RECLAMATION

Managing Water in the West

Combining paleo-reconstructed variability with observed and projected future flows

The hydrologic sensitivity analyses in the recent Shortage FEIS and an ongoing study

Nevada TreeFlow Workshop

James R. Prairie, PhD

Nov 13, 2008

U.S. Department of the Interior
Bureau of Reclamation

Discussion Topics

- Overview of the Basin
- Drought and Current System Conditions
- Hydrologic Sensitivity Analysis
- Incorporating Projected Climate

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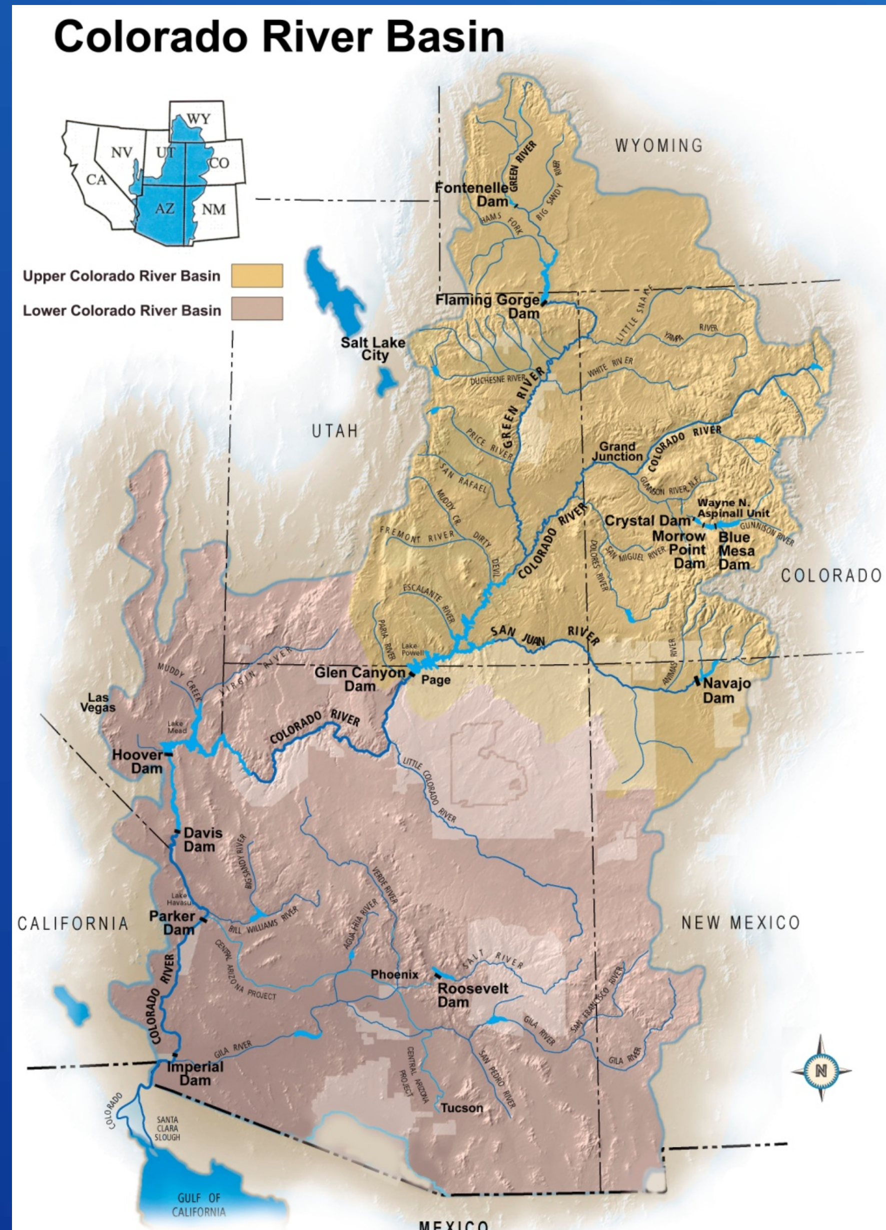
Colorado River Basin Hydrology

- 16.5 million acre-feet (maf) allocated annually
- 13 to 14.5 maf of consumptive use annually
- 60 maf of storage
- 15.1 maf average annual “natural” inflow into Lake Powell over past 100 years
- Inflows are highly variable year-to-year



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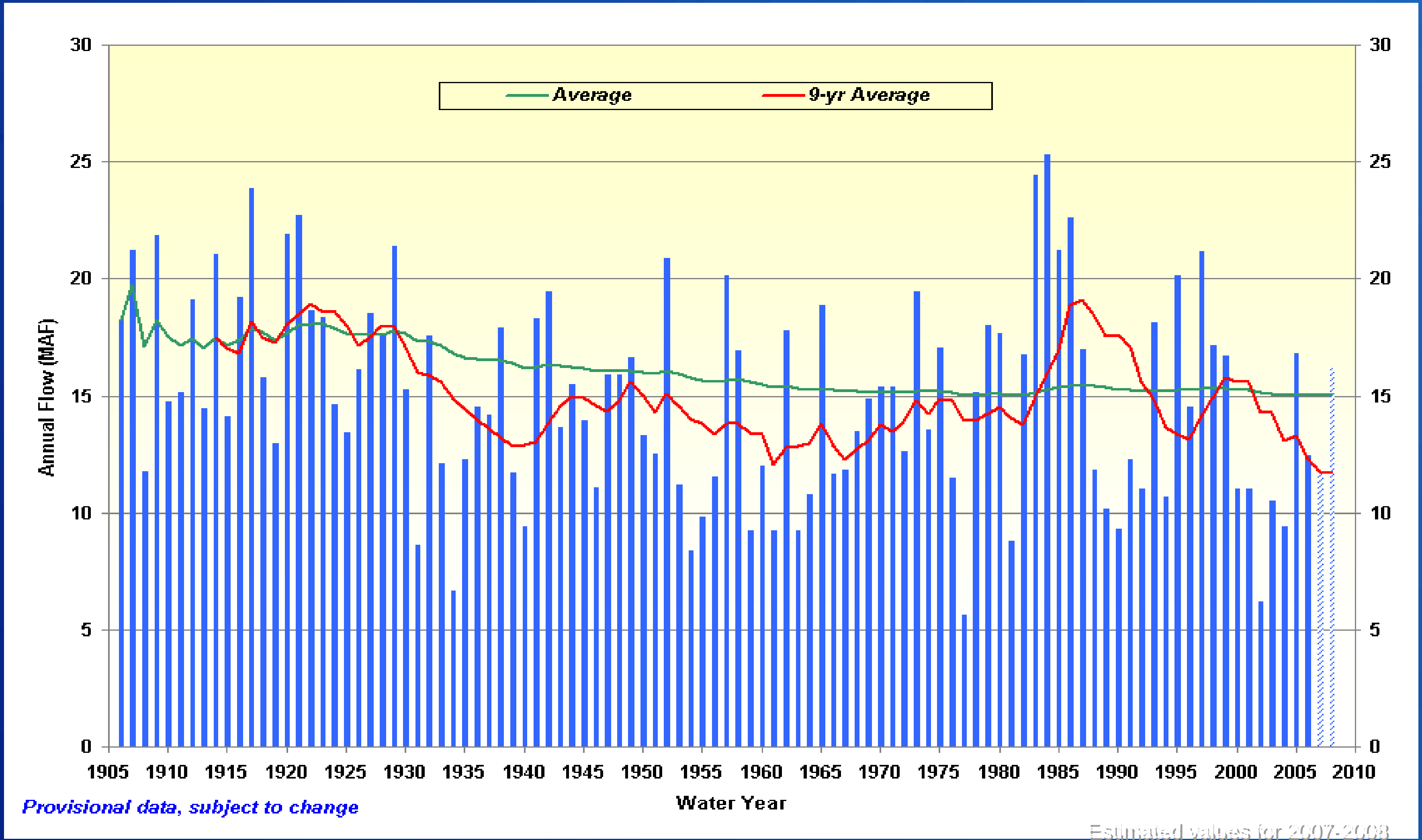
Natural Flow
Colorado River at Lees Ferry Gaging Station, Arizona
Water Year 1906 to 2008



Estimated values for 2007-2008

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State of the System (1999-2008)

WY	Unregulated inflow into Powell % of Average	Powell and Mead Storage, maf	Powell and 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	104	27.24	54
2006	72	25.80	51
2007	68	24.43	49
*2008	102	26.52	53

*Based on October 24 Month Study

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Colorado River Drought

- **2000-2008 has been the driest 9-year period in the 100-year historical record (WY 2007 and WY 2008 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 2008 April through July runoff was 112% of average (as of Oct 6, 2008)**
- **Not unusual to have a few years of above average inflow during longer-term droughts (e.g., the 1950's)**

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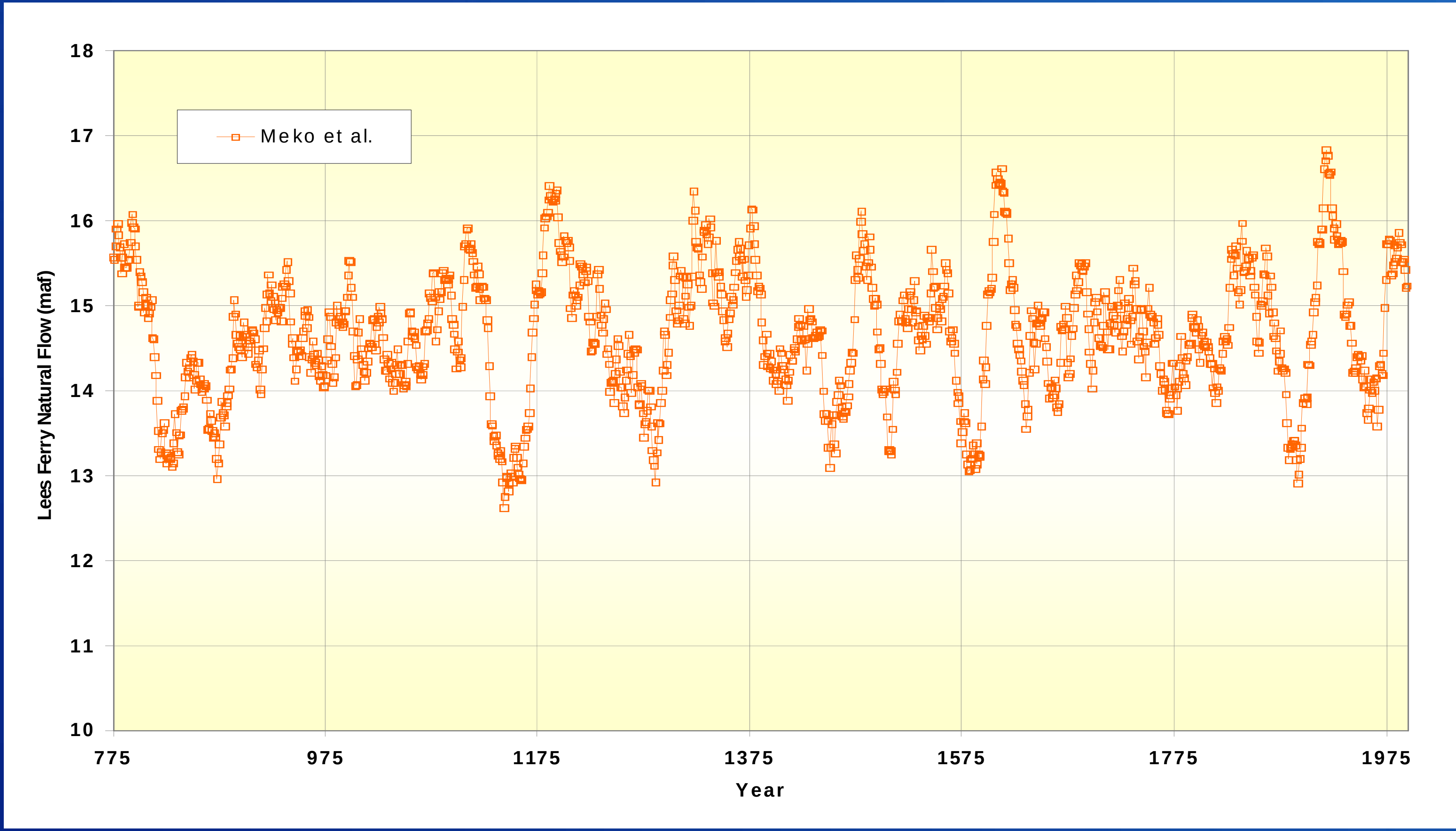
Annual Natural Flow at Lees Ferry
Tree-ring Reconstruction (Meko et al., 2007)
25-Year Running Mean



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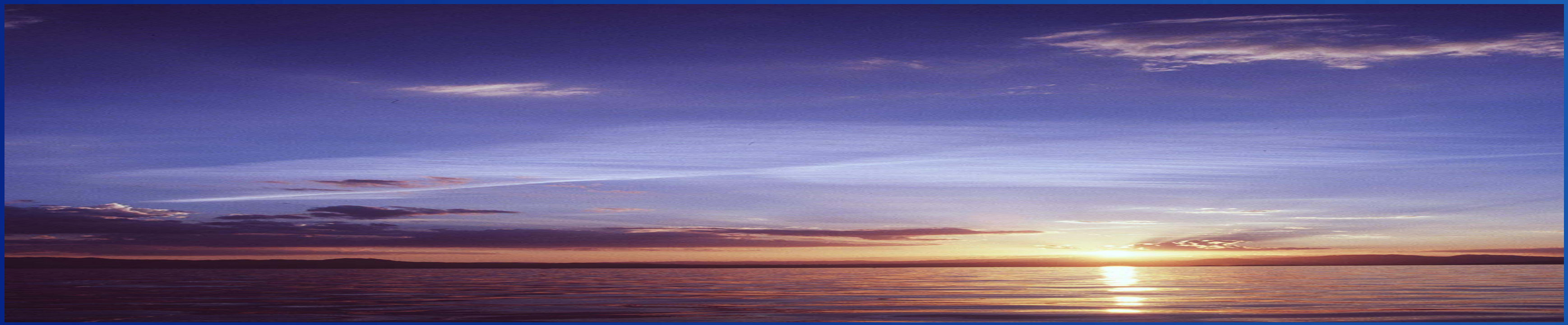
Interim Guidelines

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**



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Potential Impacts of Changing Climate

- **Historical data shows slight change in mean annual flows over time and large variability year-to-year**
- **Potential for decreased mean annual flow as well as increased variability**
- **Recent publications project a wide range of potential impacts (from 0 to up to 45% decrease in the mean annual flow)**
- **Additional research needed to better quantify uncertainties and improve understanding of risks**
- **Research Efforts**
  - **Climate Technical Workgroup (NOAA, UCAR, CU, UNLV, UA, Reclamation, AMEC) advised recent EIS efforts**
  - **On-going research and development in order to use climate change scenarios in our decision-making**
- **Information in Section 4.2, Appendix N and U available at:**

  http://www.usbr.gov/lc/region/programs/strategies.html

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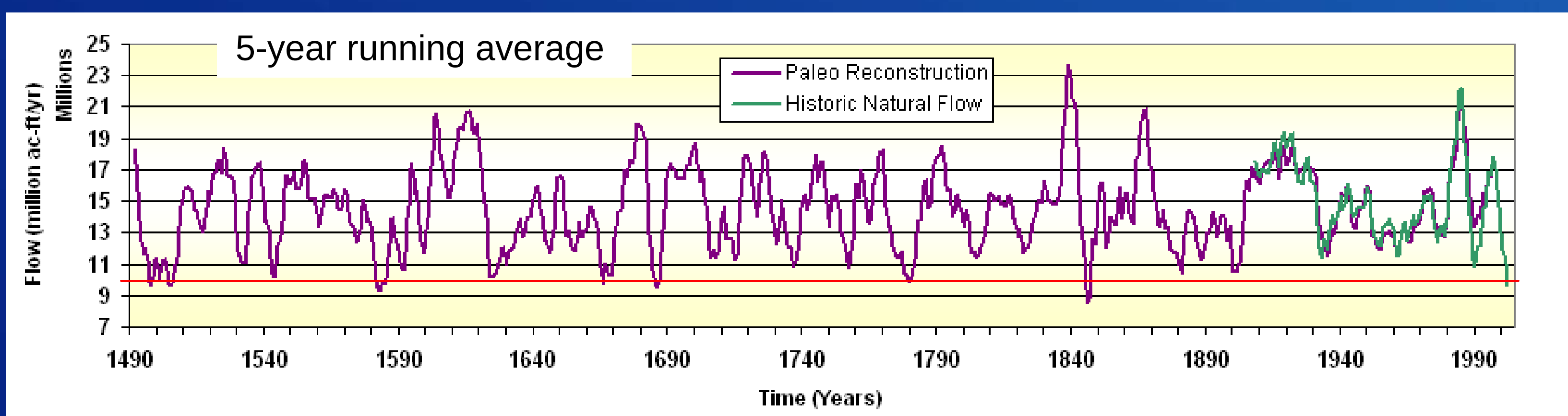
Hydrologic Sensitivity Runs

3 hydrologic inflow scenarios analyzed in FEIS Appendix N:

- **Direct Natural Flow Record**
  - **ISM applied to natural flow record (1906-2005)**
- **Direct Paleo**
  - **ISM applied to Meko - paleo flow (762-2005)** **(Meko et al., 2007)**
- **Nonparametric Paleo Conditioned**
  - **Meko - paleo conditioned** **(Prairie, 2006)**



Colorado River at Lees Ferry, AZ

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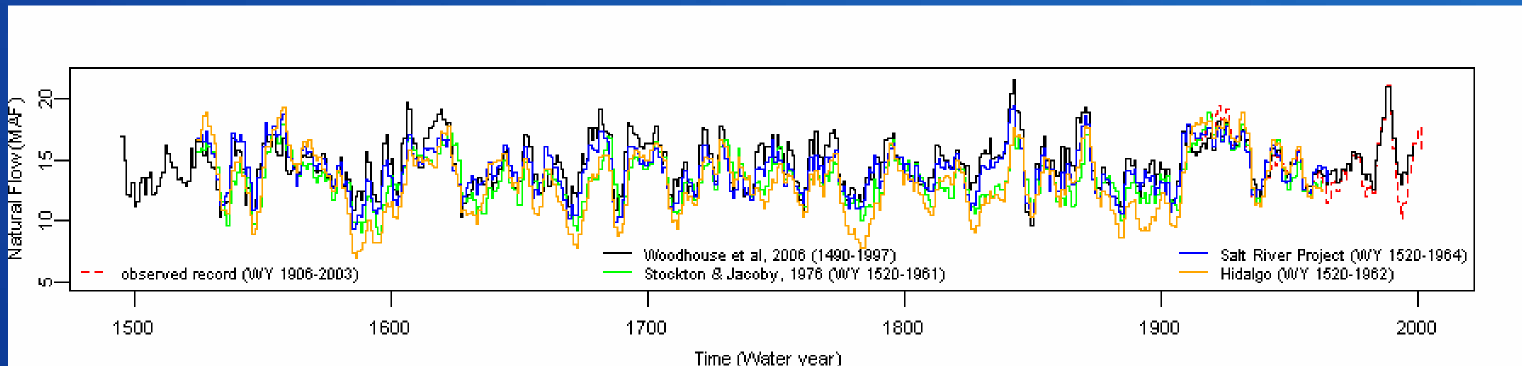


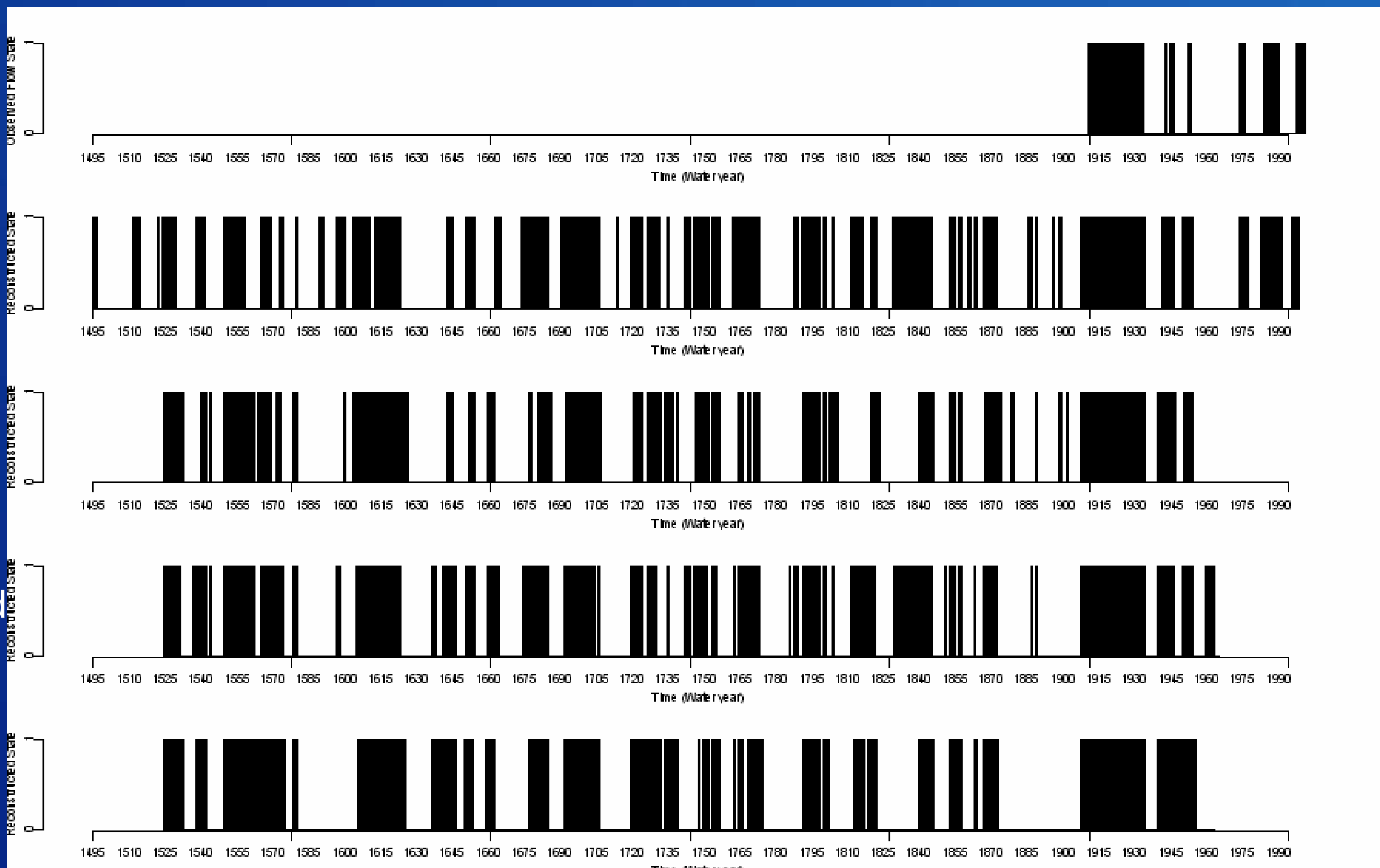
Observed Record

Woodhouse et al. 2006

Stockton and Jacoby, 1976

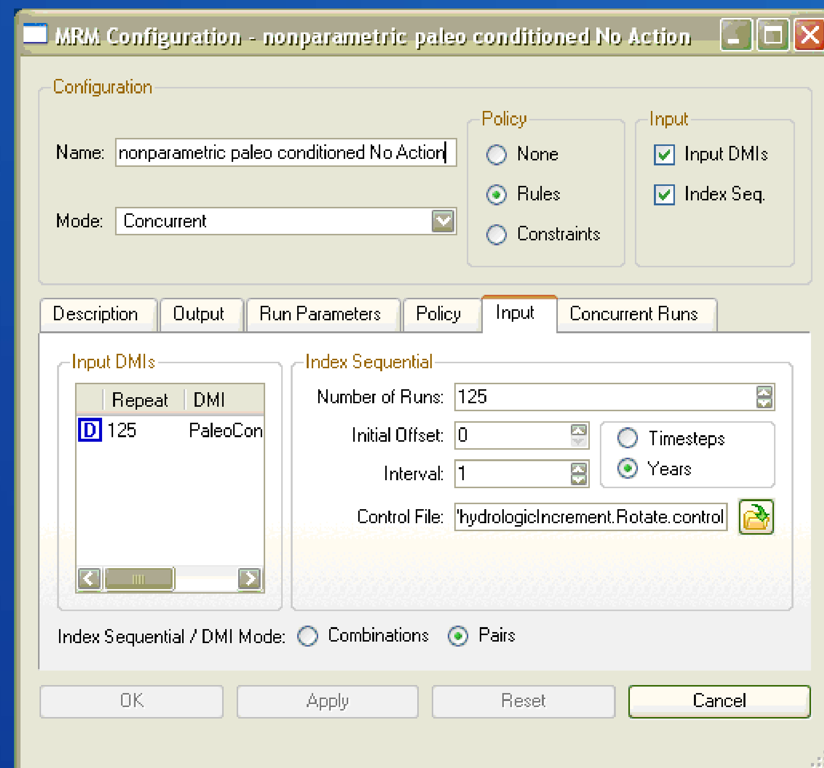
Hirschboeck and Meko, 2005

Hildalgo et al. 2002



Alternate Stochastic Techniques

- **Paleo conditioned**
  - **Combines observed and paleo streamflows**
  - **Generates**
    - **Observed flow magnitudes**
    - **Flow sequences similar to paleo record**



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Paleo Conditioned Modeling Framework

Streamflow Generation Combining Observed And Paleo Reconstructed Data

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Nonparametric Space-Time Disaggregation

↓

Decision Support System

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Streamflow Generation

Nonhomogeneous Markov model

↓

Generate system state

(S_t)

i.e., wet or dry

↓

Generate flow conditionally
(K-NN resampling)

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

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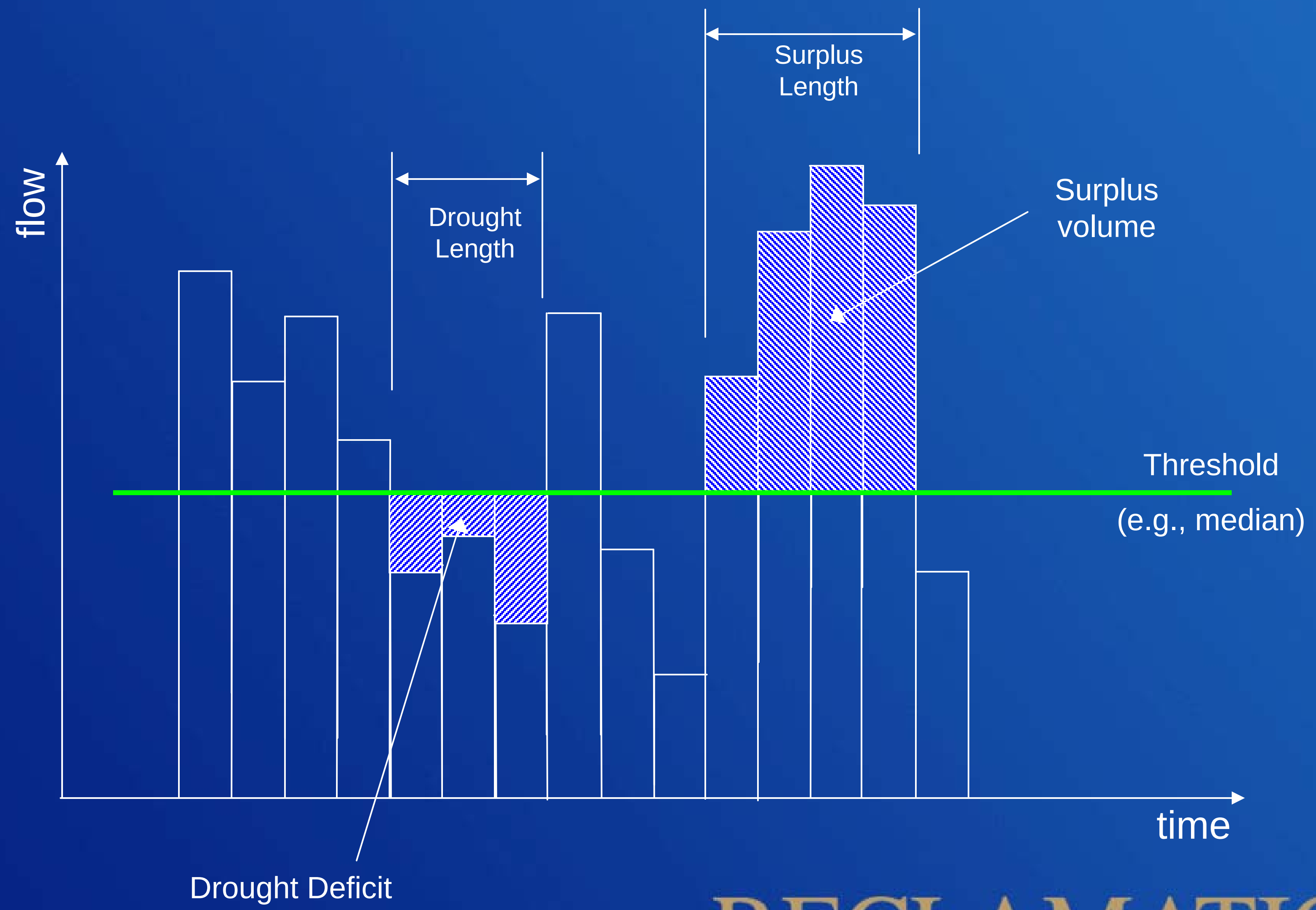
Drought and Surplus Statistics



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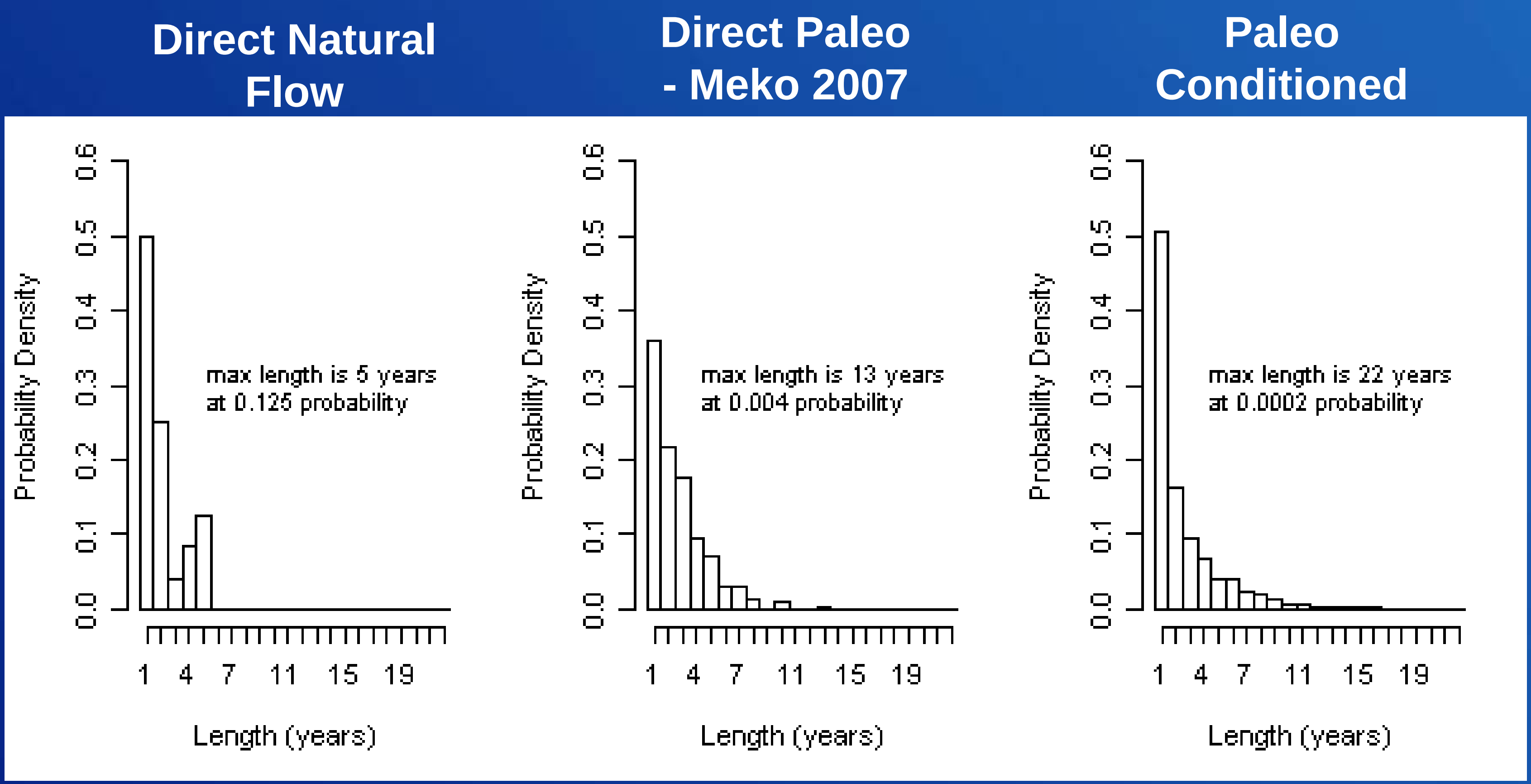
Histograms of Dry Periods



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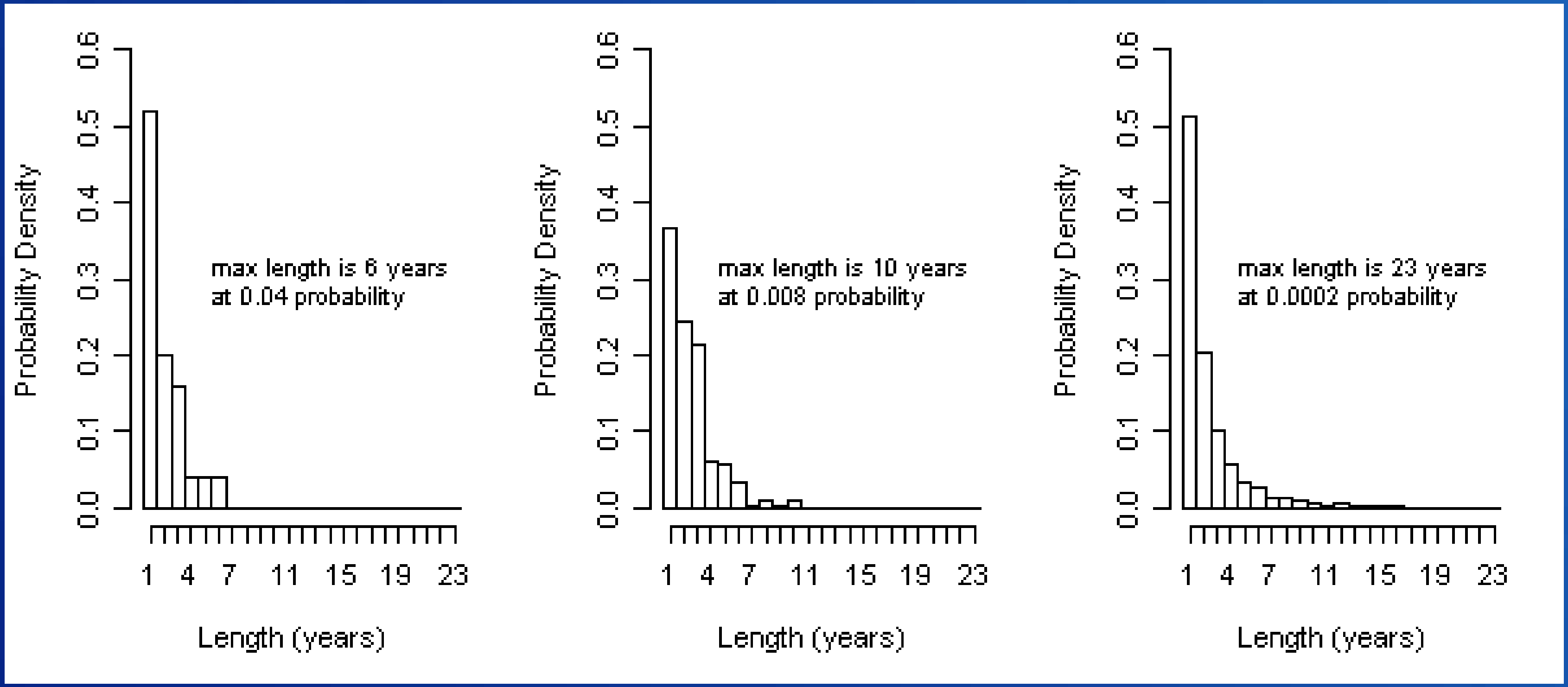
Histograms of Wet Periods

Direct Natural Flow | **Direct Paleo - Meko 2007** | **Paleo Conditioned**



RECLAMATION

Paleo Conditioned Modeling Framework

Streamflow Generation Combining Observed And Paleo Reconstructed Data

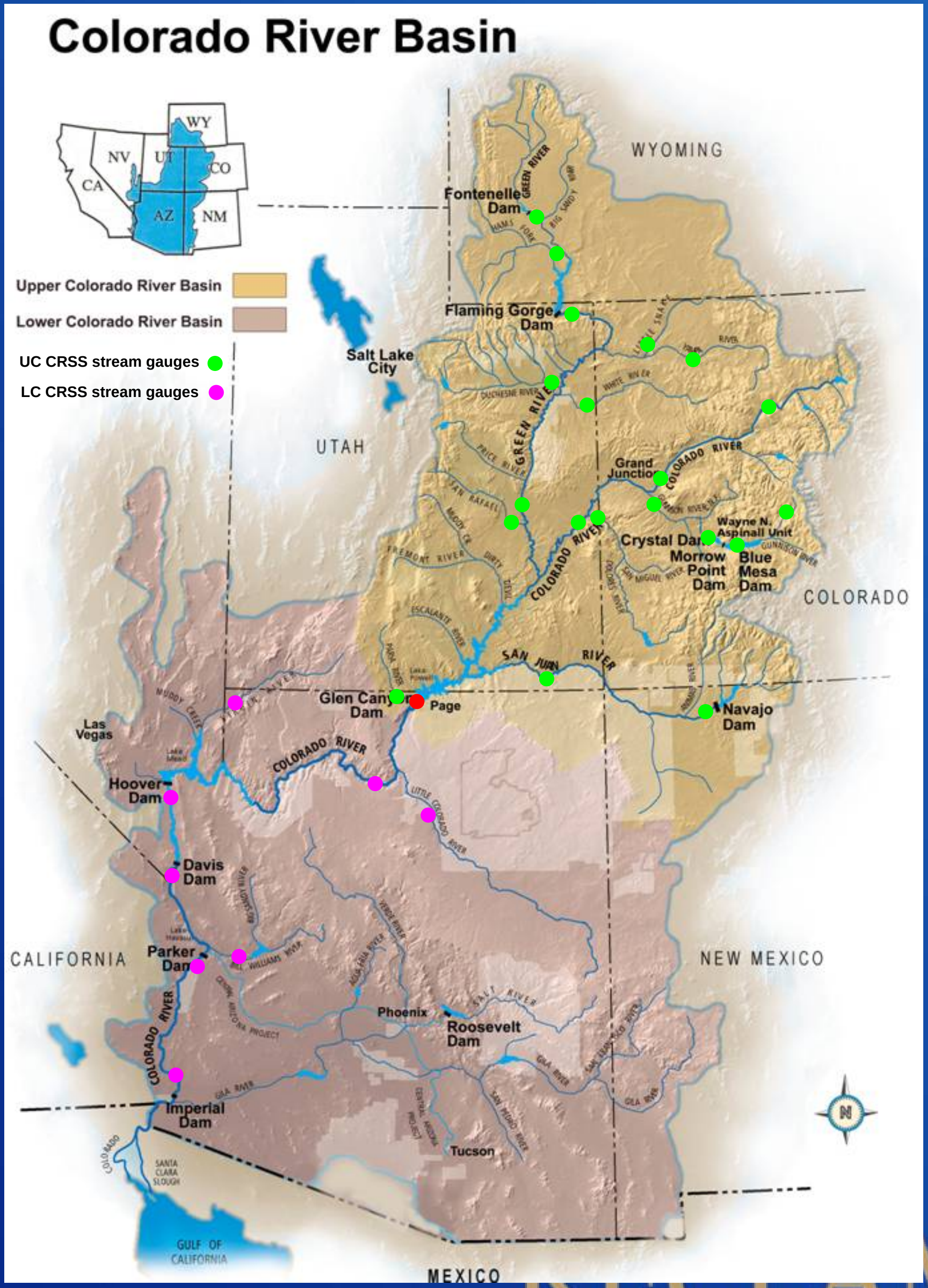
↓

Nonparametric Space-Time Disaggregation

↓

Decision Support System

RECLAMATION



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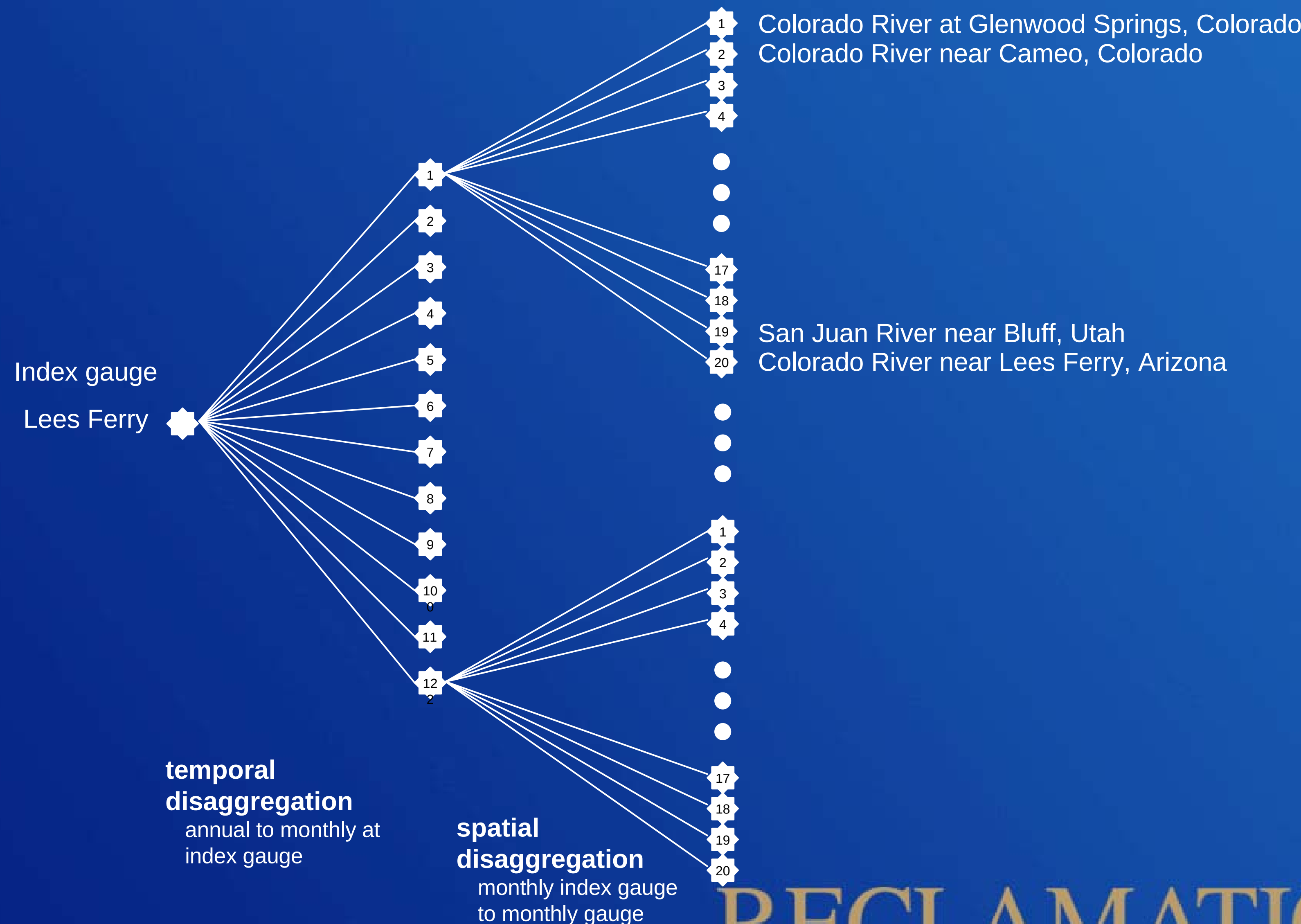
Disaggregation scheme



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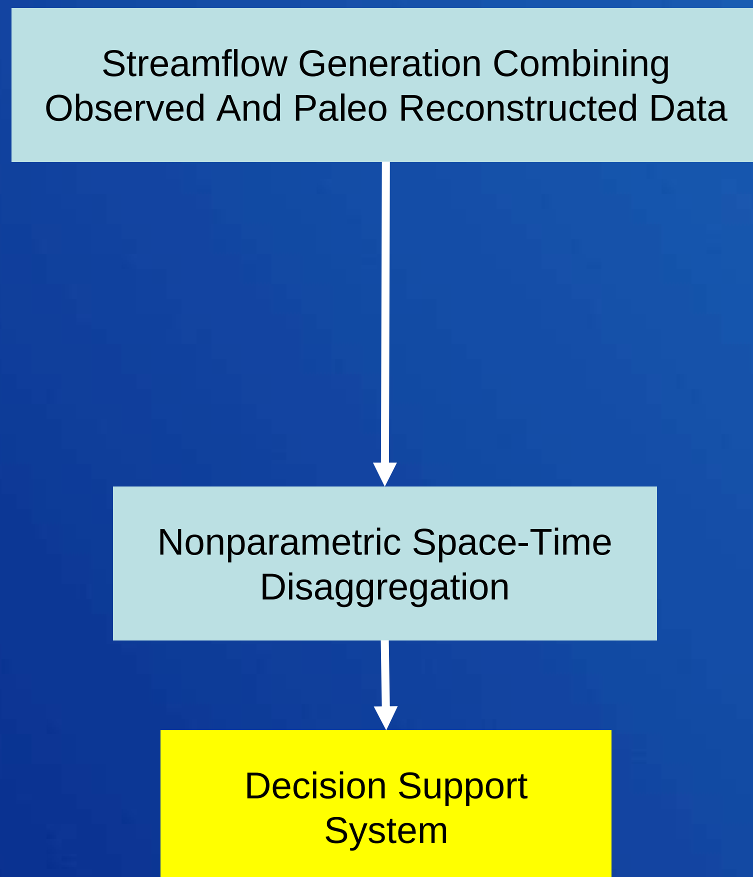
Paleo Conditioned Modeling Framework



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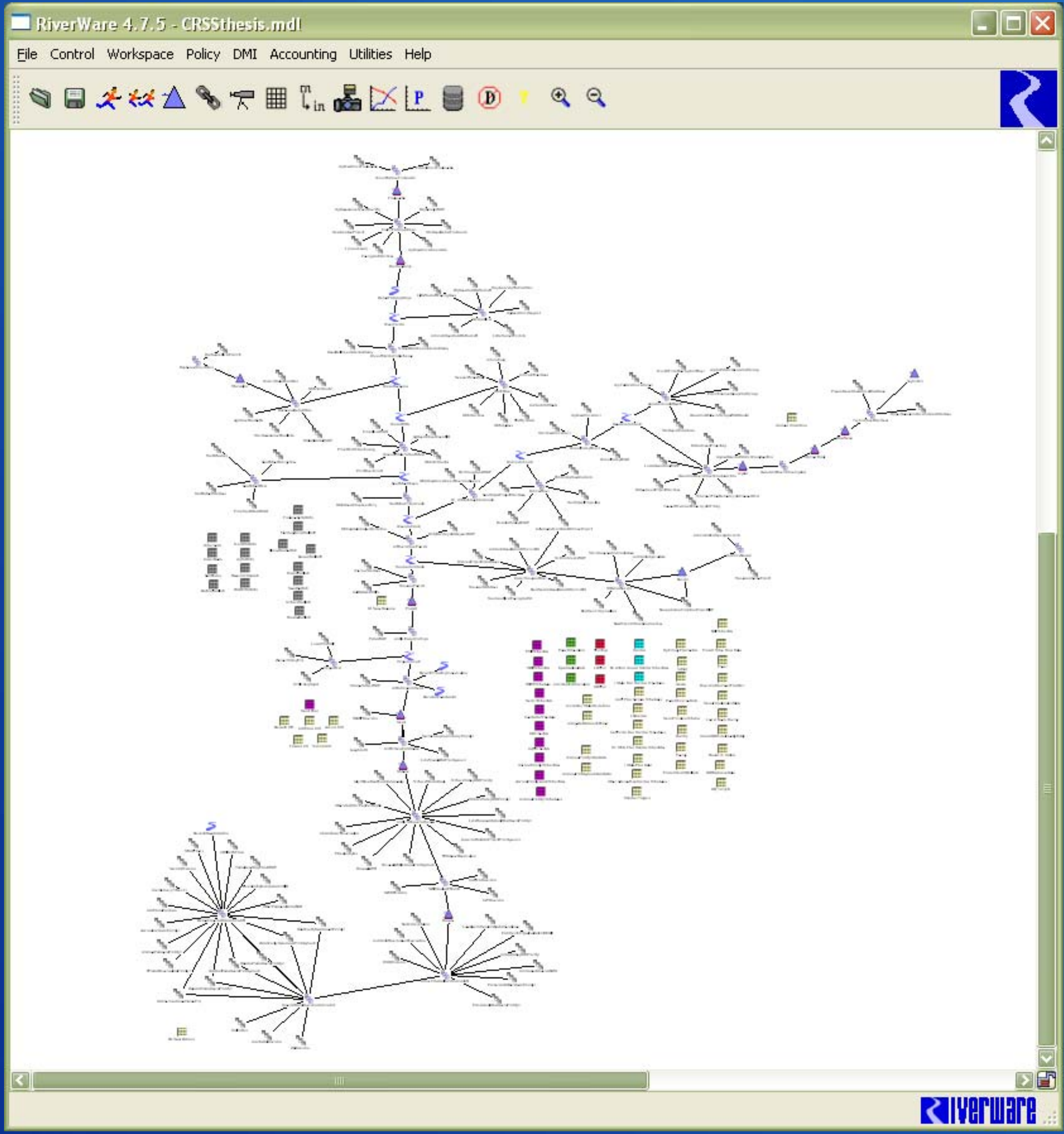
Colorado River Simulation System (CRSS)

- Requires realistic inflow scenarios
- Captures basin policy
- Long-term basin planning model
- Developed in RiverWare (Zagona et al. 2001)
- Run on a monthly time step



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CRSS Modeling Assumptions –
Alternate Hydrologic Sequences

- Index Sequential Method & Alternate Stochastic Techniques
- Alternate Hydrologic Sequences & Results

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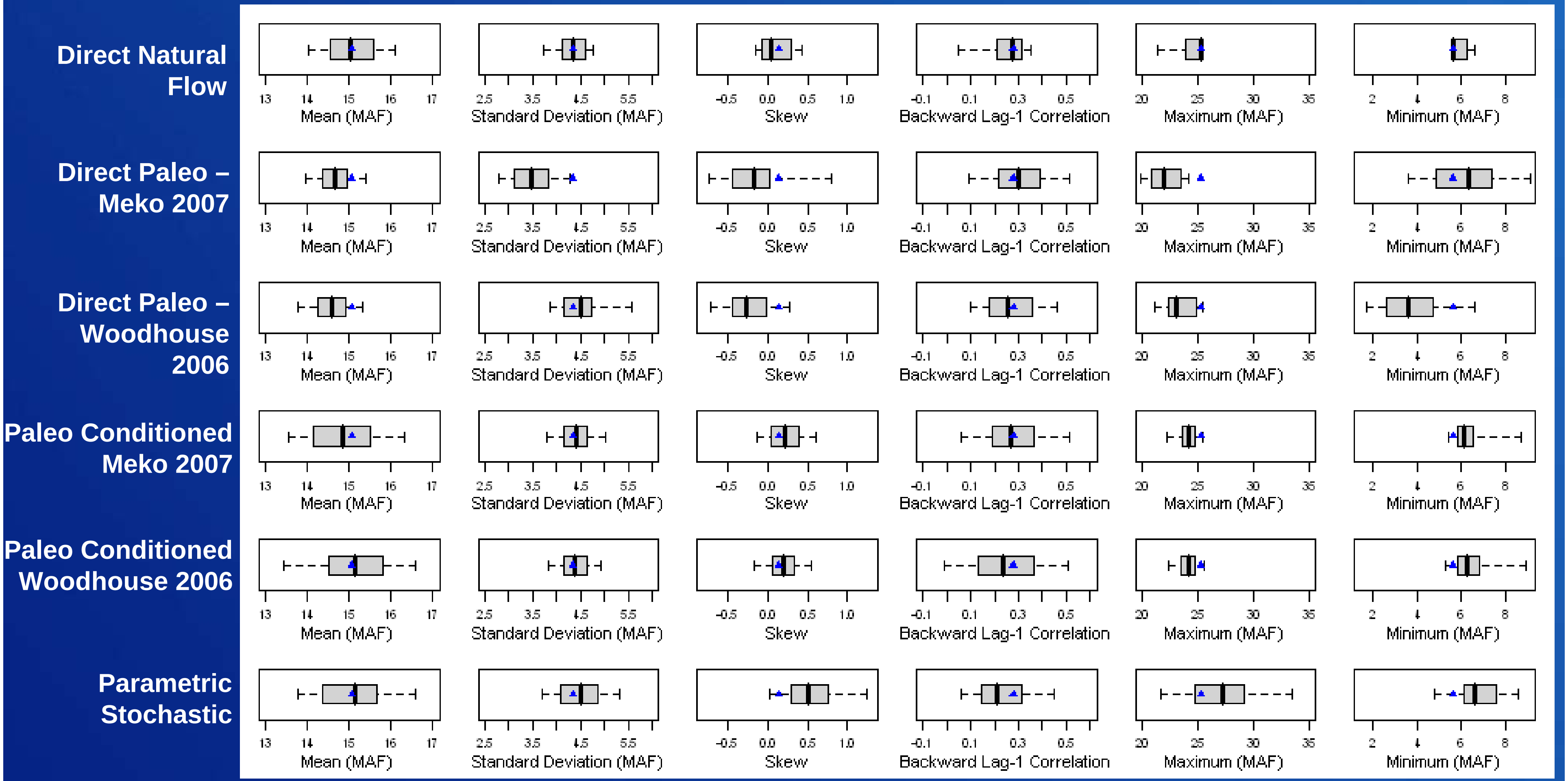
Comparison of Inflow Scenarios
"Box Plots"



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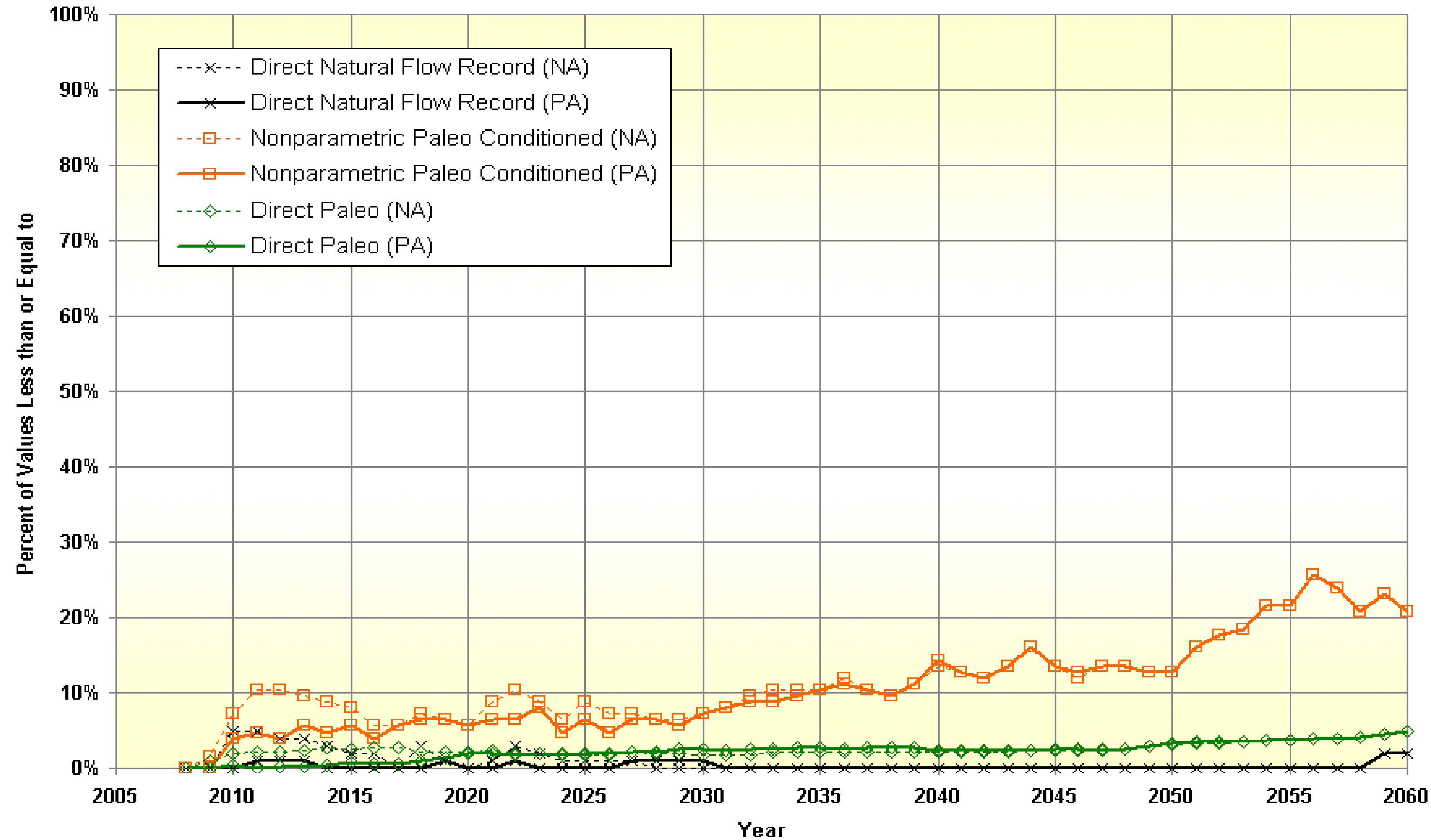
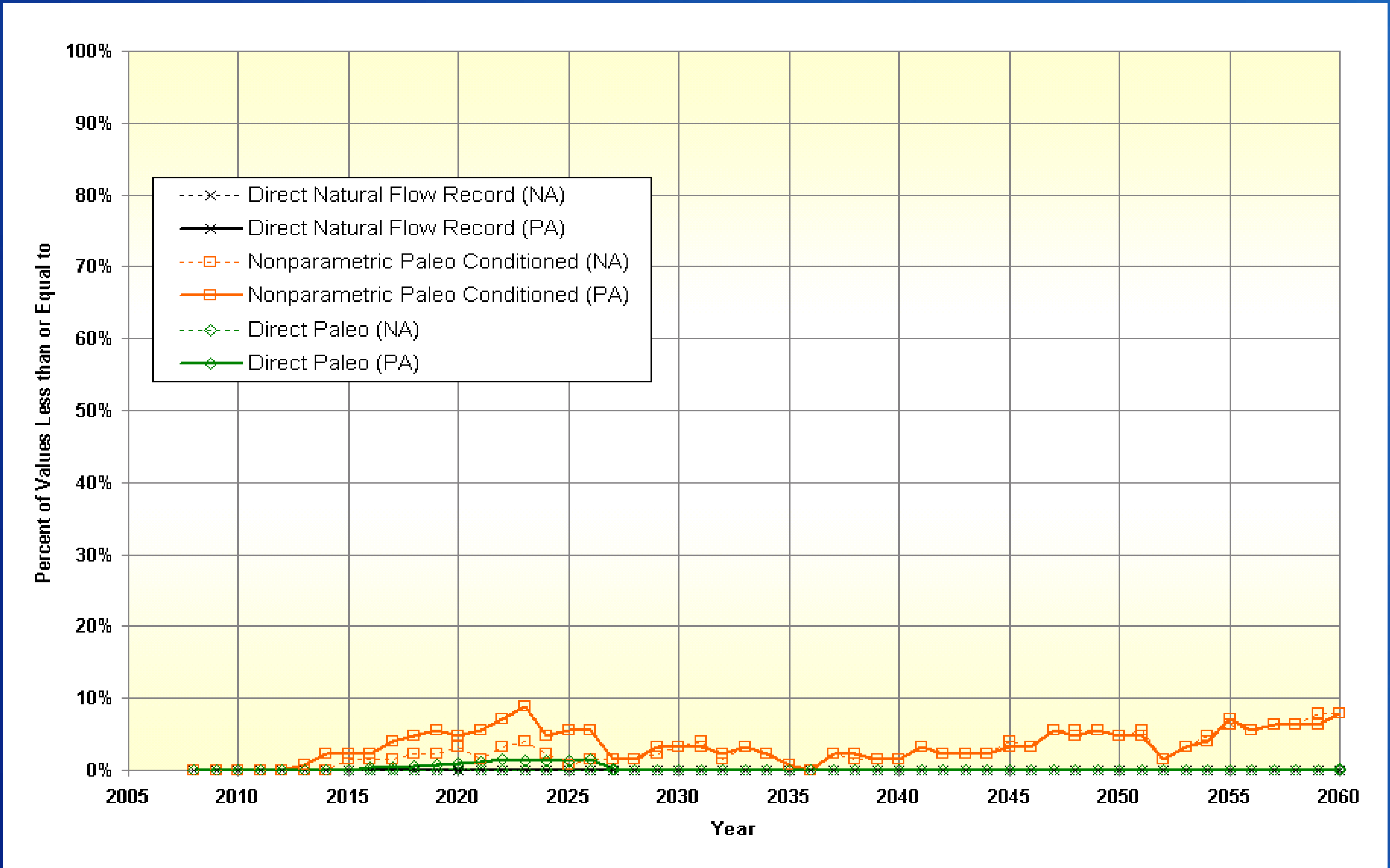
Lake Powell End-of-December Water Elevations
Probability of Being Below Minimum Power Pool
(*Percent of Values Less than or Equal to Elevation 3,490 feet msl)*



RECLAMATION

Lake Mead End-of-December Water Elevations
Probability of Being Below SNWA Intakes
(Percent of Values Less than or Equal to Elevation 1,000 feet msl)



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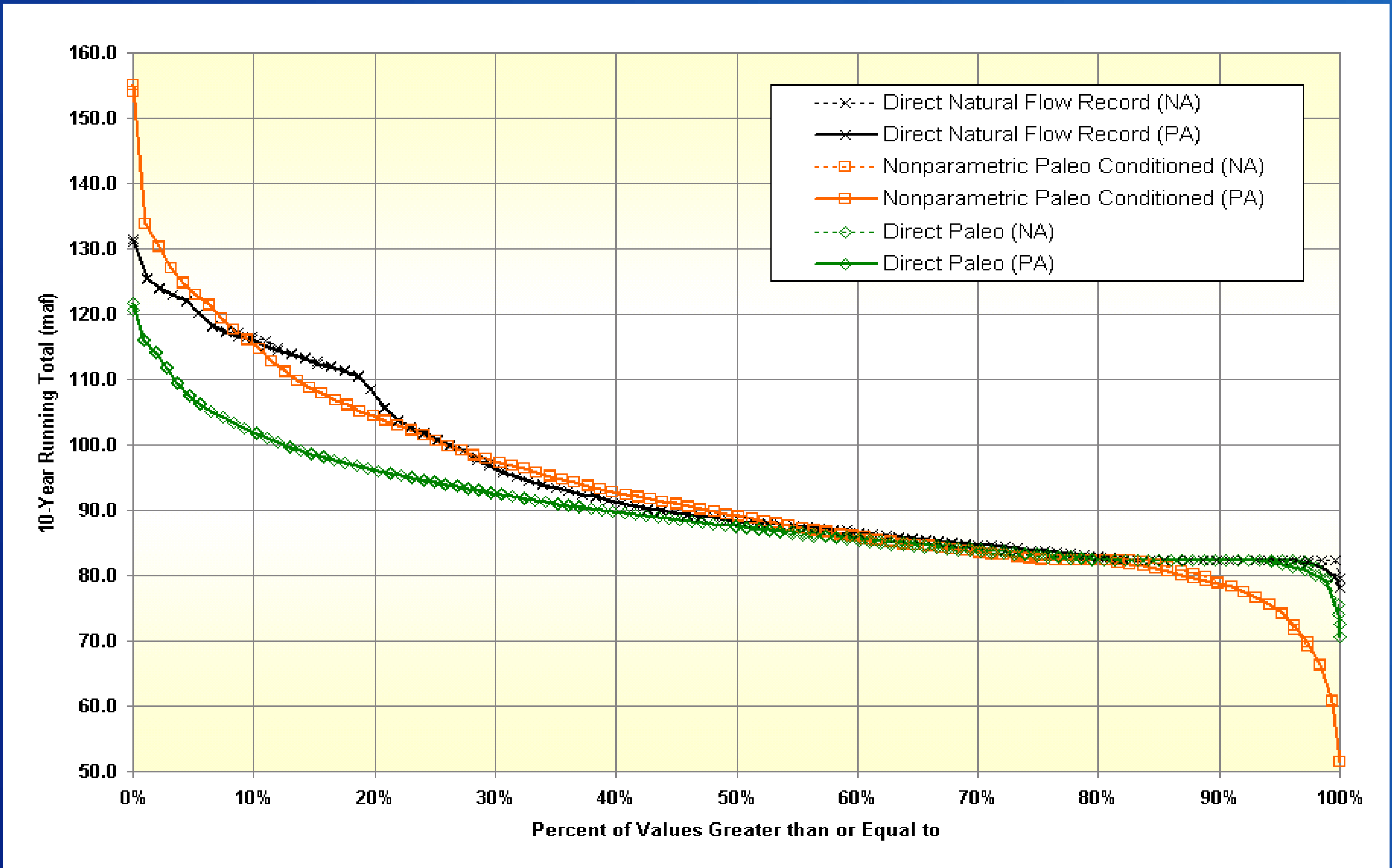
Glen Canyon Dam 10-Year Release Volume
Water Years 2009-2060



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Comparison of Long-Term Planning Hydrologies based on Different Blends of Instrumental Record, Paleoclimate, and Projected Climate Information

(Brekke, Prairie, Pruitt, Rajagopalan, Woodhouse, 2008)

(funded from S&T, UC, GP)

Research Questions

1. **How can paleoclimate and projected climate information be jointly and rationally incorporated into planning assumptions for water supplies, hereafter referred to as planning hydrology?**
2. **How would such a planning hydrology be similar to or different from planning hydrology developed to individually reflect paleoclimate or projected climate?**
3. **What implementation realities might influence choice among climate information sets when defining water supply planning assumptions for Reclamation studies?**

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Combining paleo-reconstructed variability with projected future flows

Extension of existing framework

- **System State**
  - **Paleo- reconstruciton**
  - **Woodhouse et al.**
- **Magnitudes**
  - **Replace observed record with projected climate data**
  - **Runoff magnitudes generated with CBRFC rainfall runoff model**
- **Two Case Studies**
  1. **Missouri River at Touston**
  2. **Gunnison River at Grand Junction**
- **Four climate information sets**
  1. **Null – state: observed magnitude: observed**
  2. **Alt 1 – state: paleo magnitude: observed**
  3. **Alt 2 – runoff projections direct from rainfall runoff model**
  4. **Alt 3 – state: paleo magnitude: runoff projections**

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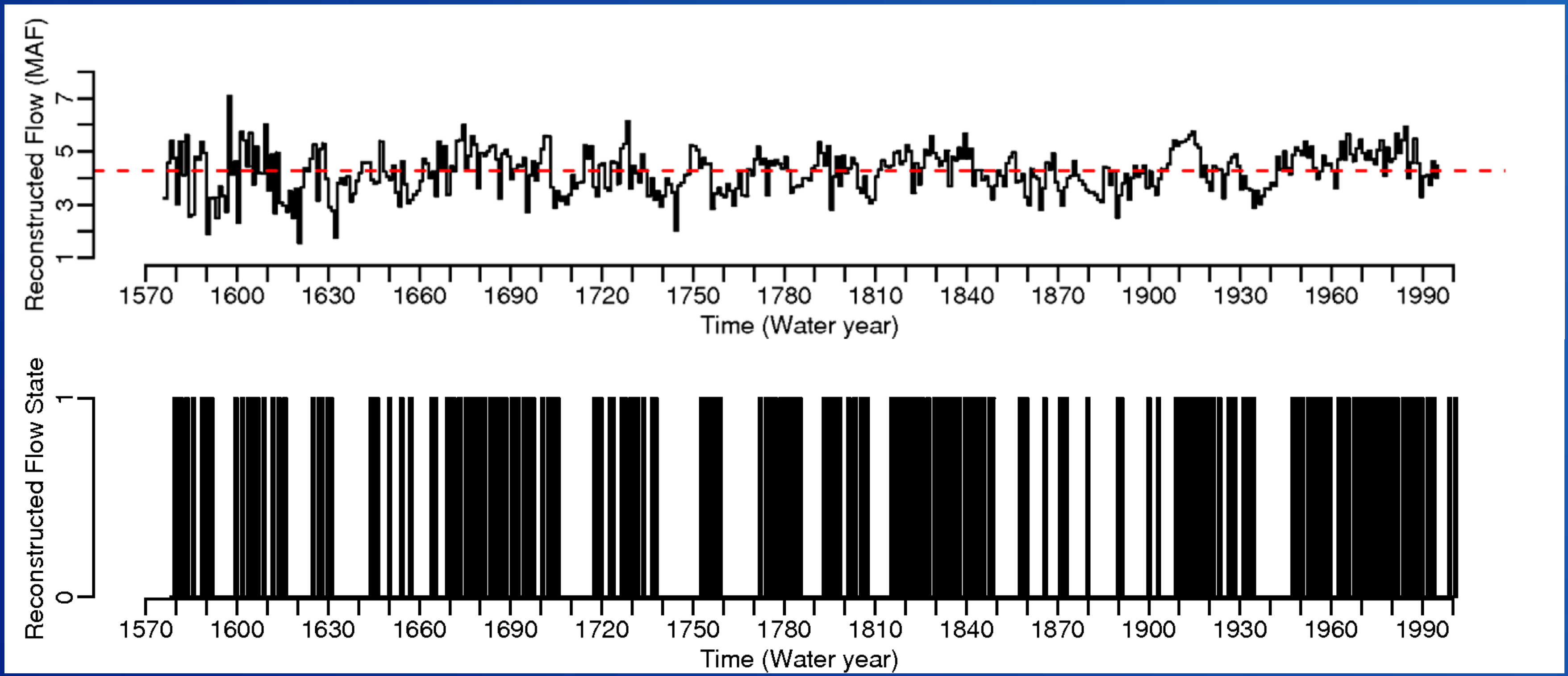
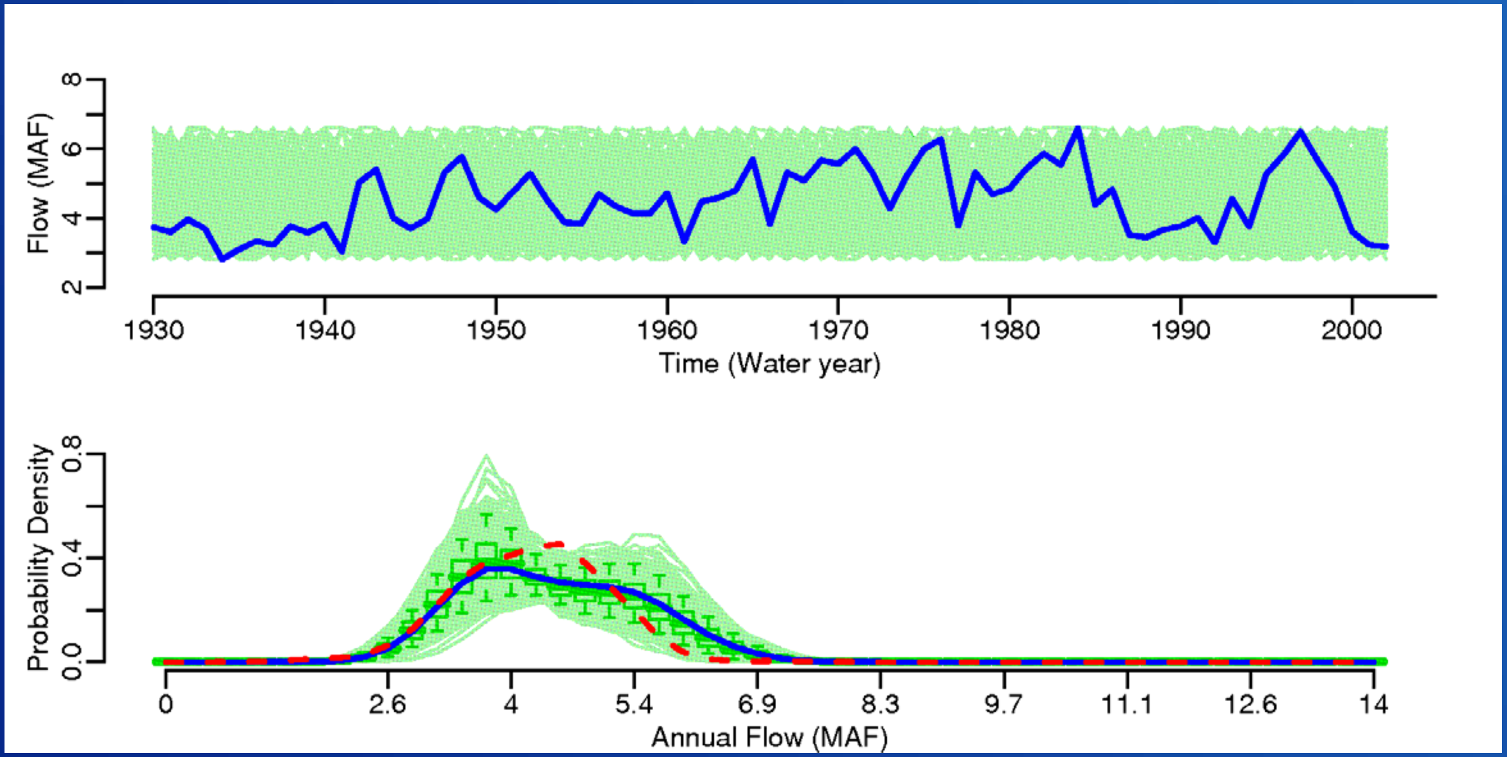
Missouri River Basin - State

- **Reconstructed streamflow**



Missouri River Basin - Magnitudes

- **Observed Record and Projected Runoff**



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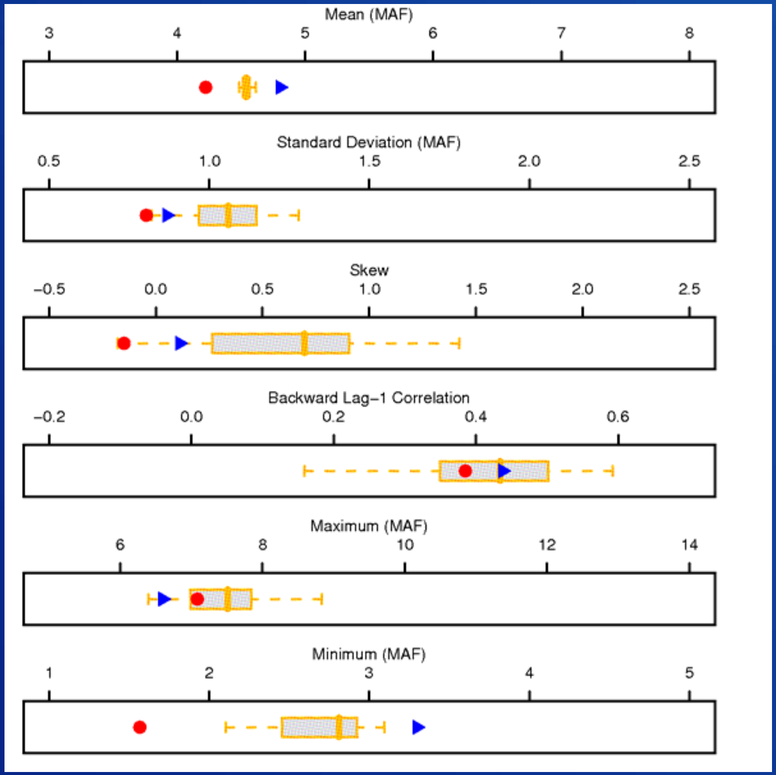
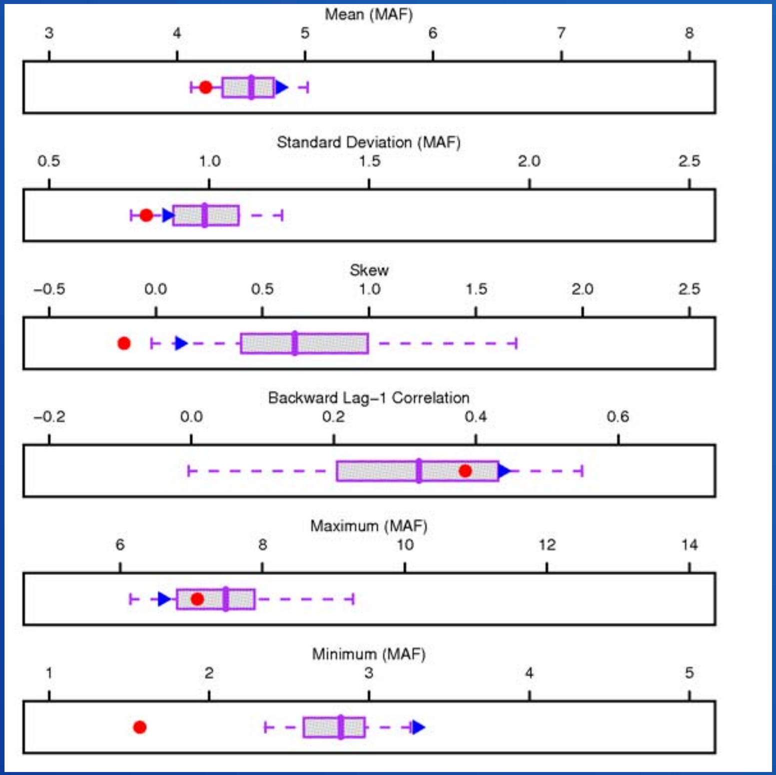
1951-1999

- Alt 2
- Only projected climate



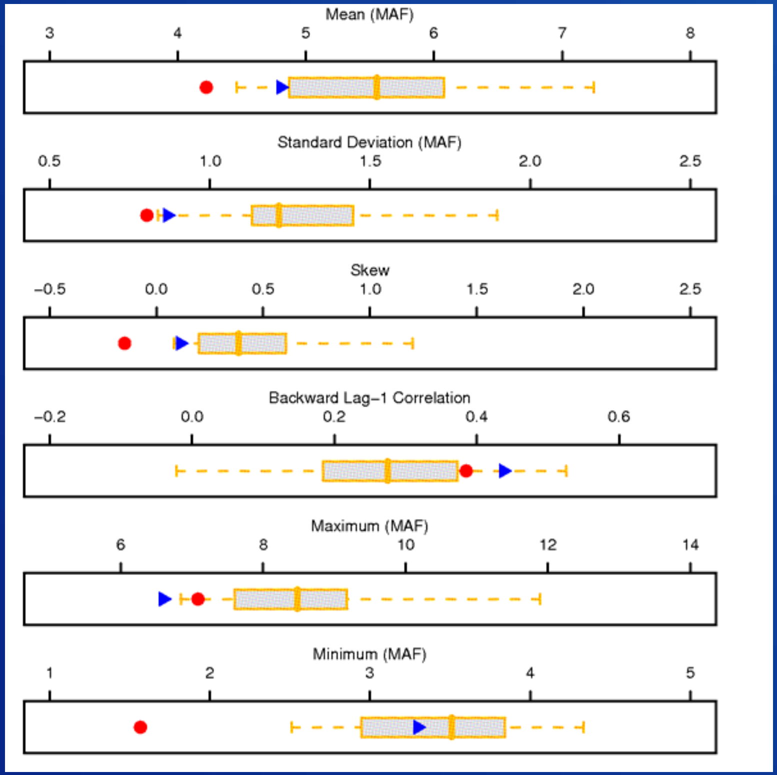
- Alt 3
- Projected climate coupled with paleo



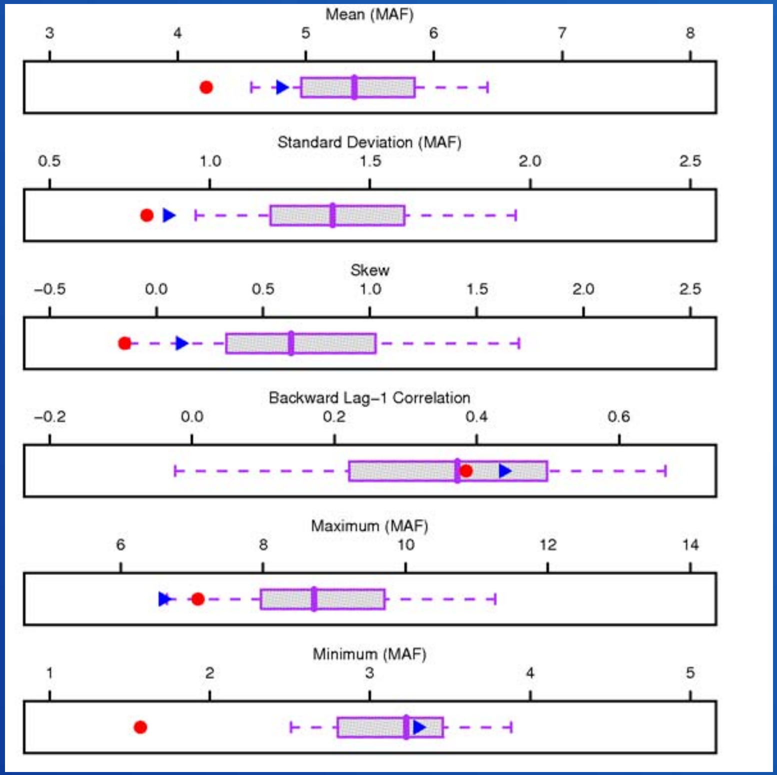
RECLAMATION

2070-2099

- **Alt 2**
- **Only projected climate**



- **Alt 3**
- **Projected climate coupled with paleo**



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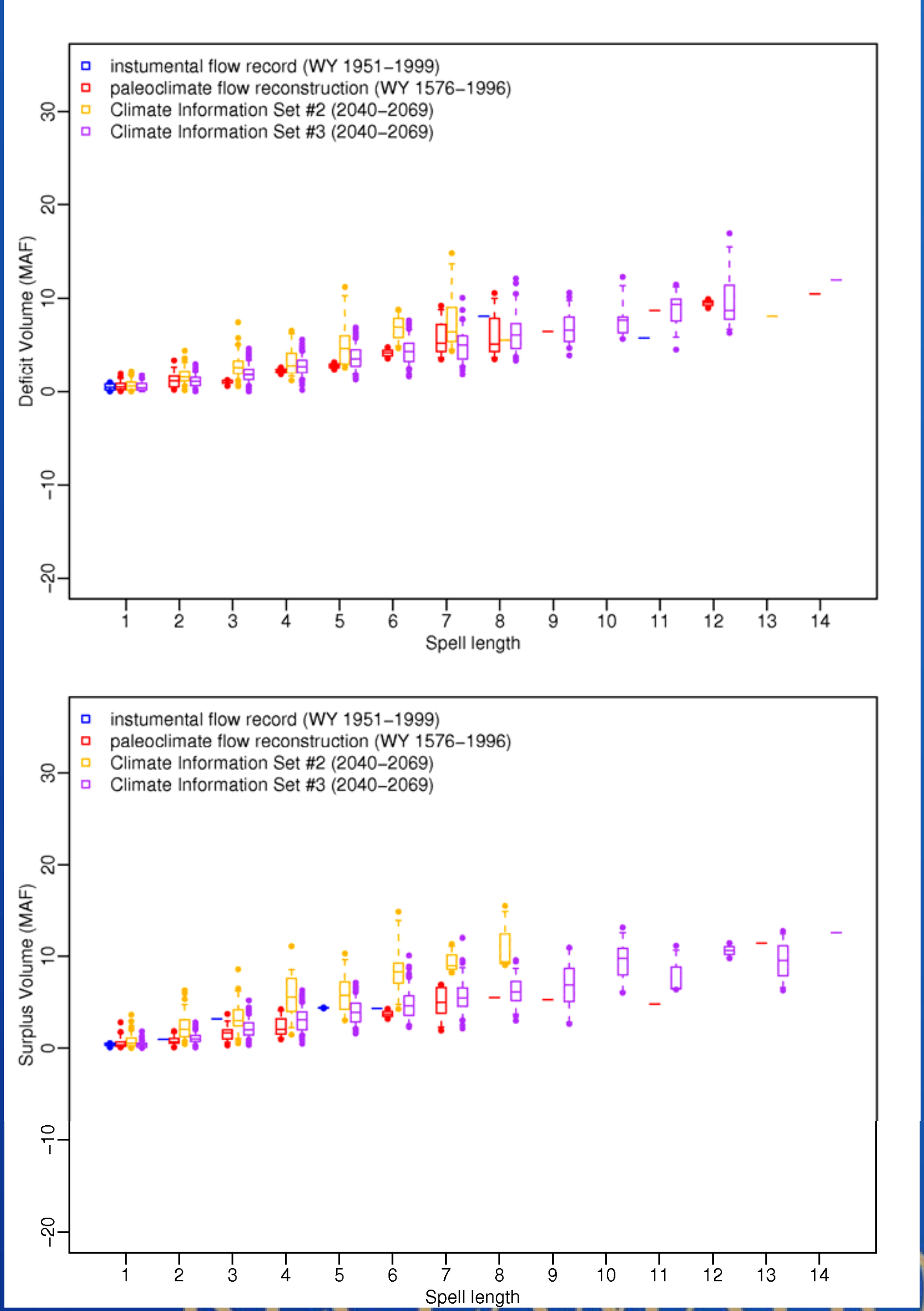
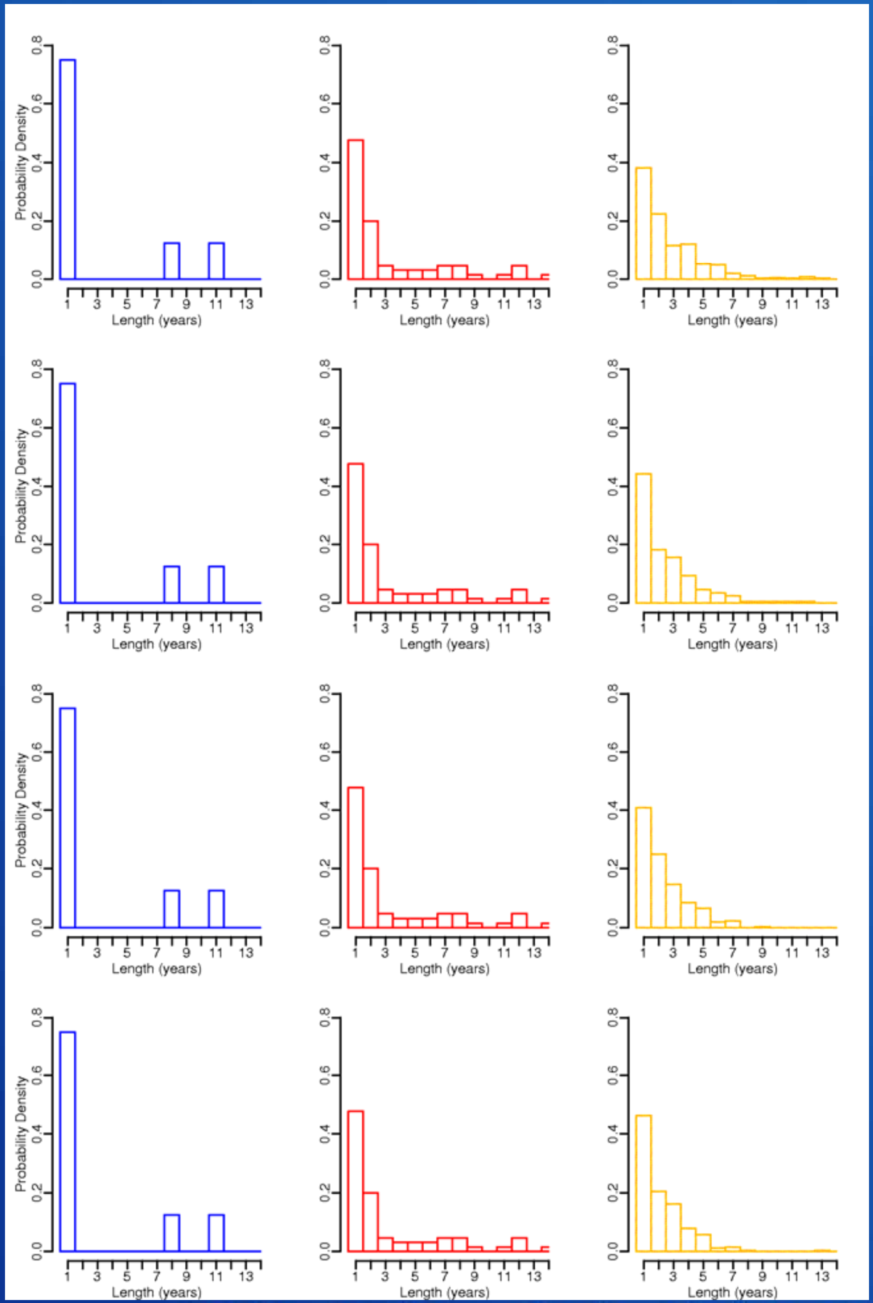
Volume by spell length

- Blue – observed
- Red – paleo
- Orange - Alt 2
- Purple – Alt 3



Drought Length Histogram

- Blue – observed
- Red – paleo
- Orange - Alt 2



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Key Study Findings

- *"How can paleoclimate and projected climate information be jointly and rationally incorporated into a planning assumptions for water supplies, hereafter referred to as planning hydrology?"* **The stochastic modeling approach used in this study illustrates one such framework. It was modified from previous demonstrations to incorporate projected runoff magnitudes rather than instrumental record magnitudes**

- *"How would such a planning hydrology be similar to or different from planning hydrology developed to individually reflect paleoclimate or projected climate?",* **Based on results summarized earlier, the Alternative 3 planning hydrology was found to exhibit similar annual runoff possibilities as Alternative 2. For the Upper Missouri, where the persistence in the reconstructed runoff record differed significantly from that in the climate projections, the longer-term drought possibilities portrayed in Alternative 3 differed accordingly from those in Alternative 2. This result was not found for the Gunnison.**

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Key Study Findings

- *"What implementation realities might influence choice among climate information sets when defining water supply planning assumptions for Reclamation studies?"* **Efforts required to disaggregate these annual, single-location hydrologic datasets into monthly, multi-location datasets suitable for planning could have significant influence on scoping choice. In addition to disaggregation issues, the relative ease of introducing flow-impairments, specifying demand and constraint assumptions, and educating stakeholders and decision-makers on the new hydrology's characteristics may also be a scoping factor. It's notable that the complete data-development procedures necessary to support Alternative 2 must still be completed before Alternative 3 can be implemented.**

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Future Direction

- **Blending climate projection data distribution with sequences generated from paleo and observed data**
- **Reconcile range of runoff reduction at Lees Ferry for many climate projections** (Nov 14 workshop)
- **Lower Basin focused paleo streamflow reconstruction**
- **Conditioning future scenarios on large scale climate features** (i.e., ENSO, PDO)
- **Colorado River Basin Hydrology Work Group**

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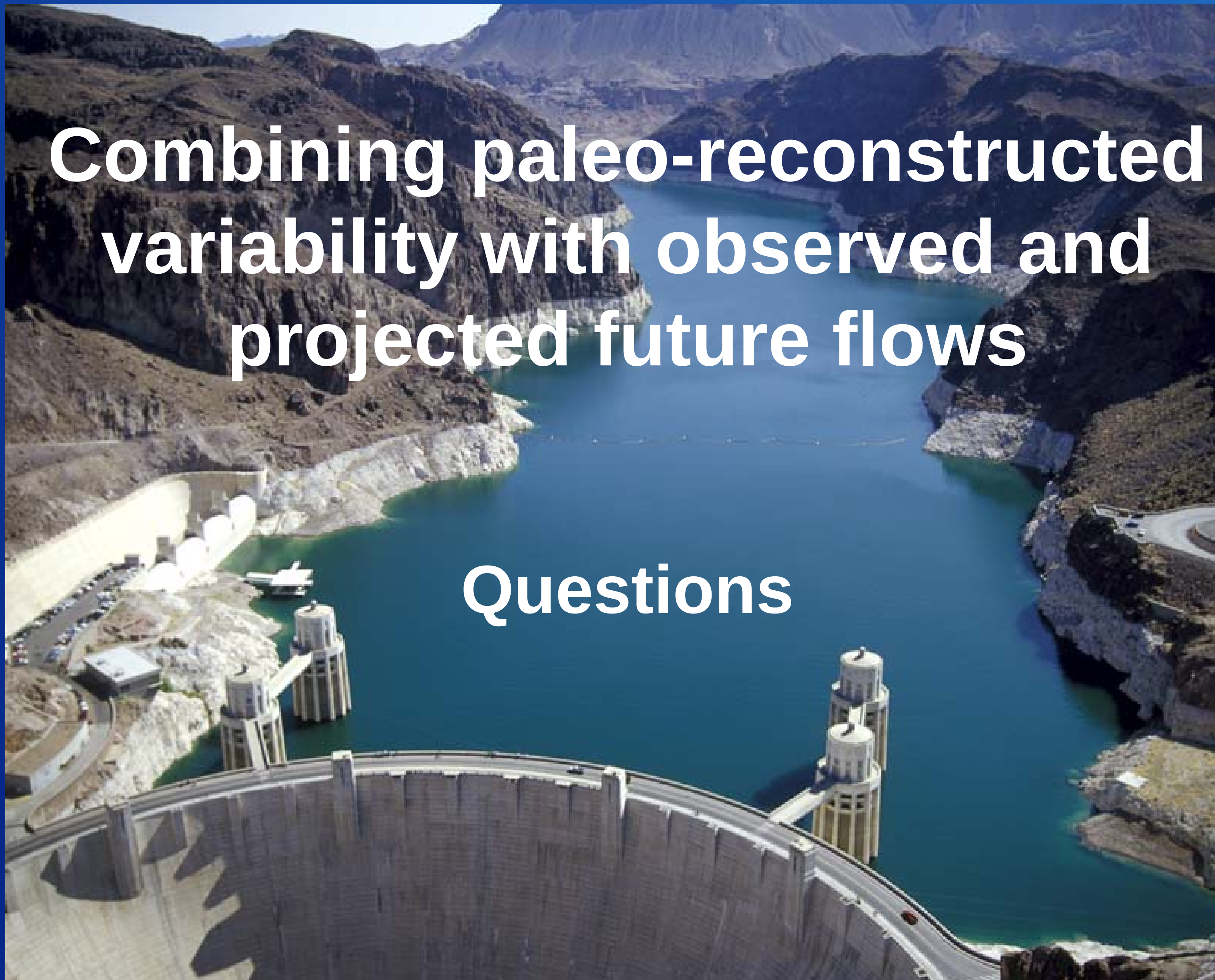
Combining paleo-reconstructed variability with observed and projected future flows



Questions

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