Water Supply Risk on the Colorado River: Can Management Mitigate?

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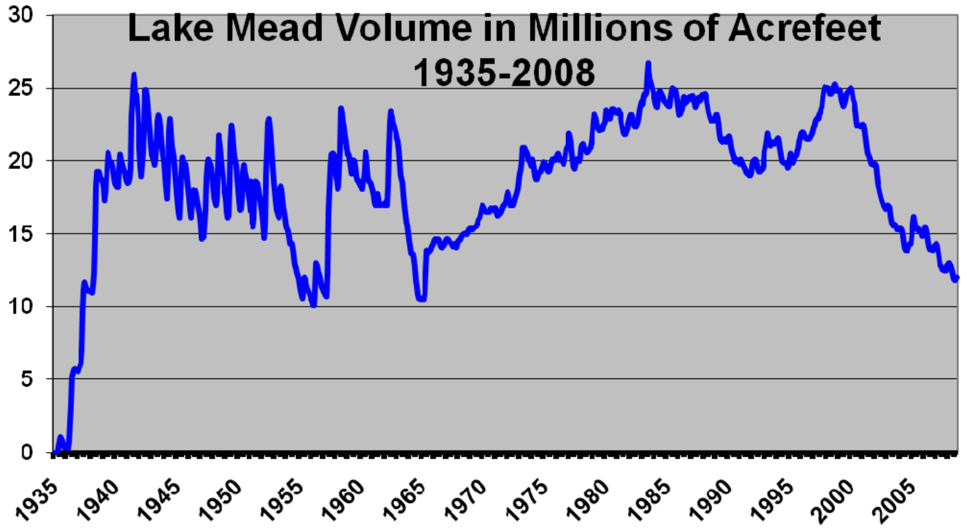
Colorado River Basin Overview

Source: US Bureau of Reclamation

- 7 States, 2 Nations
  - Upper Basin: CO, UT, WY, NM
  - Lower Basin: AZ, CA, NV
- Fastest Growing Part of the U.S.
- 60 MAF of total storage
  - 4x Annual Flow
  - 50 MAF in Powell + Mead
- Irrigates 3.5 million acres
- Serves 30 million people
- Colorado River Compact
  - 1922 Apportionment

Recent Drought and Reservoir Conditions



Source: US Bureau of Reclamation

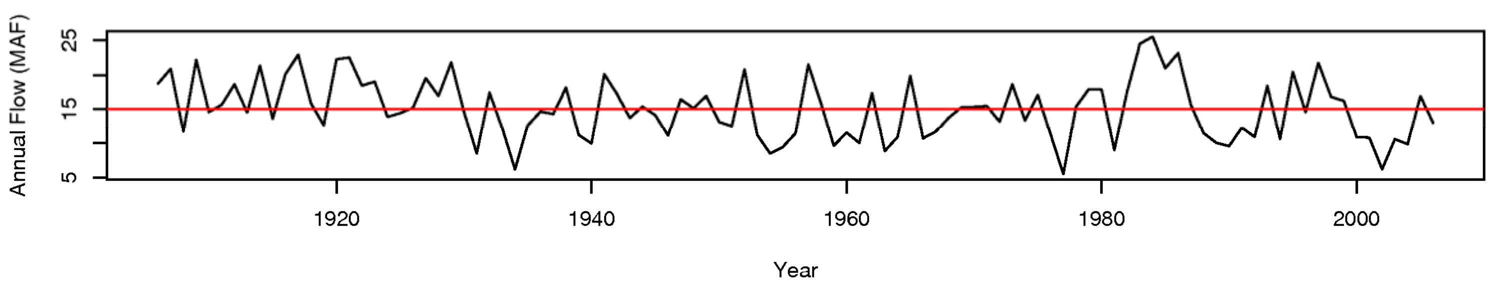
- Significant storage decline
- Shortage EIS policies

New York Times Sunday Magazine, October 21, 2007

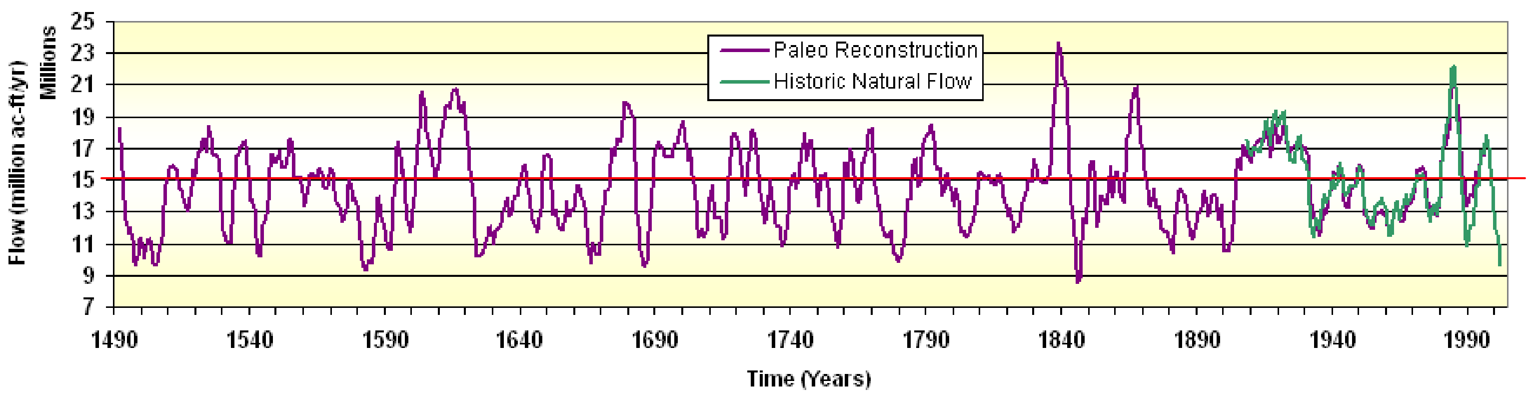
Recent Conditions in the Colorado River Basin Paleo Context

- Below average flows into Lake Powell 2000-2004
  - 62%, 59%, 25%, 51%, 51%, respectively
    - 2002 at 25% lowest inflow recorded since completion of Glen Canyon Dam

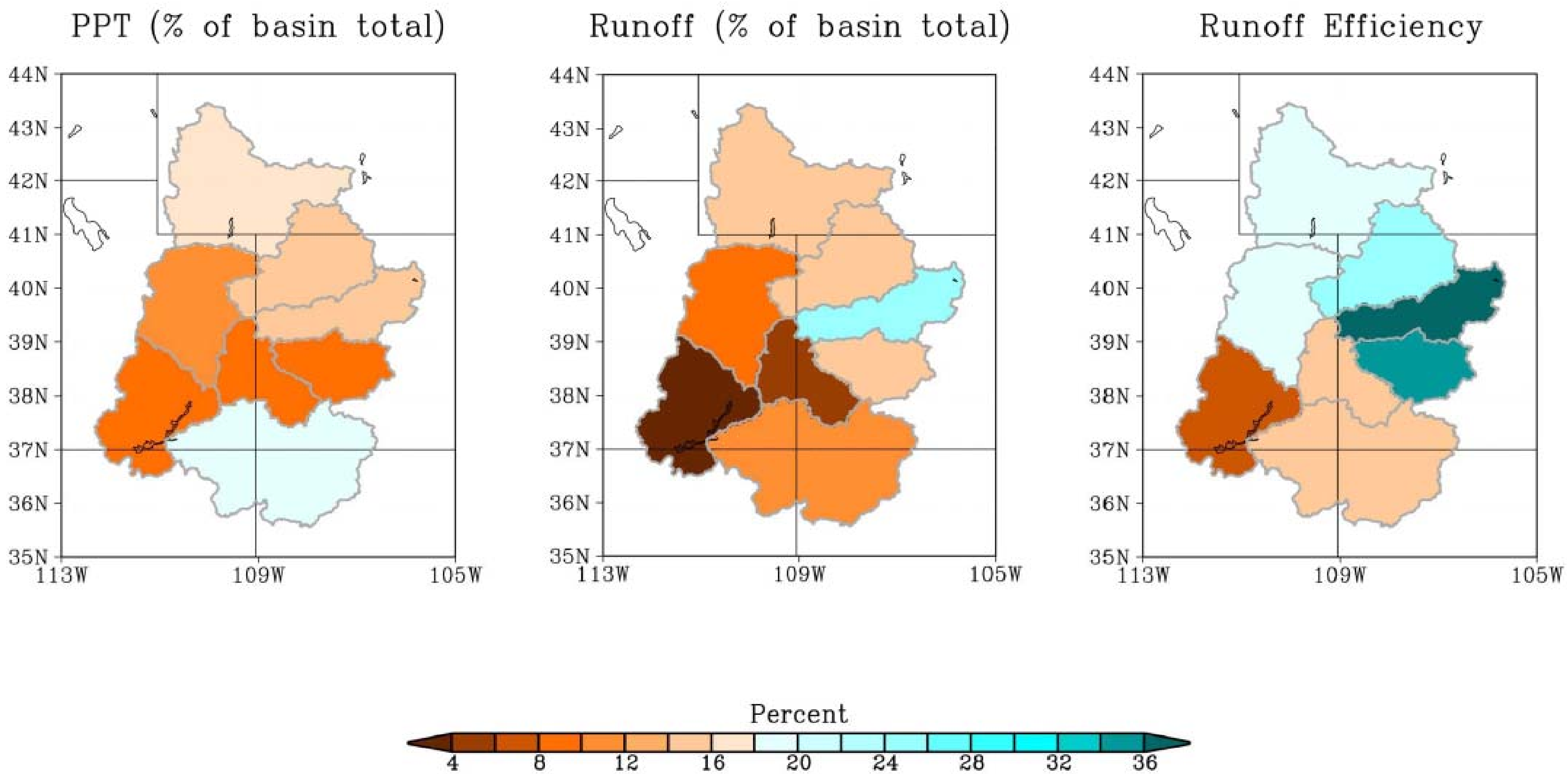
Lee's Ferry Natural Flow



Colorado River at Lee's Ferry, AZ 5 year running average

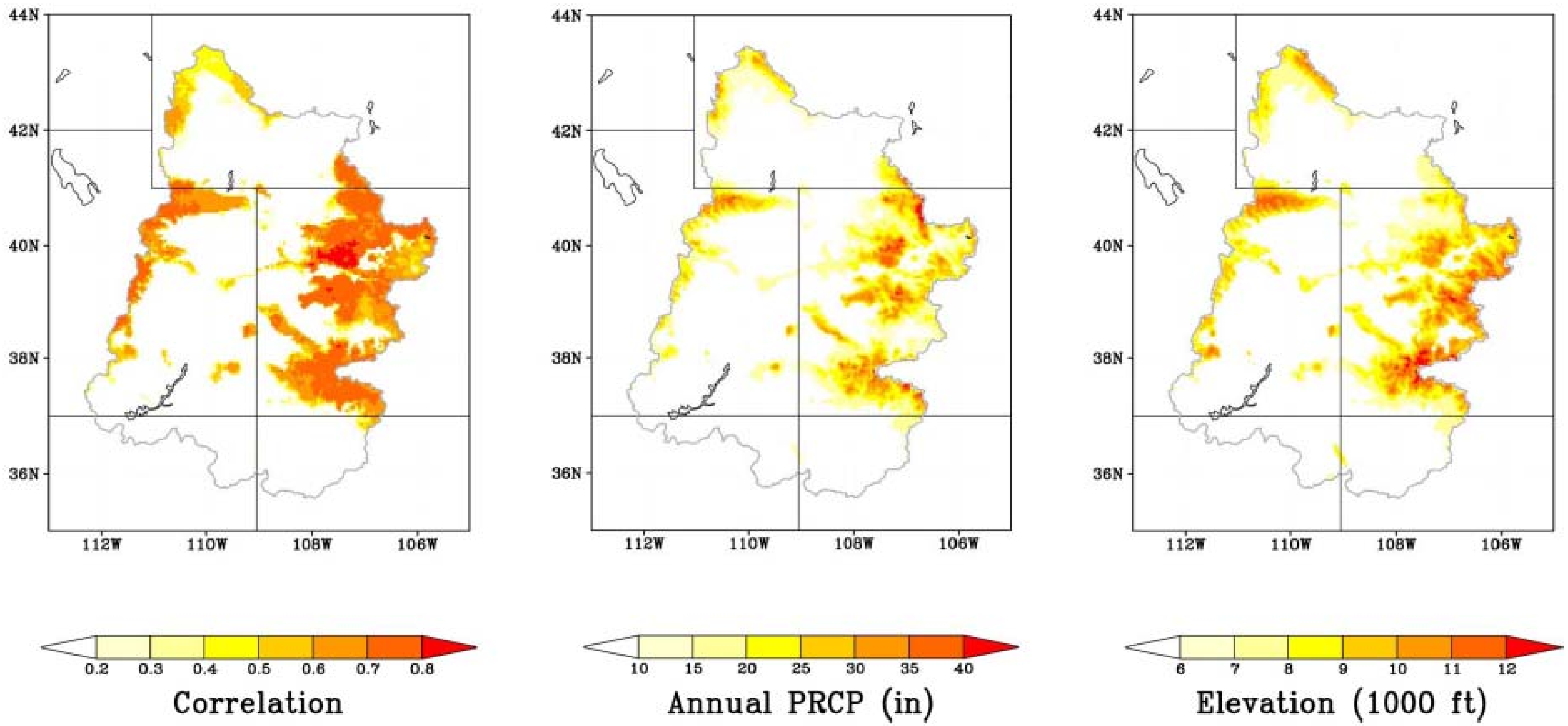


CRB Flow Production



Source: Hoerling 2008

Annual Lee's Ferry Streamflow



Source: Hoerling 2008

Climate Change Projections for CRB

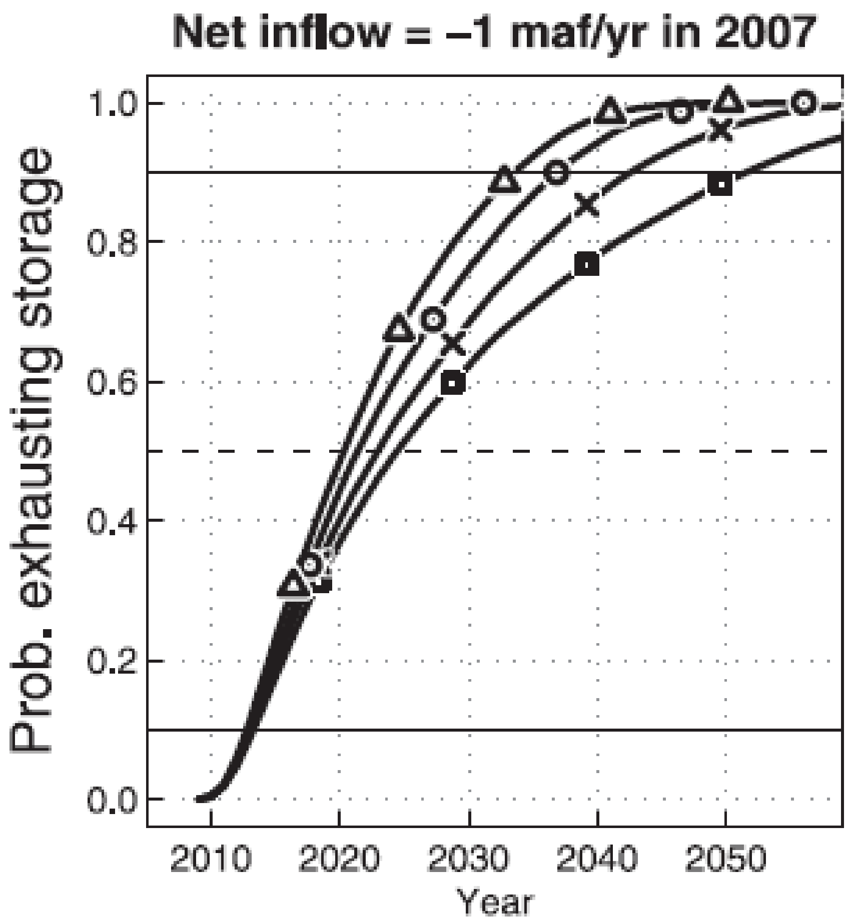
- Changes in flow [~50 year horizon]

Study	*GCMs (runs)*	*Spatial Scale*	*Temperature*	*Precipitation*	*Year*	*Runoff (Flow)*
Christensen et al. 2004	1 (3)	VIC model grid (~8 mi)	+3.1°F	-6%	2040–69	-18%
Milly 2005, replotted by P.C.D. Milly	12 (24) (~100–300 mi)	GCM grids —	—		2041–60	-10 to -20% 96% model agreement
Hoerling and Eischeid 2006	18 (42)	NCDC Climate Division	+5.0°F	~0%	2035–60	-45%
Christensen and Lettenmaier 2007	11 (22)	VIC model grid (~8 mi)	+4.5°F (+1.8 to +5.0)	-1% (-21% to +13%)	2040–69	-6% (-40% to +18%)
Seager et al. 2007*	19 (49)	GCM grids (~100–300 mi)	—	—	2050	-16% (-8% to -25%)
McCabe and Wolock 2008	—	USGS HUC8 units (~25–65 mi)	Assumed +3.6°F	0%	—	-17 %
Barnett and Pierce 2008*	—	—	—	—	2057	Assumed -10% to -30%

Source: Ray et al., 2008

When Will Lake Mead Go Dry?
Barnett & Pierce, Water Resources Research, 2008

- Net Inflow Sensitivity
  - defined as long-term mean flow minus the long-term mean of consumption plus evaporation/infiltration
  - Current Net Inflow
    - Range, “selected mean”
  - Climate Projections
- Results With 20% Reduction
  - 50% Chance Live Storage Gone by 2021
- Is that so?

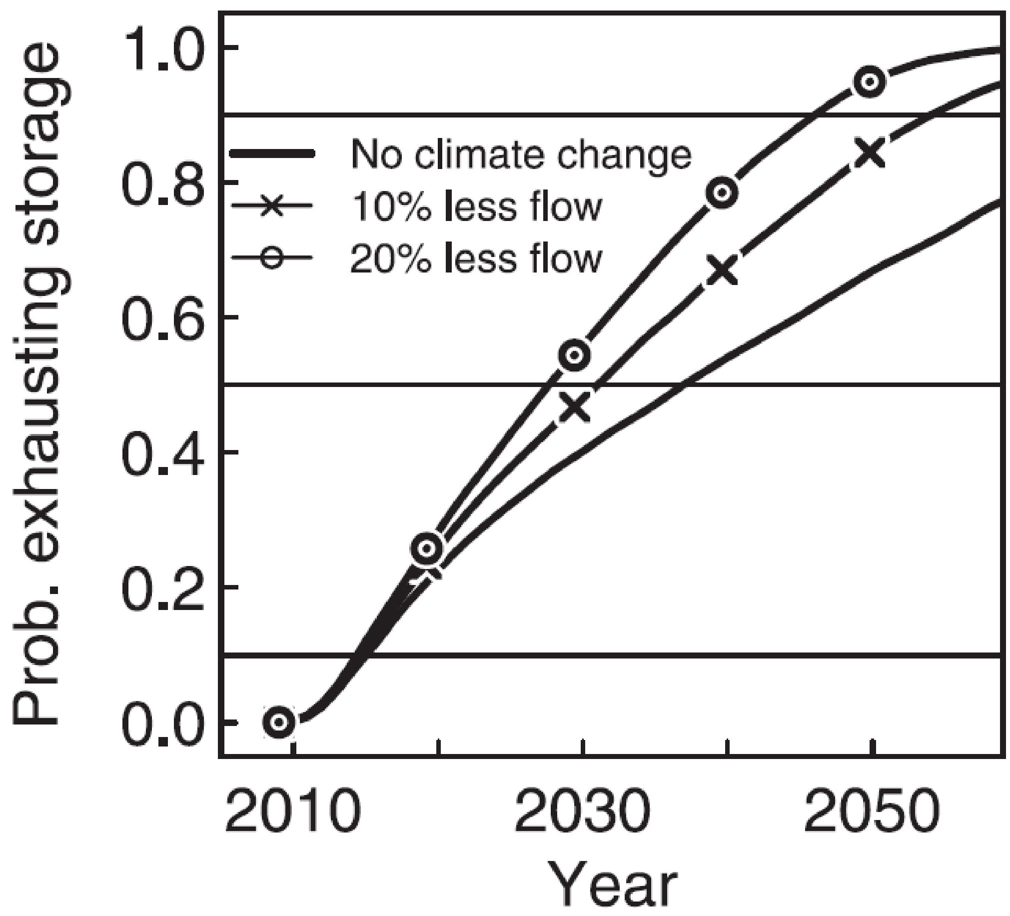


Colorado Basin Net Flow Balance

System Component	**Value (MAF)**
Upper Basin Natural Flow (Lee's Ferry)	15.0
Demands	-13.5
Losses from Powell and Mead	-1.4
Inflow Between Powell and Mead	0.86
Losses Below Hoover Dam	-1.0
Inflow Below Hoover Dam	0.45
Net System Balance	**0.4**

When Will Lake Mead Go Dry?
Barnett & Pierce, Water Resources Research, 2008

- Water Budget Analysis
  - Reservoir
  - Demands/Losses
  - Climate Projections
  - Metric
- Results With 20% Reduction
  - 10% Chance Live Storage Gone by 2013
  - 50% Chance Live Storage Gone by 2027
  - 50% Chance Loss of Power by 2017
- Is that so?



Simple Water Balance Model

- "Lump Bucket Model"
- Storage in any year is computed as:

  Storage = Previous Storage + Inflow - ET- Demand
- Colorado Basin current demand = 13.5 MAF/yr (shortage EIS depletion schedule)
- Total live storage in the system 60 MAF reservoir
- Initial storage of 30 MAF (i.e., current reservoir content)
- Inflow values are natural flows at Lee's Ferry, AZ + local flows between Powell and Mead and below Mead
- ET computed using lake area – lake volume relationship
- Transmission losses ~6% of releases accounted for

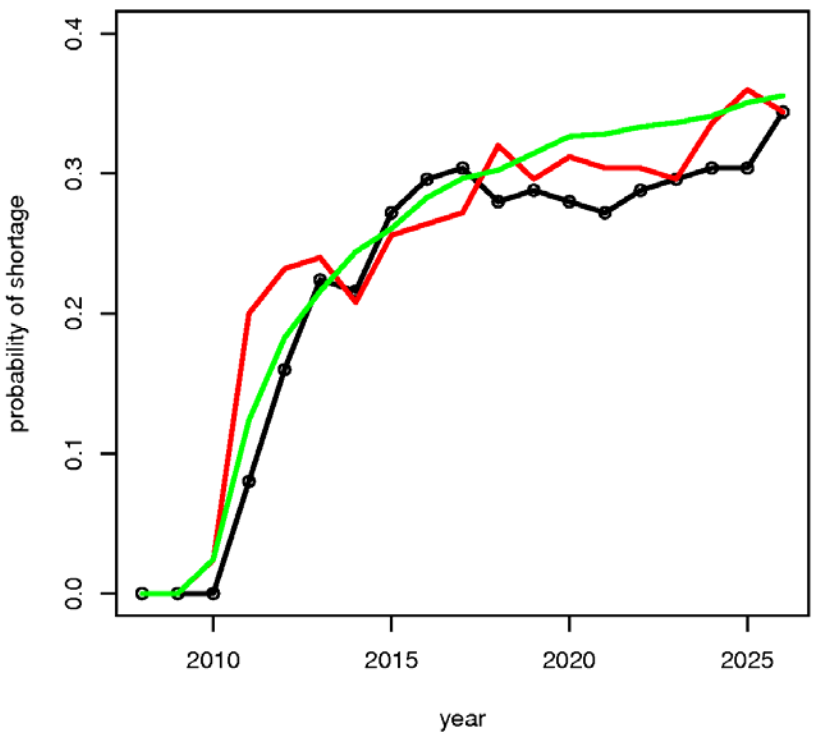
Streamflow Data

- 10,000 traces, 50 years in length
- Generated using Non-Homogeneous Markov technique (Prairie et al., 2008)
  - Combines paleo-reconstructed state information with observed flow values
- Climate change induced reductions in flow
  - 3 scenarios explored; 0, 10 and 20% linear reduction trend applied to synthetic data over 50 year horizon

Management Alternatives

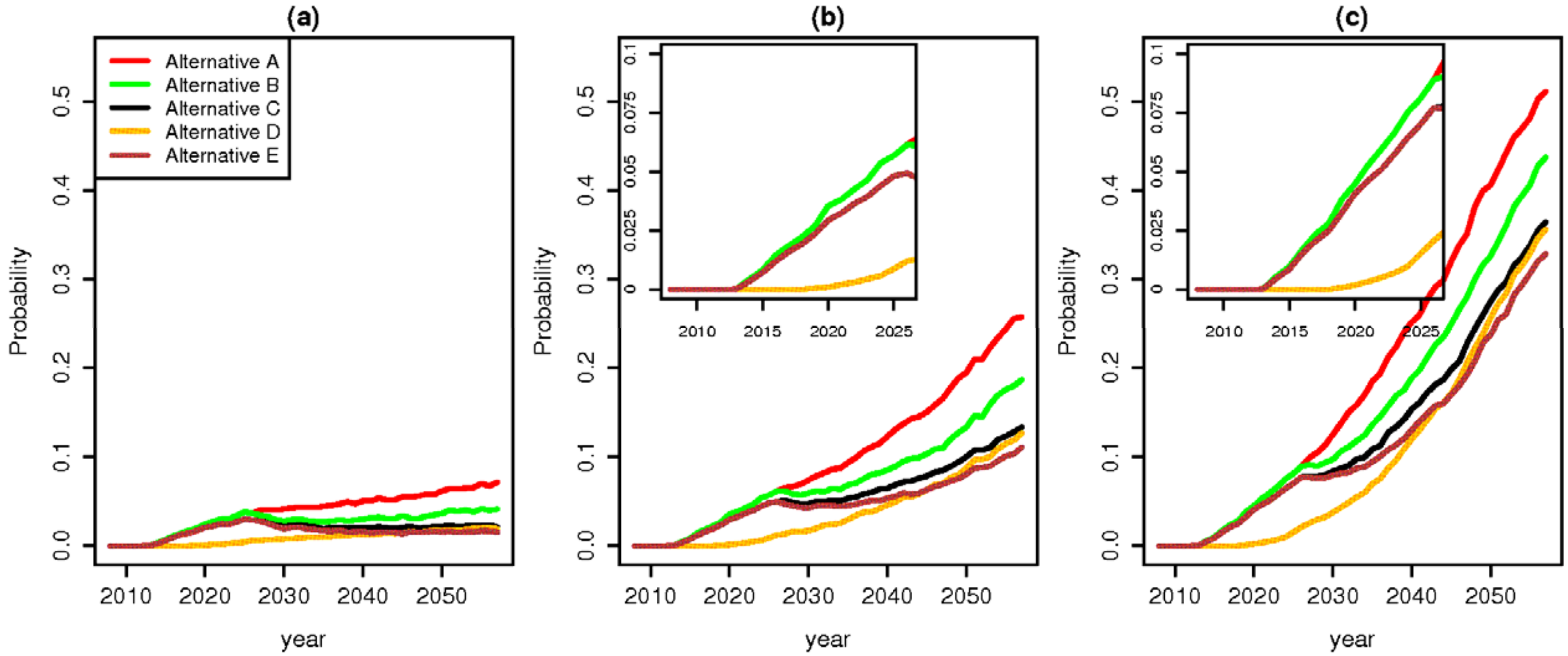
- Alternatives consist of three components
  - Rate of demand growth
  - Shortage policy
  - Initial reservoir storage
- Interim EIS shortage policies employed through 2026
- Current depletion schedule vs. slowed depletion schedule
- Variety of shortage policies; action threshold and magnitude

Model Validation – Interim Period



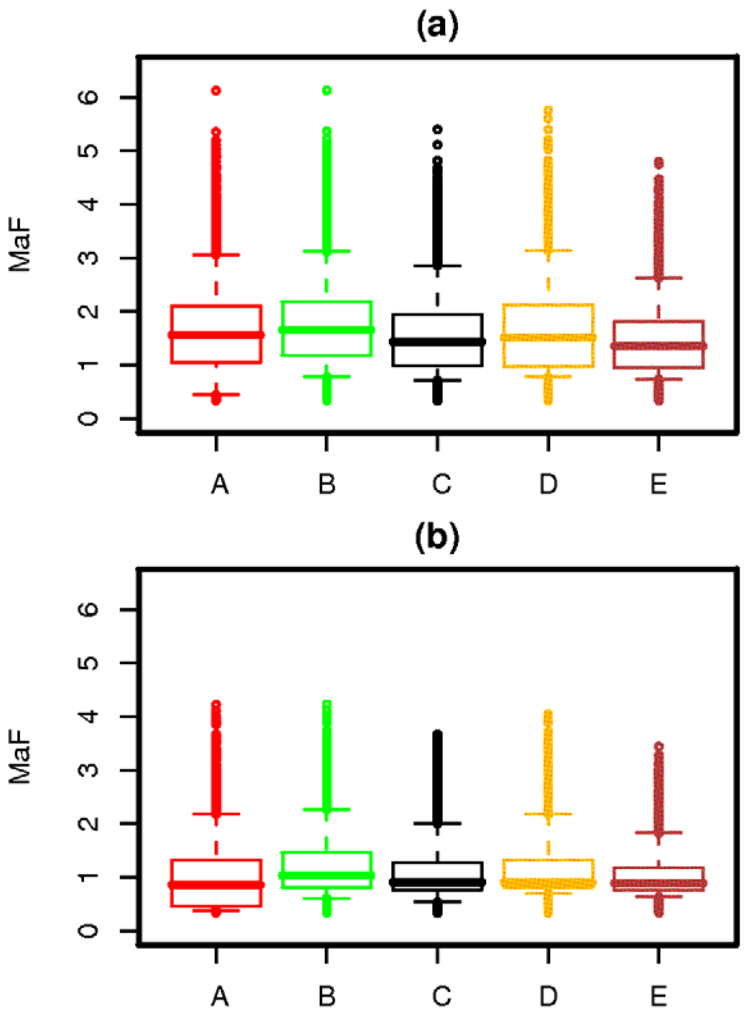
- Black line is CRSS probability of operating under shortage conditions based on 125 paleo-conditioned traces
- Green line is our model probability of operating under shortage conditions based on 10,000 paleo-conditioned traces
- Red line is our model probability of operating under shortage conditions based on 125 randomly selected paleo-conditioned traces
- Validation limitations of lump model – individual reservoir conditions can not be compared

Risk of Live Storage Depletion



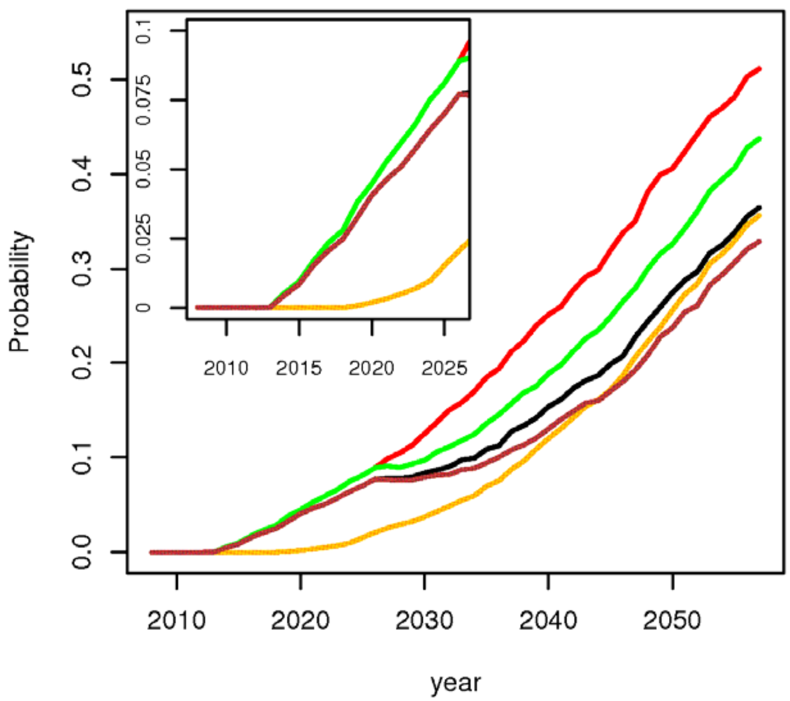
- 5 Alternatives examined
- Near-term risks relatively low
- Management can offer risk mitigation
- Climatic regime largest factor

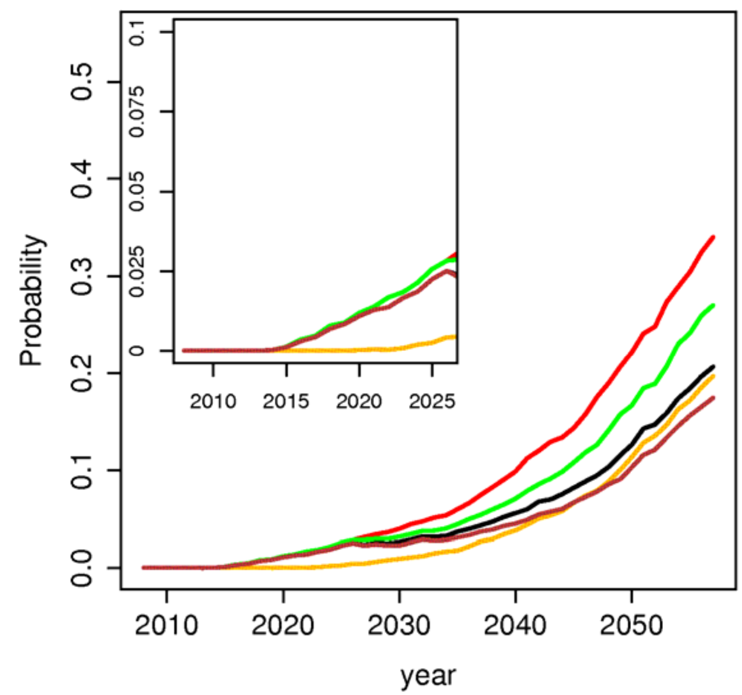
Mean Delivery Deficit Volume



- "Deficit" any time full demand is not met
- Average value by which demand is not met in a 50 year period (not per year)
- (a) 20% flow reduction, (b) 10% flow reduction
- Median values fairly similar across alternatives
- Alternative E reduces std. dev. by 25% in (a) and by 35% in (b)
- May be desirable for stakeholders

Current Basin Consumptive Use





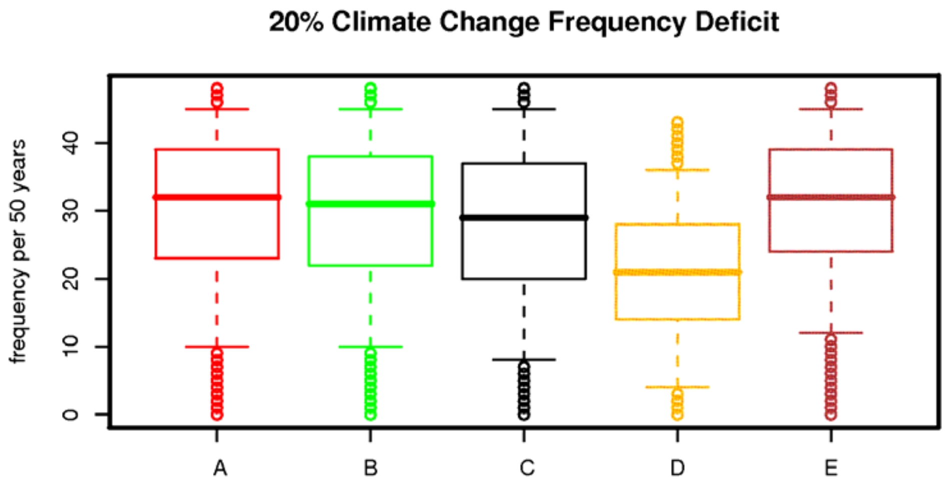
- 20% flow reduction trend, same management alternatives
- Current demand based on EIS depletion schedule (left) ~13.5 MAF
- Current demand based on estimated current consumptive use (right) ~12.7 MAF [source: USBR]
- ~6% reduction in current demand results in ~37% risk reduction in 2058

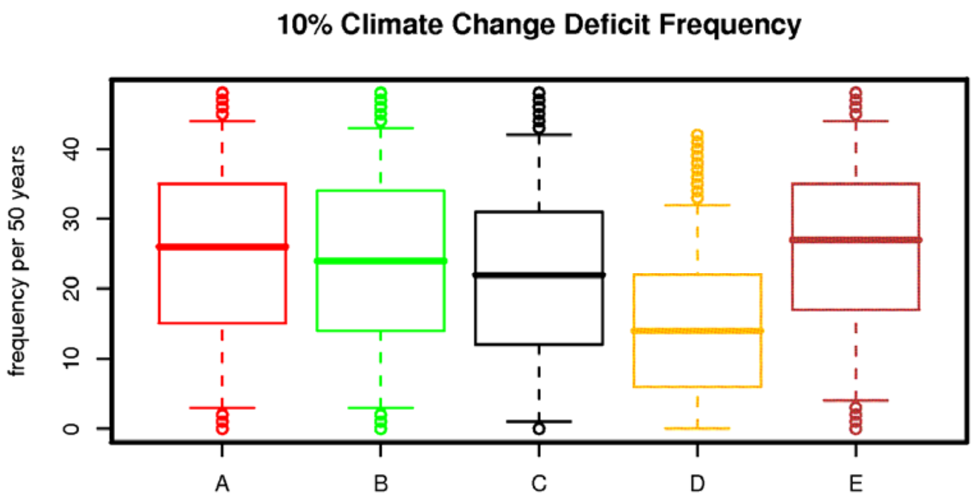
Conclusions and Discussion Points

- Interim period offers relatively low risk window to develop management strategies to mitigate water supply risk
- Actual risk profile most likely lies between those from 12.7 and 13.5 MAF current demand
- Climate projections contain considerable uncertainty
  - Majority of streamflow originates at elevations above 8,000 ft
  - Implications for increased temperature
  - Implications for reduced precipitation
- To assess threat to specific system components, full CRSS model run required

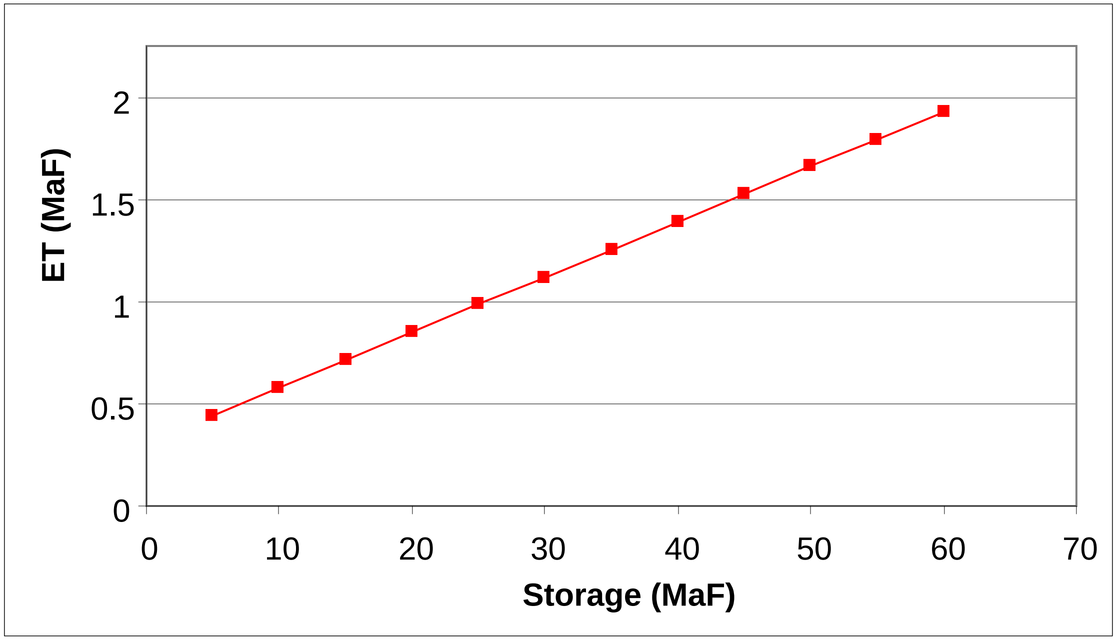
Questions?

Deficit Frequency Boxplots



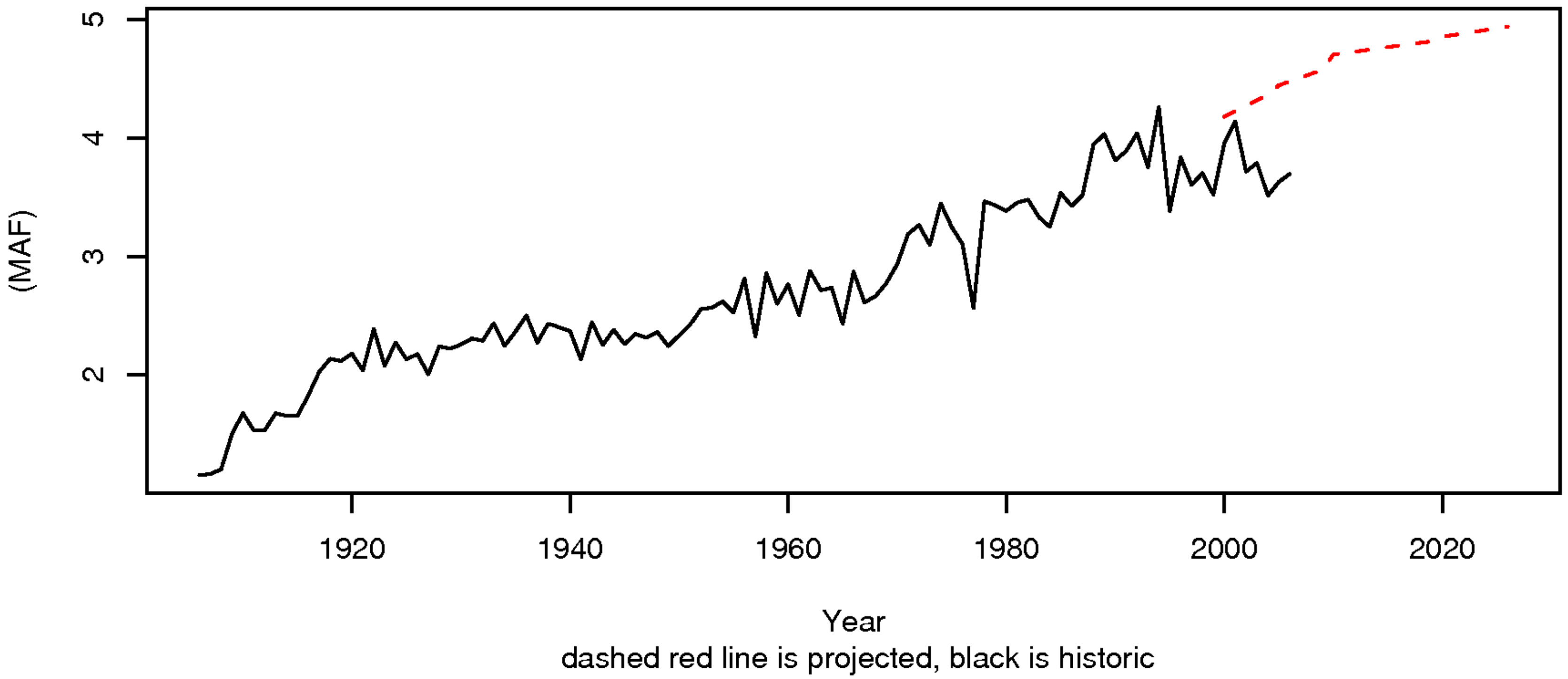


Combined Area-volume Relationship ET Calculation



ET coefficients/month
(Max and Min)
0.5 and 0.16 at Powell
0.85 and 0.33 at Mead
Average ET coefficient : 0.436
ET = Area * Average coefficient * 12

Upper Basin Consumptive Use



- Does not include UB reservoir evaporation

Streamflow Generation Framework (Prairie et al., 2008, WRR)

Natural climate variability

Nonhomogeneous markov chain model employing observed & paleo data

↓

Generate system state

(S_t)

↓

10,000 simulations, each 50-years long (2008-2057)

Generate flow conditionally
(K-NN resampling of historical flow)

$$f(x_t | S_t, S_{t-1}, x_{t-1})$$

Climate Change

Superimpose climate change trend
(10% and 20%)