Paleohydrology Workshop

Decision Center for a Desert City & Decision Theater, Arizona State University
September 11, 2009

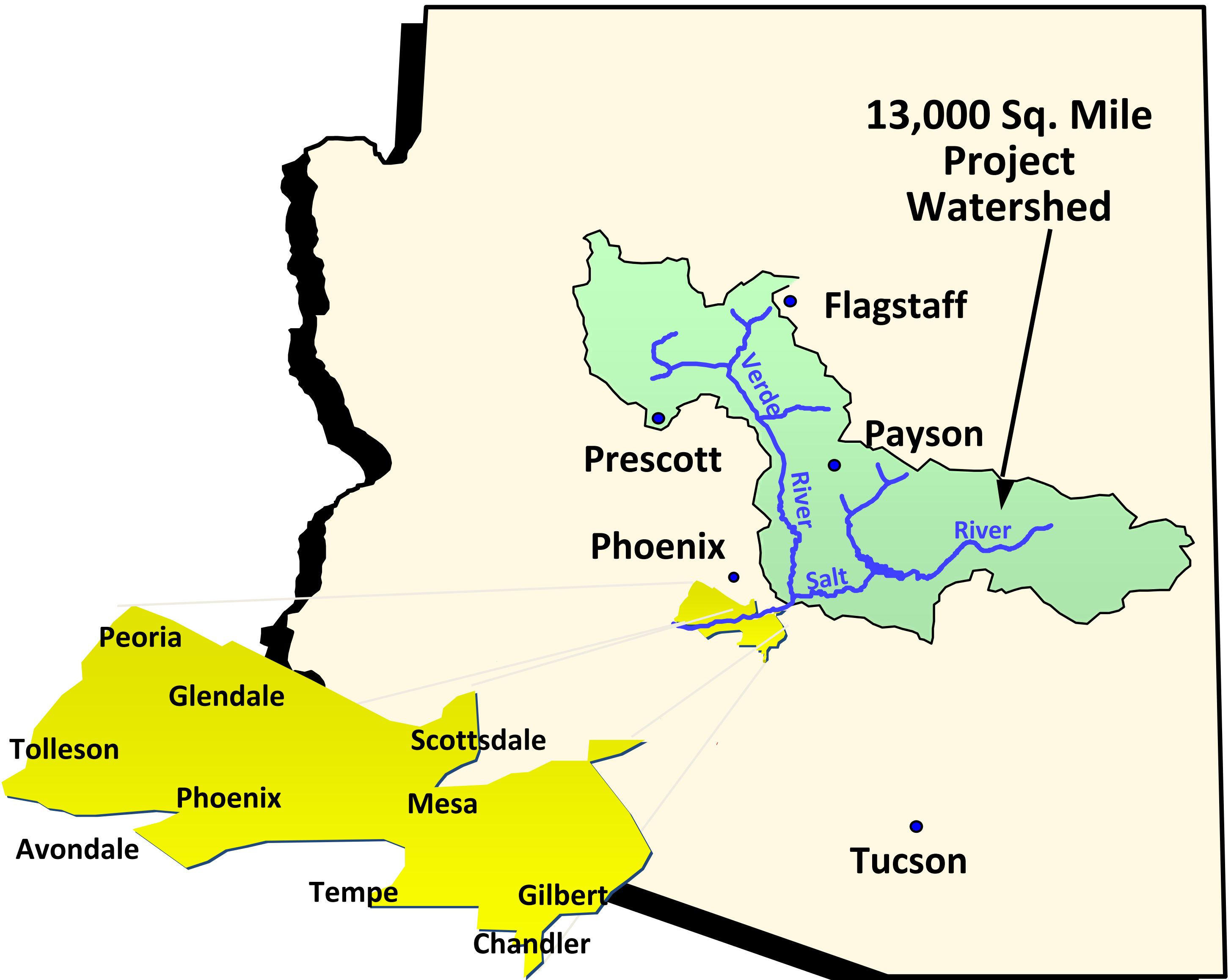
Examples of Applications of Reconstructions to Water Resource Management

- Salt River Project – *Jon Skindov (SRP)*
- City of Phoenix - *Steve Rossi (City of Phoenix)*
- Bureau of Reclamation - *Carly Jerla (BoR) and Kiyomi Morino (U. of AZ)*

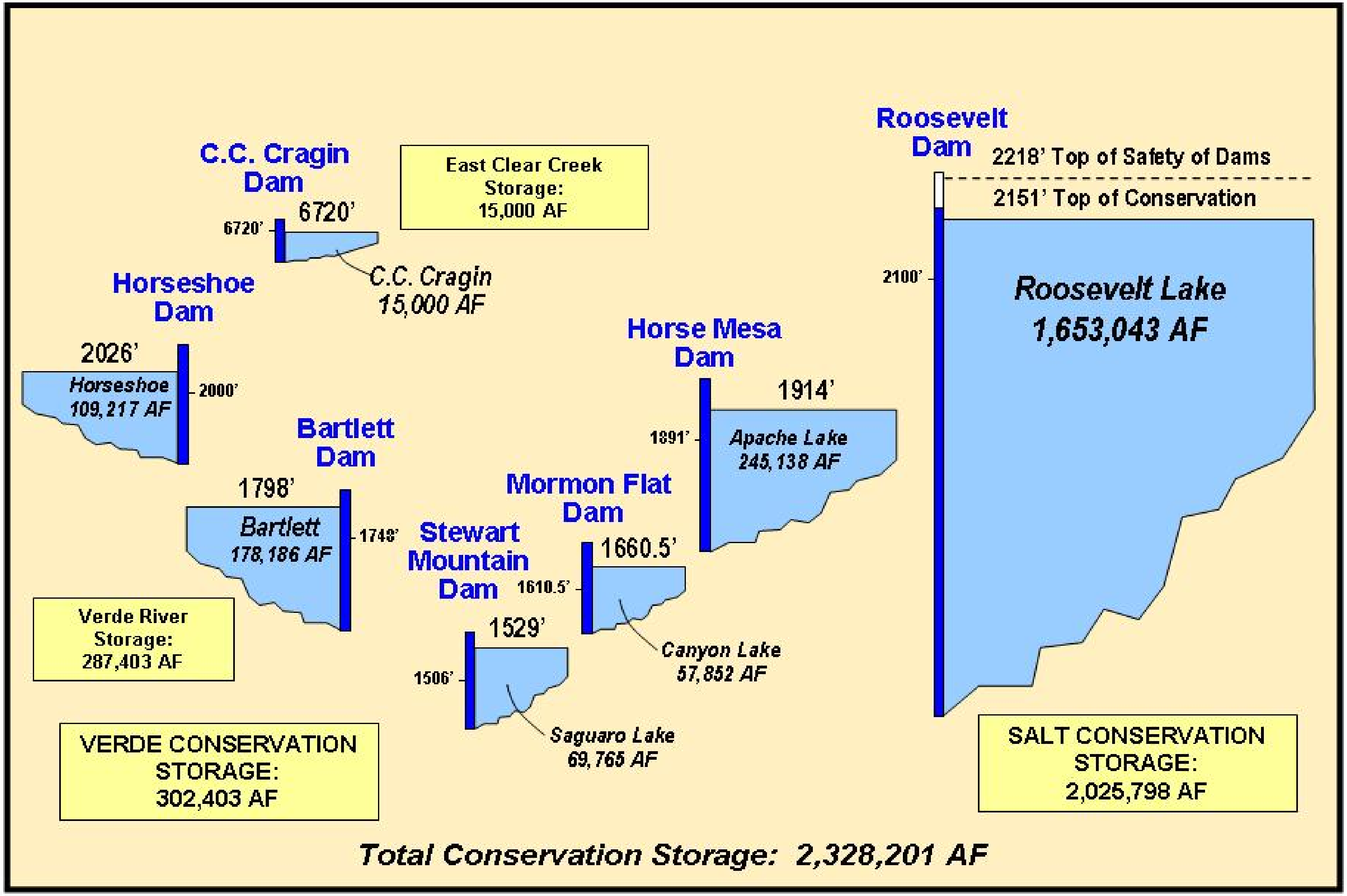
Salt River Project

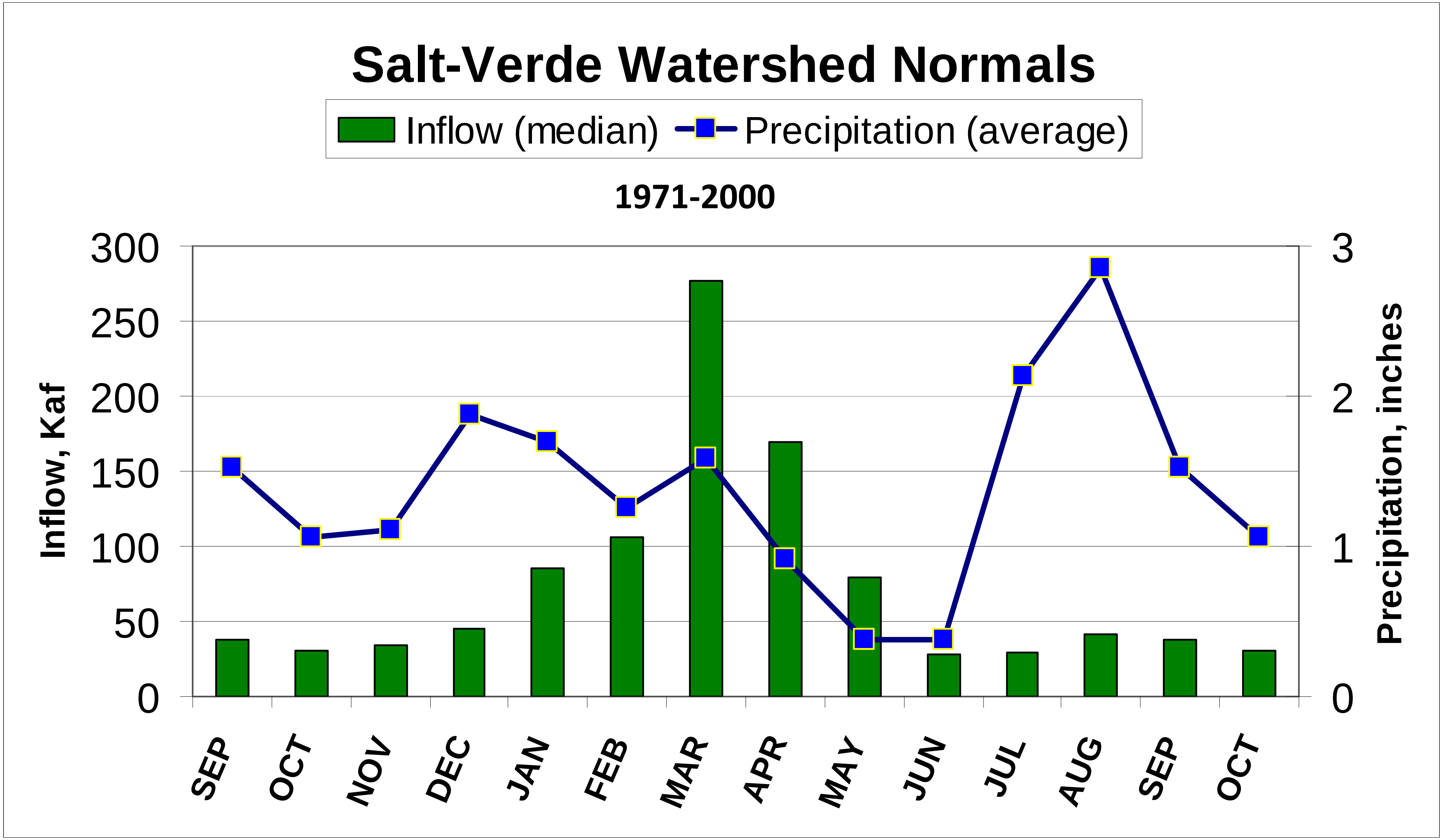
John Skindlov

SRP Water Service Area



Salt River Project Reservoir System





WINTER:

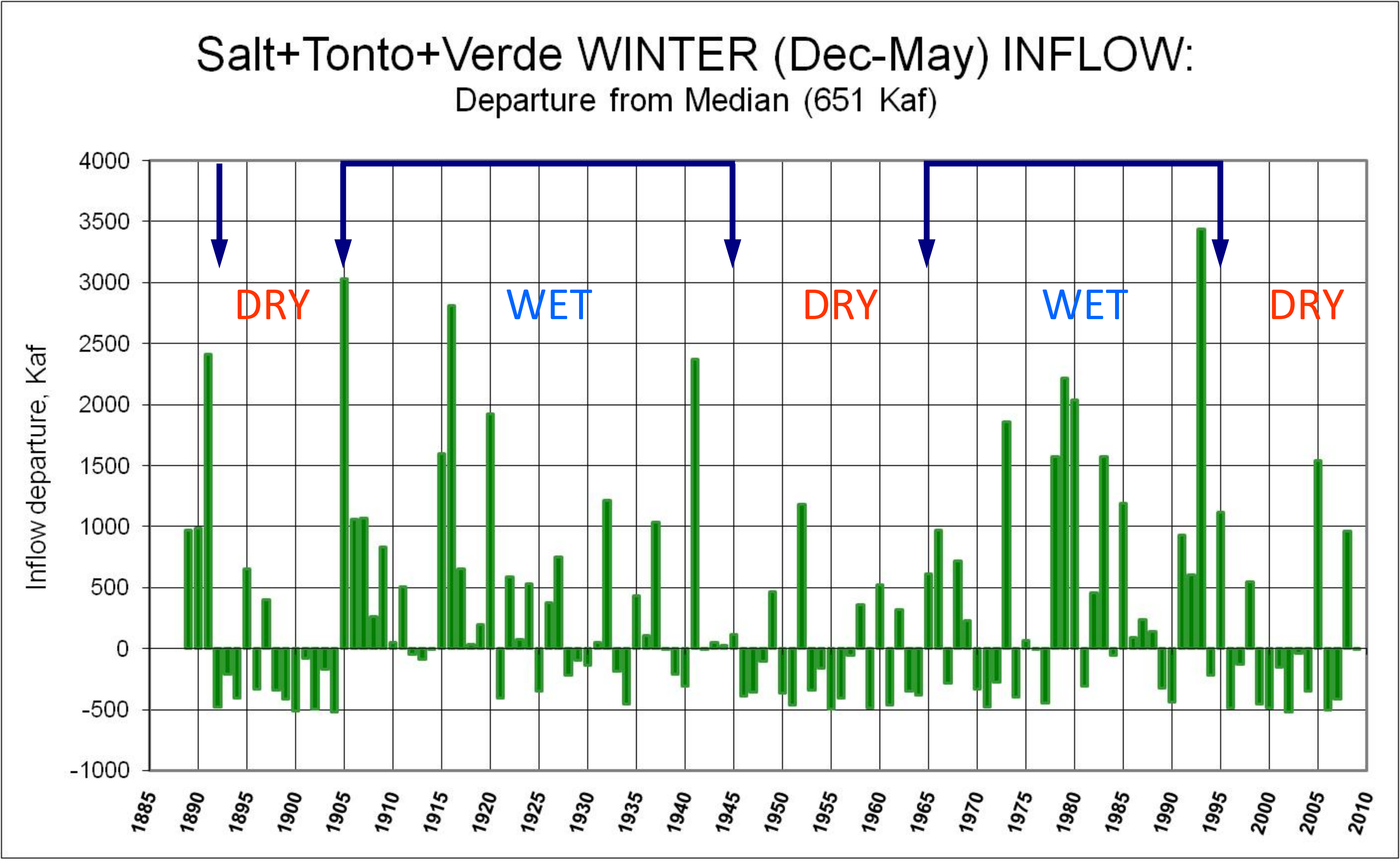
Precip. (Dec-Mar): 6.3 in

Runoff (Dec-May): 665 Kaf

SUMMER:

Precip. (Jul-Sep): 6.8 in

Runoff (Jul-Sep): 120 Kaf



1892-1904:
2 wet,
11 dry

1905-45:
28 wet,
13 dry

1946-64:
5 wet,
14 dry

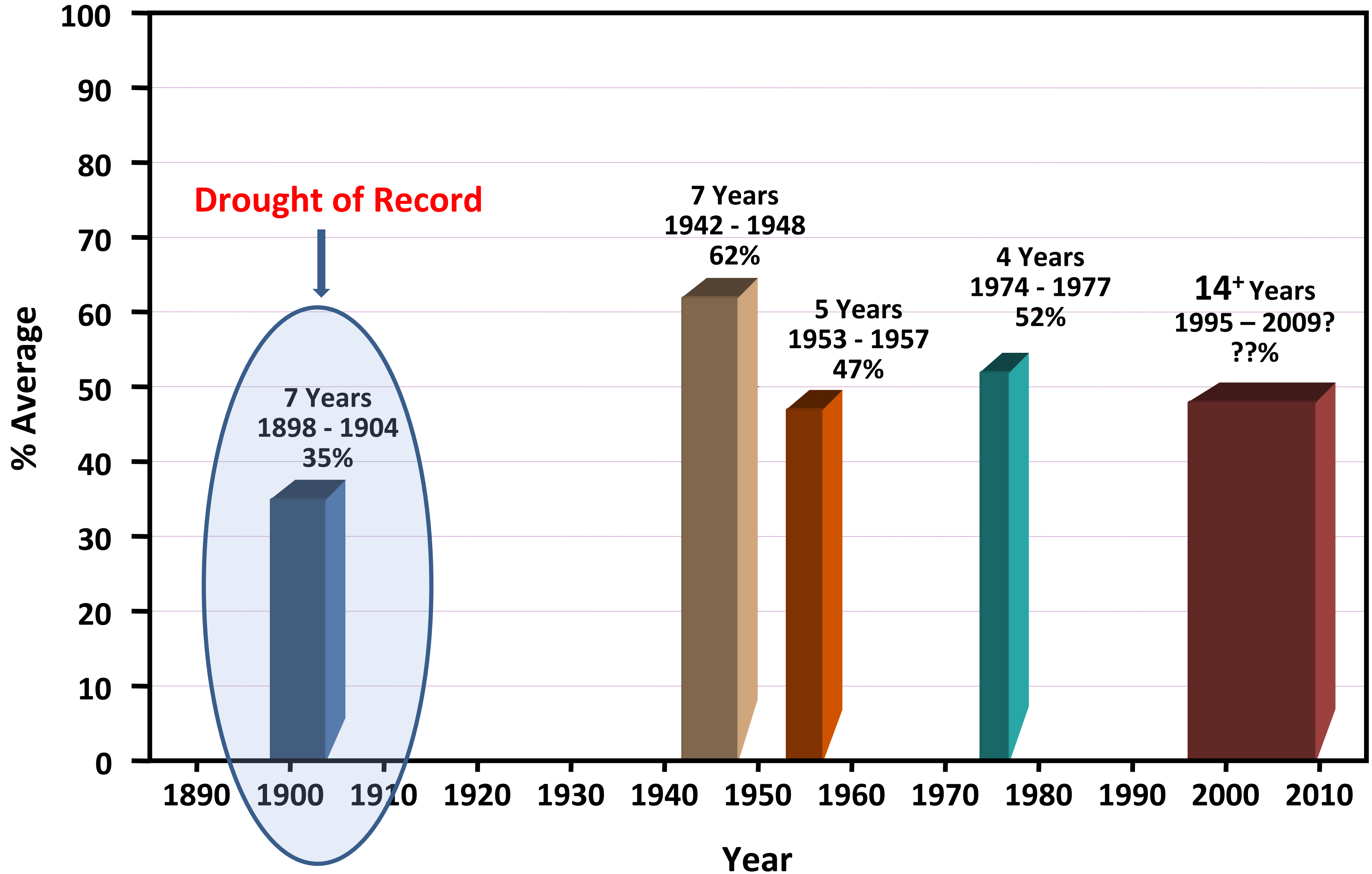
1965-95:
19 wet,
12 dry

1996-2009:
3 wet,
11 dry

SRP Water Resource Operations: jas 07/2009

Salt River Project Historic Drought Periods

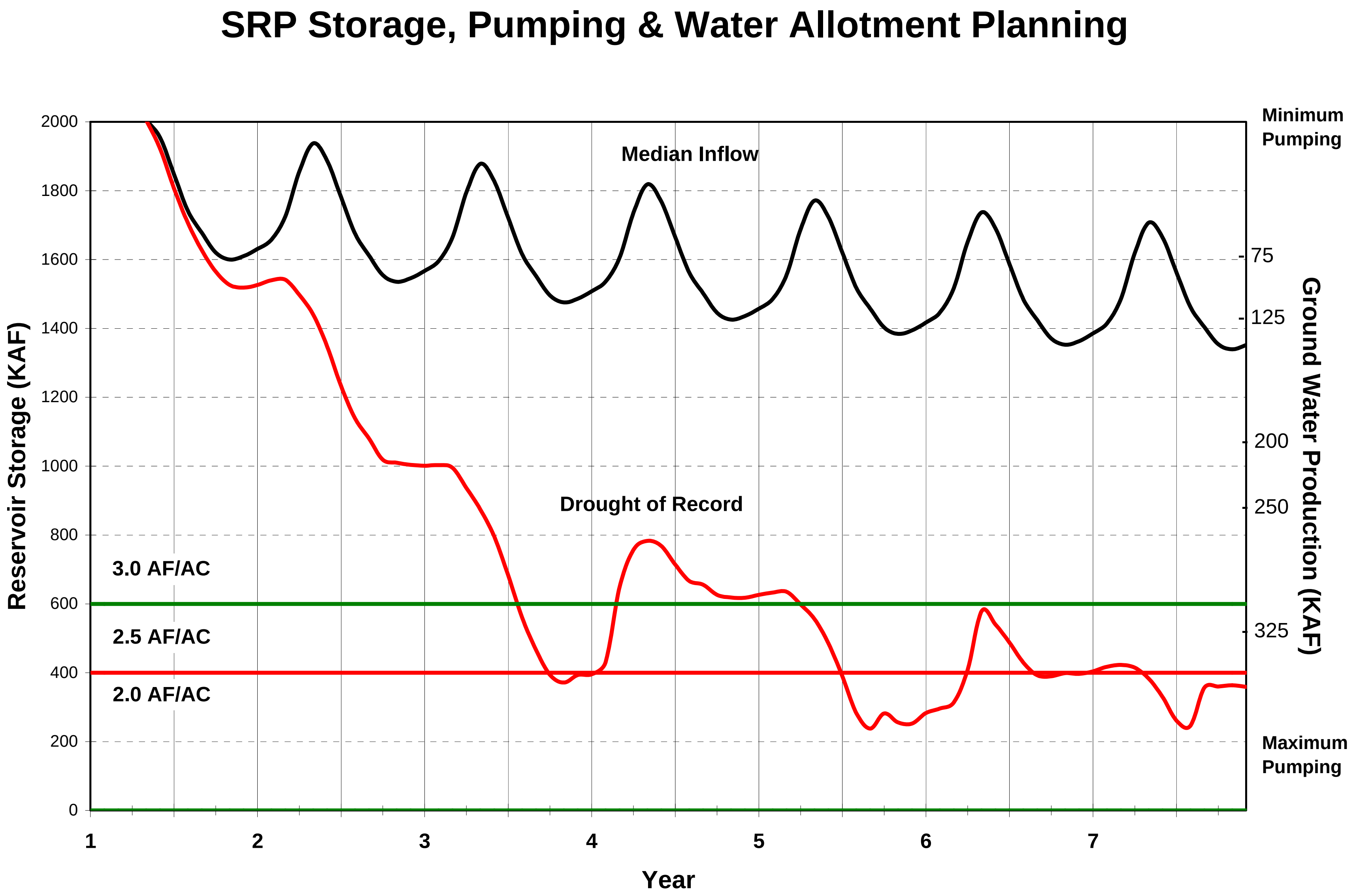
(Average Runoff 1889–2003 = 1,212,890 AF)



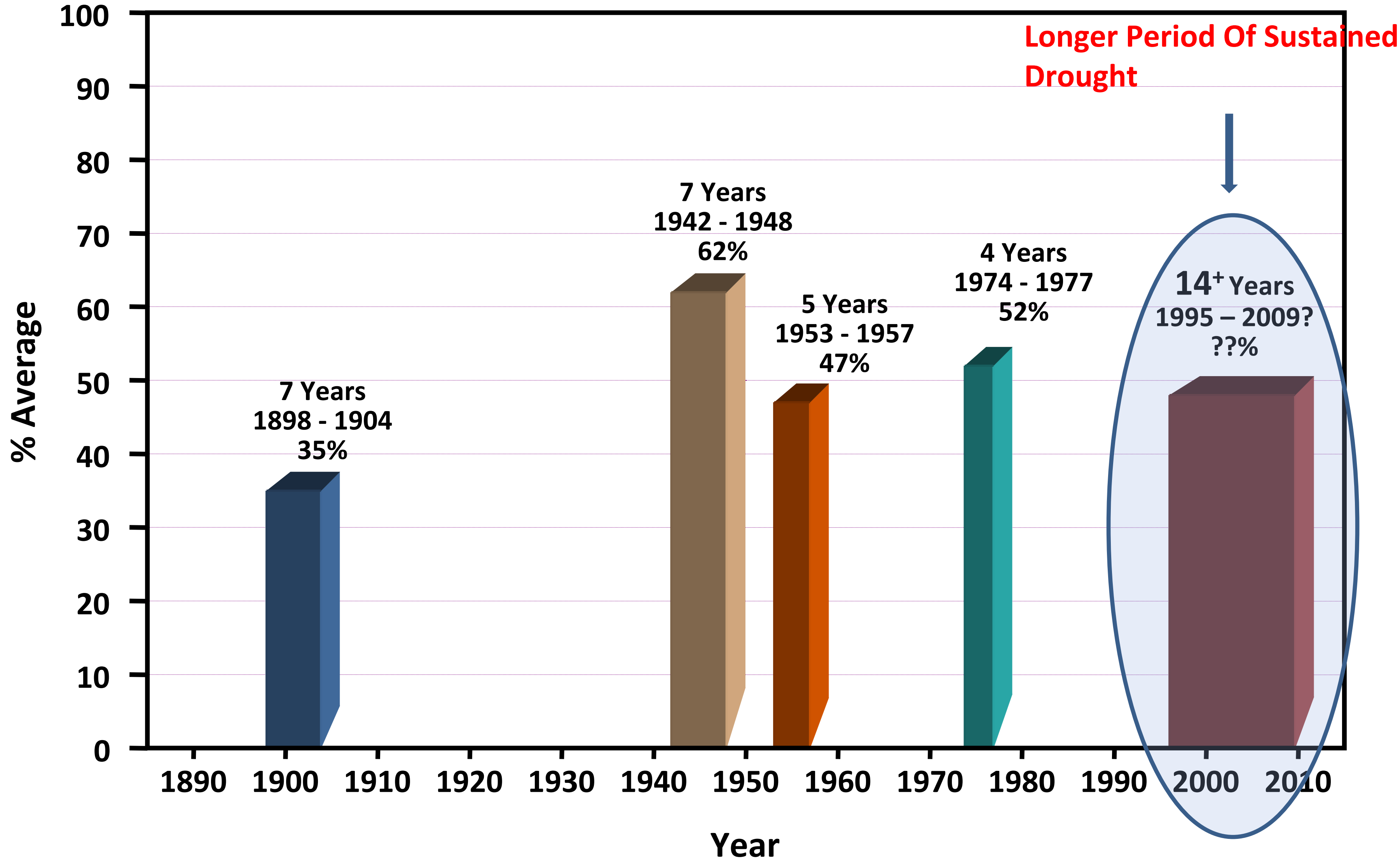
Planning Assumptions (1980s and 1990s)

- **950 KAF Full Demand**
- **325 KAF Maximum Pumping**
- **Historical Drought Of Record 1898-1904**
- **Allocation/Pumping To Manage For Drought Of Record**

Storage Planning Diagram

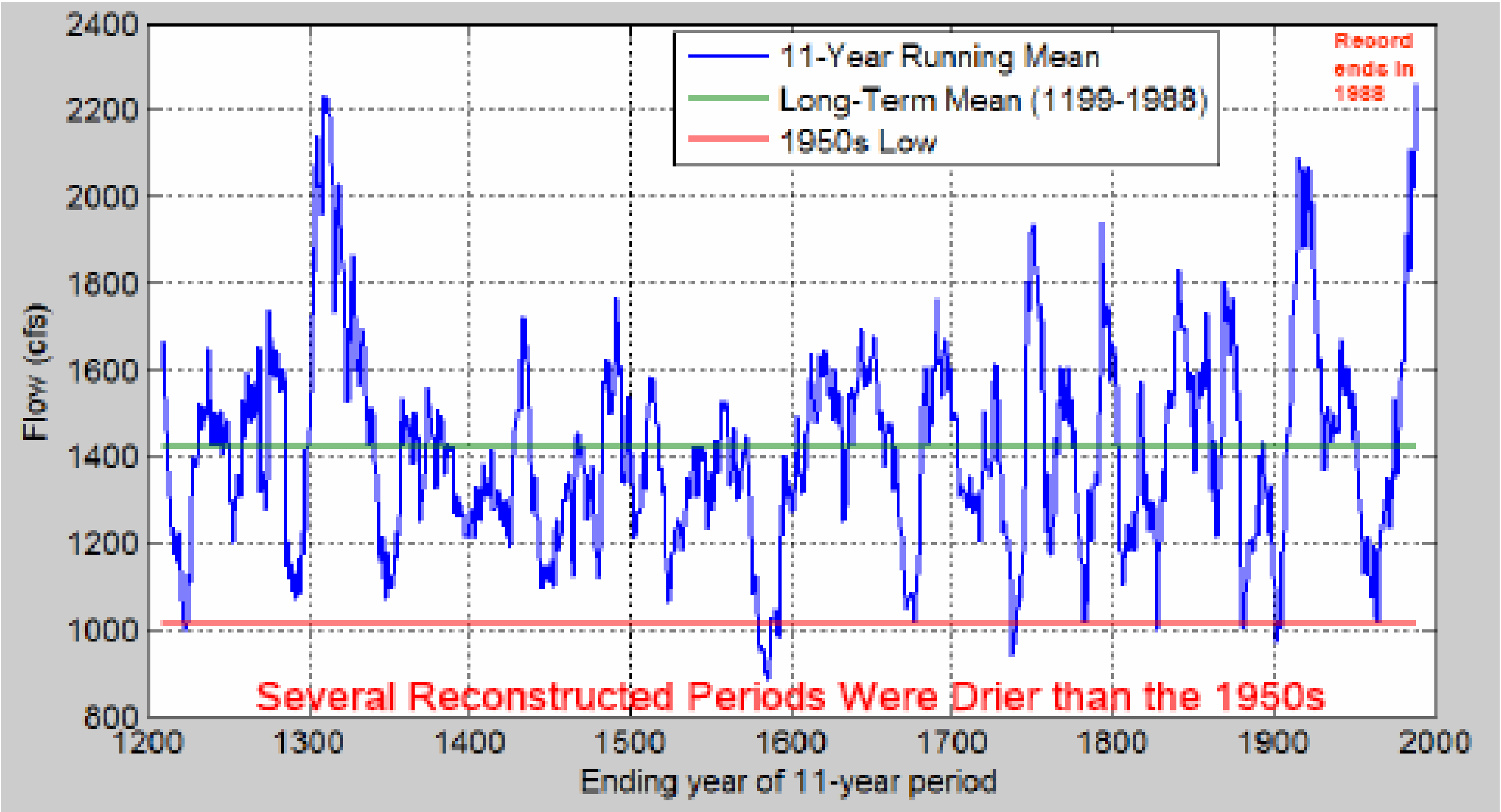


Salt River Project Historic Drought Periods
(Average Runoff 1889–2003 = 1,212,890 AF)



Severity of Current Drought in Context of Reconstructed Record: Salt + Verde + Tonto Reconstruction

Figure 23b

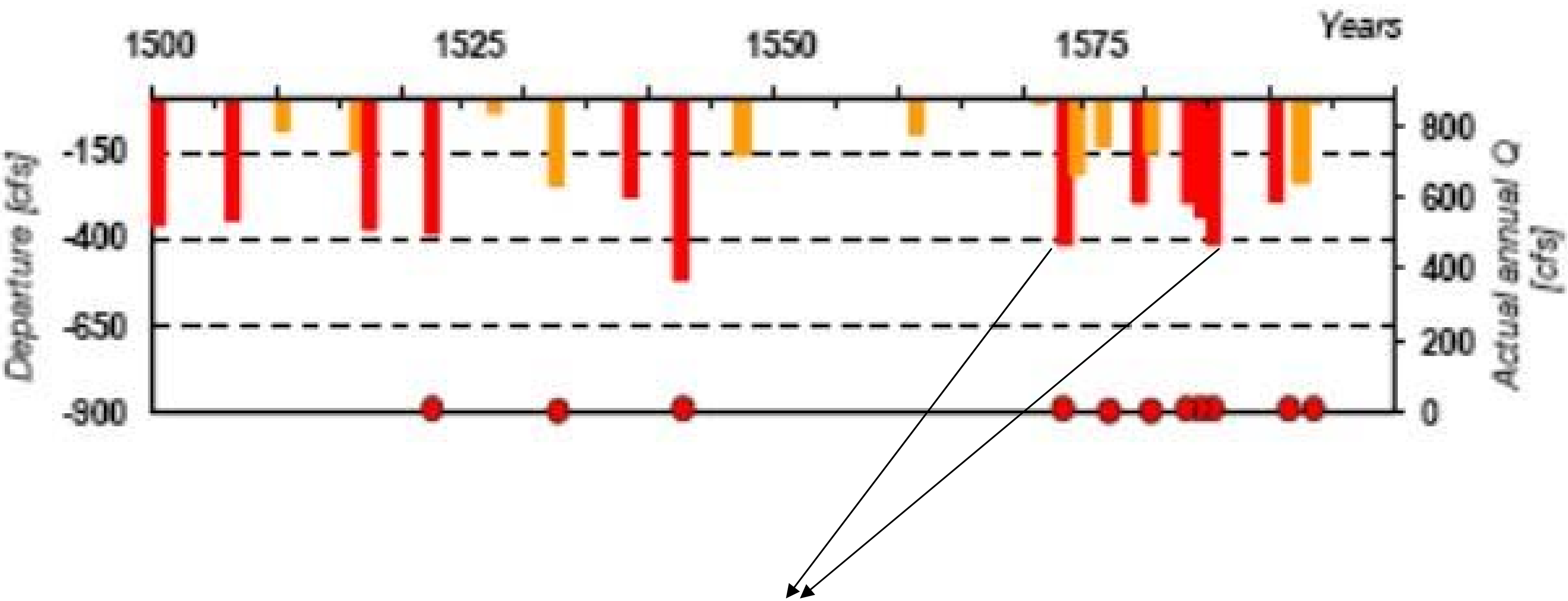


-- Current drought was about as severe as 1950s in terms of flows averaged over 11 years

-- 8 other droughts were as severe, according the tree-ring record

-- Late 1500s megadrought was much more severe

The 11-year period was 1575 - 1585.

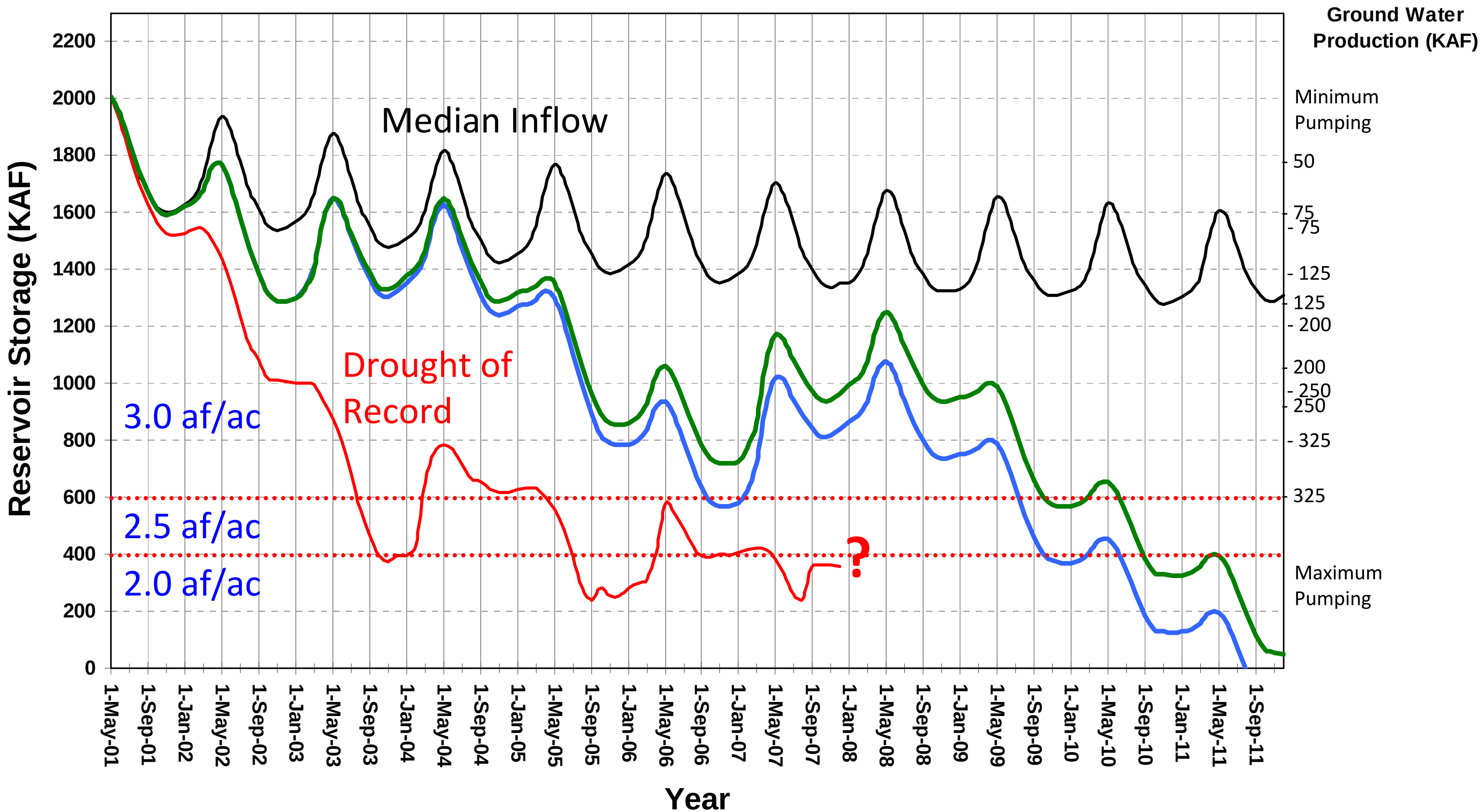


11-Year Drought With 70% Of Historical Gaged Median Inflow

Time To Rethink Old Assumptions

- **950 KAF Full Demand**
- **325 KAF Maximum Pumping**
- **Tree-Ring Drought Of Record 1575-1585**
- **Allocation/Pumping To Manage For 11-year Tree-Ring Drought**

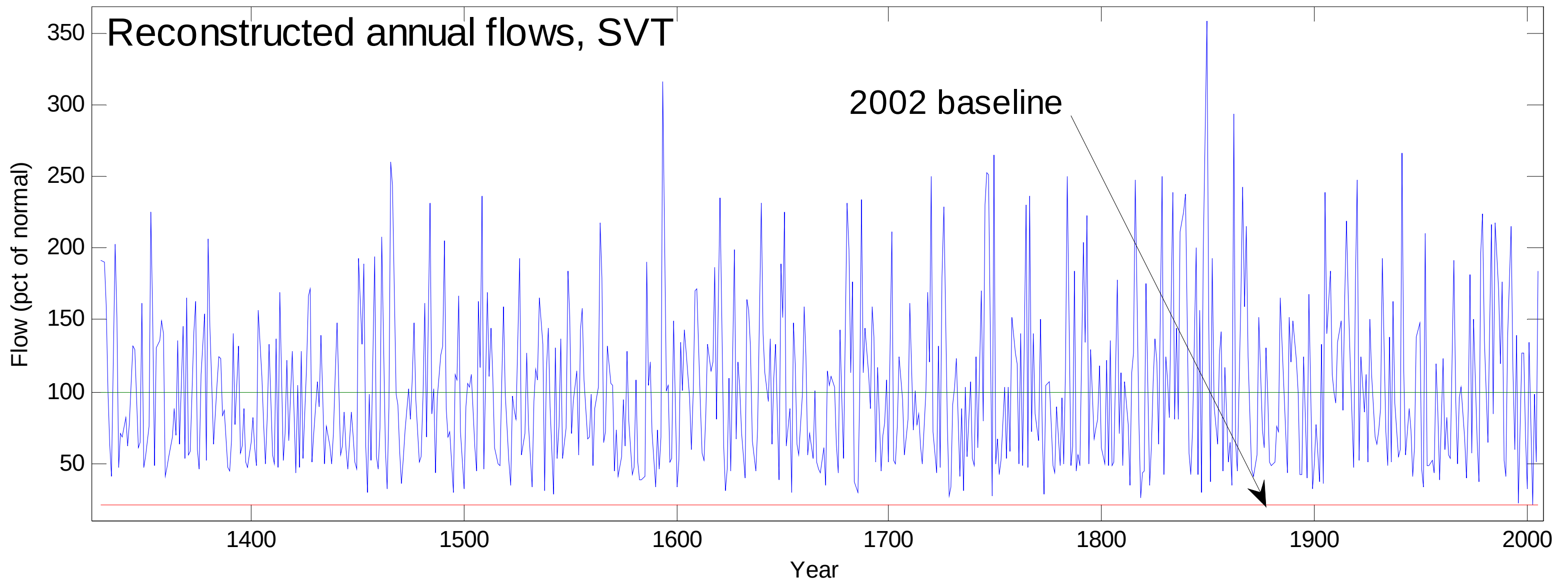
SRP Storage, Pumping & Water Allotment Planning



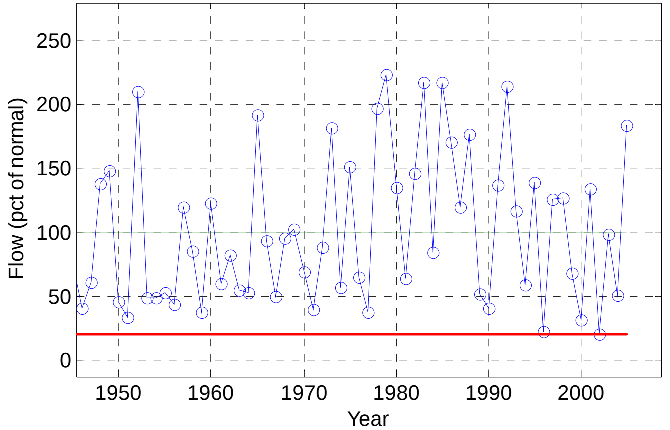
11-yr Tree-ring Drought with previous planning scenario

11-year Tree-ring Drought with new planning scenario

2002 and 1996: long-term extreme lows



- Reconstructed flow was 21% of normal* in 2002, 22% of normal in 1996
- No other reconstructed flow from 1330 to 2005 was lower than 25% of normal.
- Tree growth recovered with wetter conditions in 2005



*normal is 1914-2007 mean, water year, Salt+Verde+Tonto

How Vulnerable Are We?

- **Historical Record**
- **Tree Ring Record**
- **Climate Change Scenarios**

Key Question:

What is <u>minimum flow</u> that allows SRP to maintain carryover storage in perpetuity?

In a climate changing world the question becomes: How much worse (drying) before previous droughts become a problem?

Severe Droughts Capable of Depleting Surface Water Supply With The Noted Reduction In Flow

Period	Source	Duration (yrs)	Flow Reduction	Average Annual % of Median
1214-1217	Tree-ring	4	20%	40%
1579-1585	Tree-ring	7	15%	50%
1666-1670	Tree-ring	5	20%	45%
1817-1823	Tree-ring	6	20%	48%
1898-1904	Historical	7	20%	48%
1999-2002	Historical	4	20%	40%

Climate Change Projections

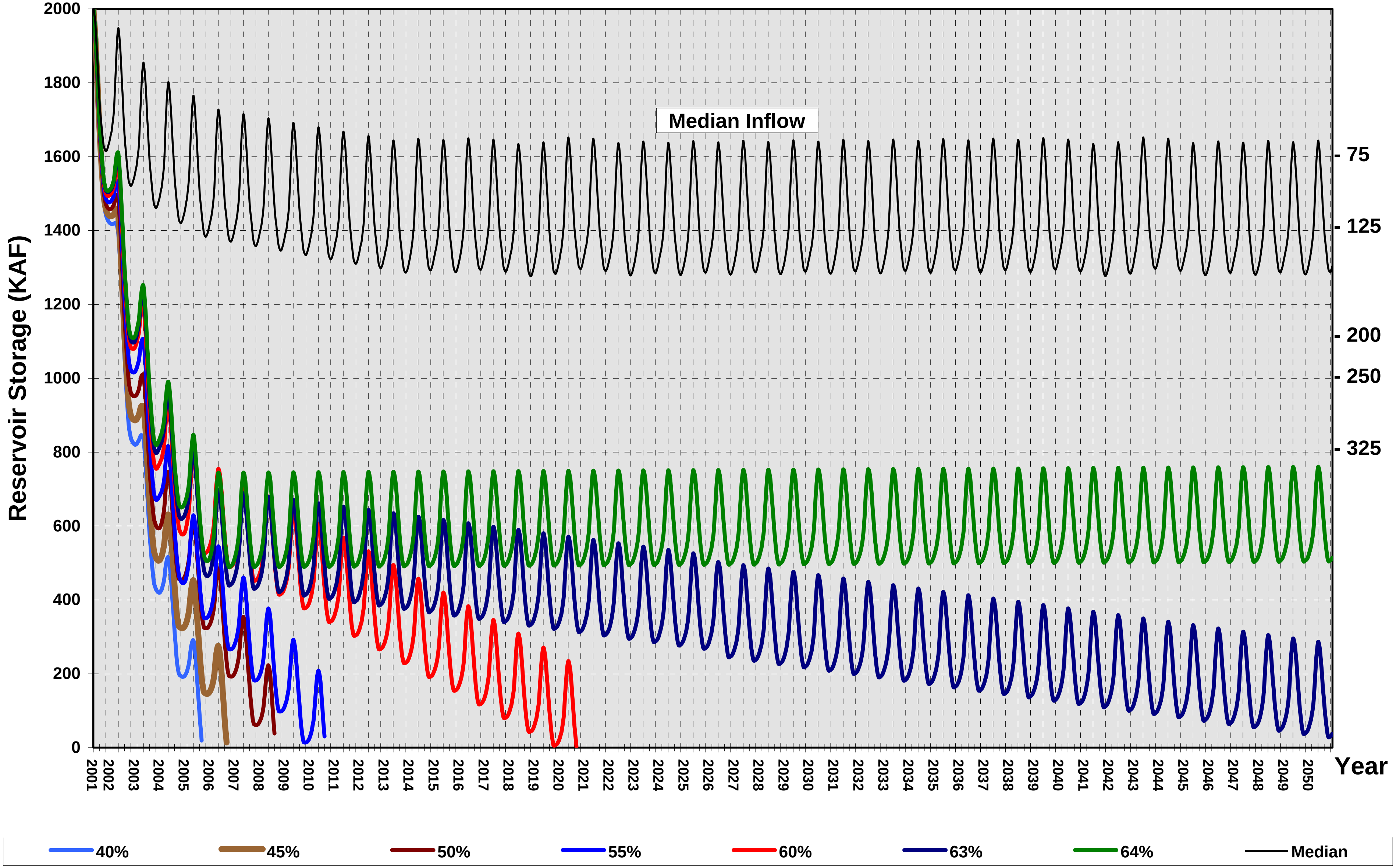
ASU Sensitivity Analyses:

- **Each 1 Degree Of Rise = 6-7% Reduction In Streamflow**
- **10% Less Precipitation = 15-20% Less Streamflow**
- **+3 Degrees With 10% Less Precipitation = 37-42% Less Streamflow**

Bottom Line:

- **Continued Warming**
- **20-50% Decrease In Runoff In The Next Several Decades.**

SRP Storage, Pumping & Water Allotment Planning



Simulated Reservoir Storage for a Range of Perpetually Reduced Inflows
(as a percent of historical median)

How Vulnerable Are We?

PERCENT OF MEDIAN INFLOW	YEARS TO RESERVOIR DRYUP
64	INDEFINITE
63	50+
60	19.5
55	9.3
50	7.3
48	6.4
45	5.4
40	4.4

Response To Decreasing Supply

“Augment” Supply To 63% Line

When Storage Drops Below The Target 63% Line:

Activate Augmentation Efforts to Raise Storage Back to the 63% Line…

Menu Of Options:

Increase Groundwater Pumping (Restoration Program)

Reduce Allocation Of Water

Purchase Central Arizona Project Water

Exercise Lease Options—Indian And NonIndian Agriculture

Recover Long Term Underground Storage Credits

Conservation Efforts

Watershed Management/Weather Modification Activities

Purchase NCS Credits

Increase Water Use Efficiency

When Storage Drops Below The Target 63% Line:

Activate Augmentation Efforts to Raise Storage Back to the 63% Line…

Long-Term Potential Areas To Consider:

1. Joint Use or Seasonal Use Of Dedicated Roosevelt Flood Control Space

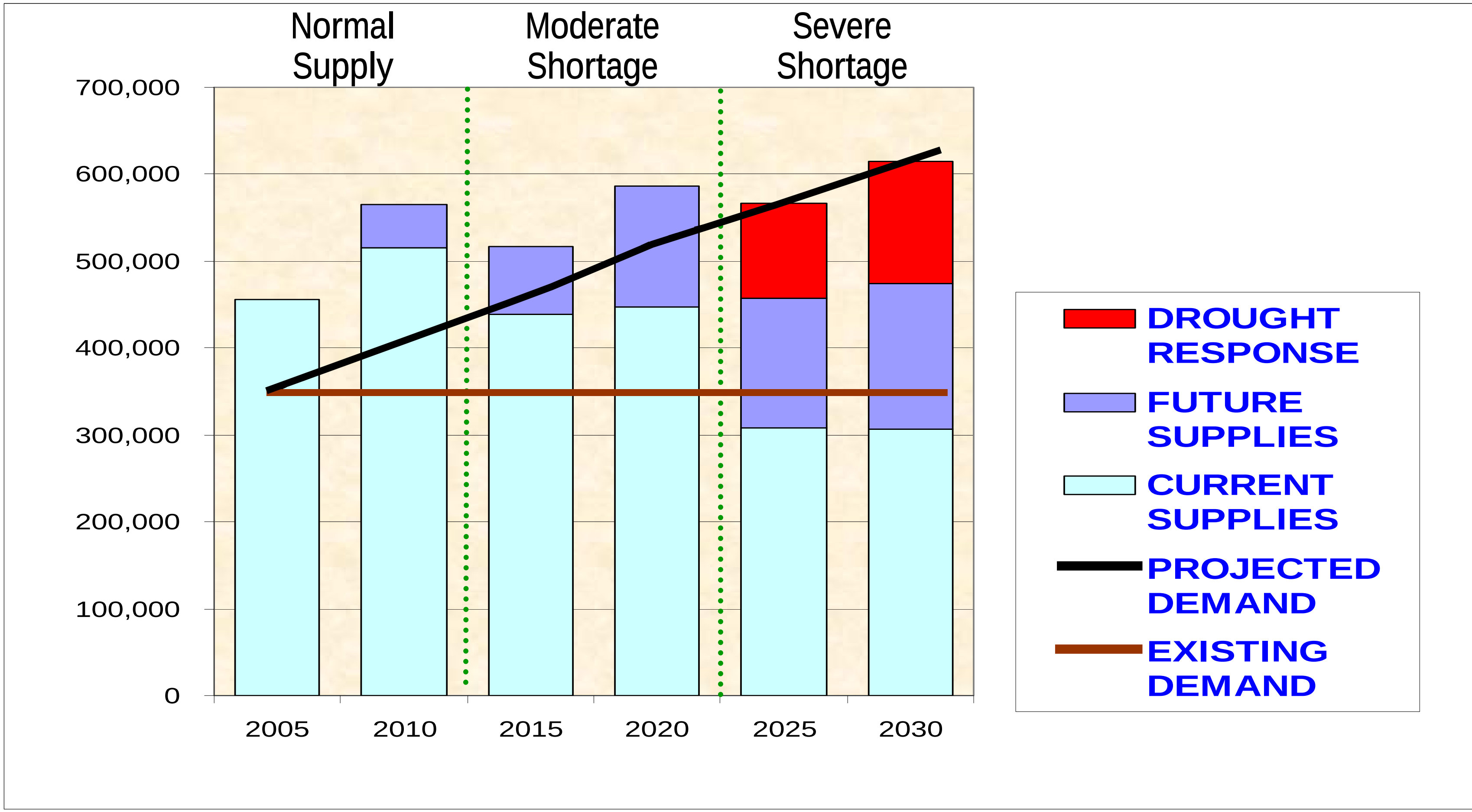
2. Modification Of State Law To Allow Long-Term Storage Of Salt And Verde Water Underground

City of Phoenix

Steve Rossi

Planning Timeline:

Hypothetical Worsening Shortage to 2030



Bureau of Reclamation

Carly Jerla

RECLAMATION

Managing Water in the West

Paleo-Hydrology in Long-Term Planning on the Colorado River Basin

Planning for Climate Change Workshop Series
Decision Theater, Arizona State University
September 11, 2009

U.S. Department of the Interior
Bureau of Reclamation

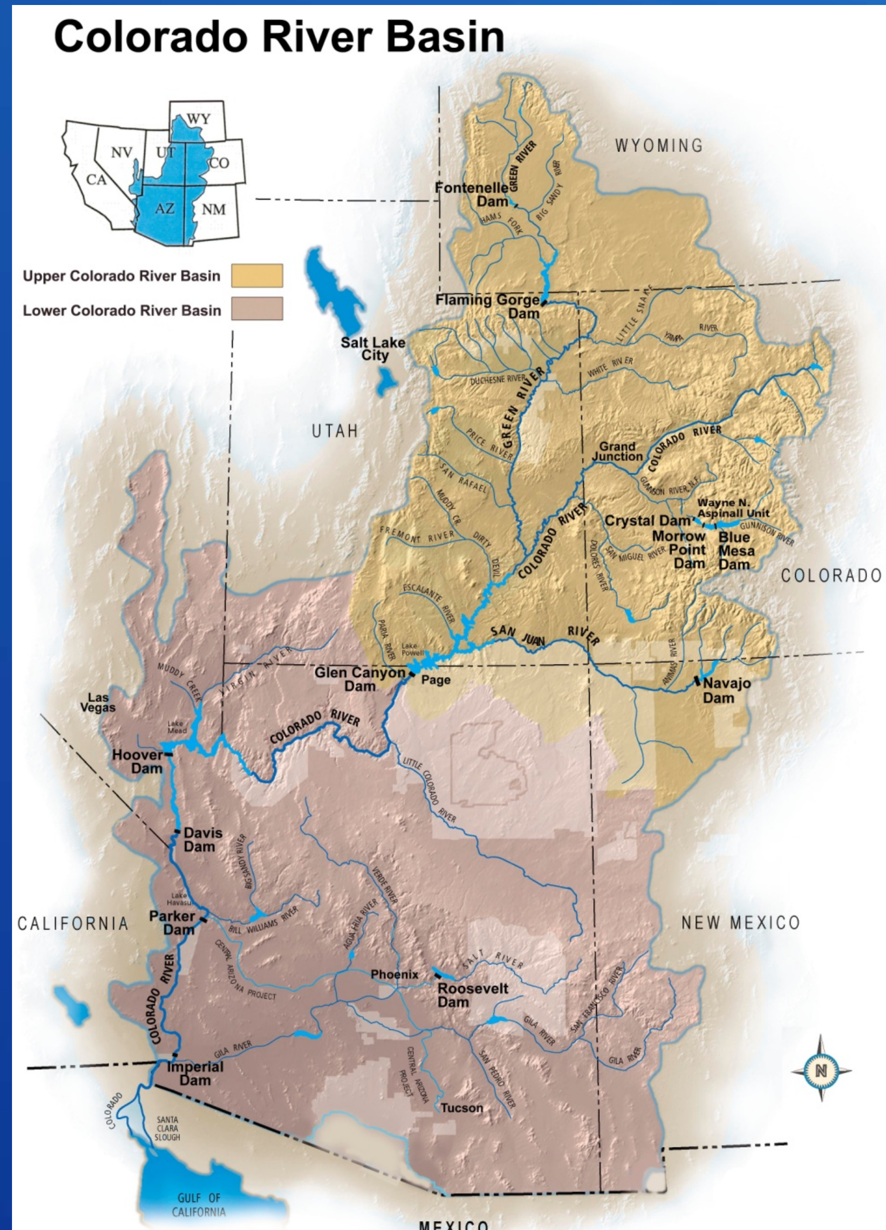
Overview

- Basin Overview
- Observed Hydrology
- Colorado River Drought
- Paleo-Hydrology
- Use of Paleo-Hydrology in *Colorado River Interim Guidelines* Final EIS
- Moving Beyond the Observed Record

RECLAMATION

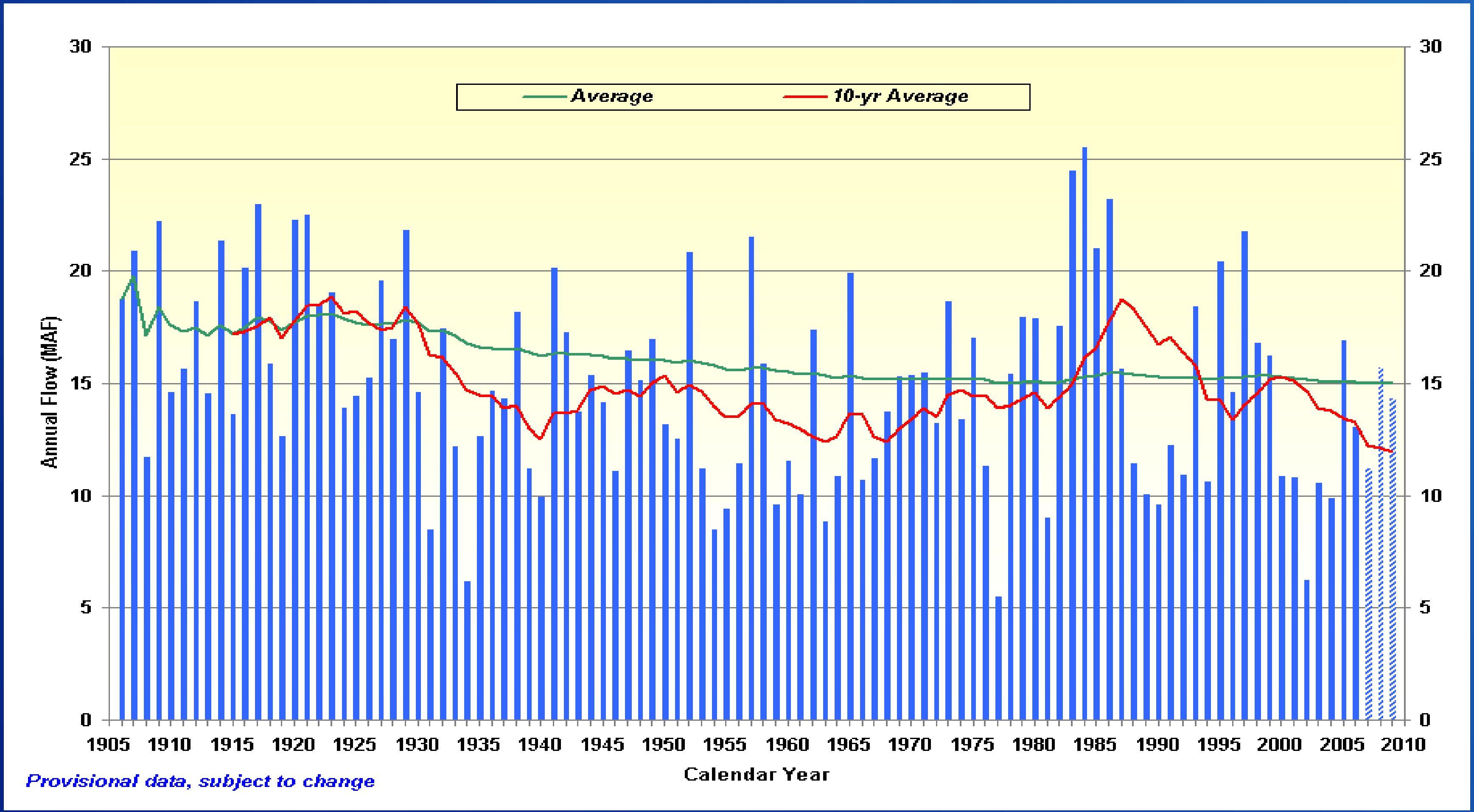
Colorado River Basin Hydrology

- 16.5 million acre-feet (maf) allocated annually
- 13 to 14.5 maf of consumptive use annually
- 60 maf of storage
- 15.0 maf average annual “natural” inflow into Lake Powell over past 103 years
- Inflows are highly variable year-to-year



RECLAMATION

Natural Flow
Colorado River at Lees Ferry Gaging Station, Arizona
Calendar Year 1906 to 2009



RECLAMATION

State of the System (1999-2009)

WY	Unregulated Powell Inflow, % of Average	Powell & Mead Storage, maf	Powell & Mead, % Capacity
1999	109	47.59	95
2000	62	43.38	86
2001	59	39.01	78
2002	25	31.56	63
2003	52	27.73	55
2004	49	23.11	46
2005	105	27.16	54
2006	72	25.80	51
2007	68	24.43	49
2008	103	26.52	53
2009*	89	26.50	53

* Based on Sep 2009 24-Month Study.

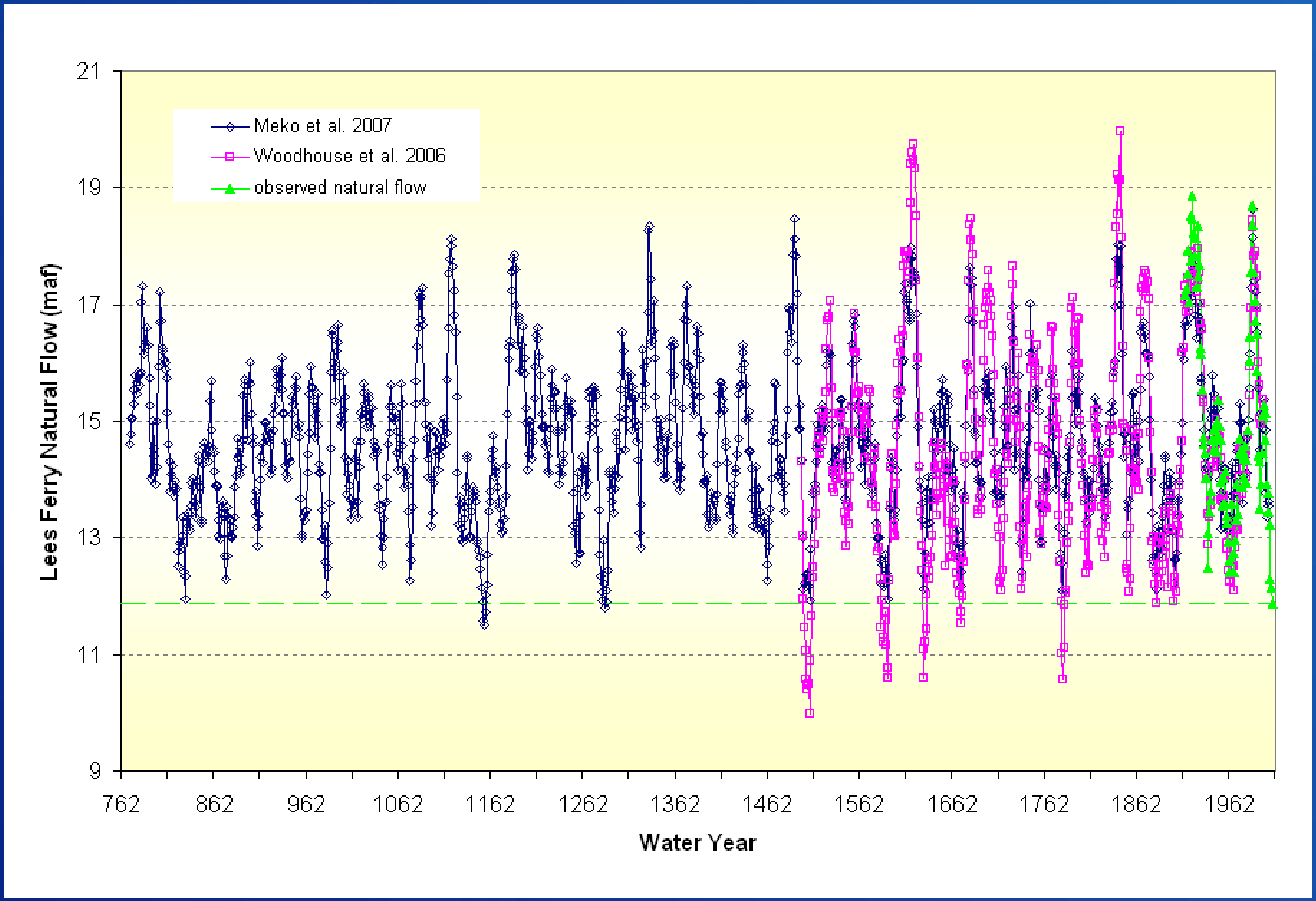
RECLAMATION

Colorado River Drought

- 2000-2009 has been the driest 10-year period in the observed historical record (2007 through 2009 data are estimated)
- Tree-ring reconstructions show more severe droughts have occurred over the past 1200 years (e.g., drought in the mid 1100's)
- Observed 2009 April through July runoff is 99% of average (as of September 4, 2009)
- Not unusual to have a few years of above average inflow during longer-term droughts (e.g., the 1950's)

RECLAMATION

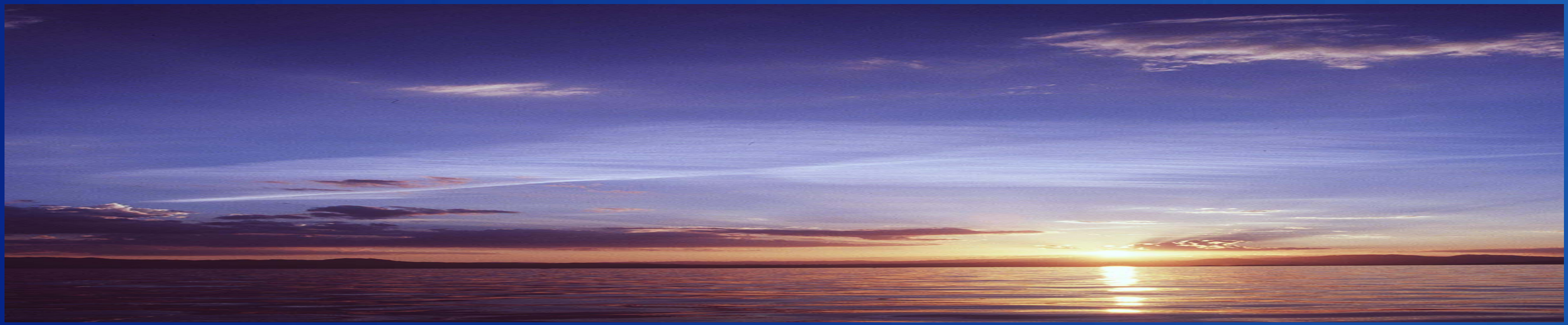
Annual Natural Flow at Lees Ferry
Tree-ring Reconstruction and Observed Record
10-Year Running Mean



RECLAMATION

Interim Guidelines
A Robust Solution

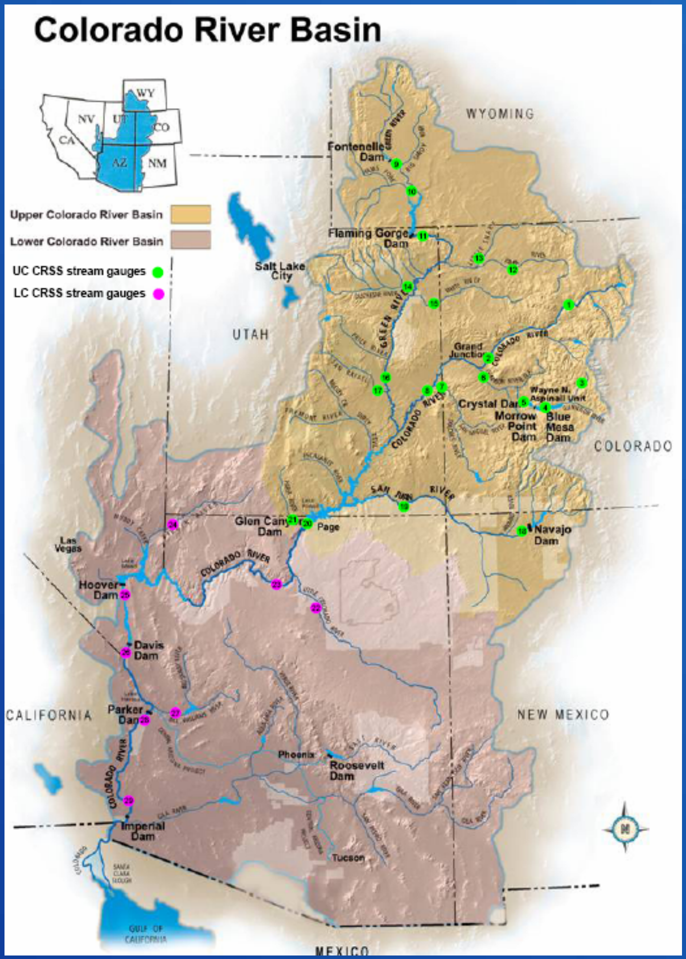
- Operations specified through the full range of operation for Lake Powell and Lake Mead
- Encourage efficient and flexible use and management of Colorado River water through the ICS mechanism
- Strategy for shortages in the Lower Basin, including a provision for additional shortages if warranted
- In place for an interim period (through 2026) to gain valuable operational experience
- Basin States agree to consult before resorting to litigation



RECLAMATION

Colorado River Simulation System (CRSS) *A Long-Term Planning Model*

- Comprehensive model of the Colorado River Basin
- Developed by Reclamation (early 1970s) and implemented in RiverWare™ (1996)
- Primary tool for analyzing future river and reservoir conditions in planning context (NEPA EIS)
- A projection model, not a predictive model
- Excellent for comparative analysis
- Gives a range of potential future system conditions (e.g., reservoir elevations, releases, energy generation)
- Simulates on a monthly timestep over decades
- Operating policy is represented by “rules” that drive the simulation and mimic how the system operates



RECLAMATION

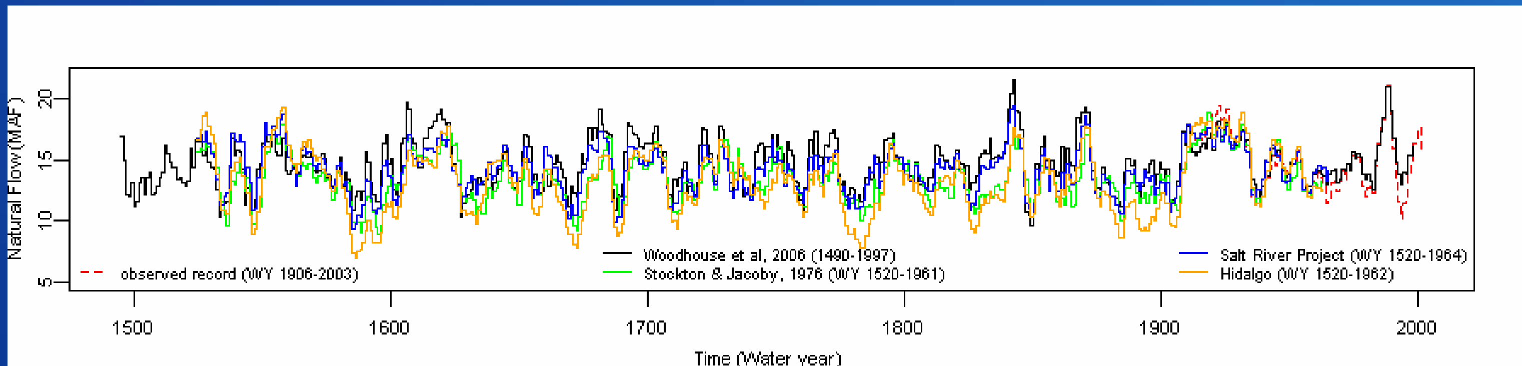
Climate Technical Work Group

- Empanelled during the development of the Interim Guidelines to:
  - Assess state of knowledge regarding climate change and modeling in the Basin
  - Prioritize future research and development needs
- Included members from NOAA, NCAR, CU, UNLV, UA, Reclamation’s TSC, AMEC Earth & Environmental
- Findings published in August 2007 as Appendix U to the Final EIS
- Recommended that hydrologic variability likely to be most important impact of climate change for a decision horizon of 20 years or less
- To capture hydrologic variability, recommended the use of paleo climate information to quantify impacts
- Final EIS included a quantitative analysis of increasing climate variability using paleo climate information

2007 Final EIS Hydrologic Sensitivity Analysis (Appendix N)

- **3 Hydrologic Inflow Scenarios Analyzed in Appendix N of Final EIS**
  - Direct Natural Flow Record (DNF)
    - Indexed Sequential Method (ISM) applied to observed record (1906-2005)
  - Direct Paleo (DP)
    - ISM applied to Meko paleo record (762-2005) *(Meko et al., 2007)*
  - Nonparametric Paleo Conditioned (NPC)
    - NPC applied to Meko paleo record *(Prairie, 2006)*

RECLAMATION



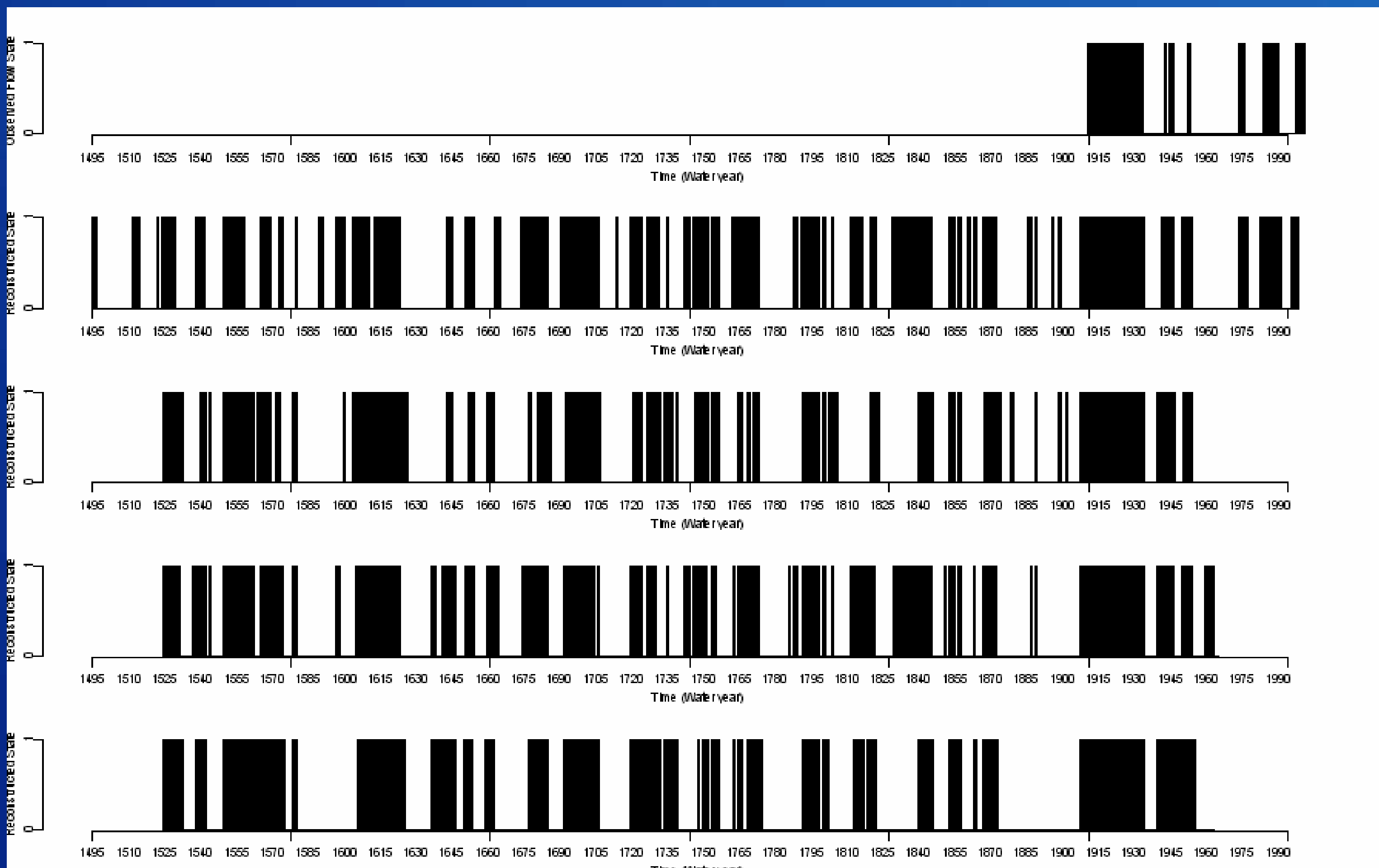
observed record

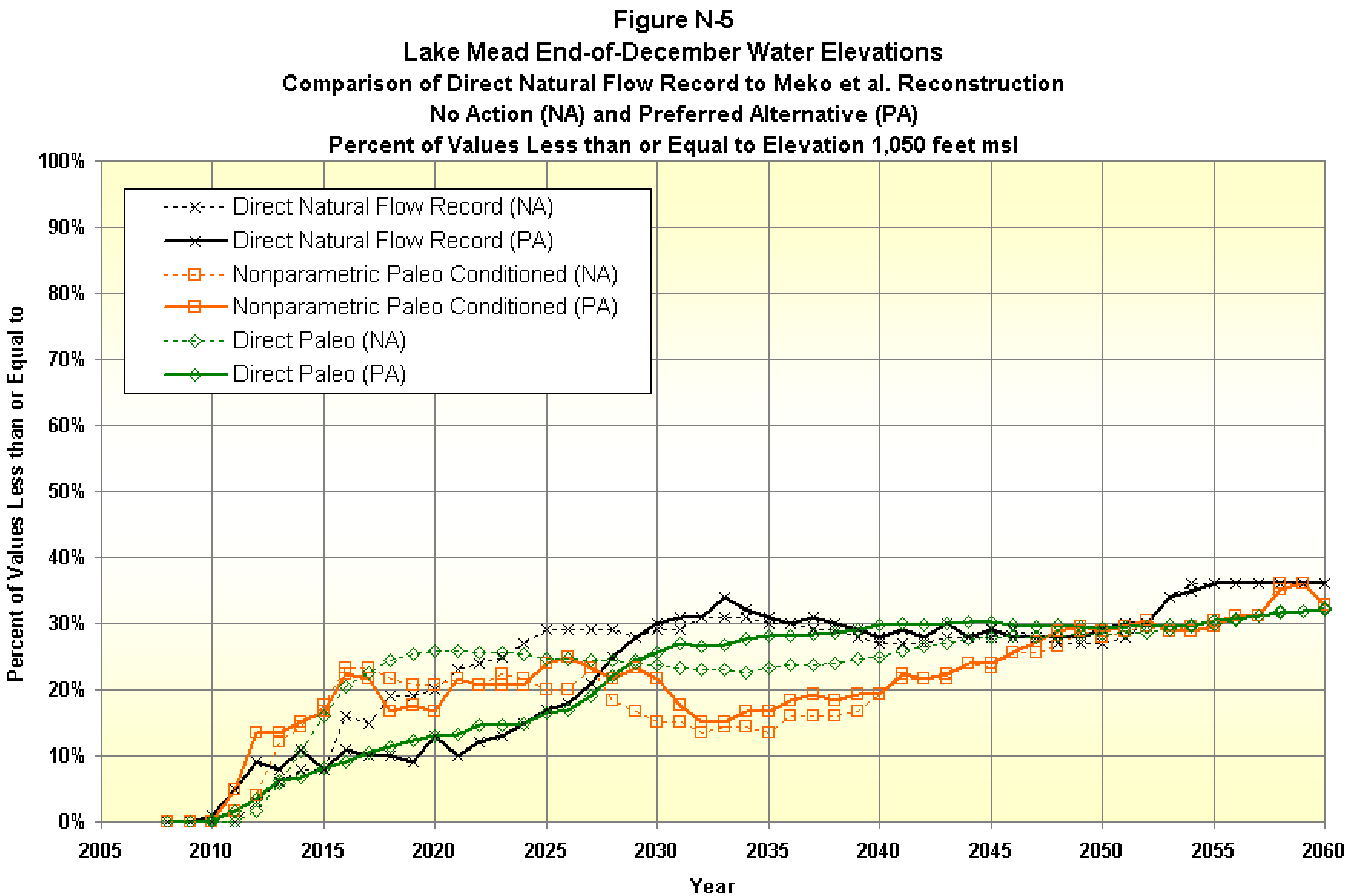
Woodhouse et al. 2006

Stockton and Jacoby, 1976

Hirschboeck and Meko, 2005

Hildalgo et al. 2002





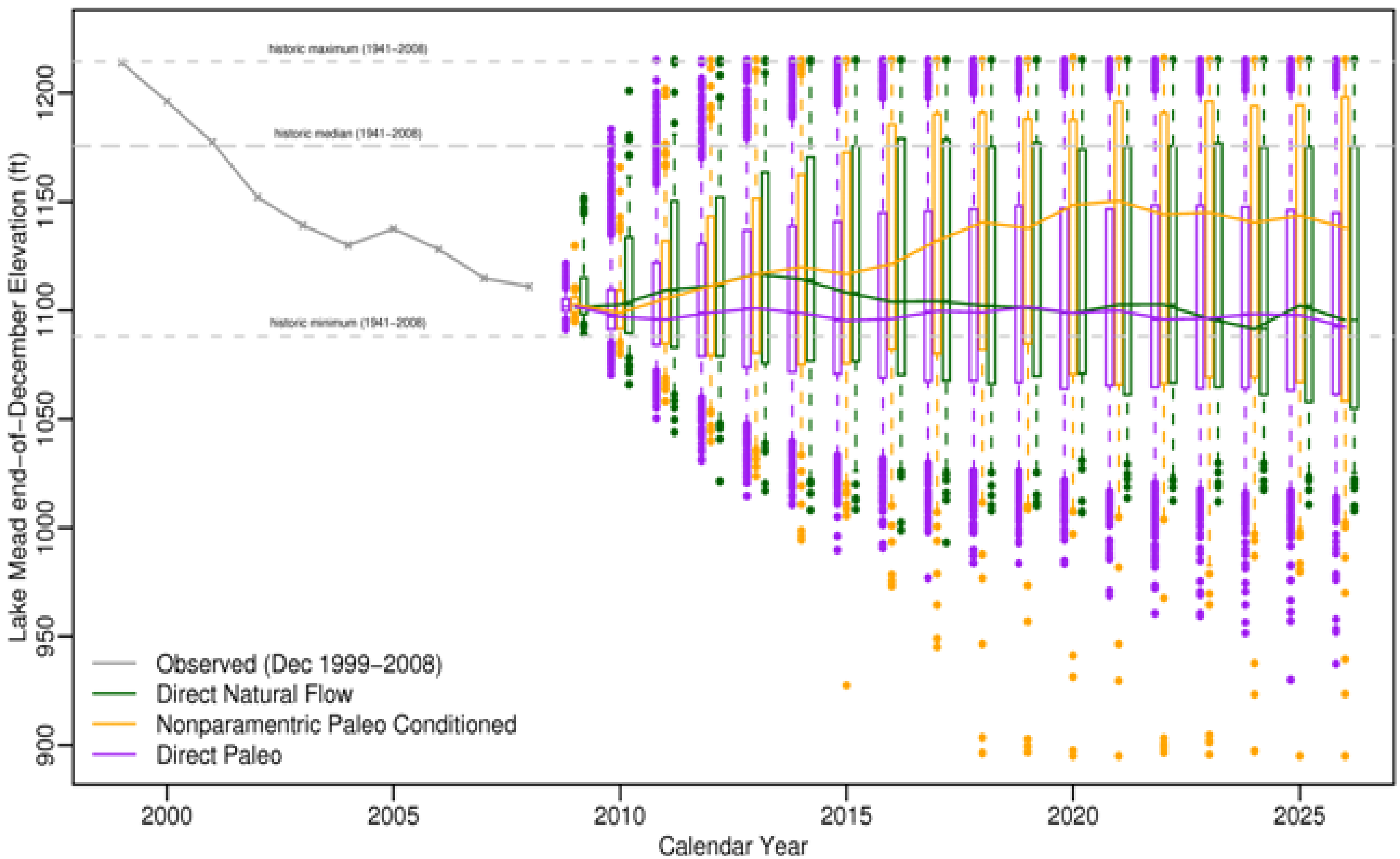
RECLAMATION

Moving Beyond the Observed Record

- Now include hydrologic inflow scenarios analyzed in Appendix N in official CRSS results
- Stakeholders requesting ability to perform simulations in CRSS with paleo data
- Reclamation sponsored research using paleo to inform yearly sequencing blended with flow magnitudes generated by General Circulation Models
- Accepted use of paleo data laying the ground work for incorporating climate change information in long-term planning

RECLAMATION

Latest CRSS Results: Lake Mead Elevation



RECLAMATION

Paleo-Hydrology in Long-Term Planning on the Colorado River Basin

Questions

RECLAMATION

ICS & Shortage: A Paleo- Perspective

Kiyomi Morino and Rosalind Bark
The University of Arizona


1075

Intentionally
Created
Surplus

- mechanism for storing water in Lake Mead
- not available during surplus or shortage conditions.

	Max Annual Put (kaf)	Max Cum ICS (kaf)	Max Annual Take (kaf)
ARIZONA	100	300	300
CALIFORNIA	400	1,500	400
NEVADA	125	300	300
Total	625	2,100	1,000

During *drought*, does the *timing* and *amount* of ICS matter?

Colorado
River
Simulation
System

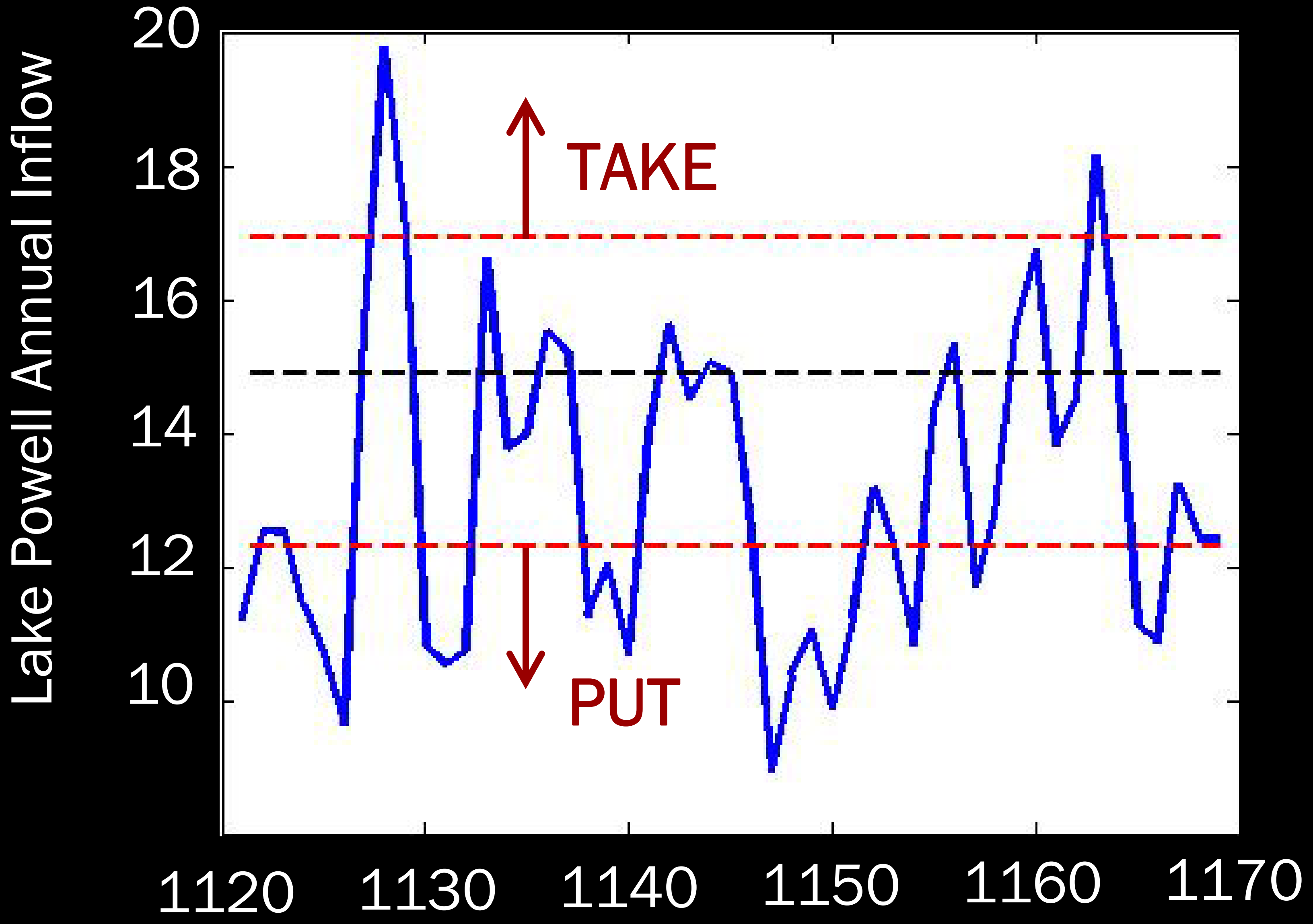
1121-1169

87%

When?

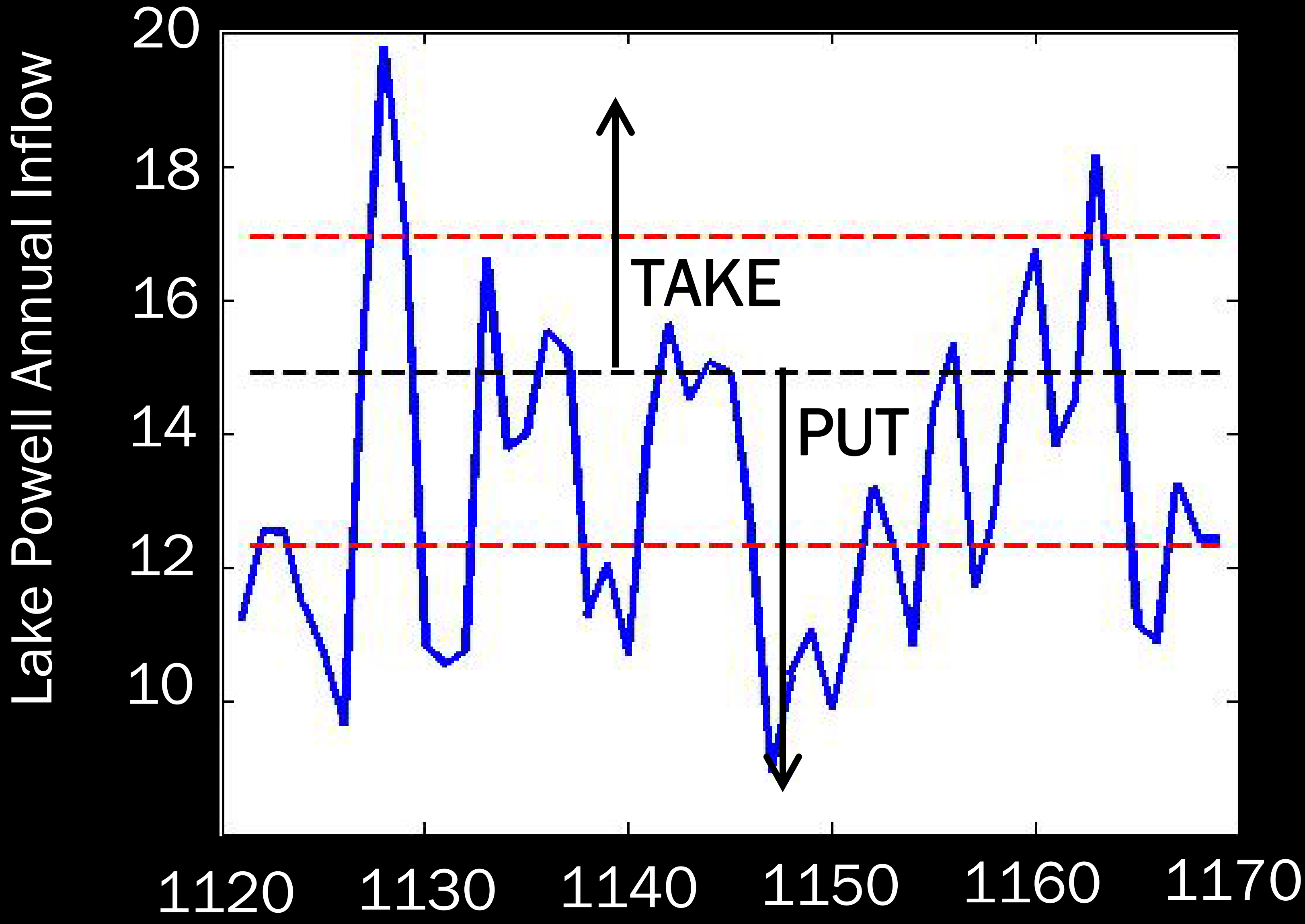
	Put	Take
SCENARIO X	<25	>75
SCENARIO E	<50	>50

--SCENARIO X--



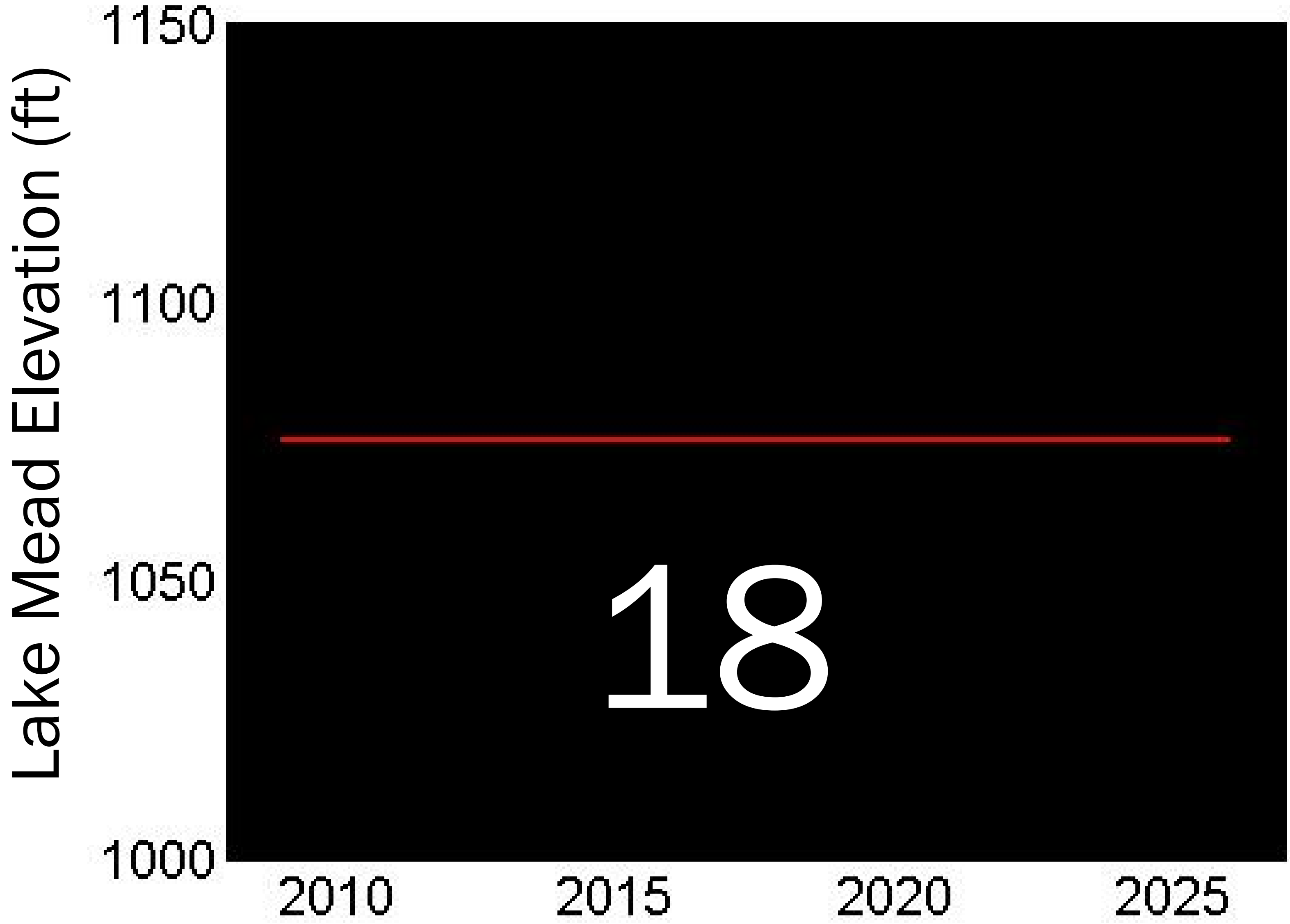
Lake Powell Annual Inflow
20
18
16
14
12
10
1120
1130
1140
1150
1160
1170
TAKE
PUT

--SCENARIO E--

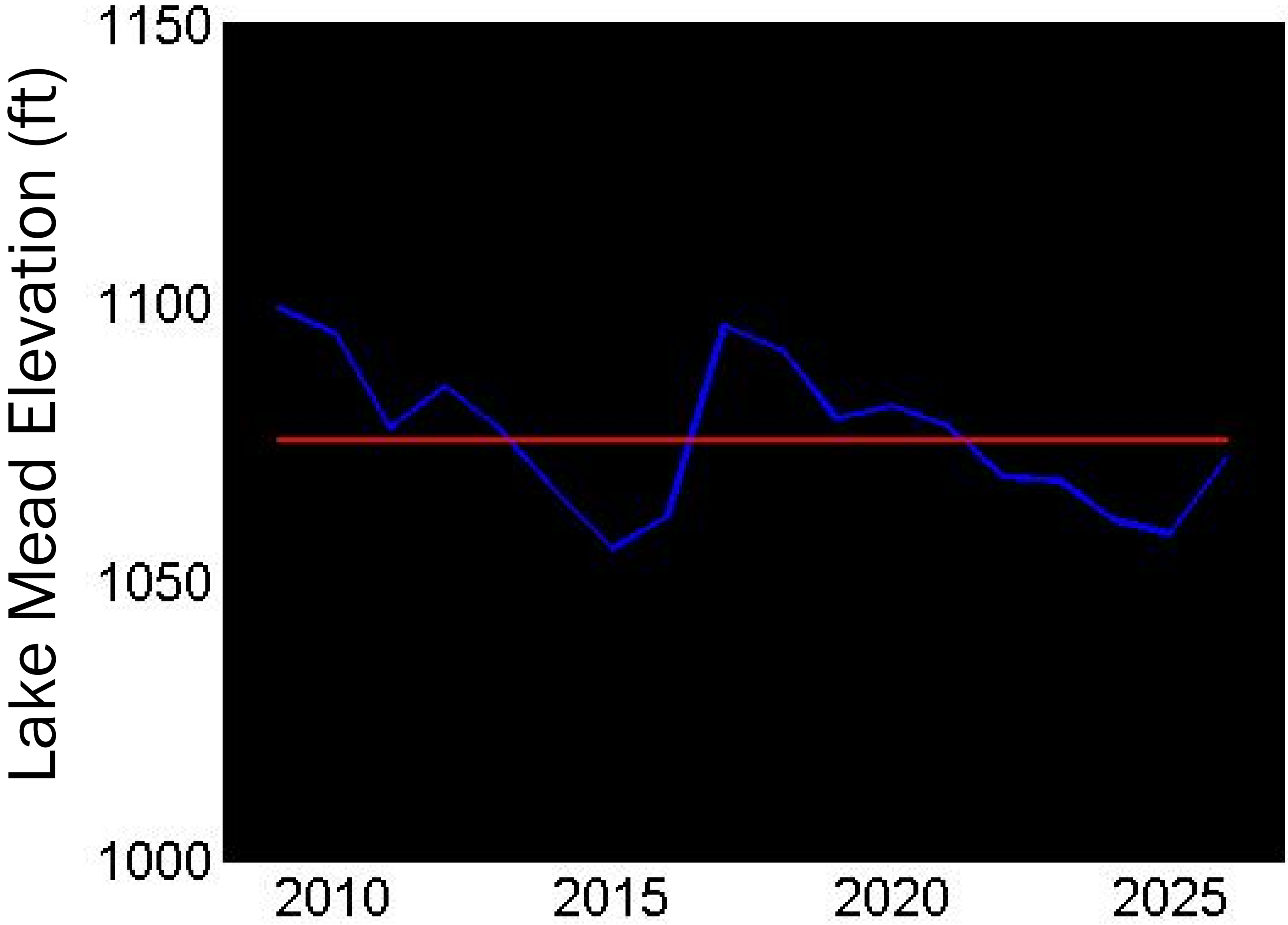

Lake Powell Annual Inflow
20
18
16
14
12
10
1120
1130
1140
1150
1160
1170
TAKE
PUT

How much?

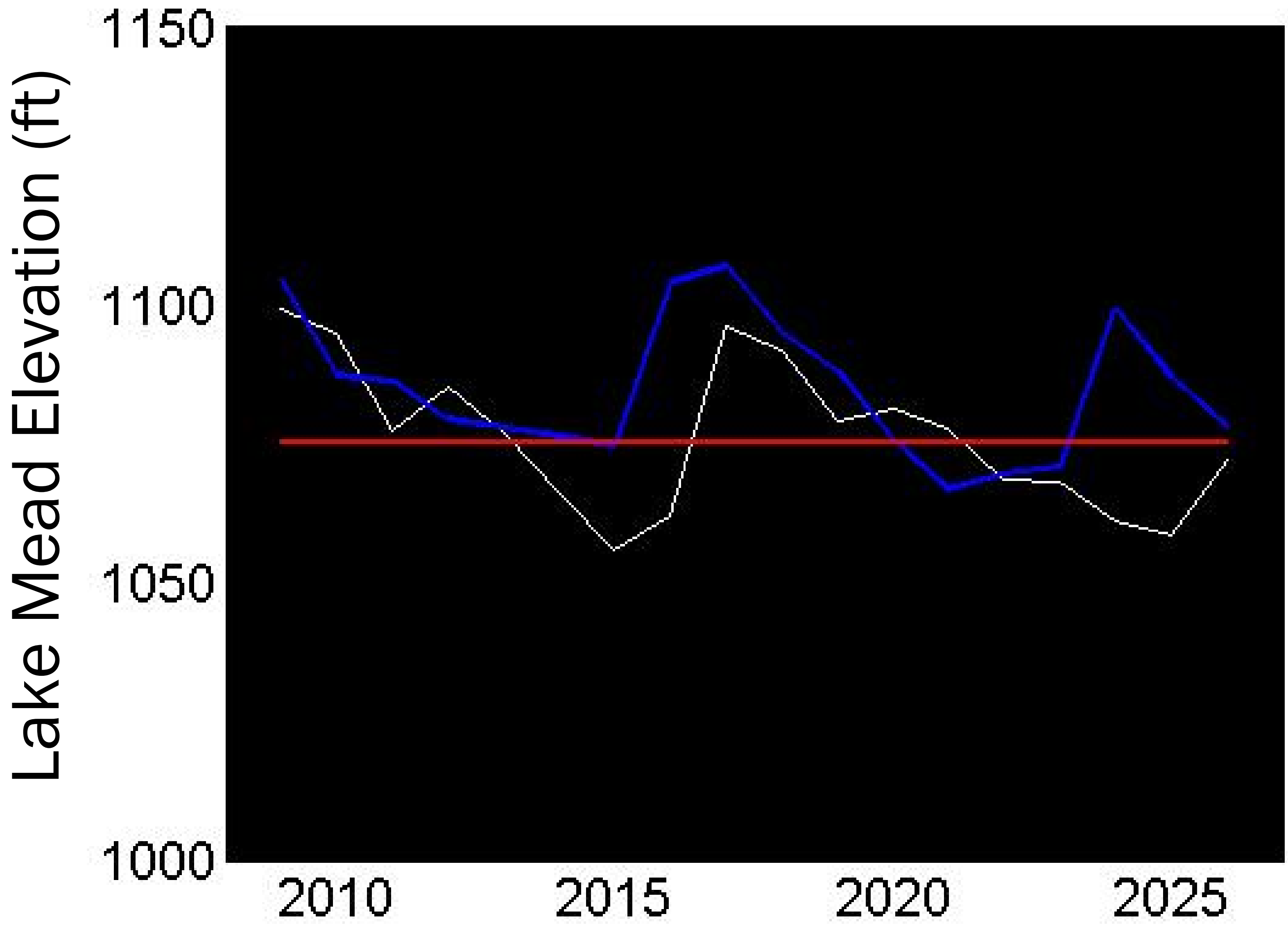
		Put	Take
SCENARIO X	1	600	200
	2	200	200
SCENARIO E	1	600	200
	2	200	200


Lake Mead Elevation (ft)
1150
1100
1050
1000
2010
2015
2020
2025
18

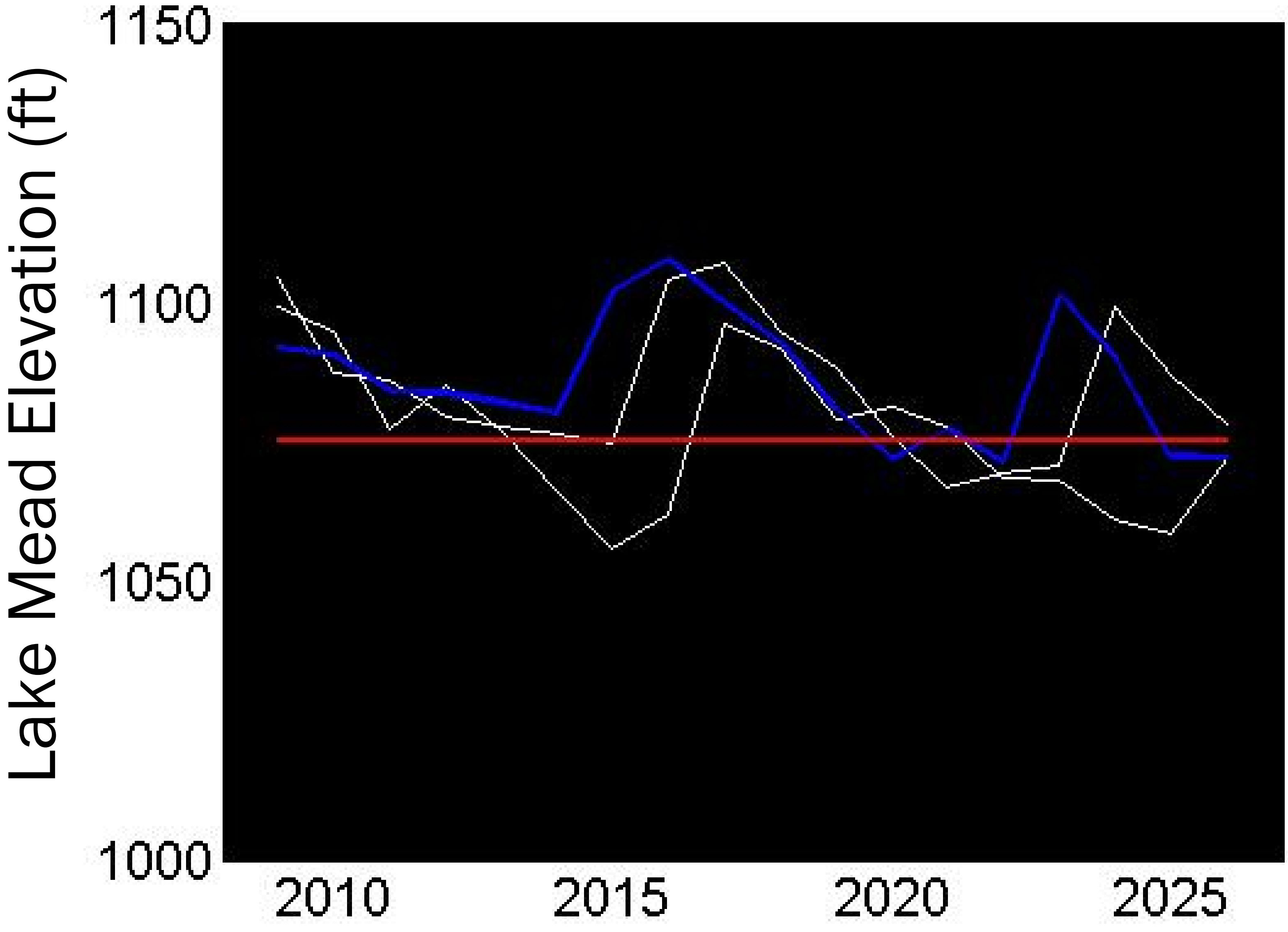
Paleodata Sequence: 1126 - 1143



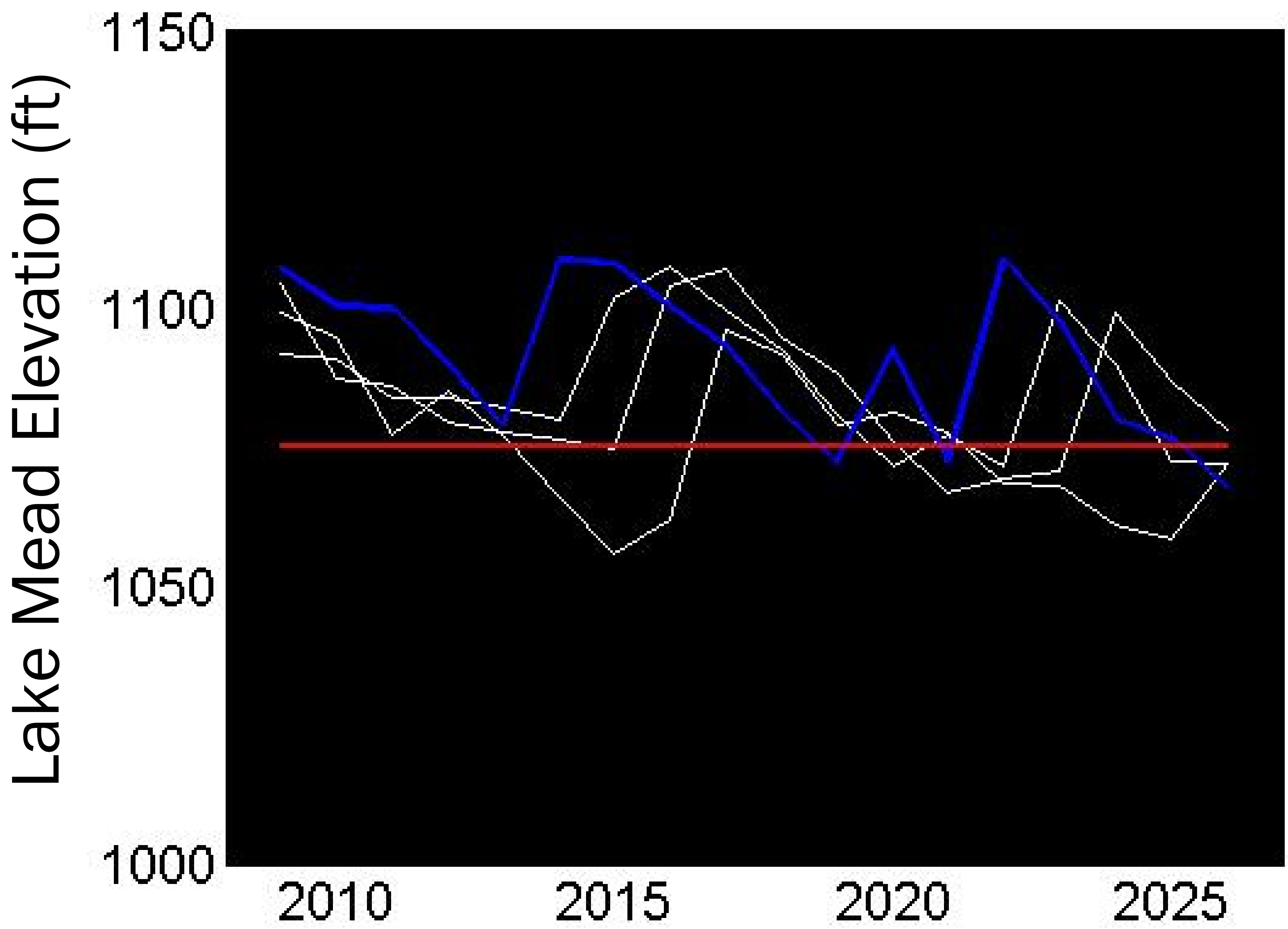
Paleodata Sequence: 1127 - 1144



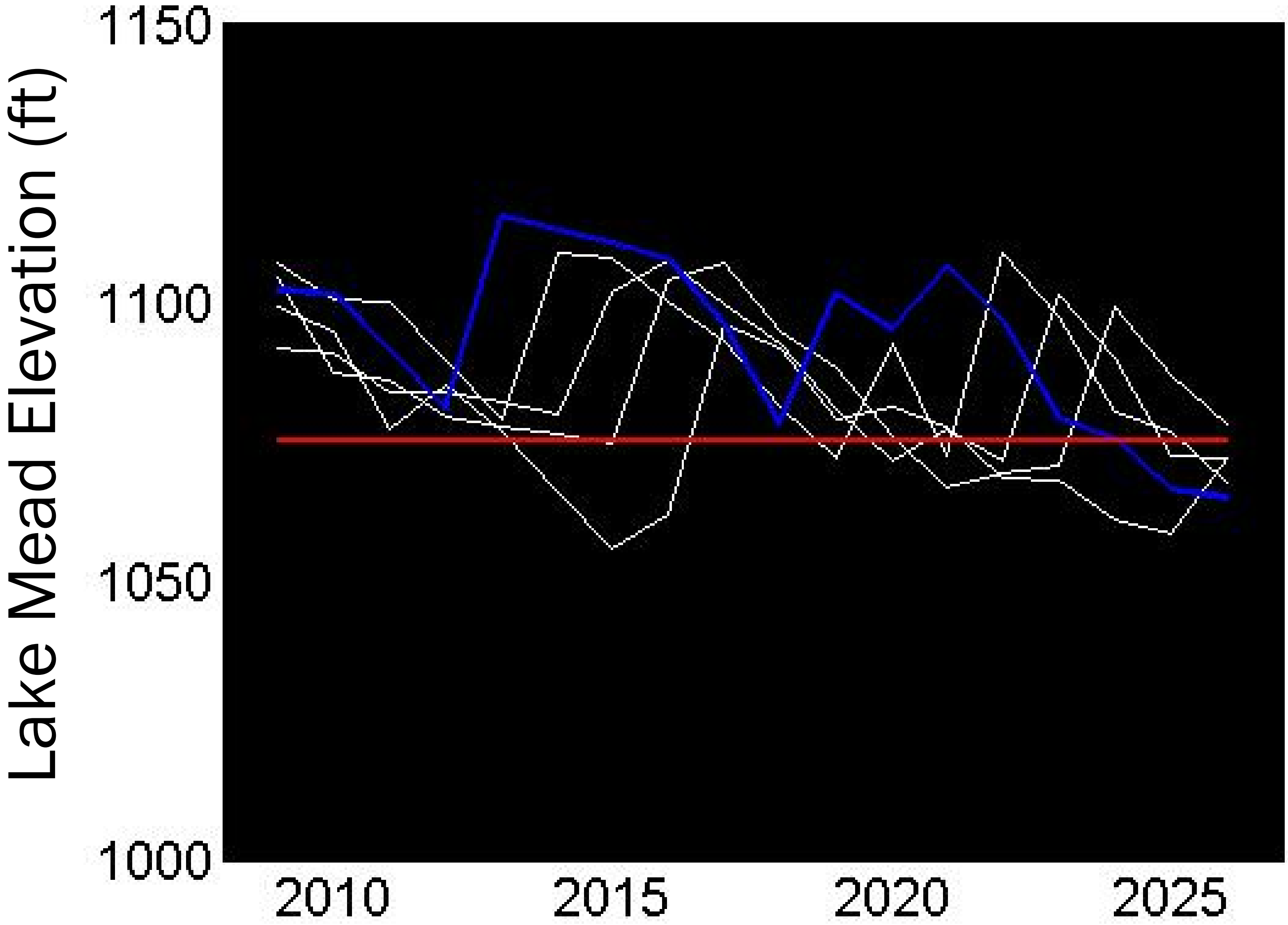
Paleodata Sequence: 1128 - 1145



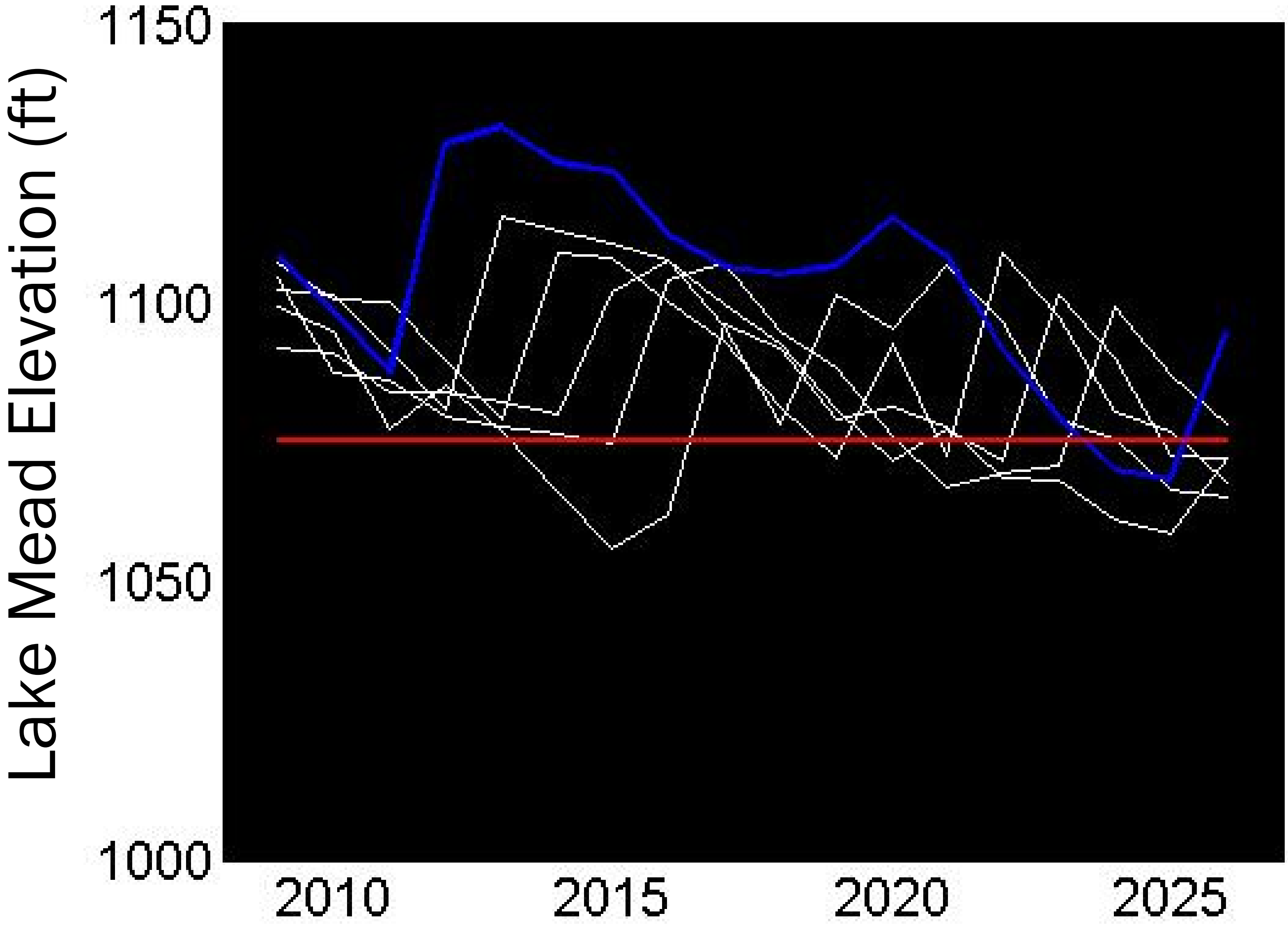
Paleodata Sequence: 1129 - 1146



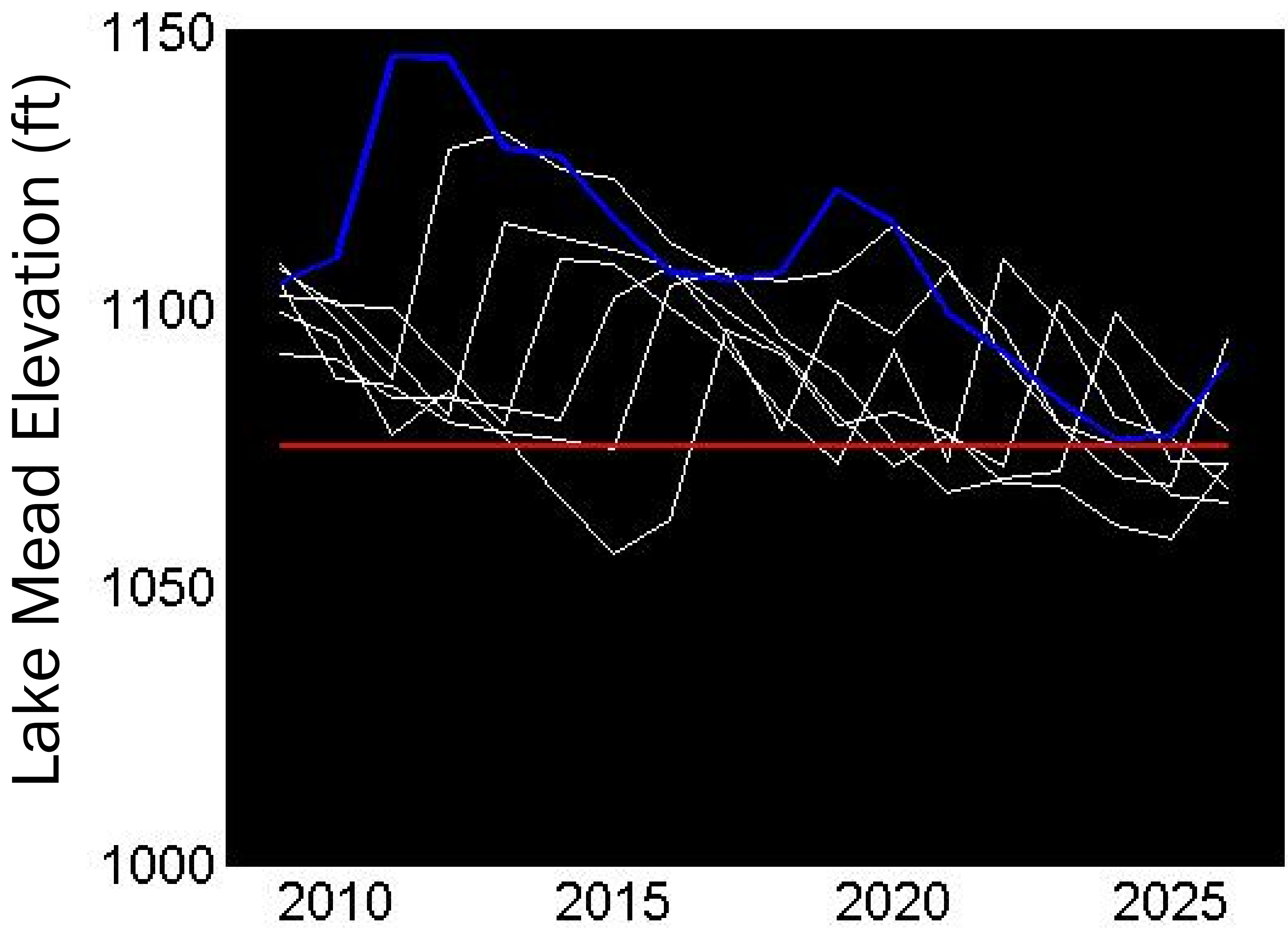
Paleodata Sequence: 1131 - 1148



Paleodata Sequence: 1132 - 1149



Paleodata Sequence: 1133 - 1150



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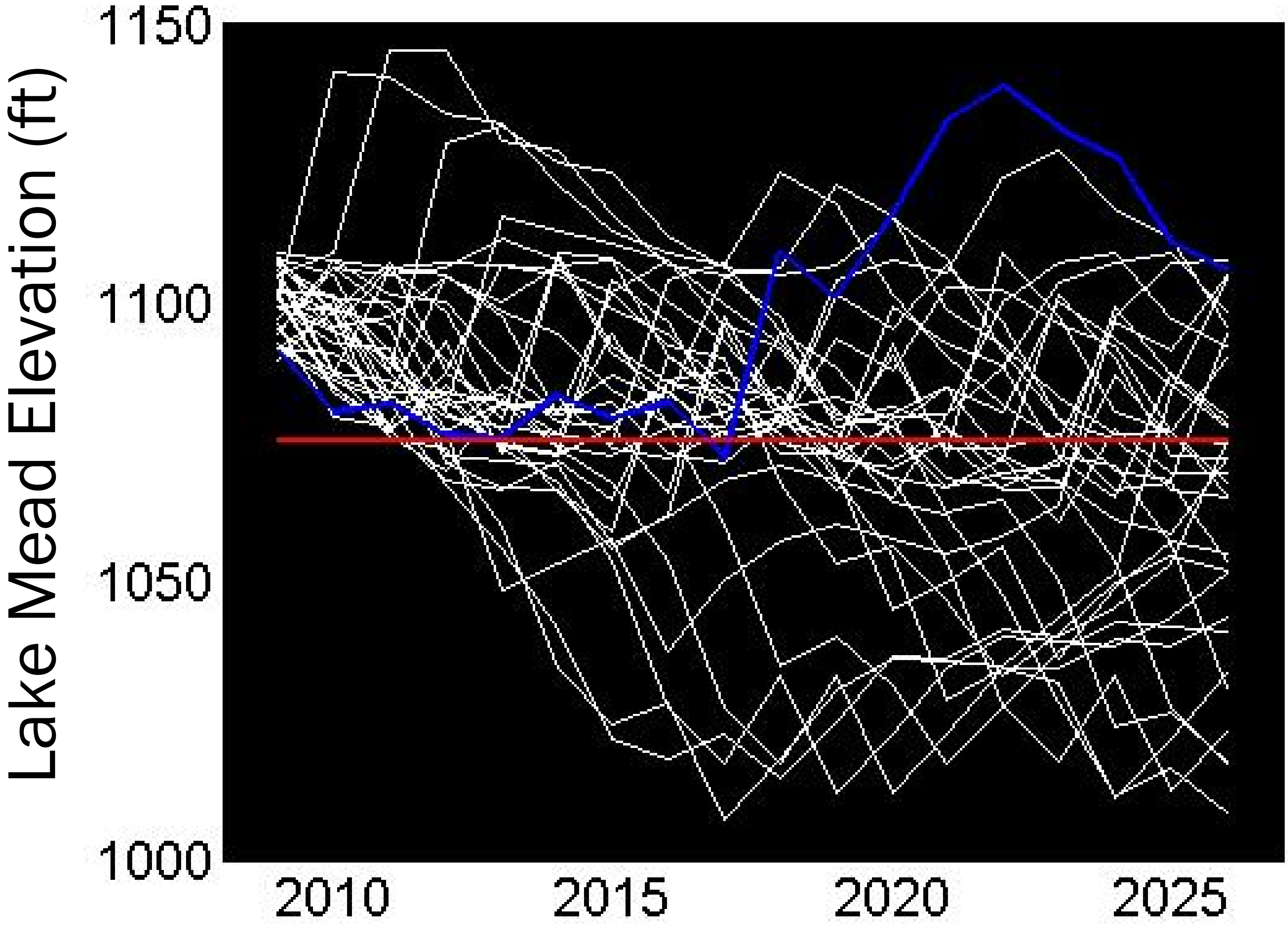
Paleodata Sequence: 1152 - 1169



$$4 + 1$$

32

0 0 0 0 0 1 1 1 0 0 1 1 1 1 1 1 1 1

0 = Above 1075 ft

1 = Below 1075 ft

0 0 0 0 0 1 1 1 0 0 1 1 1 1 1 1 1 1

0 = Above 1075 ft

1 = Below 1075 ft

1. Does ICS delay the onset of involuntary shortage?

2. Does ICS reduce the frequency of involuntary shortage?

		Mean (Min, Max)
NO ICS		6.4 (3,15) years
PUT when <25 (TAKE when >75)	P600 kaf	9.2 (4,19) years
	P200 kaf	6.9 (3,16) years
PUT when <50 (TAKE when >50)	P600 kaf	8.8 (4,19) years
	P200 kaf	7.3 (3,16) years

* TAKE = 200 kaf in all scenarios

		Mean (Min, Max)
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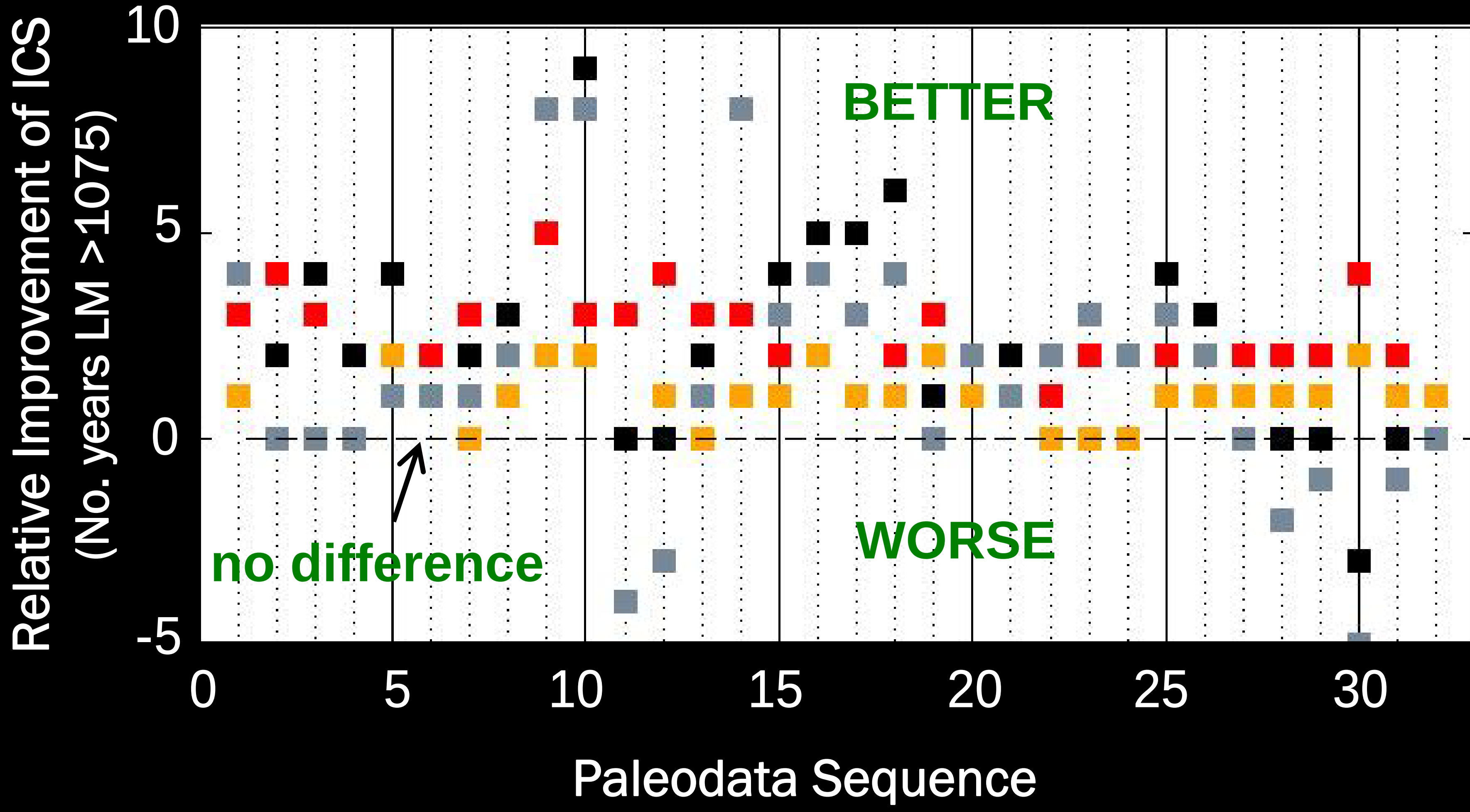
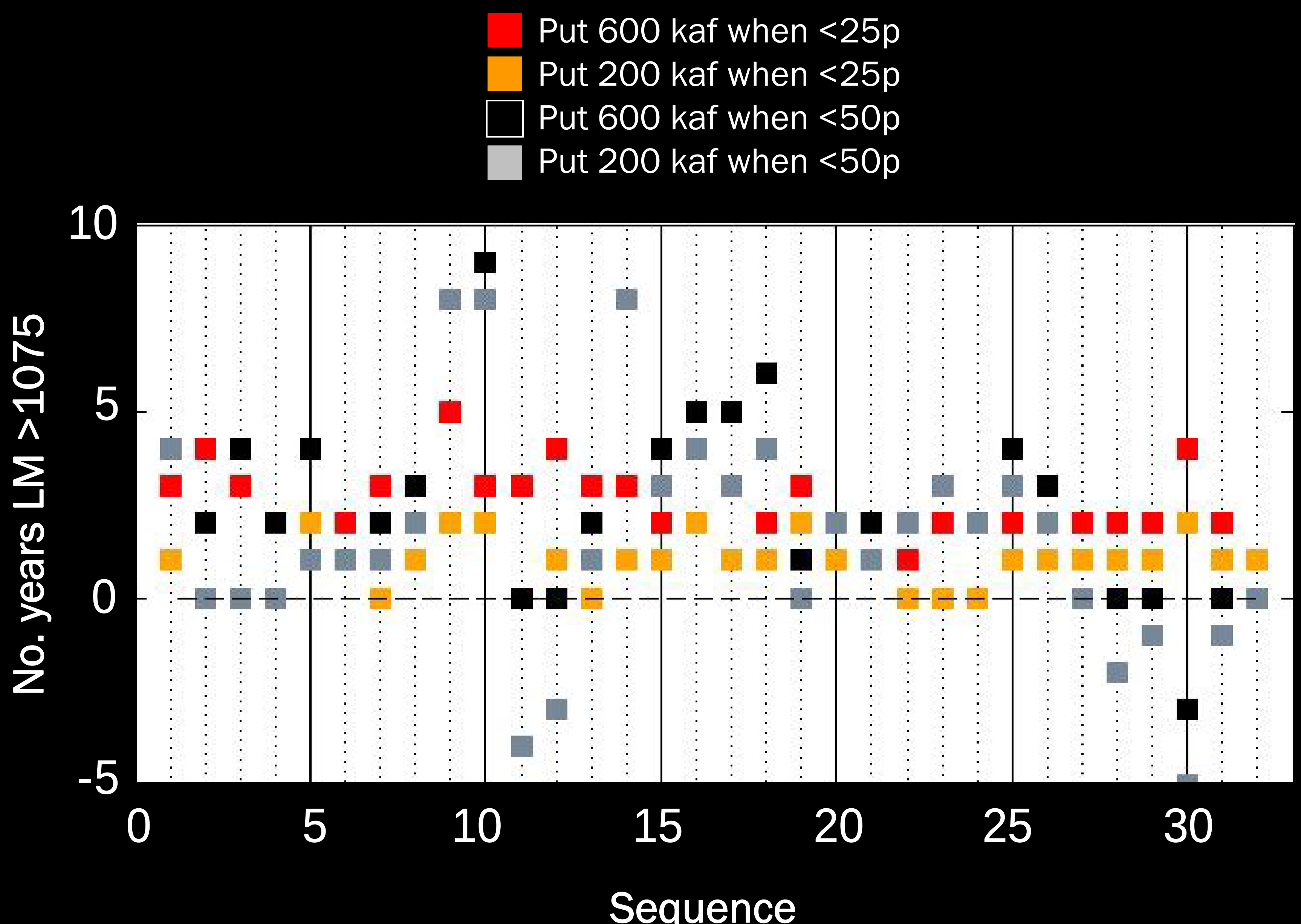
2. Does ICS reduce the frequency of involuntary shortage?

ICS Scenarios vs NO ICS





Put 600 kaf when <25p
Put 200 kaf when <25p
Put 600 kaf when <50p
Put 200 kaf when <50p
No. years LM >1075
10
5
0
-5
0
5
10
15
20
25
30
Sequence

Is it better to store more water in Lake Mead?

		600kaf vs 200kaf	
<25p	Better	30	1.7 (1,3) yrs
	No diff	2	--
	Worse	0	--
<50p	Better	22	1.7 (1,4) yrs
	No diff	10	--
	Worse	0	--

Is it better to store water in Lake Mead under more extreme inflow?

		<25p vs <50p	
600kaf	Better	13	2.3 (1,7) yrs
	No diff	5	--
	Worse	14	2.3 (1,6) yrs
200kaf	Better	11	2.6 (1,7) yrs
	No diff	4	--
	Worse	17	2.6 (1,7) yrs

4 CONCLUSIONS

ICS delays the onset and reduces the frequency of shortage.

ICS delays the onset and reduces the frequency of shortage.

Sequence matters.

ICS delays the onset and reduces the frequency of shortage.

Sequence matters.

Larger “Puts” reduce the frequency of shortage.

ICS delays the onset and reduces the frequency of shortage.

Sequence matters.

Larger “Puts” reduce the frequency of shortage.

For smaller “Puts,” it is better to “Put” more often.