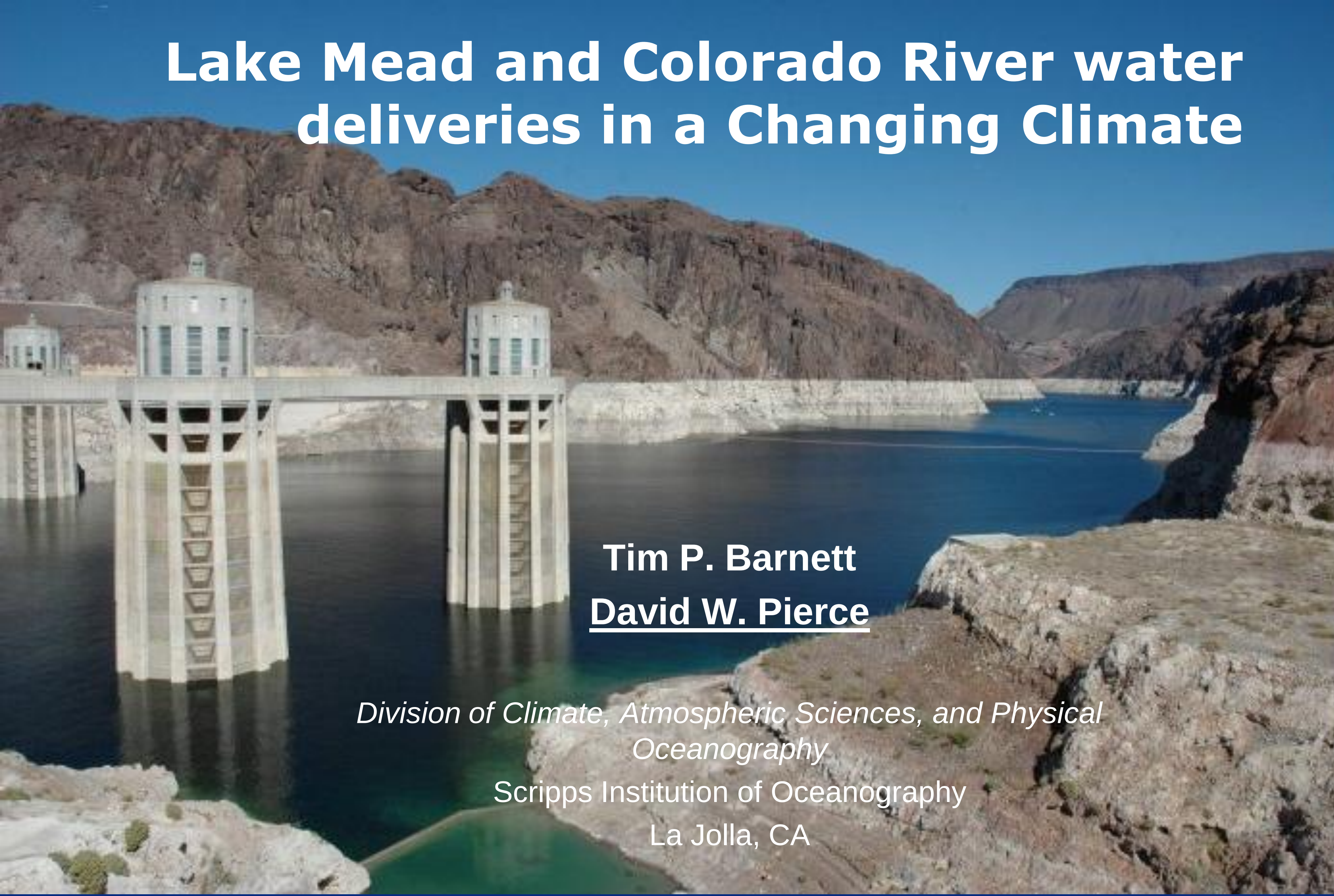

Lake Mead and Colorado River water deliveries in a Changing Climate

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Colorado River drainage

Water supply for:

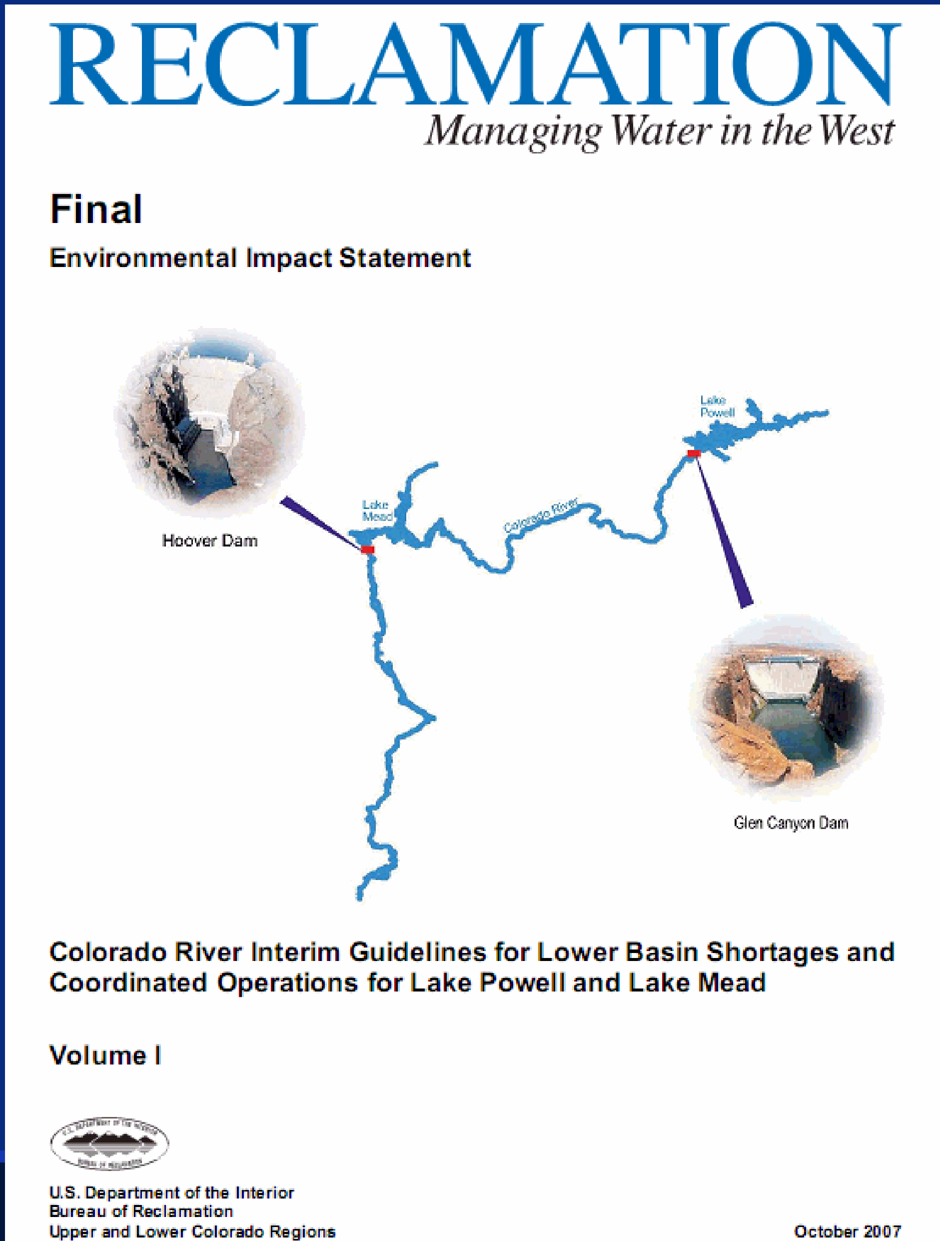
- 27 million people
- 3.5 million acres of farmland

Users in:

- 7 states
- 2 countries
- Several Native American tribes

Current deliveries: ~13.5 maf/yr, increase to ~14.4 maf/yr by 2060

Context


RECLAMATION

Managing Water in the West

Final

Environmental Impact Statement

Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead

Volume I

U.S. Department of the Interior
Bureau of Reclamation
Upper and Lower Colorado Regions

October 2007

- "Based on the current inability to precisely project future impacts of climate change at the spatial scale needed for CRSS, Reclamation based its hydrologic analysis primarily on the resampled historical record." (pg. ES-23)

- "Acknowledging the potential for impacts due to climate change … these guidelines be interim in duration and extend through 2026" (pg. ES-24)

- Outlined "preferred alternative" for operating reservoirs

COLORADO water storage

End of Oct. of year:	Mead storage (kaf)	Change from prev yr (kaf)	Powell storage (kaf)	Change from prev yr (kaf)	Mead + Powell storage (kaf)	Change from prev yr (kaf)
1997	24,343	N/A	22,554	N/A	46,897	N/A
1998	25,278	+935	22,198	-356	47,476	+579
1999	24,717	-561	22,534	+336	47,251	-225
2000	22,435	-2,282	20,753	-1,781	43,188	-4,063
2001	19,882	-2,553	18,802	-1,951	38,684	-4,504
2002	17,032	-2,850	14,270	-4532	31,302	-7,382
2003	15,517	-1,515	11,935	-2335	27,452	-3,850
2004	14,094	-1,423	9,148	-2,787	23,242	-4,210
2005	15,078	+984	12,016	+2,868	27,094	+3,852
2006	13,964	-1,114	12,526	+510	26,490	-604
2007	12,510	-1,454	11,930	-596	24,440	-2050
2008	12,213	-297	14,172	2,242	26,385	+1945
Average, kaf/year		**-1,102**		**-762**		**-1864**

Overview

"Lake Mead" paper
(J. Water Resour. Res., 2008)

- What happens to Lake Mead if the climate changes and you do nothing?
  - Reach dead pool elevation (i.e., Lake Mead "goes dry") between 2021 and 2050 or so, depending on the assumptions
  - Looked at 30 different sets of assumptions covering idealized delivery cuts, changes in runoff, etc.
- "Of course, water managers and other decision makers will do everything in their power to see that Lakes Mead and Powell do not go dry."

"Colorado River sustainability" paper
(Proc. Nat. Acad. Sci., *2009*)

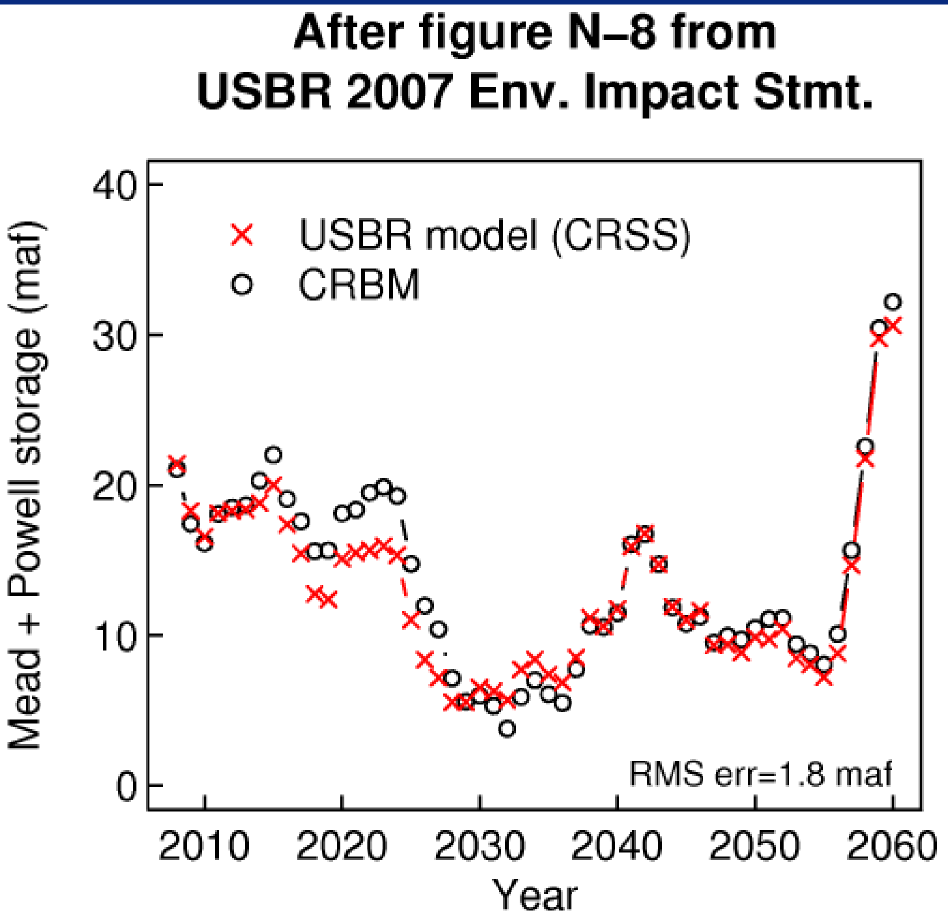
- If maintain 1000' elevation:
  - Are currently scheduled deliveries sustainable?
  - How big are the required cuts?
  - How often do they occur?
- How much water can the Colorado River sustainably deliver under climate change?

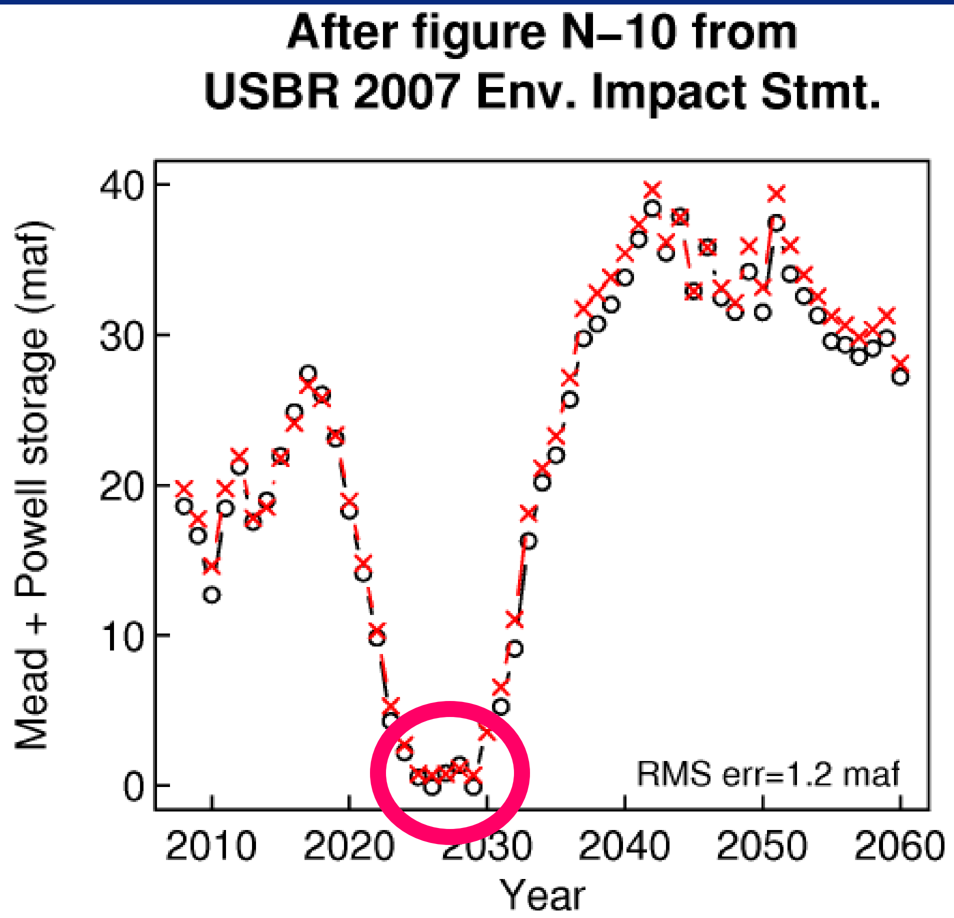
Preferred Alternative delivery cuts

Lake Mead elevation (feet msl)	Cuts to Lower Basin states (maf/yr)	Total cuts including Mexico (maf/yr)
1050-1075’	0.333	0.4
1025-1050’	0.417	0.5
<1025’	0.500	0.6

Represent cuts of ~3-4.5% of current deliveries

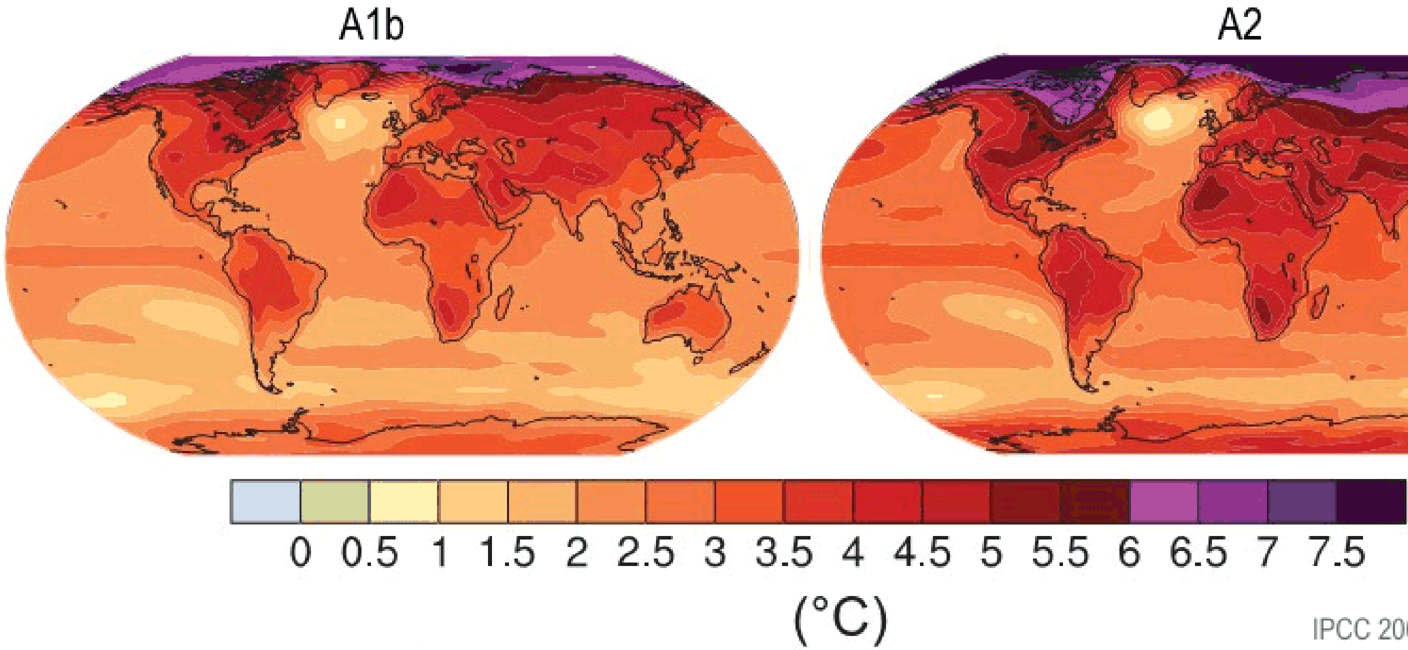
Model Calibration





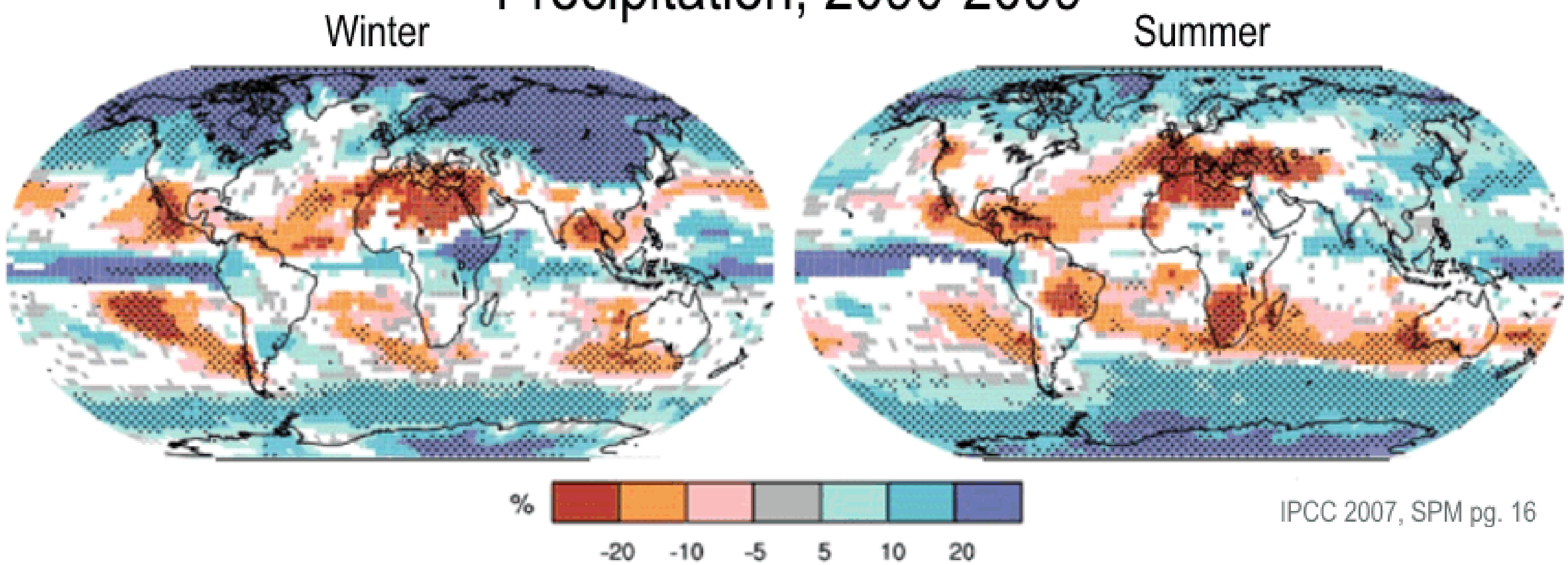
"Modeling assumptions…allowed a maximum shortage of 3.3 maf, resulting in the inability to absolutely protect Lake Mead elevation 1,000 feet msl." (pg. N-18)

Projection of Surface Temperatures, 2090-2099



IPCC 2007, SPM pg. 15

Precipitation, 2090-2099



IPCC 2007, SPM pg. 16

Uniform warming drives aridity

- *Warmer:* Increased evaporation and water loss from plants
- *Precipitation:* Can either add to or overcome drying tendency

- Temperature/precipitation tradeoff:
  - With 2 C warming, need 5-10% increase in precipitation for parity
  - With 4 C warming, need 10-20% increase

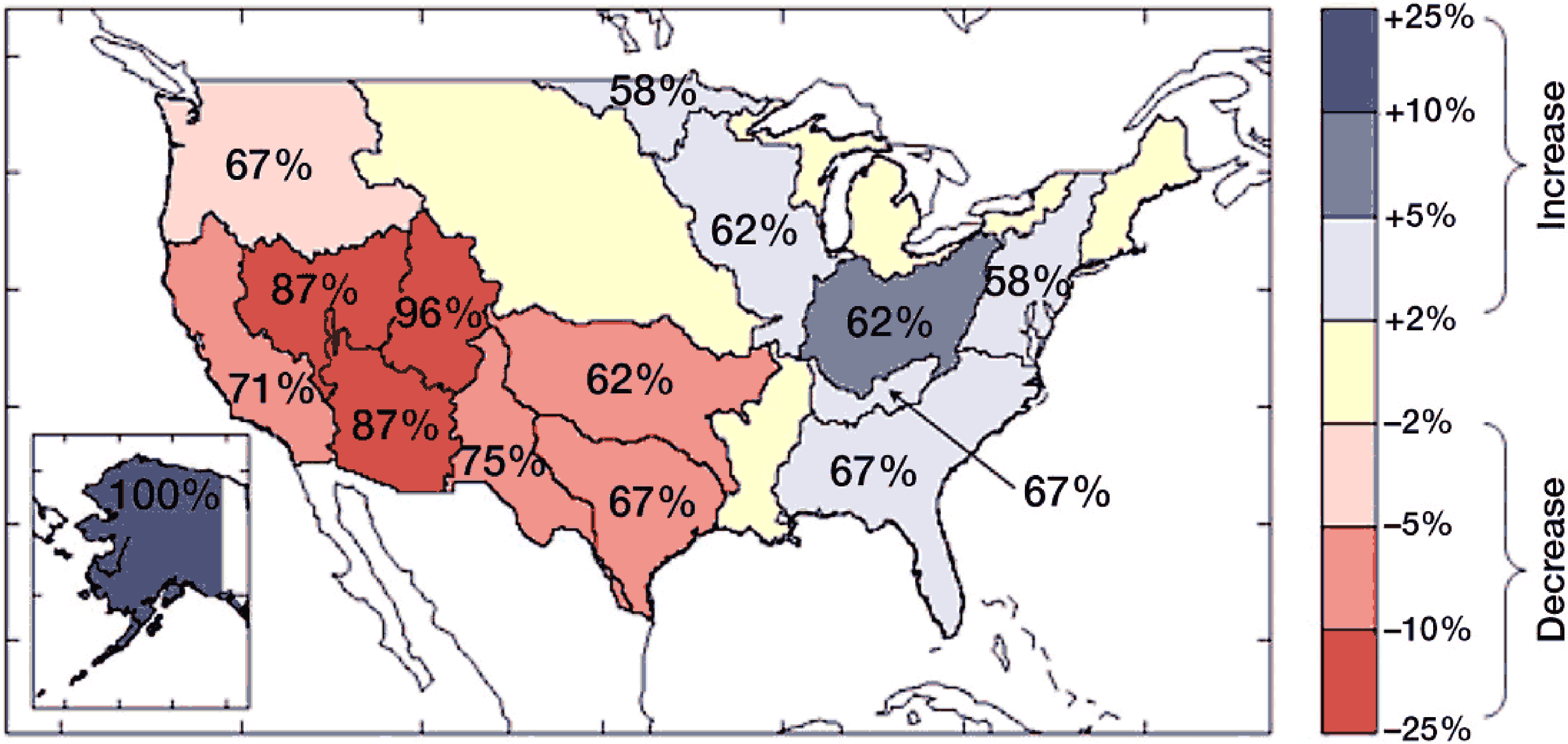
(Nash & Gleick, 1991)

- Southwest: likely *decrease* in precipitation (Seager et al., 2007)

- Current models project 10-25% less runoff (Milly et al., 2005)

Changes in Runoff by midcentury

(Numbers show *model agreement*; colors show *change*)



From Milly et al., *Nature*, 2005, as redrawn in Lettenmaier et al., CCSP report SAP 4.3, 2008

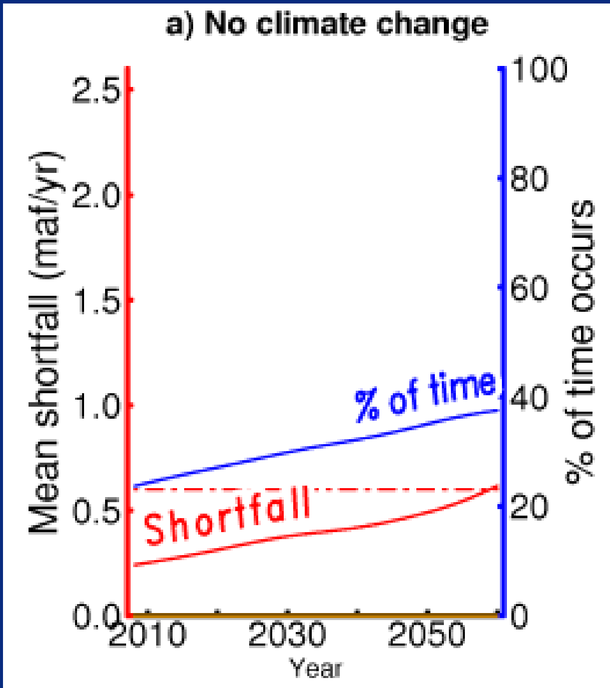
Climate change assumptions

- Two areas of inquiry
  1. How will the *river runoff change?*
  2. How will the change *affect deliveries?*

Source	Runoff reduction
Nash and Gleick (1991)	12-31% (depends on scenario)
Nash and Gleick (1993)	8-20%
Christensen et al. (2004)	18%
Milly et al. (2005)	10-25%
Seager et al. (2007)	15-20%
Christensen & Lettenmaier (2007)	6-7%
Hoerling and Eischeid (2007)	45% (under revision)
McCabe and Wolock (2007)	8-17%

- We use idealized changes of -10%, and -20% runoff.

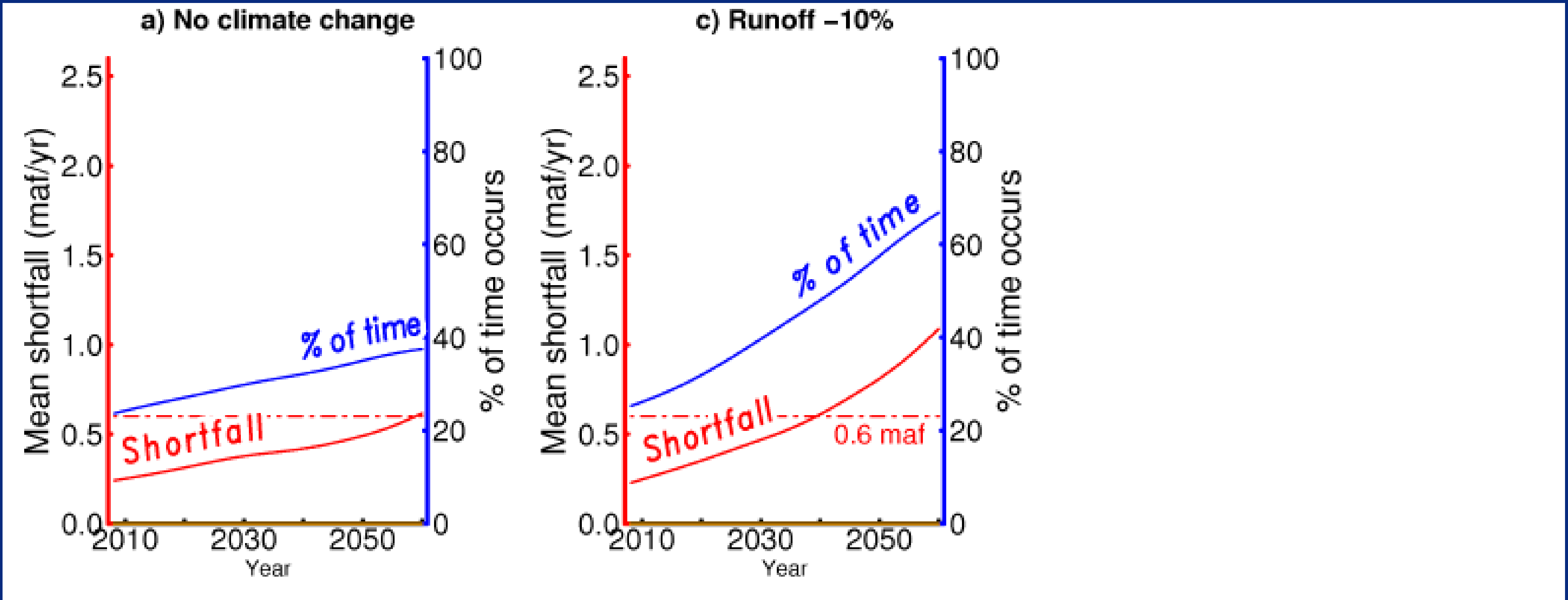
Results



1. “Shortfall” is mean *when shortfalls occur*

2. All results are relative to delivery schedules in the 2007 USBR Final Environmental Impact Statement (EIS), which shows deliveries increasing from ~13.6 to 14.4 maf/yr by 2060.

Results



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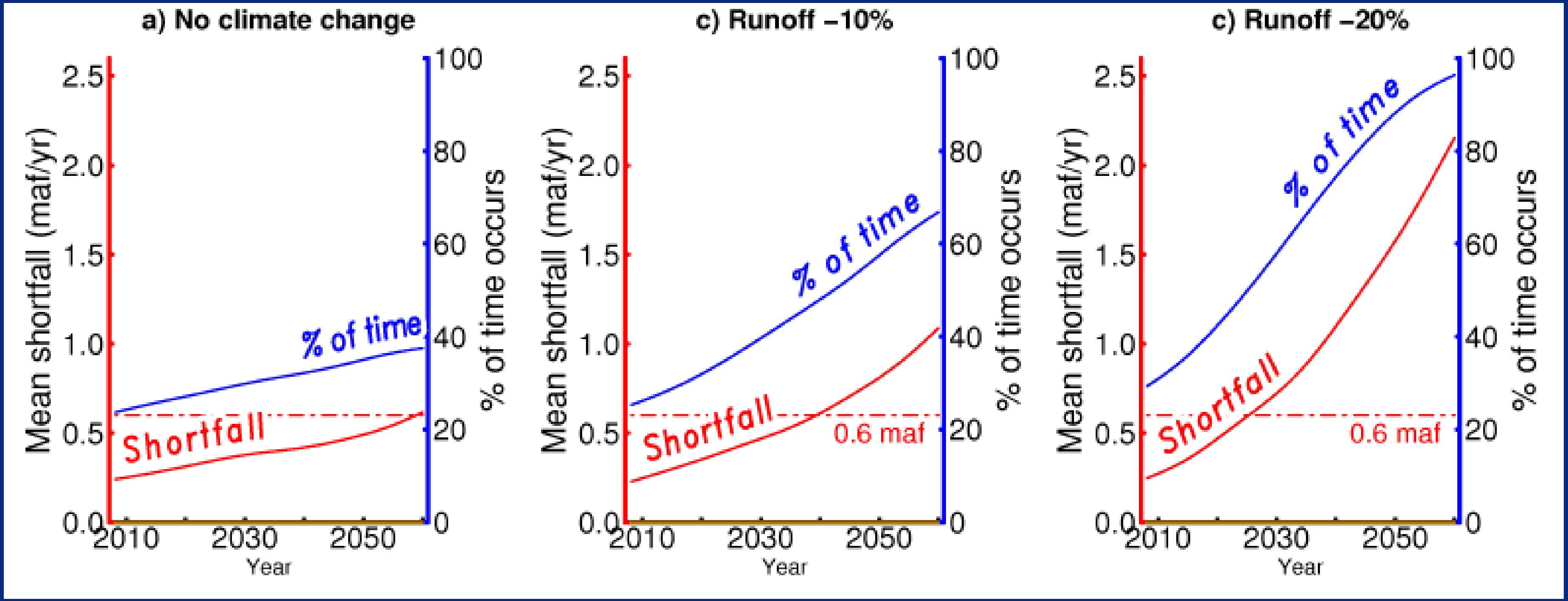

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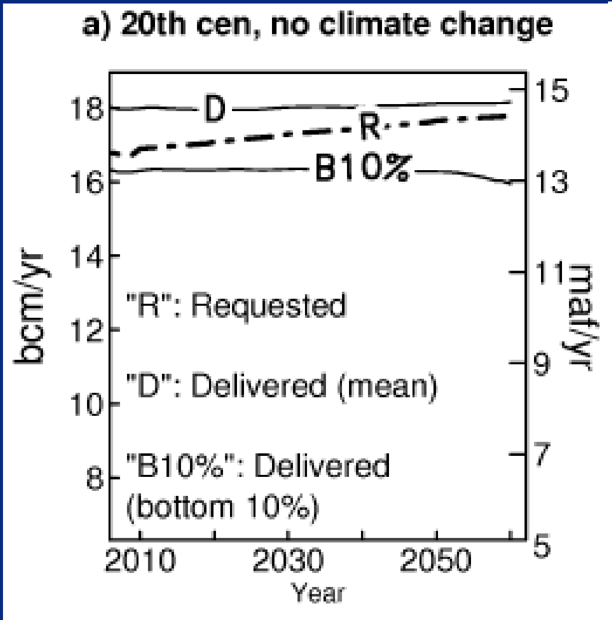
2. All results are relative to delivery schedules in the 2007 USBR Final Environmental Impact Statement (EIS), which shows deliveries increasing from ~13.6 to 14.4 maf/yr by 2060.

Results: by 2050

Runoff reduction	Scheduled deliveries missed (% of time)	Mean delivery shortage (maf)
10%	58%	0.8
20%	88%	1.5

How much water can the river supply?



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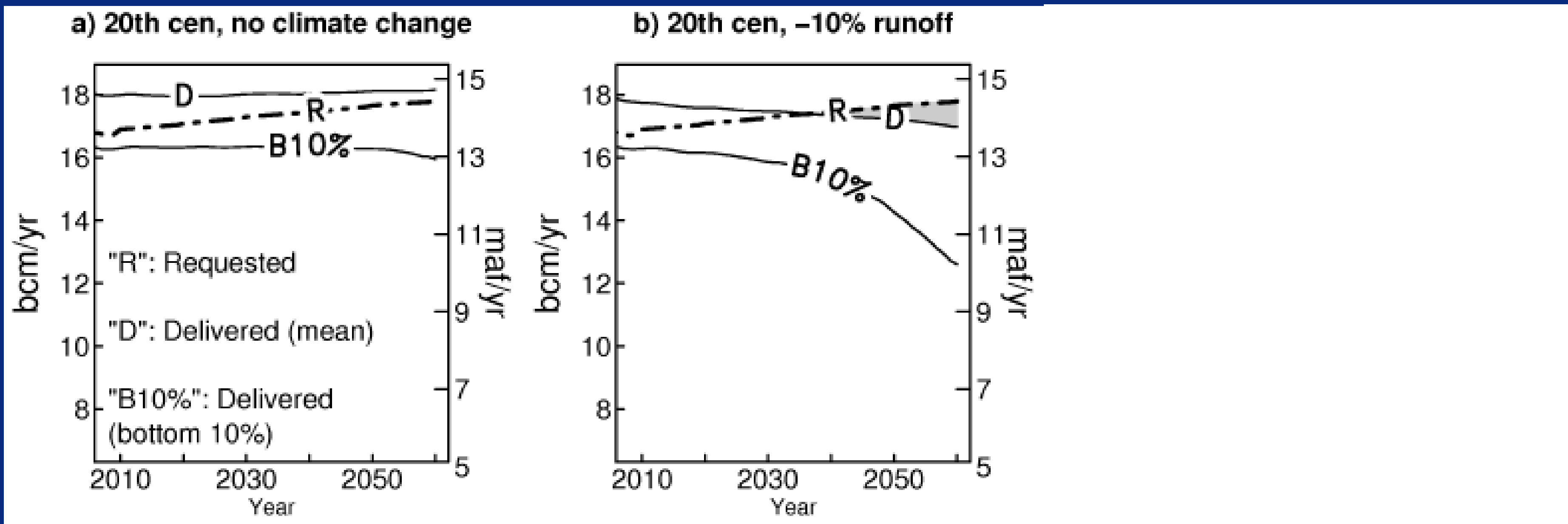

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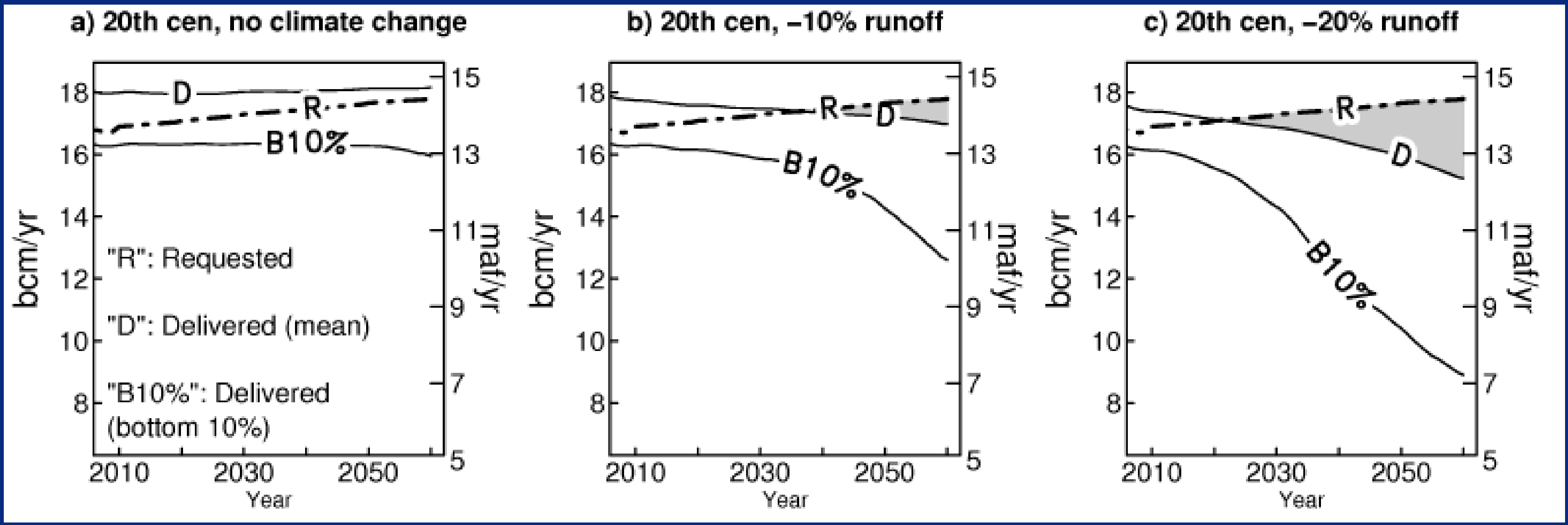
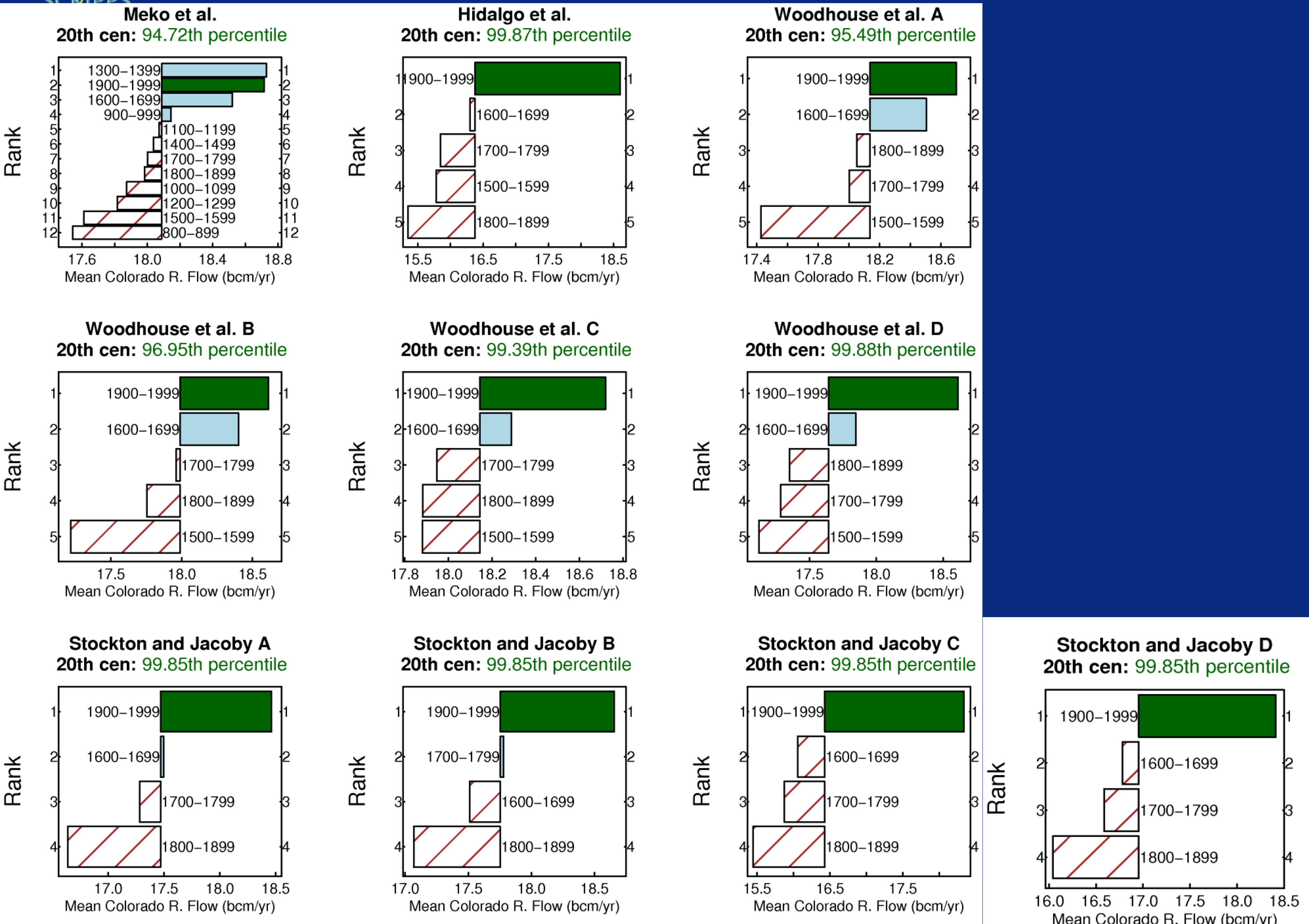


Assuming 20th century flows:
-10% runoff: ~13.7 maf/yr
-20% runoff: ~12.5 maf/yr

Mother Nature has a say

- USBR assumes long term flow a constant
- Assumes 20th cen flows
- 20th C wettest in last 1000+ years
- Repeating error of Law of River folks
- The fix is in!!!


Meko et al.
20th cen: 94.72th percentile
1300–1399
1900–1999
1600–1699
900–999
1100–1199
1400–1499
1700–1799
1800–1899
1000–1099
1200–1299
1500–1599
800–899
Rank
Mean Colorado R. Flow (bcm/yr)
Hidalgo et al.
20th cen: 99.87th percentile
1900–1999
1600–1699
1700–1799
1500–1599
1800–1899
Woodhouse et al. A
20th cen: 95.49th percentile
1900–1999
1600–1699
1800–1899
1700–1799
1500–1599
Woodhouse et al. B
20th cen: 96.95th percentile
1900–1999
1600–1699
1700–1799
1800–1899
1500–1599
Woodhouse et al. C
20th cen: 99.39th percentile
1900–1999
1600–1699
1700–1799
1800–1899
1500–1599
Woodhouse et al. D
20th cen: 99.88th percentile
1900–1999
1600–1699
1800–1899
1700–1799
1500–1599
Stockton and Jacoby A
20th cen: 99.85th percentile
1900–1999
1600–1699
1700–1799
1800–1899
Stockton and Jacoby B
20th cen: 99.85th percentile
1900–1999
1700–1799
1600–1699
1800–1899
Stockton and Jacoby C
20th cen: 99.85th percentile
1900–1999
1600–1699
1700–1799
1800–1899
Stockton and Jacoby D
20th cen: 99.85th percentile
1900–1999
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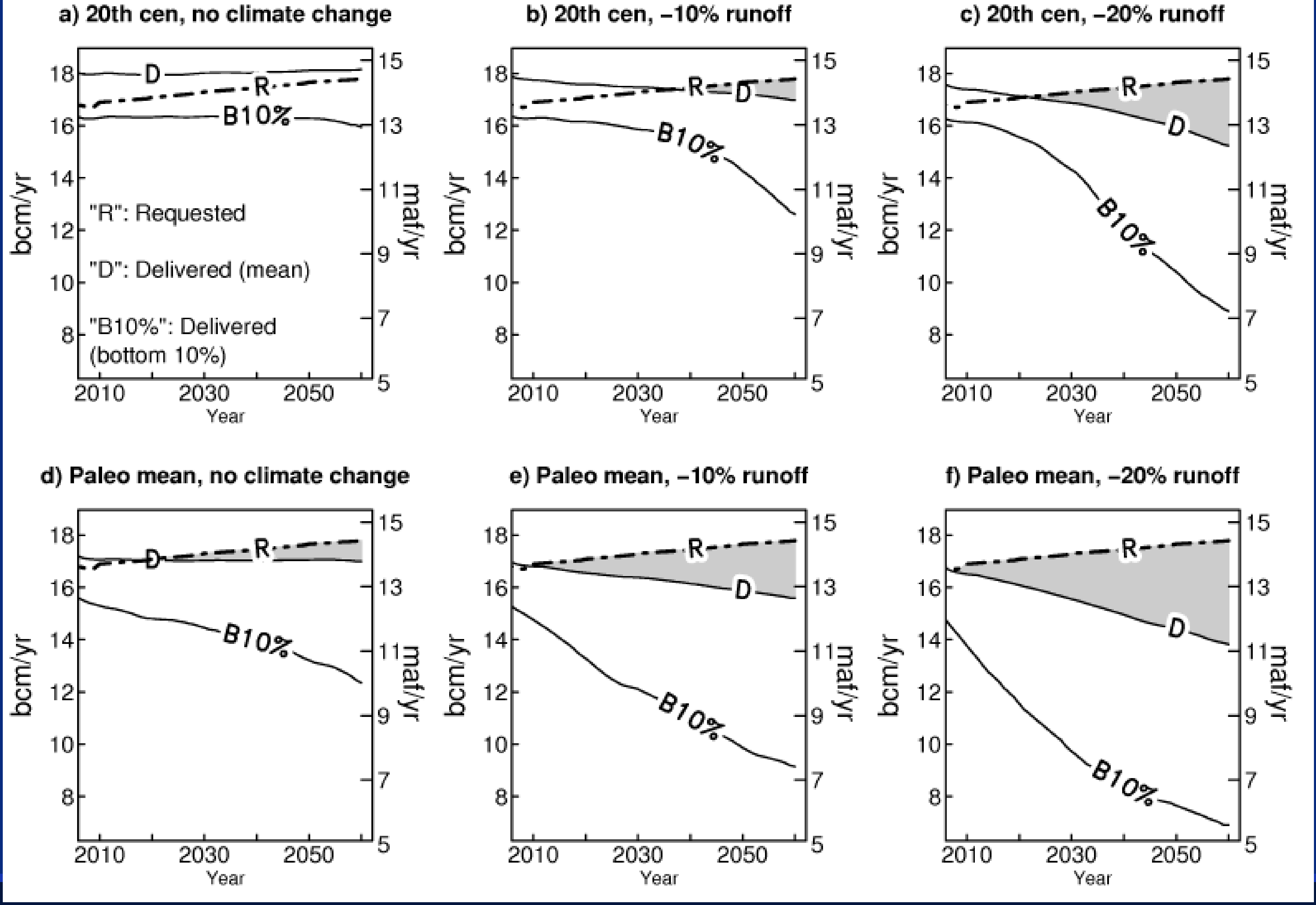
a) 20th cen, no climate change
b) 20th cen, –10% runoff
c) 20th cen, –20% runoff
d) Paleo mean, no climate change
e) Paleo mean, –10% runoff
f) Paleo mean, –20% runoff
"R": Requested
"D": Delivered (mean)
"B10%": Delivered (bottom 10%)
bcm/yr
maf/yr
Year
R
D
B10%
2010
2030
2050
18
16
14
12
10
8
15
13
11
9
7
5

Summary

- "Are scheduled water deliveries sustainable w/climate change?"

  NO!

- If runoff declines:
  - 10%: deliveries missed ~58% of the time by 2050; 13.7 maf/yr sustained
  - 20%: deliveries missed ~88% of the time by 2050; 12.5 maf/yr sustained
- Biggest effect is on low-delivery years
  - 10%: Bottom decile mean ~11.5 maf/yr in 2050
  - 20%: Bottom decile mean ~8.5 maf/yr in 2050
  - Can be mitigated if average deliveries reduced
- Too pessimistic?
  - Assuming 20th century flows but was one of the wettest periods in 1,200 yrs!
    - Paleo mean sustainable delivs: -10%: 12.7 maf/yr; -20%: 11.1 maf/yr
  - Emissions increasing faster than any IPCC scenario
  - Started runs in 1960

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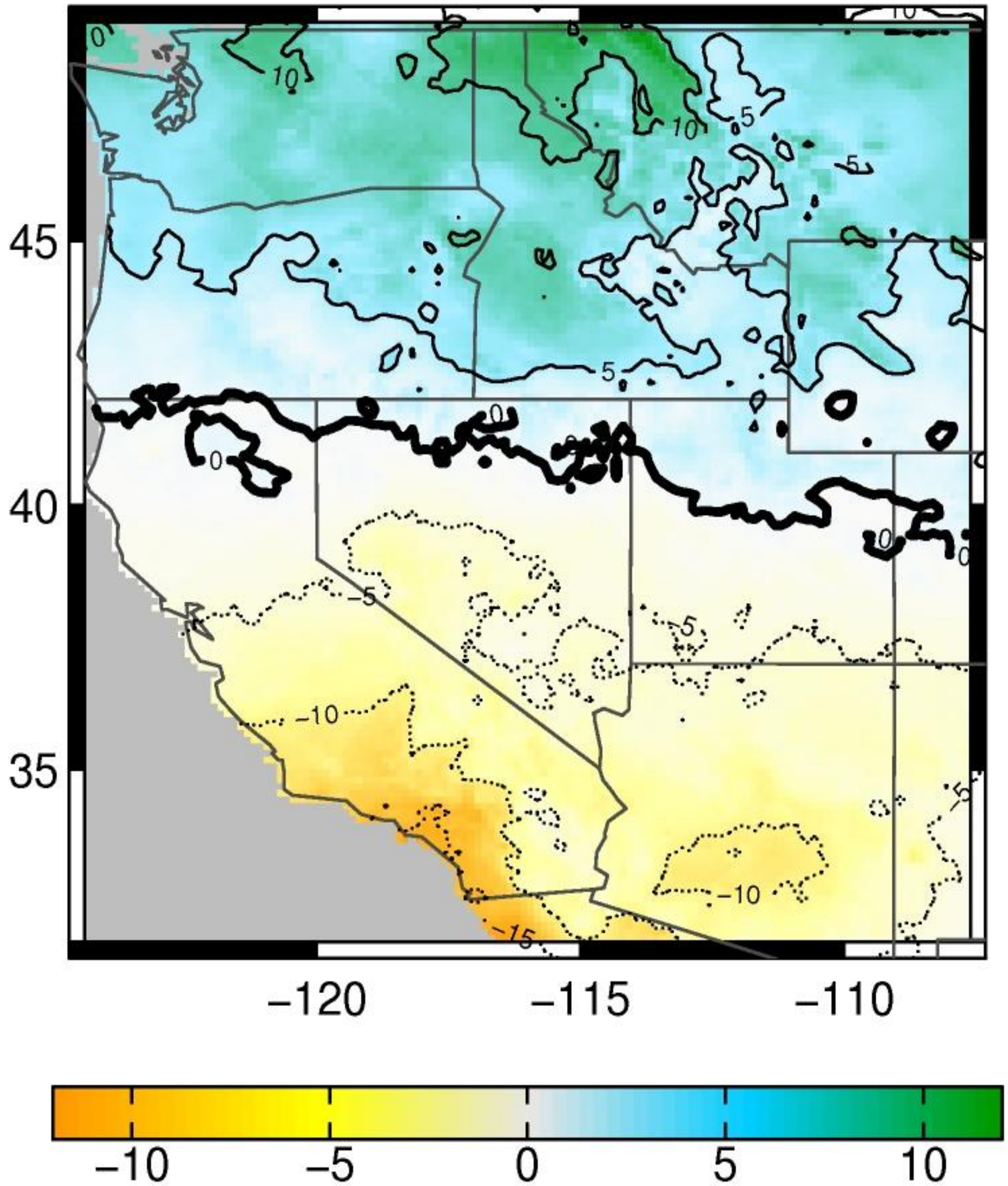
INSTITUTION OF
OCEANOGRAPHY
UCSD

Change in Precip (%) by mid–century (2040–2059)
Weighted mean of best 5 models



Effect of changes

Overall effect: delay problems by ~4-10 years, depending on scenario

- Example 1
  - Fixed net inflow (INTO Lake Mead minus OUT) of -1.0 maf/yr

Water Year	Change in Storage (maf)	
1999	-0.7	(La Nina)
2000	-2.3	(La Nina)
2001	-2.5	
2002	-2.9	
2003	-1.4	(El Nino)
2004	-1.6	
2005	+1.1	(El Nino)
2006	-1.2	
2007	-1.4	(El Nino)
Average over 9 years	-1.43 maf/year	

  - Control level: Old, dead pool (0% full). New, 1000’ msl (8% full).
  - Results: Old, 2021. New, 2025.

Effect of SNWA third intake

- What happens if relax 1000’ requirement?

- Little effect on sustainable deliveries
  - Gain about 0.17 maf/yr if let Lake Mead sit at dead pool

- At 1000’, Lake Mead has 4.33 maf of active storage
- ~8% of Mead + Powell capacity
- Push problems out ~2.5 - 5 years

- Avoid hard choice during droughts:
  - Let Las Vegas go dry?
  - Deliver 8 maf of water to *all* users (UB, LB, MX)?