
Bradley.Udall@colostate.edu
@bradudall

Lake Powell Contents 2000-2019



Talk Outline

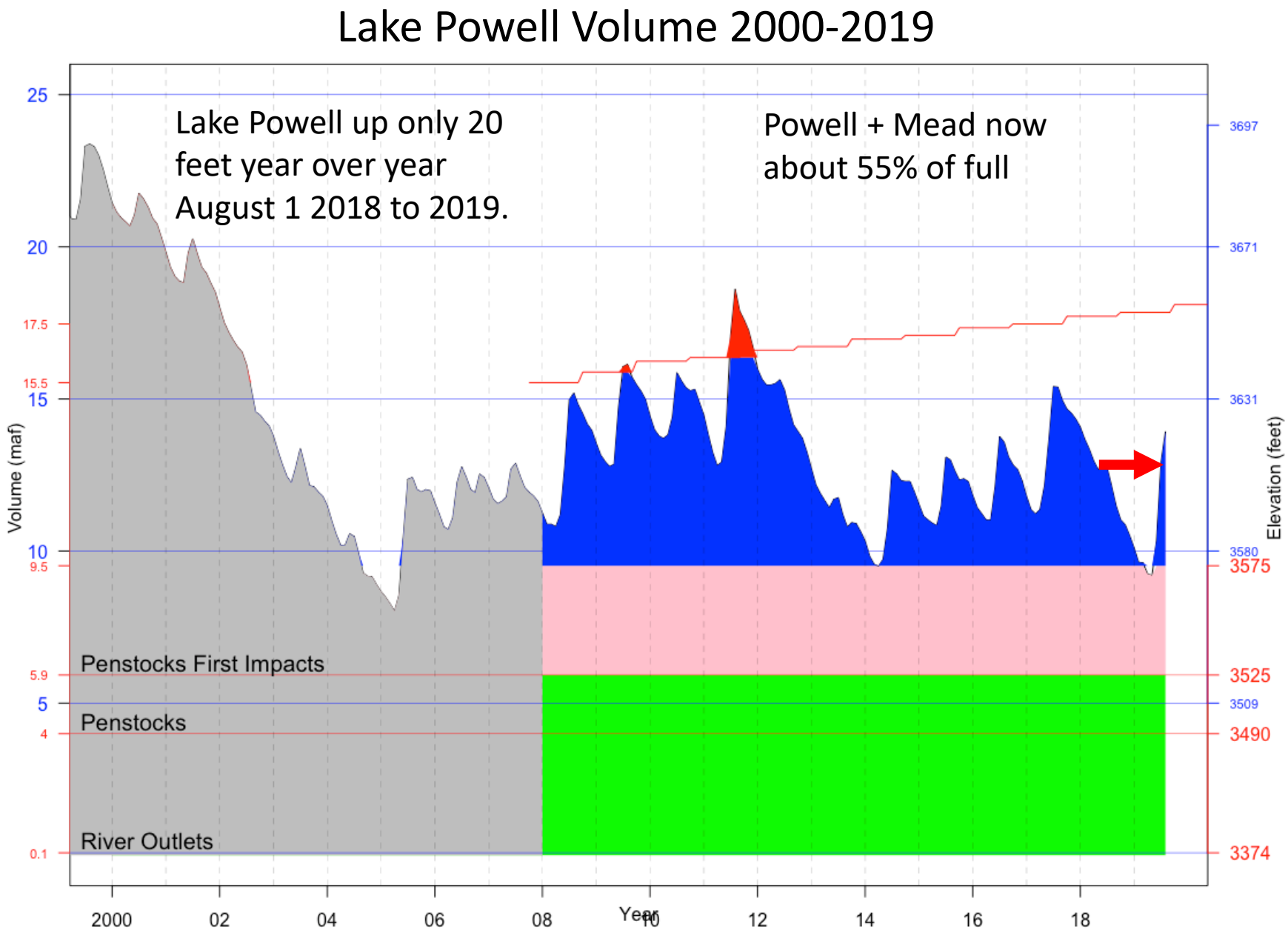
- Setting the Stage
  - Reservoir Contents, Hydrology, Operations since 2000 and 2007
- Climate Change is still here and getting worse
  - Yes, even with 2019 runoff
- Problems and Challenges post 2007
  - Inflated Demands
  - Intentionally Created Surplus Issues
  - Manipulating the System: the Good and Bad
  - Evolving understanding of climate change
- Questioning some of the 2007 Rules
  - Can we simplify?
- Concluding Thoughts

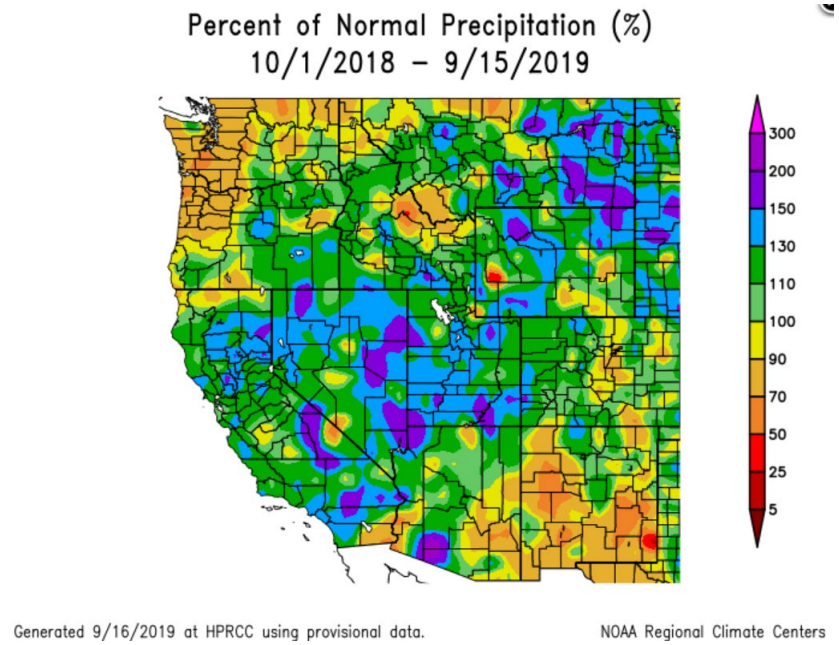


"All I'm saying is now is the time to develop the technology to deflect an asteroid."

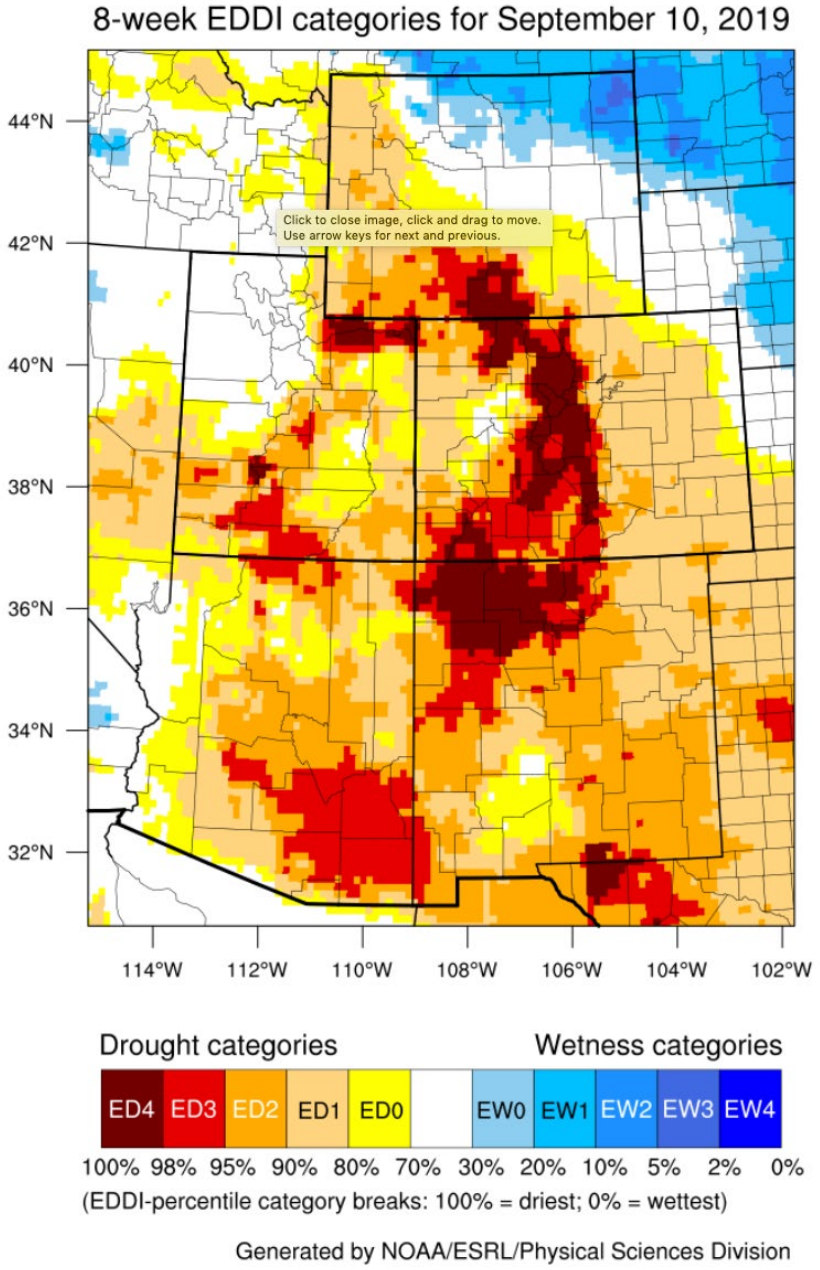
2018-2019 was a big water year but…

- 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





Wind River Mtns, WY, Sept 2019



Maps: WWA Climate Dashboard

Mead + Powell Contents 2000 – 2019 plus Hydrology

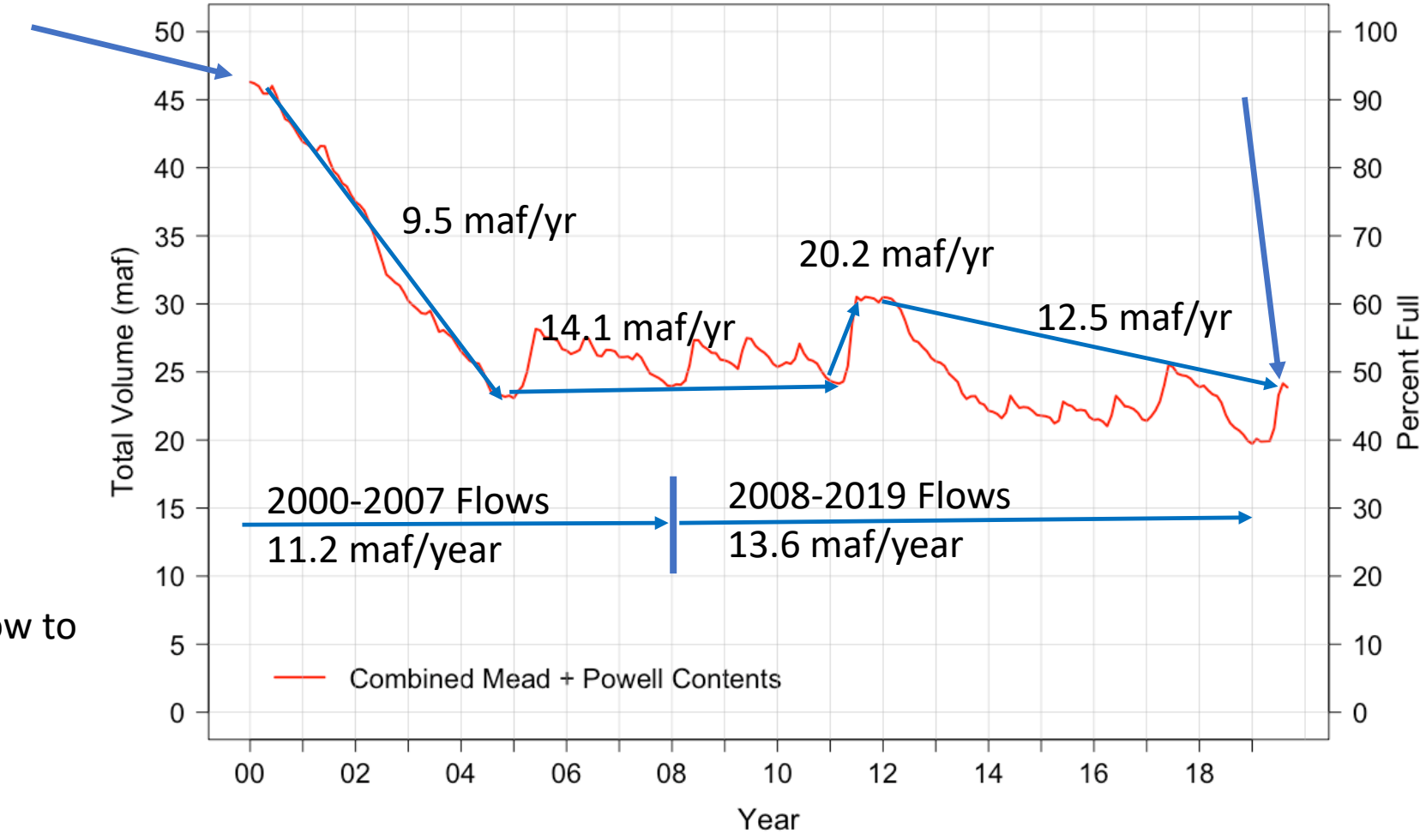
46 maf 2000
24 maf 2019
Loss of 22 maf or ~50%

4 Periods
2000 – 2004 Loss of 23 maf
2005 – 2011 Stasis, gain of ~1 maf
2011 Gain of 6 maf
2012 – 2019 Loss of 6 maf

In worst years: lose about 5 maf/year
In best years: gain about 6 maf/year

It would take 4 2011-type years in a row to refill the system to 2000 levels

Hydrology 2000-2007
2.4 maf/yr
worse than 2008-2018



Lake Mead Contents 2000-2019

Loss of 15 maf over 19 Years
800 kaf/year loss, 40% remains

4 Periods

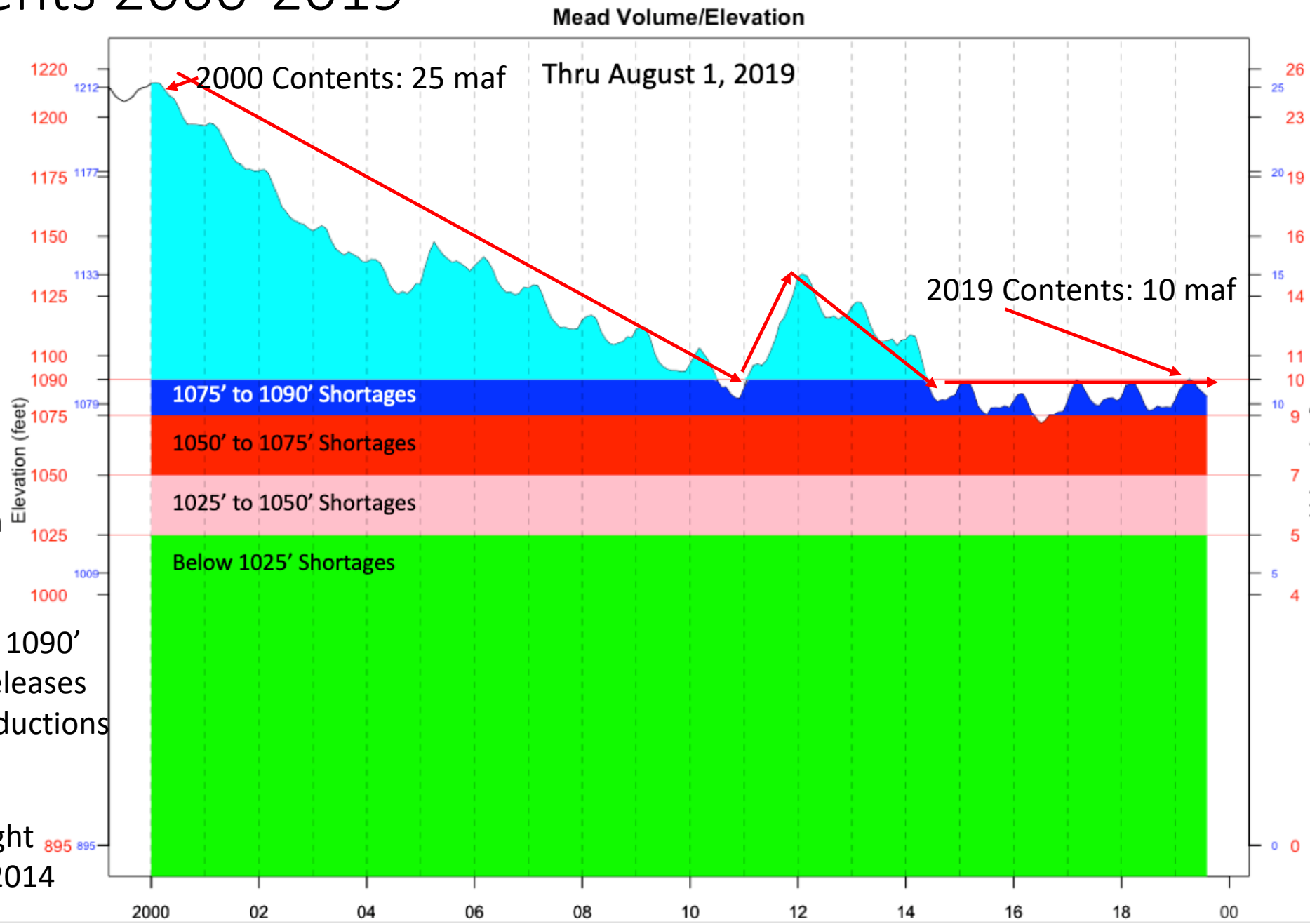
2000-2011 -- Loss of 15 maf
1.4 maf loss/year

2011 – Equalization
5 maf gain

2012-2104 – Loss of Equalization
5 maf loss

2014-2019 -- Stabilization below 1090'
9 maf/yr Powell Releases
Small Demand Reductions

Interesting to speculate what might have occurred if DCP in place in 2014
~ 340 kaf/yr reductions



Powell Releases 2000 – 2019 Relative to 8.23 maf

Cumulative Releases above 8.23 maf/year (red line)

13 maf total since 2000
11 maf total since 2008

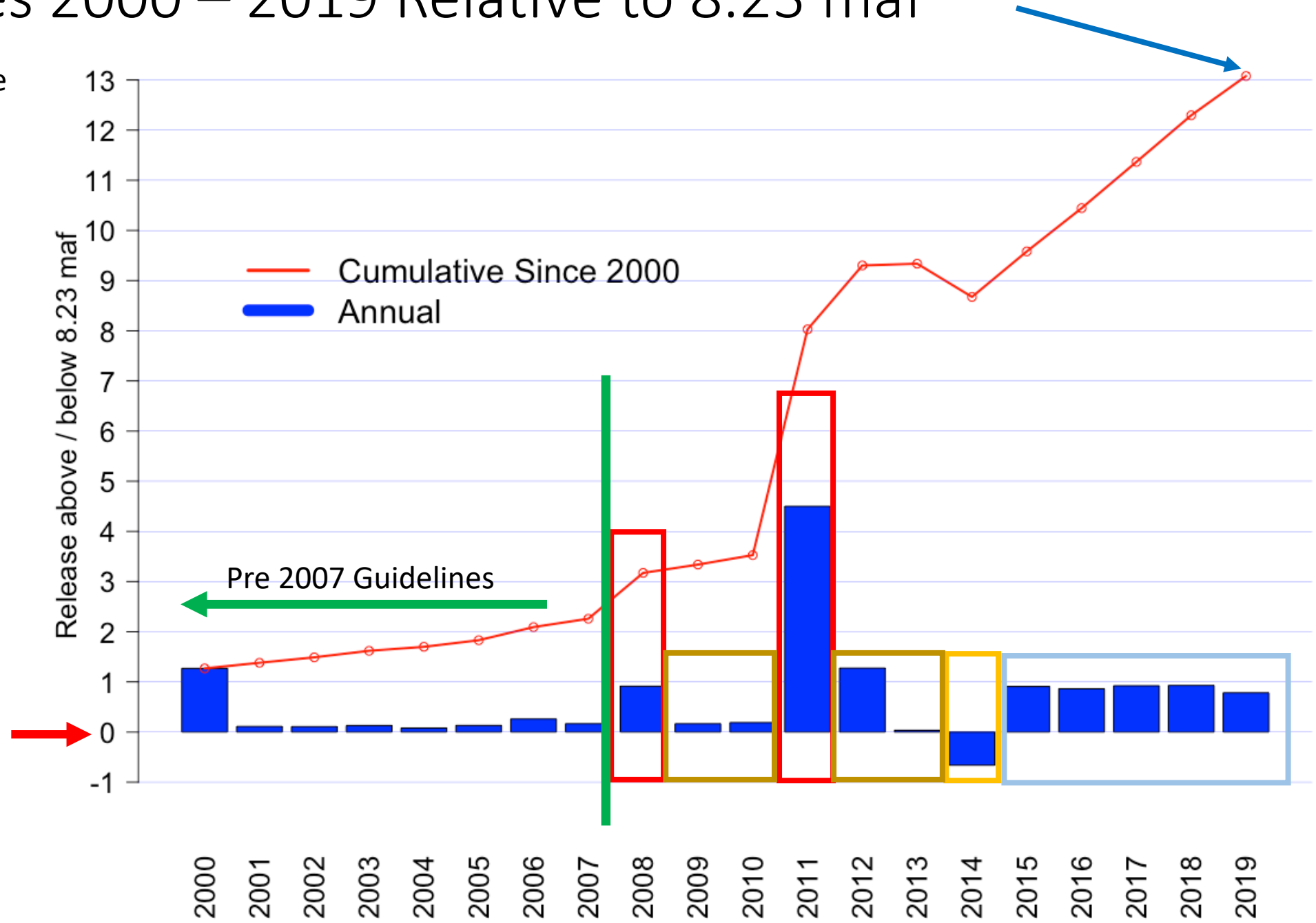
1 Year at 7.48 maf
2014

4 Years at 8.23
2009,2010,2012,2013

5 Years at 9 maf
2015-2019

2 Equalization Years
2008,2011 (plus 2012**)

7/12 Years >= 9.00 (60%)
4/12 Years = 8.23 (33%)
1/12 Years < 8.23 (7%)



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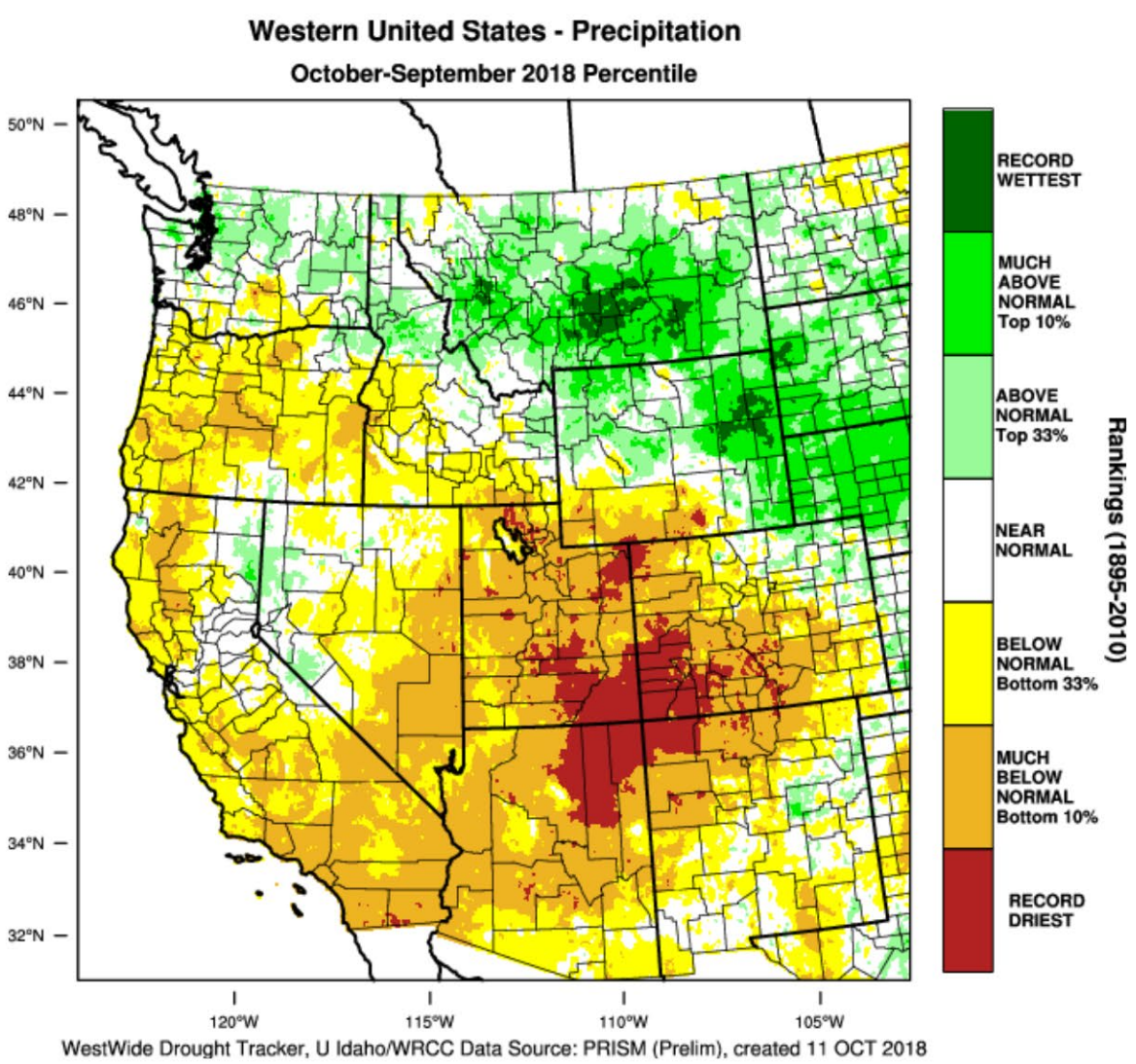
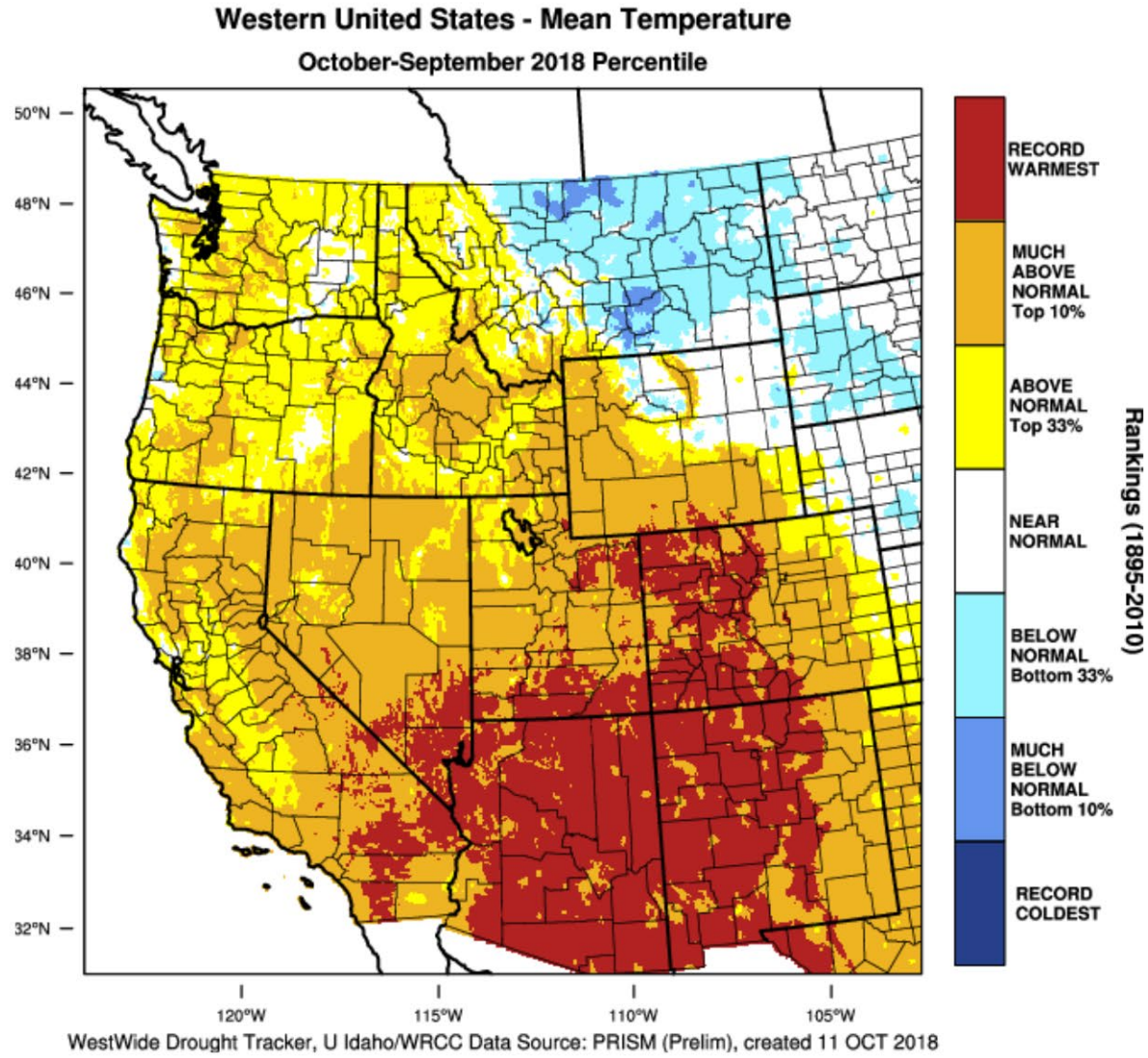
"I like to think we aren't so much anti-science as we are pro-myth."

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

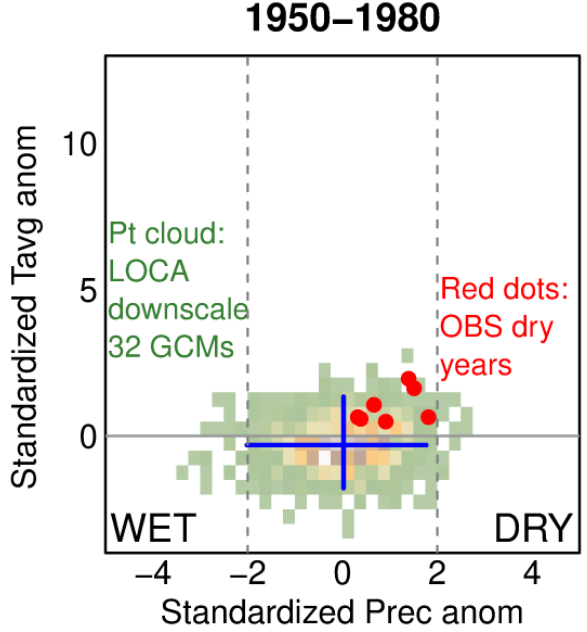
Lowest Precipitation on Record 4 Corners Area



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



21st Century warmth will be unlike anything we've seen



Dave Pierce, Scripps

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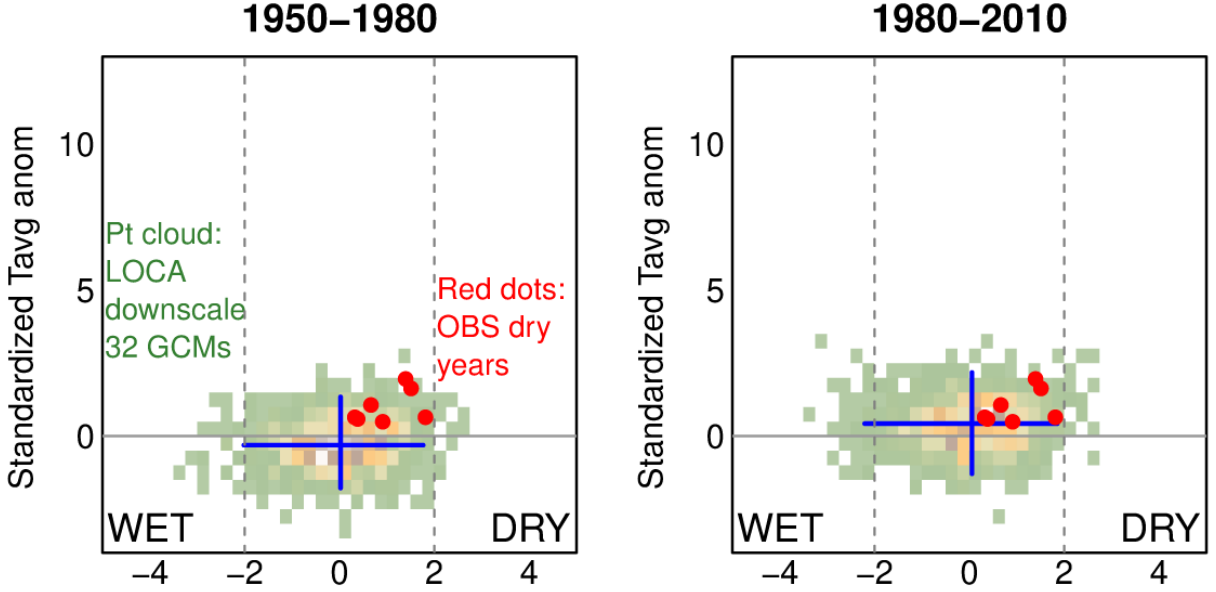

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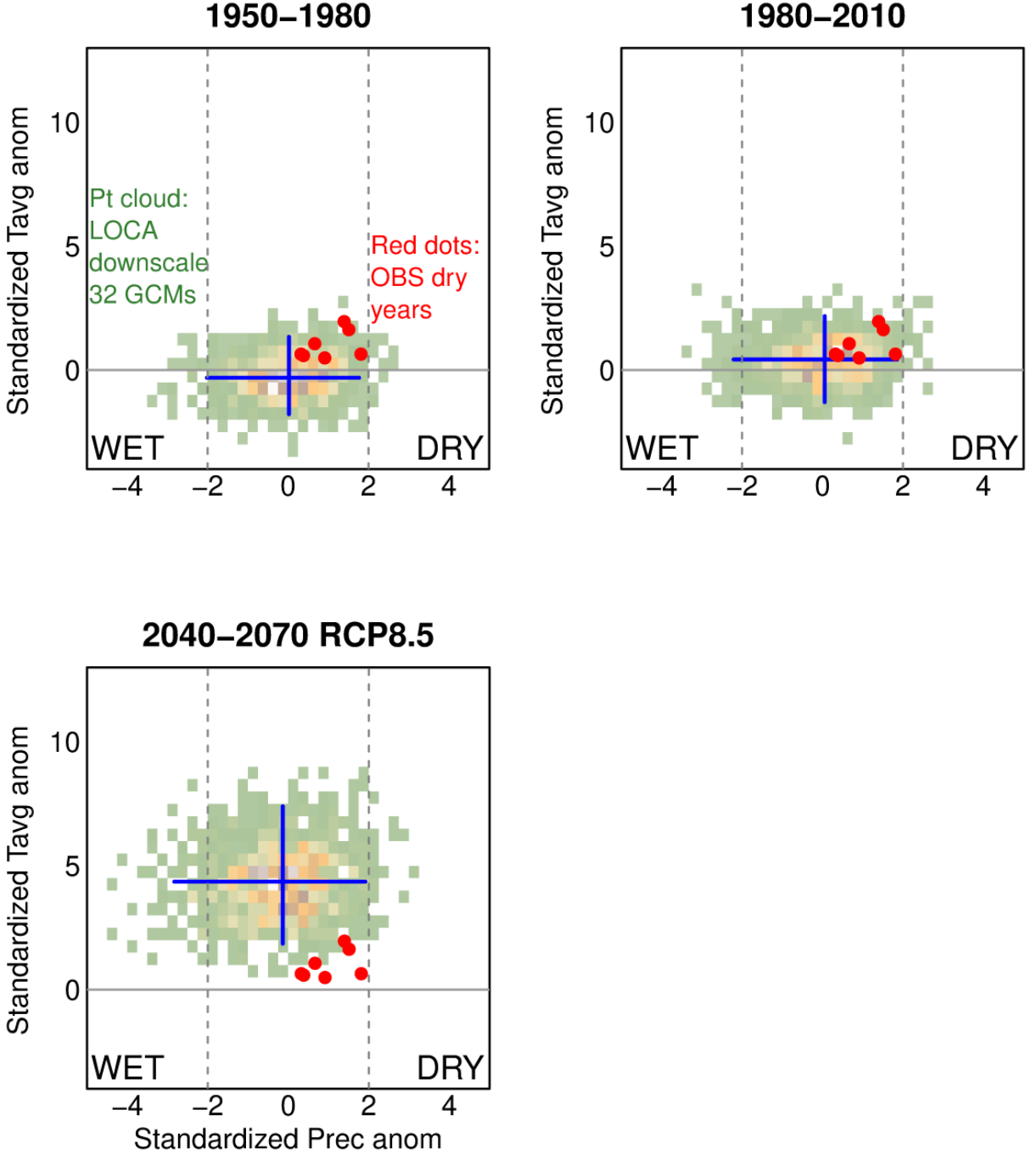


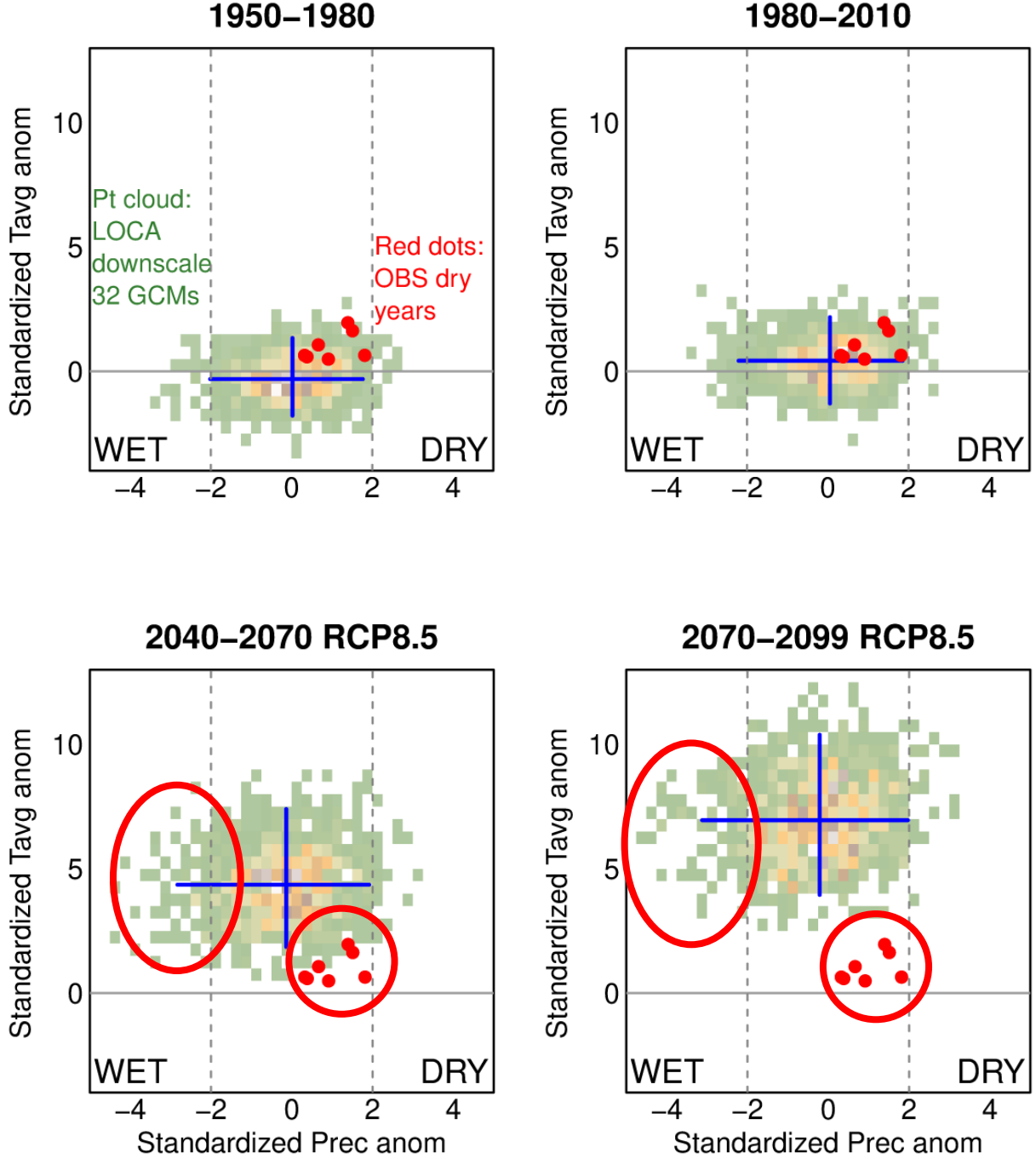
Dave Pierce, Scripps

21st Century warmth will be unlike anything we've seen

Recent Hot Years will be relatively cool (mid-century) or even "too cold" (end-century) to occur

Hint of more occurrences of extreme wet than extreme dry

Note: extra precipitation will not necessarily turn into additional runoff due to high temps.



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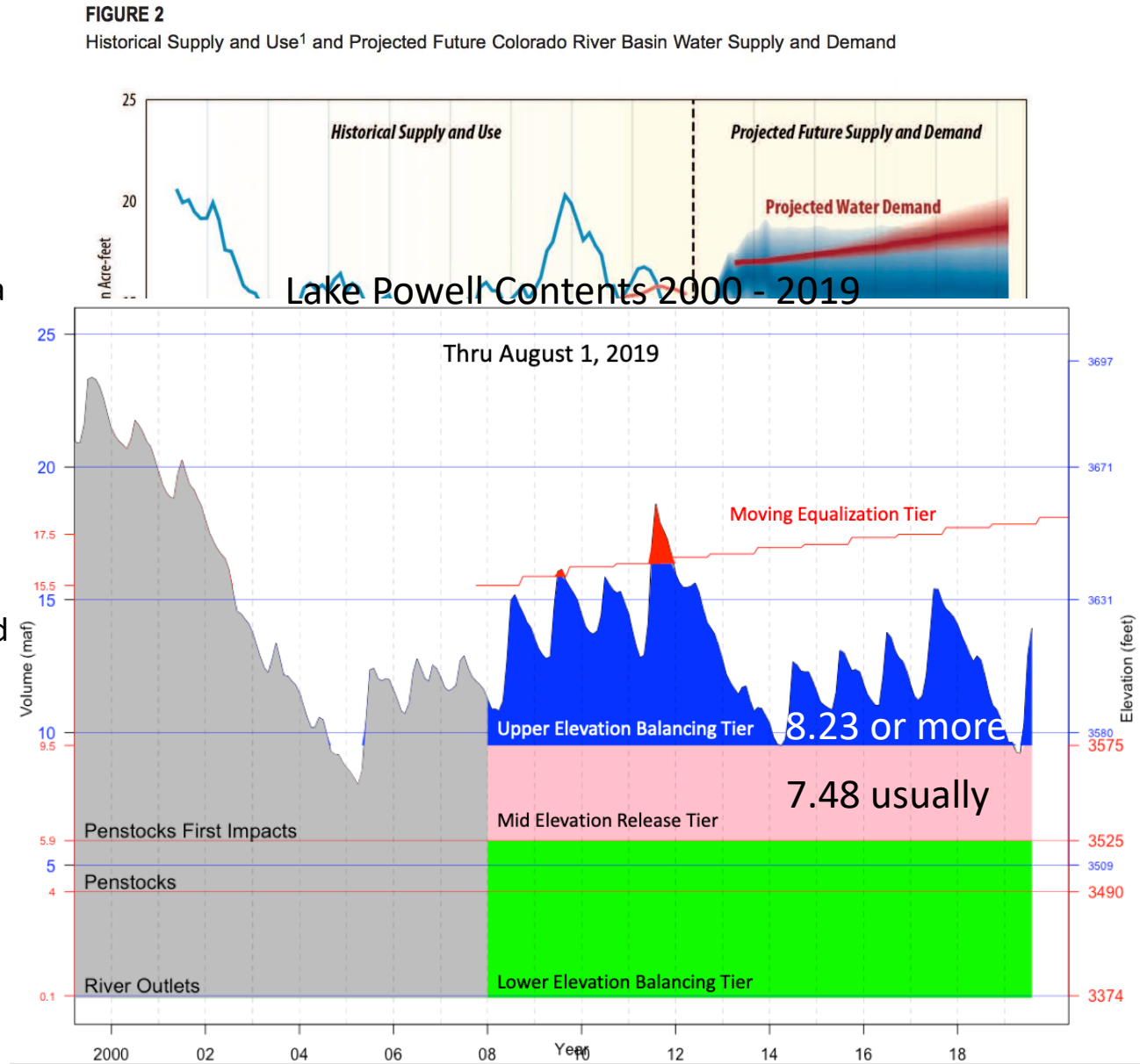
"It's always 'Sit,' 'Stay,' 'Heel'—never 'Think,' 'Innovate,' 'Be yourself.'"

First, an apology to creators of the 2007 and DCP Rules

- A lot of good thought went into the 2007 and DCP Rules
- We had to start somewhere
- Hindsight is always 20-20
- But in the interests of sparking discussion and thought, I'm going to pick some nits with these rules
- In so doing, I fully acknowledge that…
  - I sit in the 'cheap seats' where the cost of being wrong is low
  - Some 'solutions' might create other problems
  - But I do hope there are least some useful thoughts here…along with some probably wrong-headed ones, too.

Inflated Demands in Models can lead to Bad Outcomes

- 2012 Letter from Pacific Institute / WRA re Basin Study
- Demands not consistent with 6 different storylines
  - Not consistent with historic or recent trends in muni savings
- Not using best, updated information
  - One state had growth of 150% by 2030 despite 1%/yr now
  - Another state had 35% increase over 4 years in large metro area
- Too High Demands have Model World Impacts
  - Skew imbalances in supply/demand
  - Skew options and strategies to correct the imbalances
- Too High Demands have Real World Impacts
  - In 2007, UB wanted to hedge continued low flow hydrology risk with 7.48 maf/year releases without giving up too many 9.0 maf/year releases
  - Modeling results with (alas, high) demands showed idea worked well
    - But modeled high demands forced Powell lower, leading to more 7.48 releases than were likely given realistic demands
  - Reality has been vastly different than the modeling
    - ~60% of releases >= 9maf /year
    - Only 7% at 7.48 maf/year
- Note: DCP Demands were recently modified by Reclamation



Intentionally Created Surplus (ICS) Issues

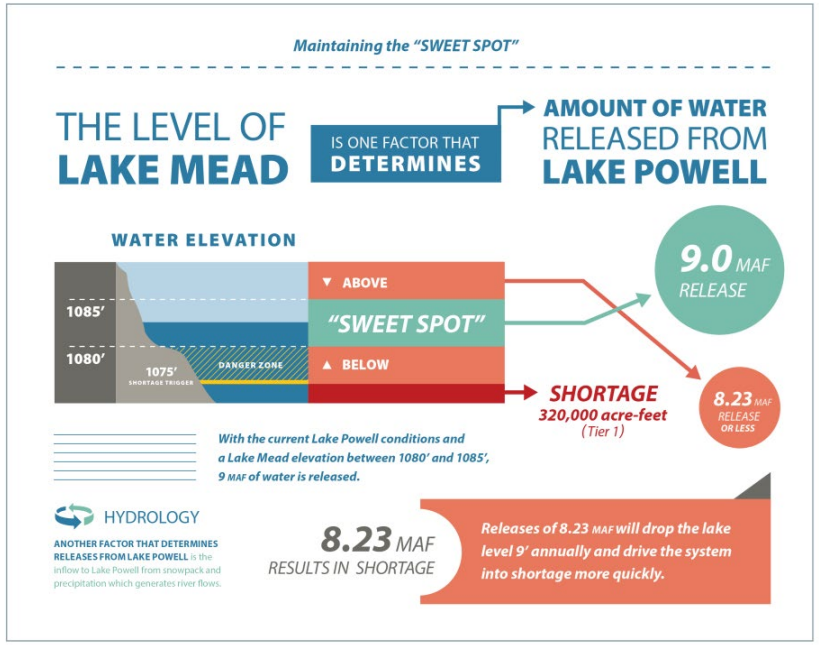
- 4 Types created in 2007 and a new type created in the DCP
- 2007 IG Solved 'Use it or Lose it' Problem with ICS in the LB
- Intentionally Created Surplus of any kind can be later recovered
  - 2007 Rules – above 1075' before (No ICS delivery to replace shortage loss)
  - DCP Rules – above 1025' (Normal ICS can be taken in lieu of shortages)
- ICS Withdrawals could make low flow / low reservoir years worse
  - Main worry: withdrawals more likely in precisely those years
  - 'Bank Run' to avoid stranding, eg. MWD January 2019
- 2007 ICS Issues
  - Pretend we have saved water and point to higher reservoirs
  - But not real conservation, merely shifting use in time
  - Yet another technique to maximize use from the system
- New DCP ICS ("Shortage ICS") has another problem
  - Entity being shorted gets DCP ICS credit
  - DCP ICS credit can be taken when Mead > 11 maf (1110' or ~40%)
  - Worry that DCP ICS deliveries will deplete reservoirs just when recovering
  - Some bad debts may need to be written off to allow system recovery
  - DCP shortages fundamentally different than 2007 shortages due to DCP ICS
- Note: most people agree that overall ICS is a benefit. It allowed inter-year storage rather than use it or lose it. But the devil is in the details.

One Simple ICS Solution

- In 2007 Guidelines
  - ICS was counted as ‘system water’ for purposes of determining LB shortages
    - But ICS is really private water – can’t be used for ‘system’ purposes
  - But ICS withdrawals not allowed below 1075’
  - Created two problems: ‘double counting’ of ICS (system + private ownership) and ’bank runs’ to avoid stranding water below 1075’
- Simple Solutions
  - Remove ICS from the LB Shortage Calculations
  - Allow ICS withdrawals at all levels, except in dire circumstances
    - Note: DCP allows withdrawals down to 1025’

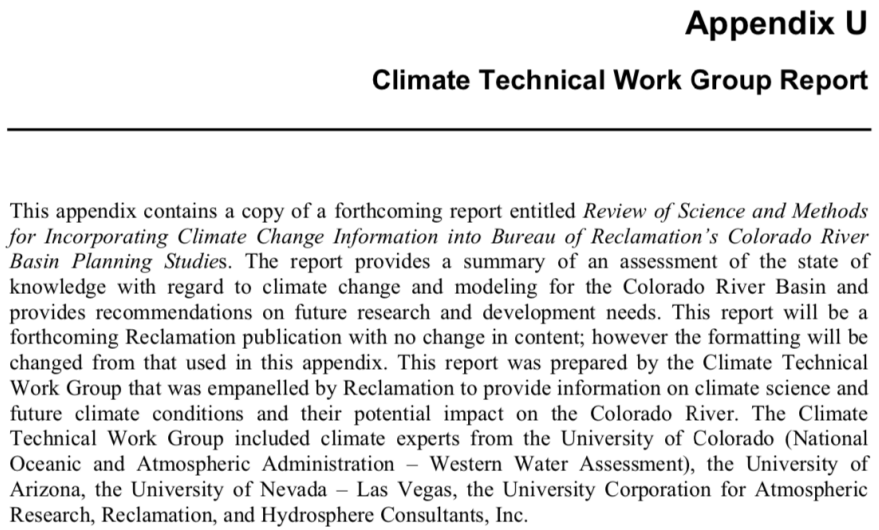
Manipulating the System

- "Actions to Keep us from reaching an undesirable target"
  - Good Versions – System Conservation Pilot Projects
  - Bad Version – CAP "Sweet Spot"
- Need to explicitly consider human manipulation / behavior in all targets and operational rules
- Maximize opportunities for good manipulation
  - System Conservation Pilot Projects
  - ICS may be an example in some cases
- Minimize opportunity for bad manipulation
  - Simple, clear, transparent rules help, assuming good vetting of rules



Evolving Climate Change Understanding

- 2007 Appendix U
  - First Attempt to incorporate climate change
- 2012 Basin Study
  - False Assumption 1: climate model output adequately samples the future and thus provides a probability distribution of that future
  - False Assumption 2: managing to the middle of that future is adequate (e.g. focus on median outcomes)
- High Temperatures are reducing flows significantly
  - Vano et al, Woodhouse et al, Udall & Overpeck, Xiao et al.
- Precipitation is far more unknown
  - Reasons to think South decrease, North increase
  - Still possible to get big years / decades
- 2018 National Climate Assessment:
  - "Must manage for a future we can not fully foresee"
- With all hydrologies…
  - Move away from using probabilities…we can not connect probabilities to real world likelihood
  - Build scenarios
  - Need robust management at all conceivable low flows



Appendix U

Climate Technical Work Group Report

This appendix contains a copy of a forthcoming report entitled *Review of Science and Methods for Incorporating Climate Change Information into Bureau of Reclamation's Colorado River Basin Planning Studies*. The report provides a summary of an assessment of the state of knowledge with regard to climate change and modeling for the Colorado River Basin and provides recommendations on future research and development needs. This report will be a forthcoming Reclamation publication with no change in content; however the formatting will be changed from that used in this appendix. This report was prepared by the Climate Technical Work Group that was empanelled by Reclamation to provide information on climate science and future climate conditions and their potential impact on the Colorado River. The Climate Technical Work Group included climate experts from the University of Colorado (National Oceanic and Atmospheric Administration – Western Water Assessment), the University of Arizona, the University of Nevada – Las Vegas, the University Corporation for Atmospheric Research, Reclamation, and Hydrosphere Consultants, Inc.

"This is a river ravaged by climate change"
~ Pat Mulroy, June 6, 2019

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  - **Can we simplify?**
- Concluding Thoughts

"These smug pilots have lost touch with regular passengers like us. Who thinks I should fly the plane?"

2007 Reservoir Operation Rules

A. Equalization Tier

In each Water Year, the Lake Powell equalization elevation will be as follows:

Lake Powell Equalization Elevation Table	
Water Year	**Elevation** (feet)
2008	3,636
2009	3,639
2010	3,642
2011	3,643
2012	3,645
2013	3,646
2014	3,648
2015	3,649
2016	3,651
2017	3,652
2018	3,654
2019	3,655
2020	3,657
2021	3,659
2022	3,660
2023	3,662
2024	3,663
2025	3,664
2026	3,666

Equalization Tier

1. In Water Years when Lake Powell elevation is projected on January 1 to be at or above the elevation stated in the Lake Powell Equalization Elevation Table, an amount of water will be released from Lake Powell to Lake Mead at a rate greater than 8.23 maf per Water Year to the extent necessary to avoid spills, or equalize storage in the two reservoirs, or otherwise to release 8.23 maf from Lake Powell. The Secretary shall release at least 8.23 maf per Water Year and shall release additional water to the extent that the additional releases will not cause Lake Powell content to be below the elevation stated in the Lake Powell Equalization Elevation Table or cause Lake Mead content to exceed that of Lake Powell; provided, however, if Lake Powell reaches the elevation stated in the Lake Powell Equalization Elevation Table for that Water Year and the September 30 projected Lake Mead elevation is below elevation 1,105 feet, the Secretary shall release additional water from Lake Powell to Lake Mead until the first of the following conditions is projected to occur on September 30: (i) the reservoirs fully equalize; (ii) Lake Mead reaches elevation 1,105 feet; or (iii) Lake Powell reaches 20 feet below the elevation in the Lake Powell Equalization Elevation Table for that year.

B. Upper Elevation Balancing Tier

1. In Water Years when the projected January 1 Lake Powell elevation is below the elevation stated in the Lake Powell Equalization Elevation Table and at or above 3,575 feet, the Secretary shall release 8.23 maf from Lake Powell if the projected January 1 Lake Mead elevation is at or above 1,075 feet.

2. If the projected January 1 Lake Powell elevation is below the elevation stated in the Lake Powell Equalization Elevation Table and at or above 3,575 feet and the projected January 1 Lake Mead elevation is below 1,075 feet, the Secretary shall balance the contents of Lake Mead and Lake Powell, but shall release not more than 9.0 maf and not less than 7.0 maf from Lake Powell in the Water Year.

3. When operating in the Upper Elevation Balancing Tier, if the April 24-Month Study projects the September 30 Lake Powell elevation to be greater than the elevation in the Lake Powell Equalization Elevation Table, the Equalization Tier will govern the operation of Lake Powell for the remainder of the Water Year (through September).

4. When operating under Section 6.B.1, if the April 24-Month Study projects the September 30 Lake Mead elevation to be below 1,075 feet and the September 30 Lake Powell elevation to be at or above 3,575 feet, the Secretary shall balance the contents of Lake Mead and Lake Powell, but shall release not more than 9.0 maf and not less than 8.23 maf from Lake Powell in the Water Year.

5. When Lake Powell is projected to be operating under Section 6.B.2. and more than 8.23 maf is projected to be released from Lake Powell during the upcoming Water Year, the Secretary shall recalculate the August 24-Month Study projection of the January 1 Lake Mead elevation to include releases above 8.23 maf that are scheduled to be released from Lake Powell during the months of October, November, and December of the upcoming Water Year, for the purposes of determining Normal or Shortage conditions pursuant to Sections 2.A. or 2.D. of these Guidelines.

Upper Elevation Balancing Tier

C. Mid-Elevation Release Tier

1. In Water Years when the projected January 1 Lake Powell elevation is below 3,575 feet and at or above 3,525 feet, the Secretary shall release 7.48 maf from Lake Powell in the Water Year if the projected January 1 elevation of Lake Mead is at or above 1,025 feet. If the projected January 1 Lake Mead elevation is below 1,025 feet, the Secretary shall release 8.23 maf from Lake Powell in the Water Year.

Mid Elevation Release Tier

D. Lower Elevation Balancing Tier

1. In Water Years when the projected January 1 Lake Powell elevation is below 3,525 feet, the Secretary shall balance the contents of Lake Mead and Lake Powell, but shall release not more than 9.5 maf and not less than 7.0 maf from Lake Powell in the Water Year.

Lower Elevation Balancing Tier

Questioning some of the 2007 Rules

- Are the current rules meeting the objectives set out in the ROD?
  - Are we addressing UB Section III (d) risk appropriately?
- No explicit consideration of UB III (d) Risk
  - Violating III (d) to meet LB Demands in excess of 8.5 maf/year seems ill-considered
  - Fundamental tension in the Compact III (d) vs III (e)
  - One solution: Hold UB Harmless for III (d) violation
- Are the current rules too complicated?
  - Would a simple (not simplistic) system be better?
  - Are the models running the show rather than humans?
- Struggling to understand the value of 9 maf Powell releases when Powell about 40% full
  - We're hitting the accelerator when maybe the brake is the right option**
- Rules seem skewed to maximizing water deliveries rather than optimizing reliability
  - DCP Shortage converted to DCP ICS, latest example
  - ICS just shifts use in time, no real conservation
  - ICS recovery now allowed at very low Mead levels
  - Mid-Year Mead release re-adjustment can only increase release

2007 ROD Objectives

The Preferred Alternative proposes:

- discrete levels of shortage volumes associated with Lake Mead elevations to conserve reservoir storage and provide water users and managers in the Lower Basin with greater certainty to know when, and by how much, water deliveries will be reduced in drought and other low reservoir conditions;
- a coordinated operation of Lake Powell and Lake Mead determined by specified reservoir conditions that would minimize shortages in the Lower Basin and avoid the risk of curtailments in the Upper Basin;
- a mechanism to encourage and account for augmentation and conservation of water supplies, referred to as Intentionally Created Surplus (ICS), that would minimize the likelihood and severity of potential future shortages; and
- the modification and extension of the Interim Surplus Guidelines (66 Fed. Reg. 7772, Jan 25, 2001) (ISG) through 2026.

Compact Clause III(d) vs III(e)

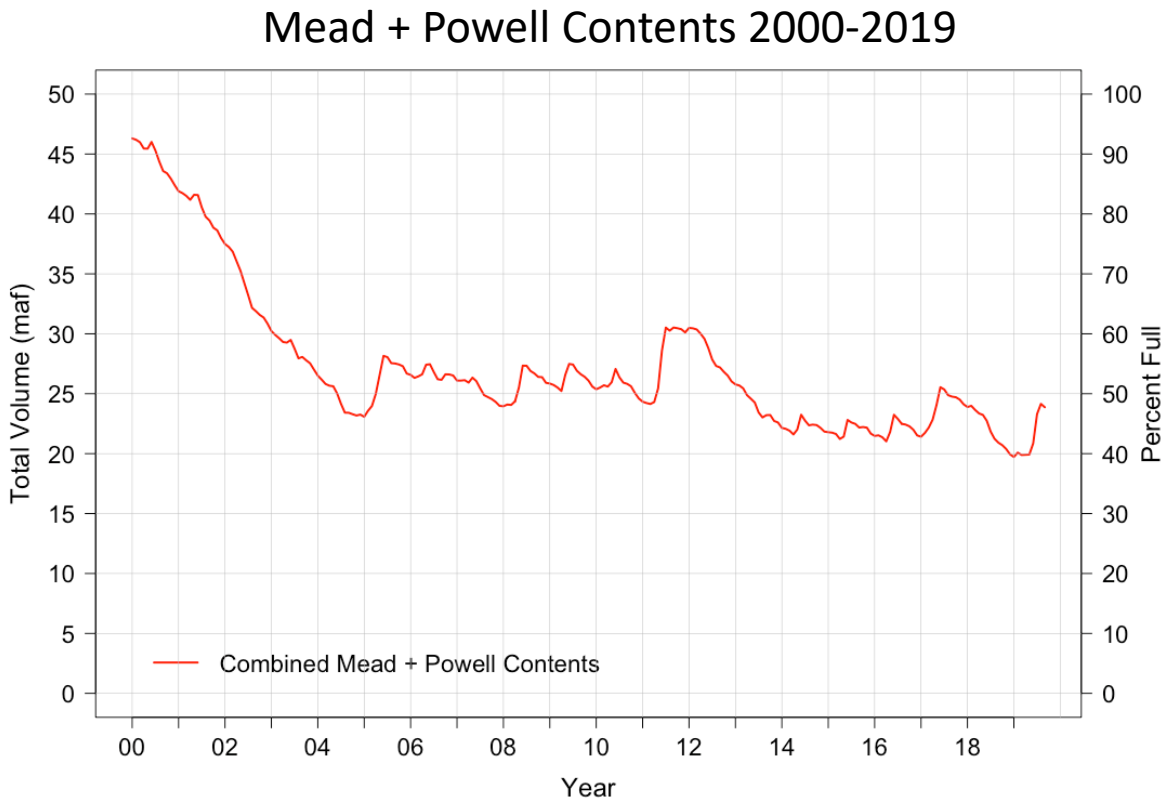
- III(d)
  - The States of the Upper Division will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of ten consecutive years reckoned in continuing progressive series beginning with the first day of October next succeeding the ratification of this compact.
- III(e)
  - The States of the Upper Division shall not withhold water, and the States of the Lower Division shall not require the delivery of water, which cannot reasonably be applied to domestic and agricultural uses.

Questioning some of the 2007 Rules

- Why are we forecasting Jan 1 Mead Contents from Aug 15 using 24-Month Model?
  - Adds complexity, 24-Month model subject to change, not generally available
  - Added 4.5 month forecast provides minimal additional information, yet some opportunity to manipulate
- Why are we using forecasted Mead elevation on just 1 date?
  - Feels more like an inadequate single marker than a thoughtful management strategy
  - Why not use easily calculated average reservoir volume over a period of time?
  - Is there a benefit to looking slightly backward in time?
- Are the Powell Tiers the right sizes and locations?
  - Is this even the right approach?
- Would there be benefits to using inflows in some cases as a partial trigger?
  - This year could justify 9 maf release when otherwise would seem unwise
  - Converse, true, too. Low flow year should generate conservation

Concluding Thoughts

- This is a very complicated system with thousands of users
- Much of the Storage loss was pre-2007
  - Worse hydrology by 2 maf/yr, but we've lost another 10 maf in storage post 2011
  - For every 2011 and 2019, we're getting 2012, 2013, 2018
- Recent Warm Temperatures may be "too cold" to occur in 2100
  - It doesn't have to be this way
  - In the UB, 2018 was horrendous
- We need to get the best possible data into our models
  - Work on getting politics out of that part of our work
- Is the whole system skewed to producing deliveries at expense of robust management at low flows ?
  - As the reservoirs are currently operated, ICS allows us to think we have more water than we do
- Make sure we consider how humans interact with the system
  - Maximize good actions, block/hinder bad actions
- My preference is to operate the system with as transparent, simple, clear rules as possible



Bradley.udall@colostate.edu
@bradudall

Slides at
https://bit.ly/2lTDWf6

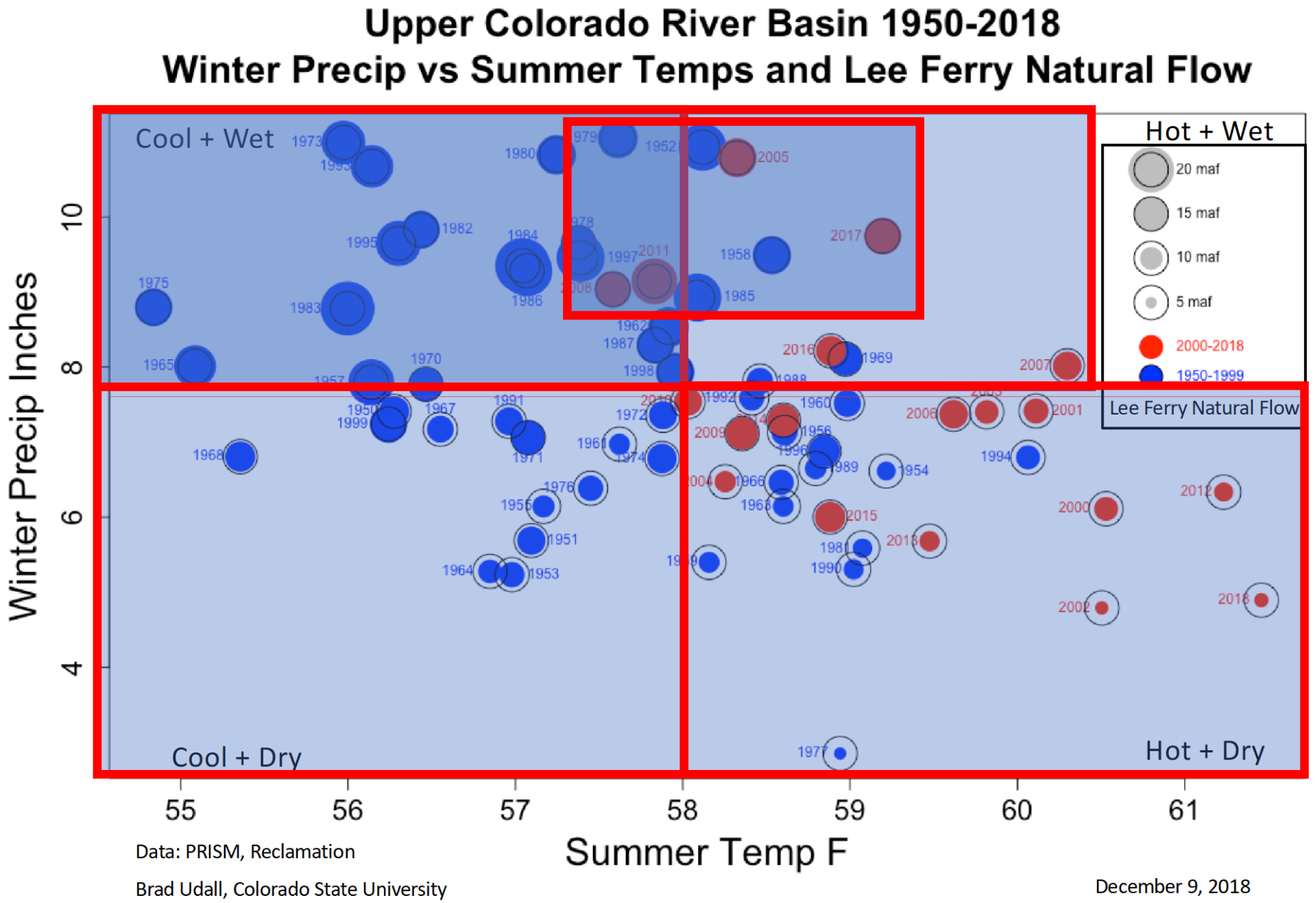
Extra Slides

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.



ICS Limits

- Annual Accural
  - 2007
  - DCP
- Total Storage
  - 2007
  - DCP
- Annual Delivery Limit
- No Delivery when Mead Below
  - 2007
  - DCP

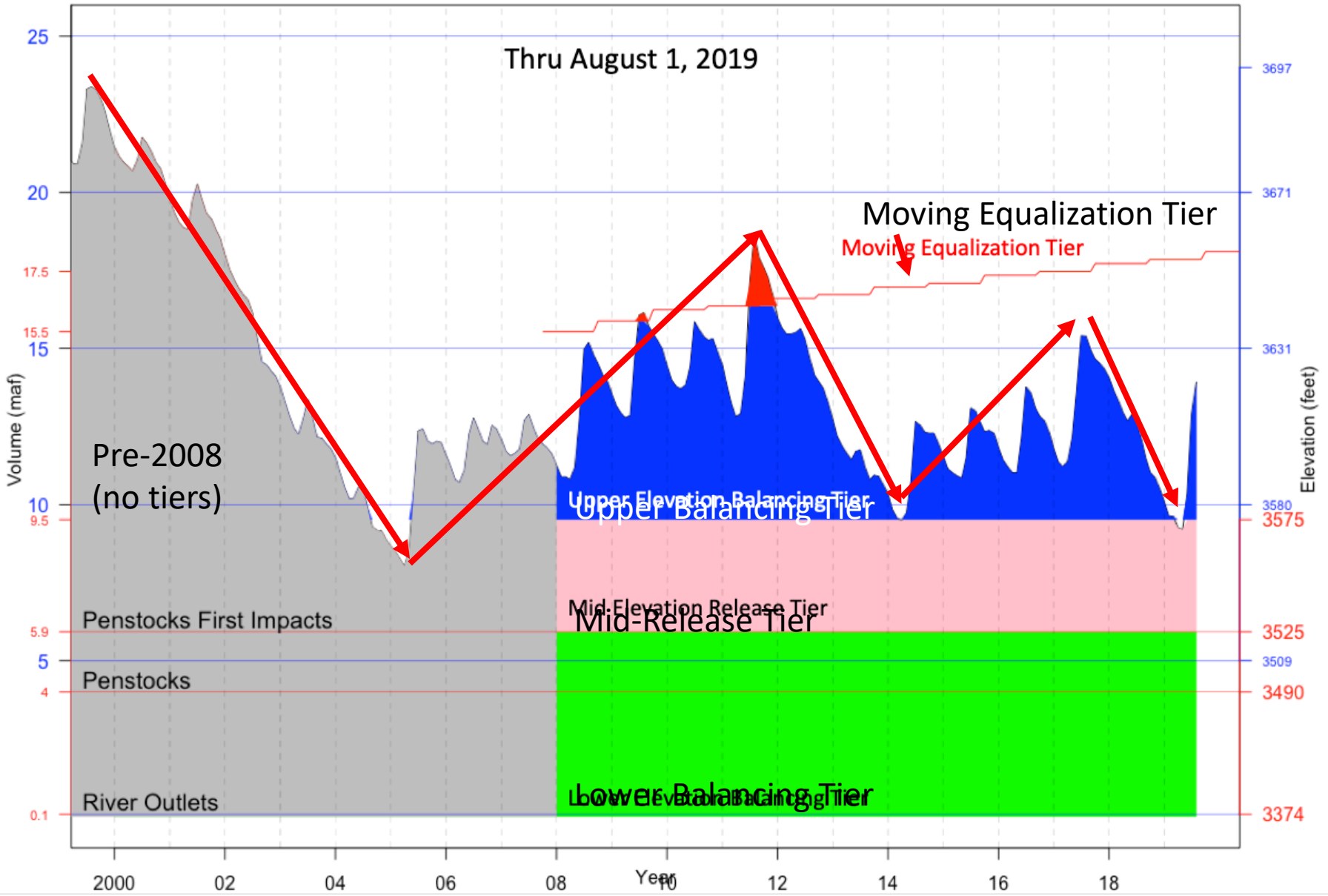
Lake Powell Contents 2000-2019

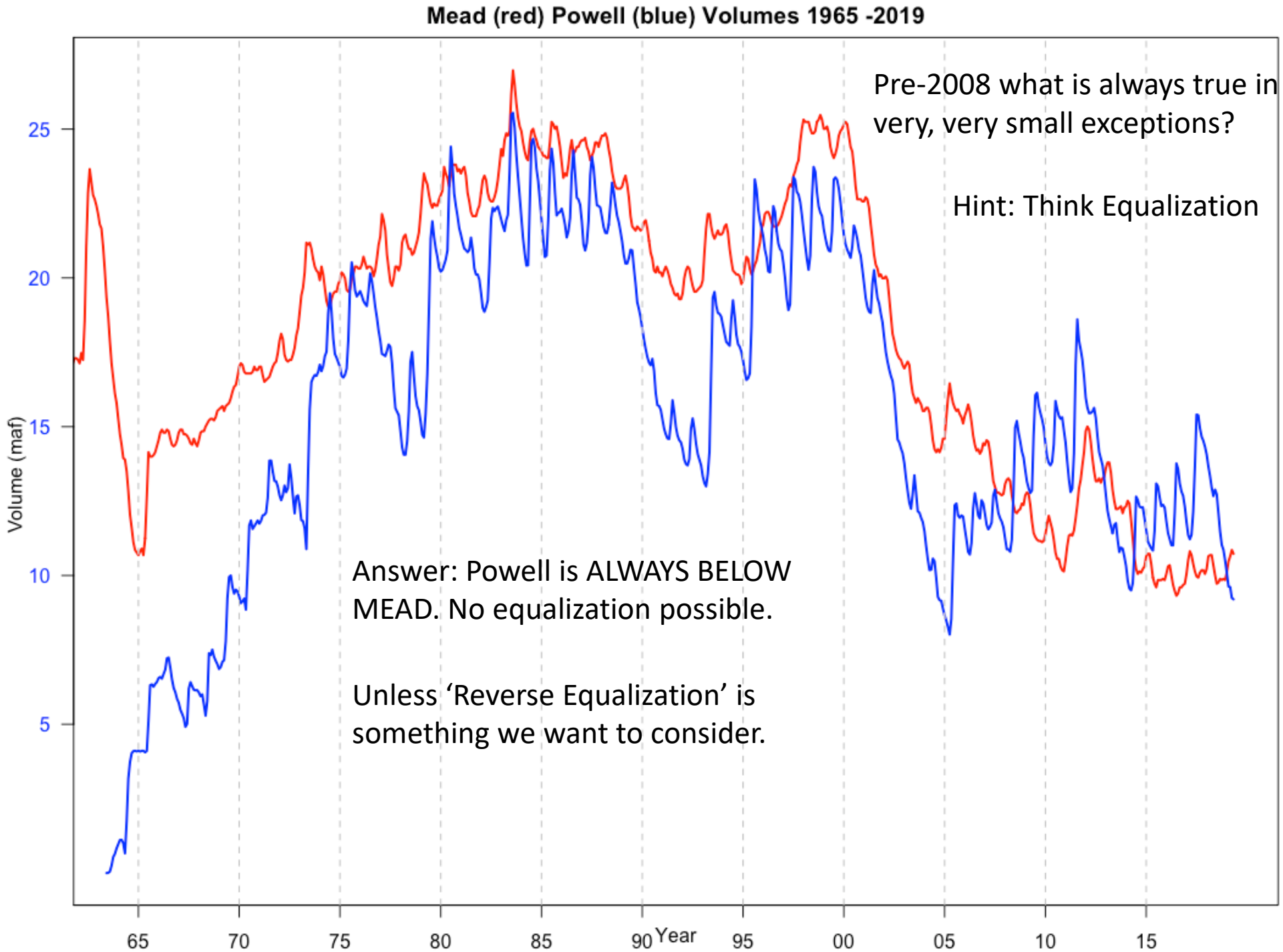
Loss of 14 maf over 19 years
740 kaf/year loss

** with 2019 inflows ~ 9 maf loss
470 kaf/year

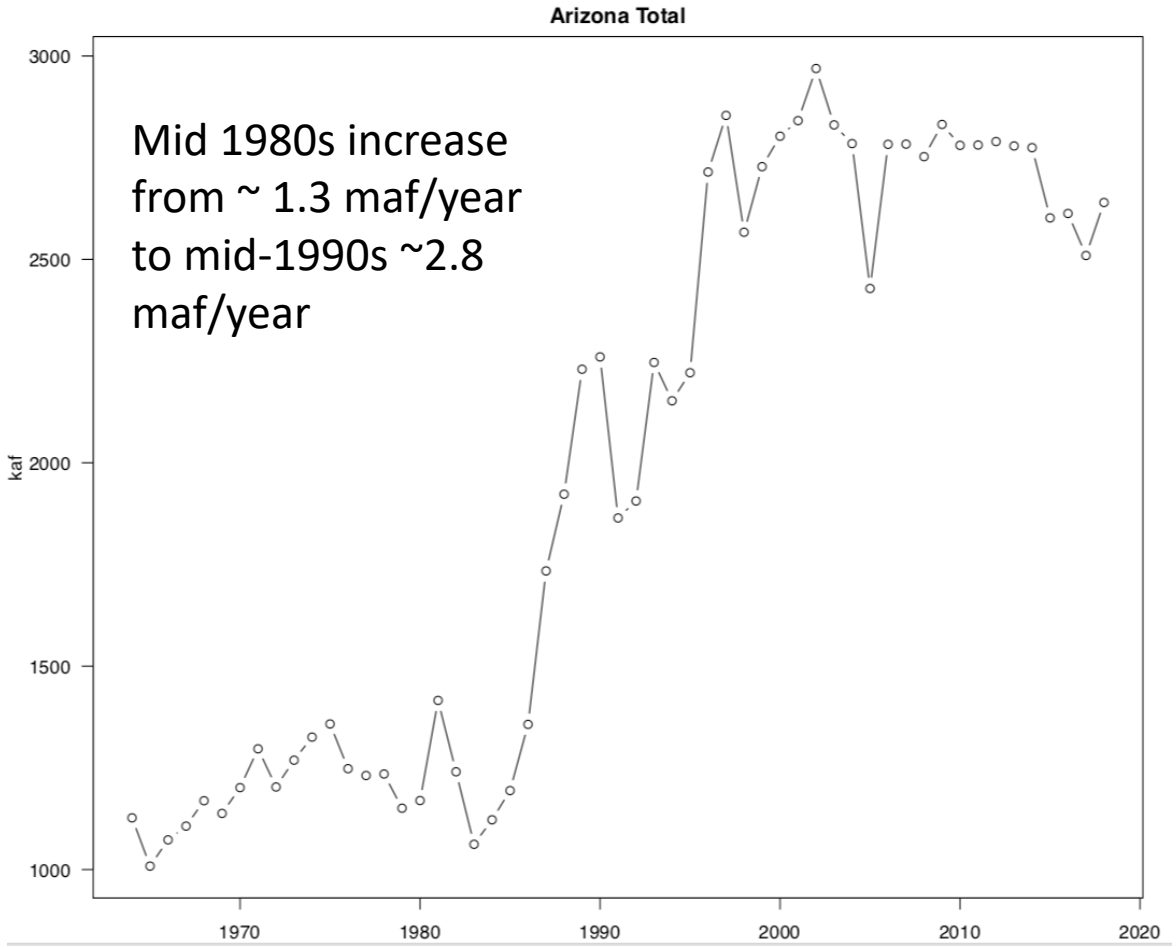
5 Periods
2000-2004 – Loss of 15 maf
2005-2011 – Gain of 10 maf
2012-2014 – Loss of 8 maf
2014-2019 – Gain of 5 maf
2018-2019 – Loss of 5 maf

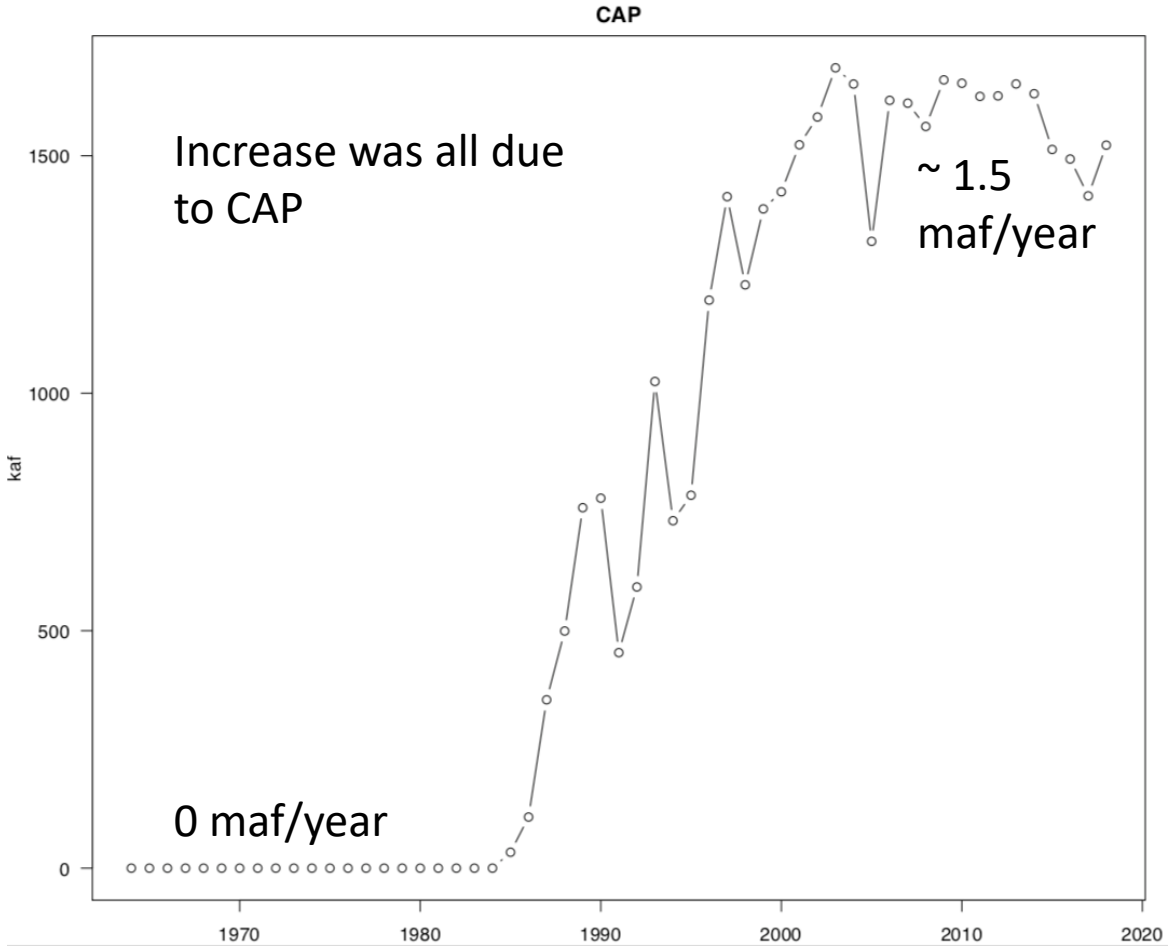
Since 2007 Operational Tiers are: AOPs?




Mead (red) Powell (blue) Volumes 1965 -2019
Volume (maf)
25
20
15
10
5
65
70
75
80
85
90
Year
95
00
05
10
15
Pre-2008 what is always true in this image with 4 very, very small exceptions?
Hint: Think Equalization
Answer: Powell is ALWAYS BELOW MEAD. No equalization possible.
Unless 'Reverse Equalization' is something we want to consider.

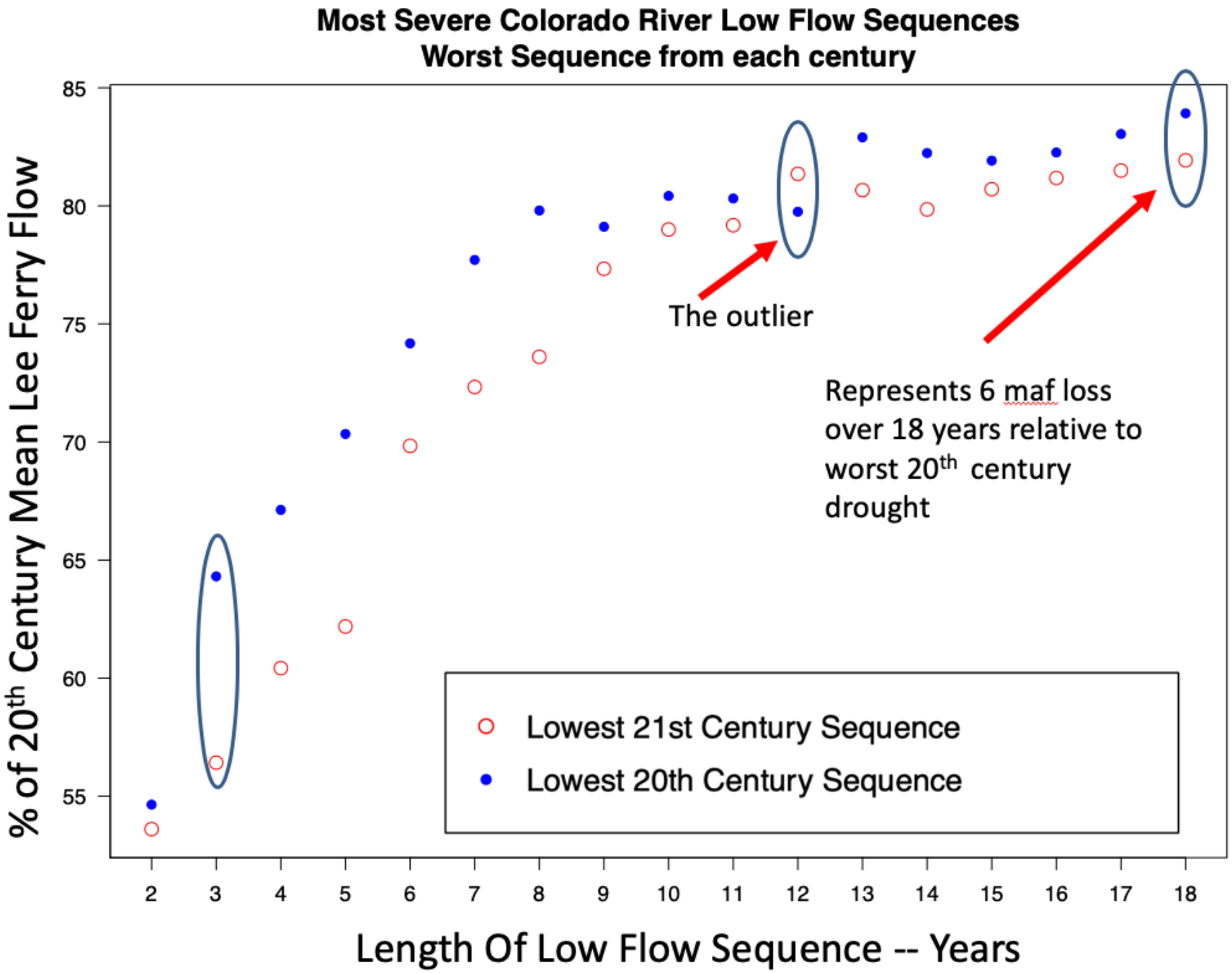
Arizona Diversions – Total and CAP





J. Fleck Lower Colorado River Accounting Data

Lake Powell Operational Tiers (subject to April adjustments or mid-year review modifications)		
Lake Powell Elevation (feet)	**Lake Powell Operational Tier**	**Lake Powell Active Storage** (maf)
3,700		**24.32**
	Equalization Tier equalize, avoid spills or release 8.23 maf	
3,636 – 3,666		**15.54 – 19.29**
(see table below)	**Upper Elevation Balancing Tier** release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf	(2008 – 2026)
3,575		**9.52**
	Mid-Elevation Release Tier release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf	
3,525		**5.93**
	Lower Elevation Balancing Tier balance contents with a min/max release of 7.0 and 9.5 maf	
3,370		**0**


Most Severe Colorado River Low Flow Sequences
Worst Sequence from each century
% of 20th Century Mean Lee Ferry Flow
85
80
75
70
65
60
55
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Length Of Low Flow Sequence -- Years
The outlier
Represents 6 maf loss over 18 years relative to worst 20th century drought
Lowest 21st Century Sequence
Lowest 20th Century Sequence