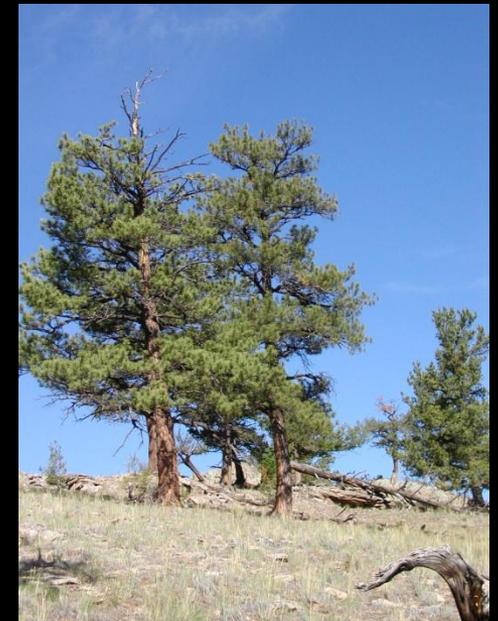


# Tree-Ring Reconstructions of Streamflow: Applications to Water Management in the Western US

Connie A. Woodhouse  
University of Arizona

Eighth Annual Climate Prediction Applications Science Workshop  
**Managing Water Resources and Drought in a Changing Climate**  
March 2-4, 2010  
San Diego, California

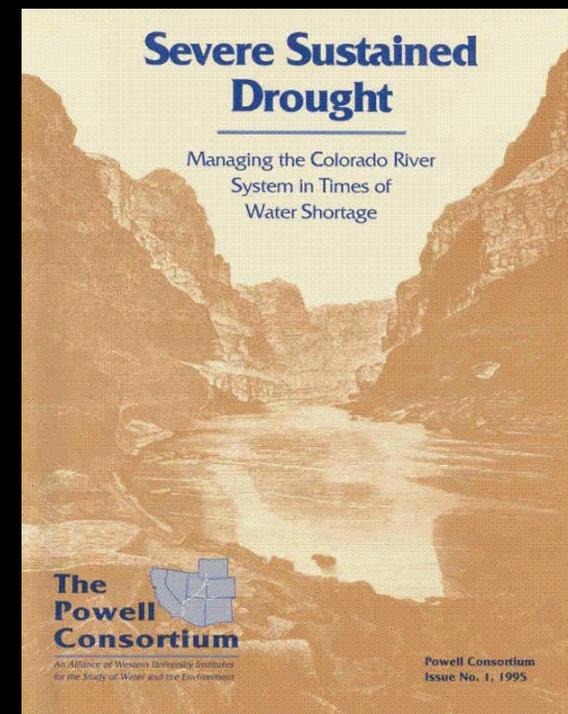
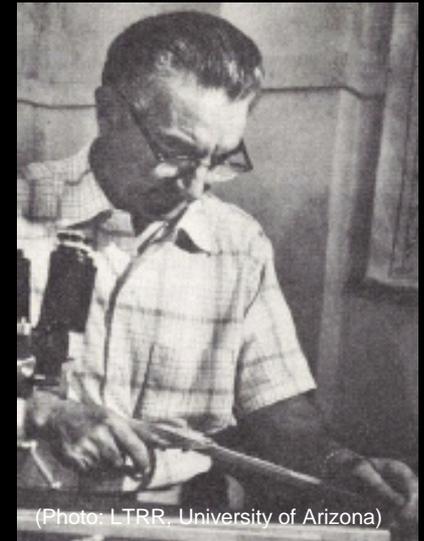


Laboratory of  
**Tree-Ring Research**  
University of Arizona

This work was supported by NOAA RISA, CCDD, and SARP programs and Denver Water

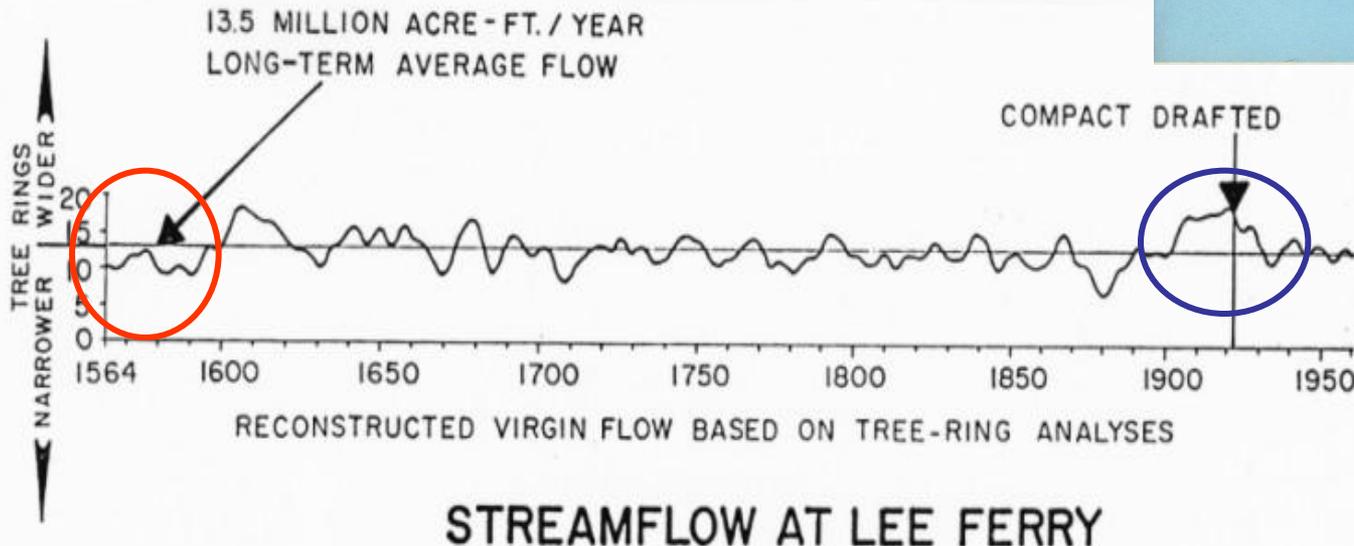
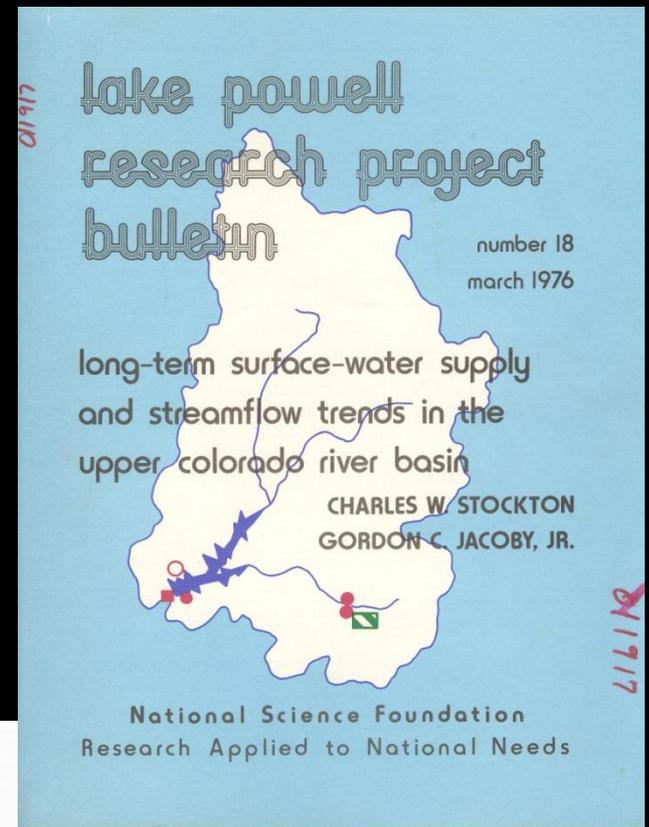
# A History of Applications

- **Hardman and Reil (1936)**: Truckee River, possible applications to water resource management; agricultural regions of the Truckee River basin.
- **Schulman (1942)** report for the Los Angeles Bureau of Power and Light. Assessment of reliable power generation from Colorado River.
- **Potts (1962)** for Denver Water Board, annual S. Platte flow, droughts for estimating future storage requirements.
- **Earle and Fritts (1986), Meko et al. (2001)** Sacramento River reconstructions for the California Department of Water Resources
- **Smith and Stockton(1981)** Salt and Verde Rivers reconstructions for the US Army Corps of Engineers
- **Severe Sustained Drought volume (1995)**, hydrologic, economic, social impacts of CO River drought



# Stockton and Jacoby's Colorado River Reconstruction, 1976

- Anomalously wet period in the early 20<sup>th</sup> century suggested over-allocation of Colorado River resources
- Prolonged drought in the late 16<sup>th</sup> century showed sustained low flows were possible



The reconstruction of Lees Ferry streamflow had important implications for future water management.

“The general picture of a collision between water demand and supply in the UCRB in the not-too-distant future is all too apparent.”

Stockton and Jacoby 1976

## Rocky Mountain News

May 3, 2002

by Joe Garner, News Staff Writer

### Drought in Colorado is foreign to new residents



... “The most disturbing day I spent in my 12 years as governor was having the tree rings explained to me,” said former Gov. Richard D. Lamm, who held office in the 1977 drought.

Renewed interest in 2002: severe drought coupled with an increase in water demand....

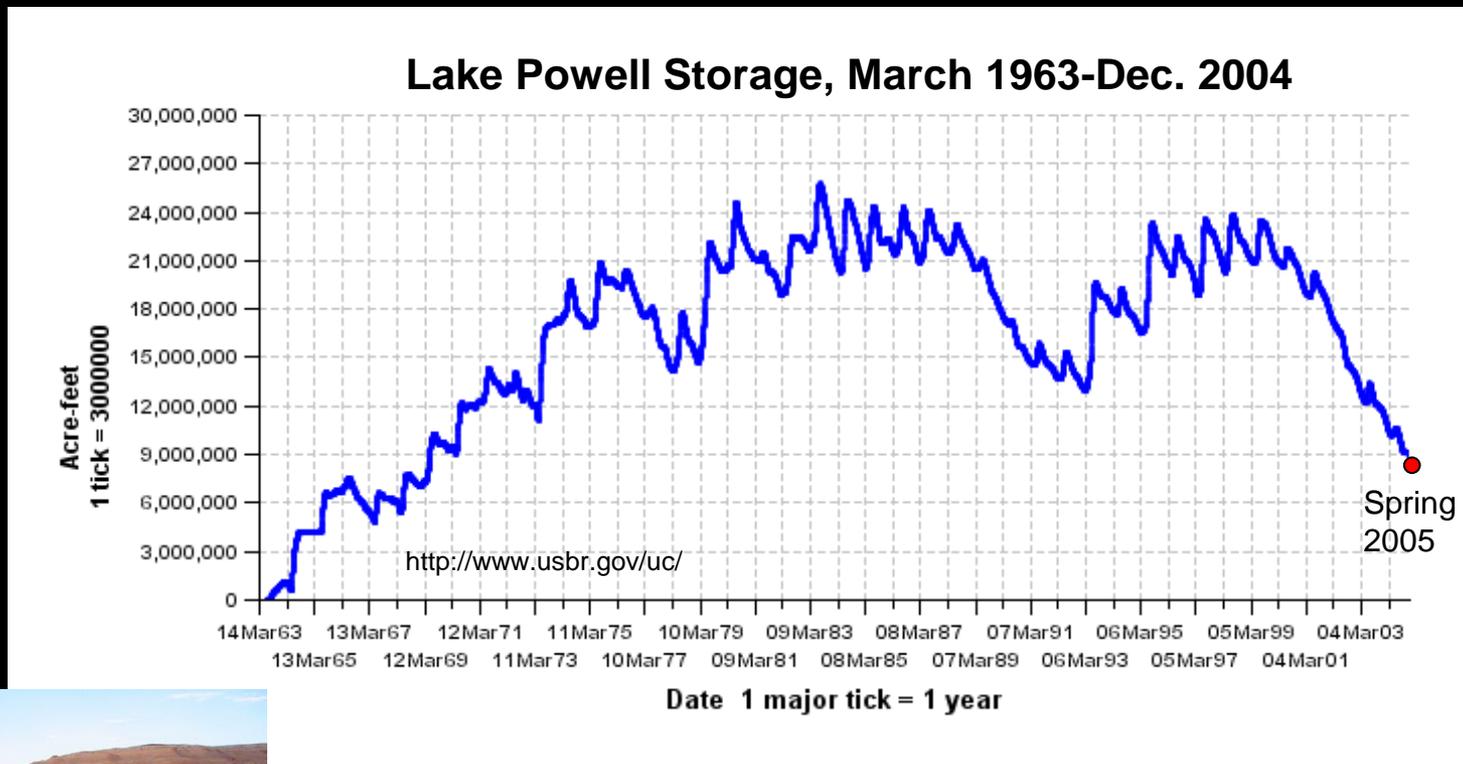


Photo: Brad Udall

Lake Powell reached a low of 33% of capacity in Spring 2005.

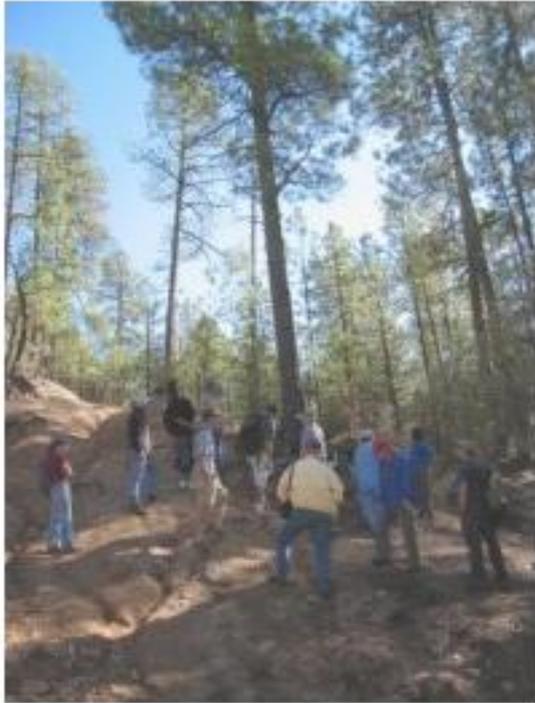
# PLANNING WORKSHOP to DEVELOP HYDROCLIMATIC RECONSTRUCTIONS for DECISION SUPPORT in the COLORADO RIVER BASIN

Tucson, Arizona  
May 5, 2005



Workshop participants identified the tree-ring reconstructions as valuable for placing gage records in a broader context of hydroclimatic variability, thus are potentially very useful for planning and decision support.

# Technical workshop for water resource professionals, 2006-2009



Boulder, Durango, Alamosa CO, Tucson, Phoenix , Albuquerque,  
Cheyenne, Salt Lake City, Las Vegas/Boulder City, Spokane

# Evolving Applications of Tree-Ring Reconstructions to Water Resource Management

1. Moving on from the gage record as a frame of reference
2. New worst case scenarios for drought
3. Testing water system resilience
4. Alternative hydrologies, water supply assessments
5. Scenarios for future planning

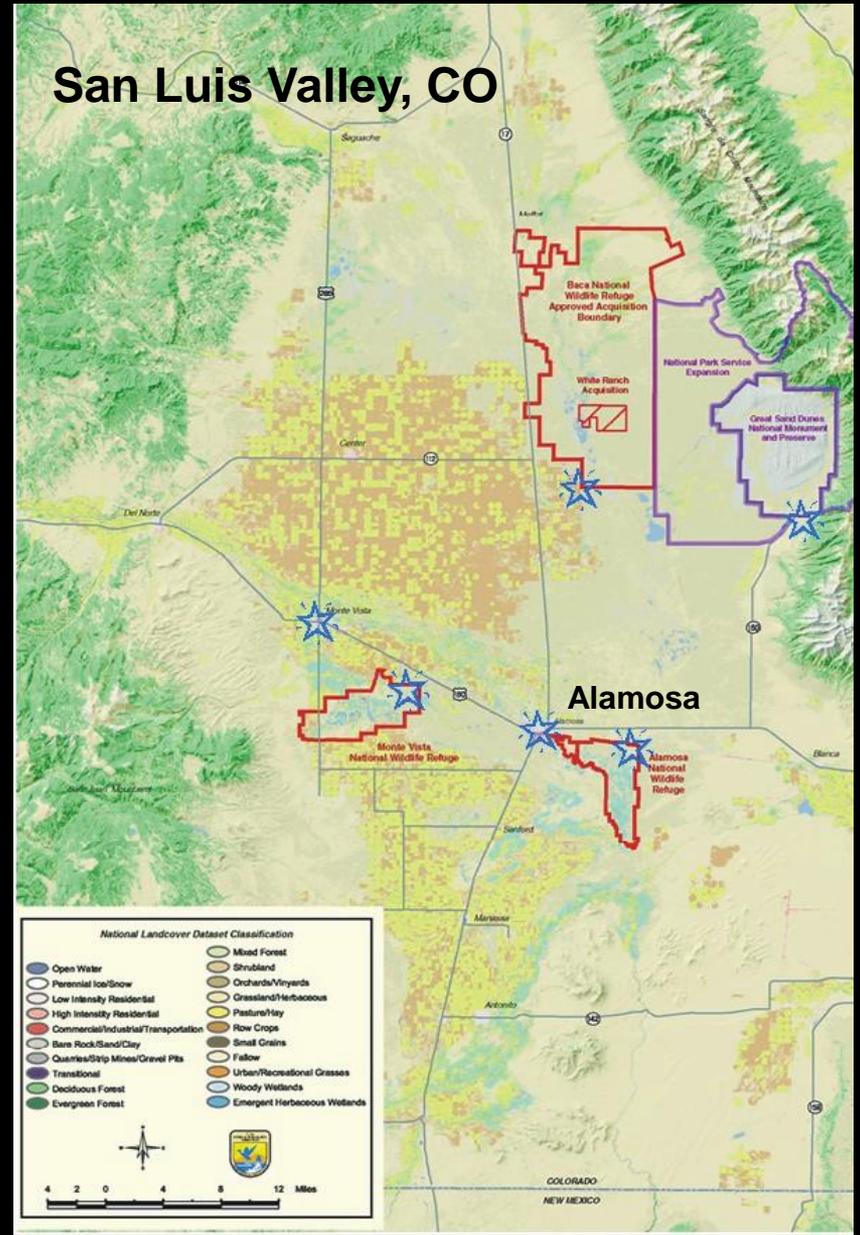
\*these uses are often not independent and can be overlapping

# 1. Moving on from the gage record as a frame of reference

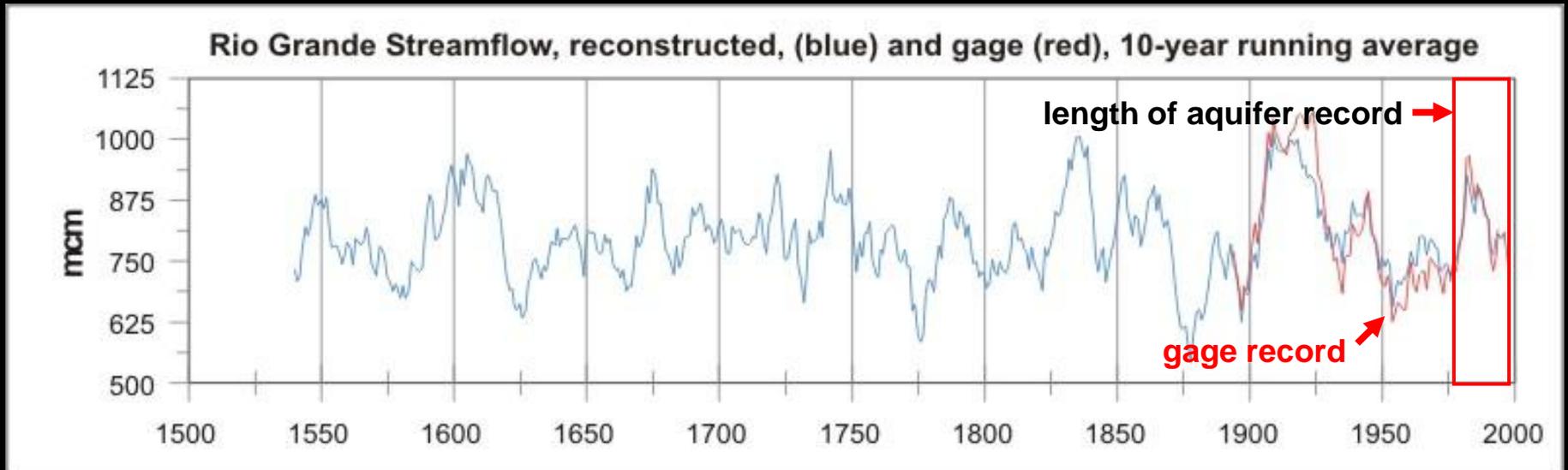
## Rio Grande Water Conservation District (Upper Rio Grande)

### Water management concerns:

- rural area dependent on agriculture
- current unsustainable groundwater withdraws
- Since 2002, the driest year on record for the Rio Grande, the level of the unconfined aquifer has dropped by nearly 800,000 acre-feet (as of Jan 06).



What is the character of long-term, low-frequency variations in water supply that affect aquifer levels?



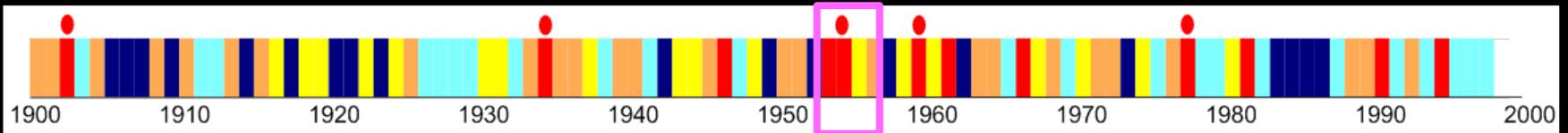
The concept of non-stationarity: the implications for long-term groundwater management

## 2. New worst case scenarios for drought

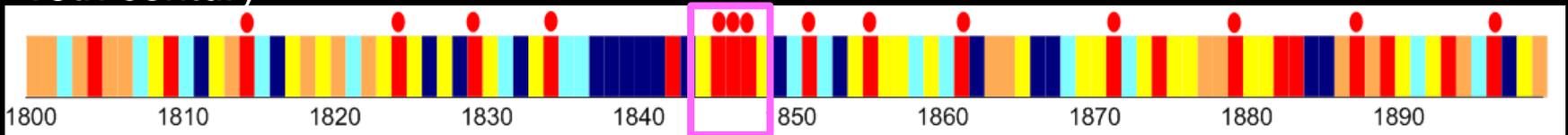
### Lees Ferry Reconstruction Streamflow values categorized by percentile



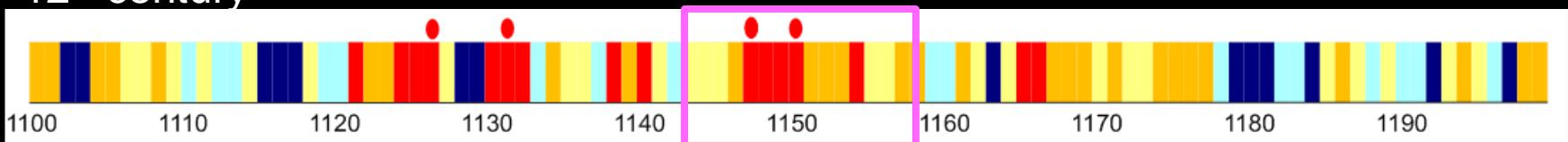
20<sup>th</sup> century



19<sup>th</sup> century

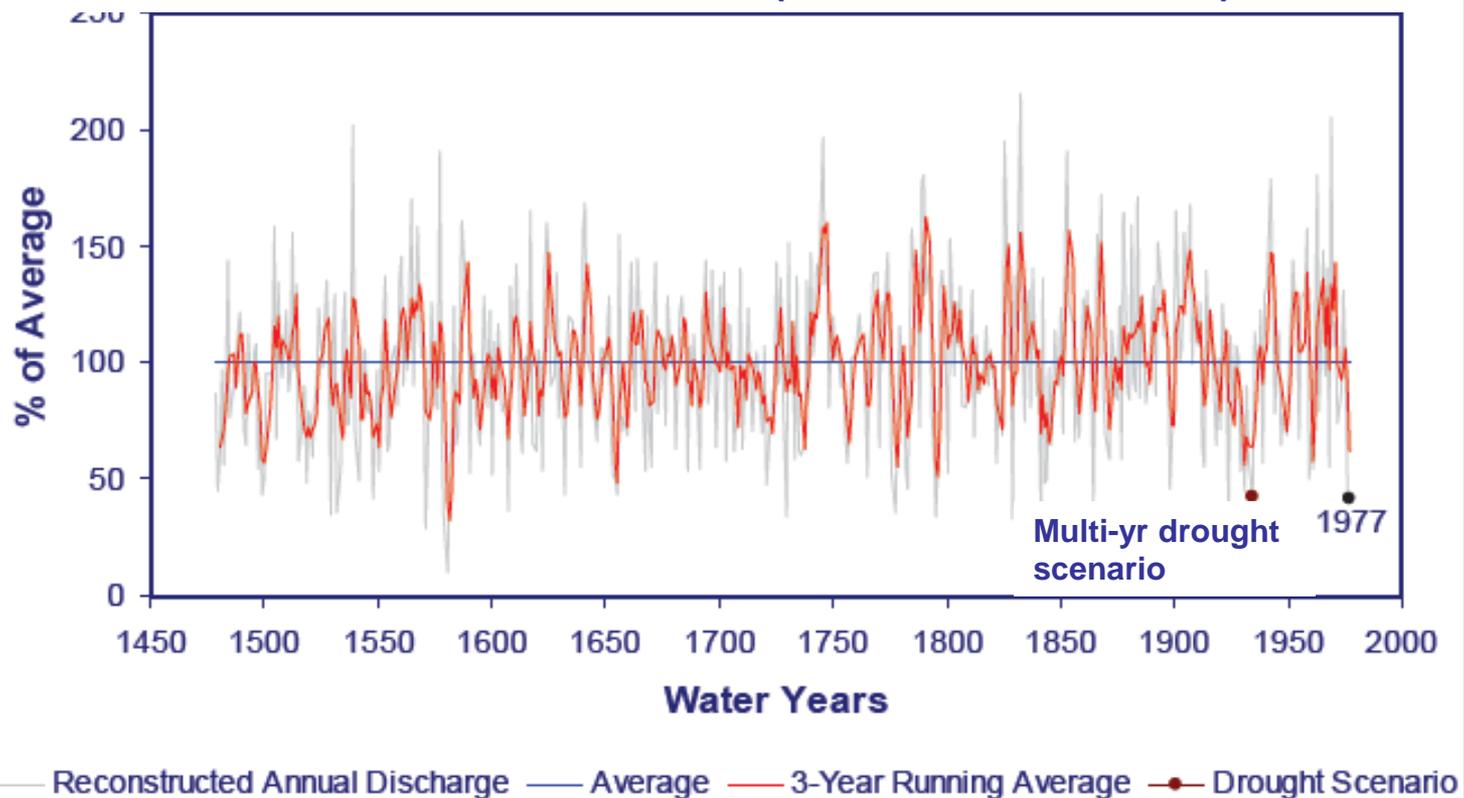


12<sup>th</sup> century



# Using California Urban Water Management Plans (UWMPs) with reconstructions of streamflow and precipitation to assess drought vulnerability

City of Sacramento, single and multiple worst drought years identified in UWMP compared to Sacramento Four Rivers reconstruction, 1478-1977 (from Meko et al. 2001)

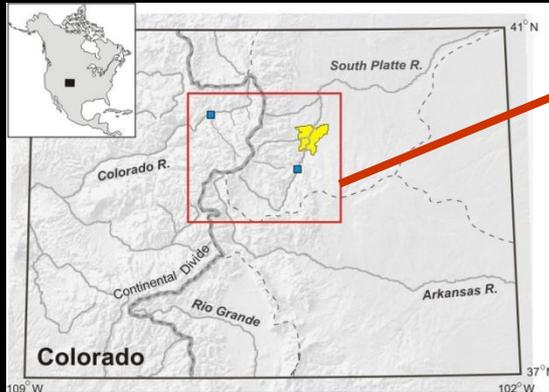


# 3. Testing water system robustness

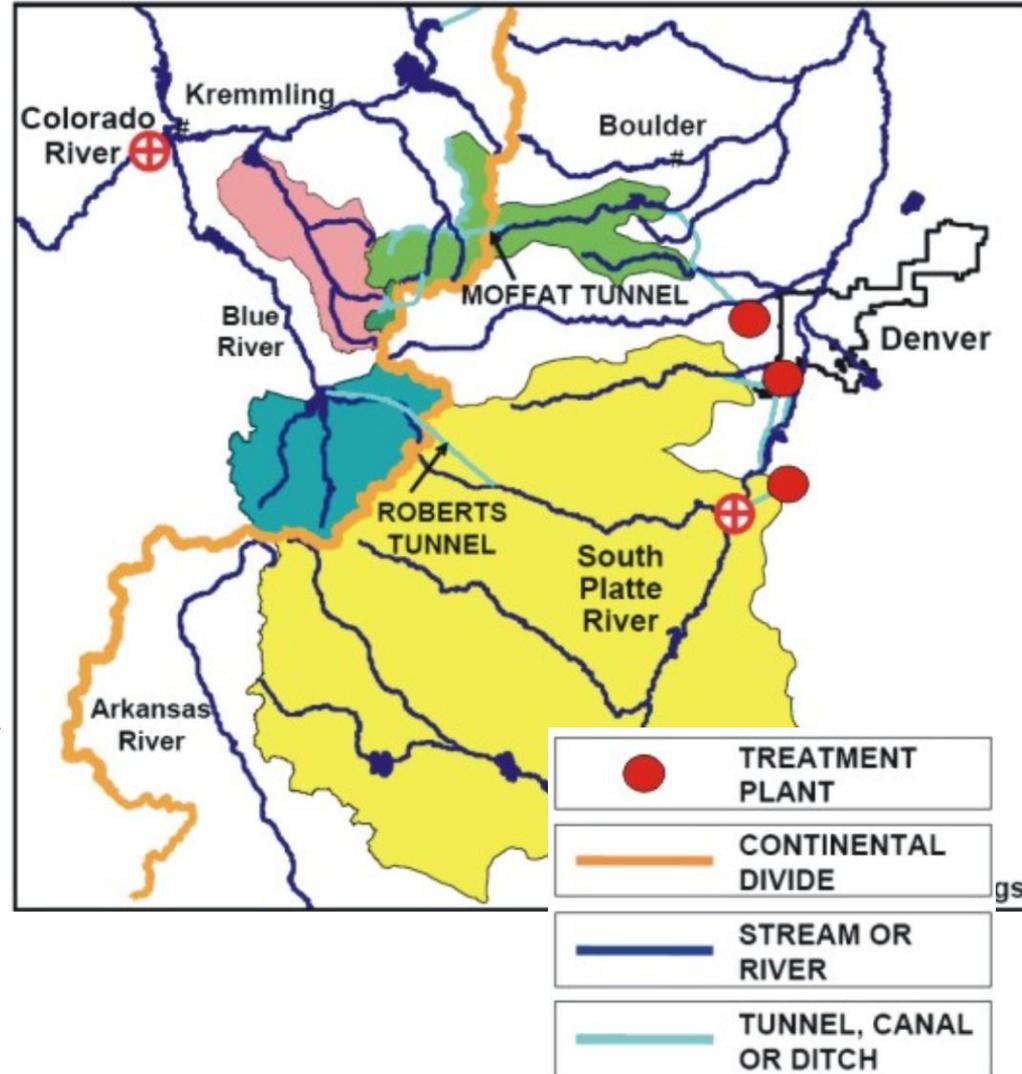
## Denver Water

Denver Water uses a water system model called the Platte and Colorado Simulation Model (PACSM), an integrated system that simulate streamflows, reservoir operations and water supply in the South Platte and Colorado River basins.

Hydrologic Period: 1947 – 1991  
Daily data, 450 locations



## Denver Water Collection System

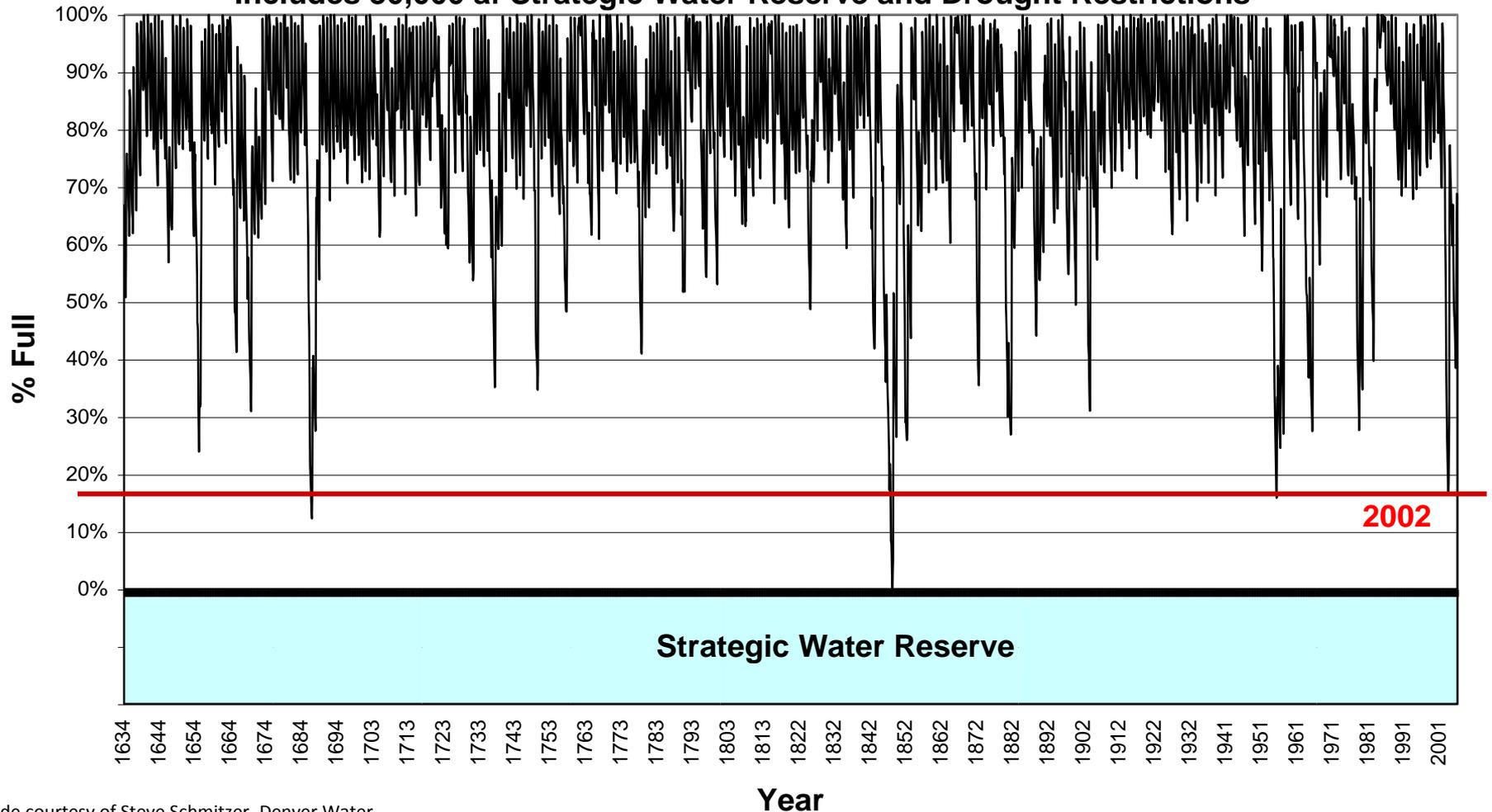


# S. Platte and Blue River Reconstructions Integrated into Denver Water System Model

## Denver Water Reservoir Contents (1634-2005)

Water Supply: 345,000 af

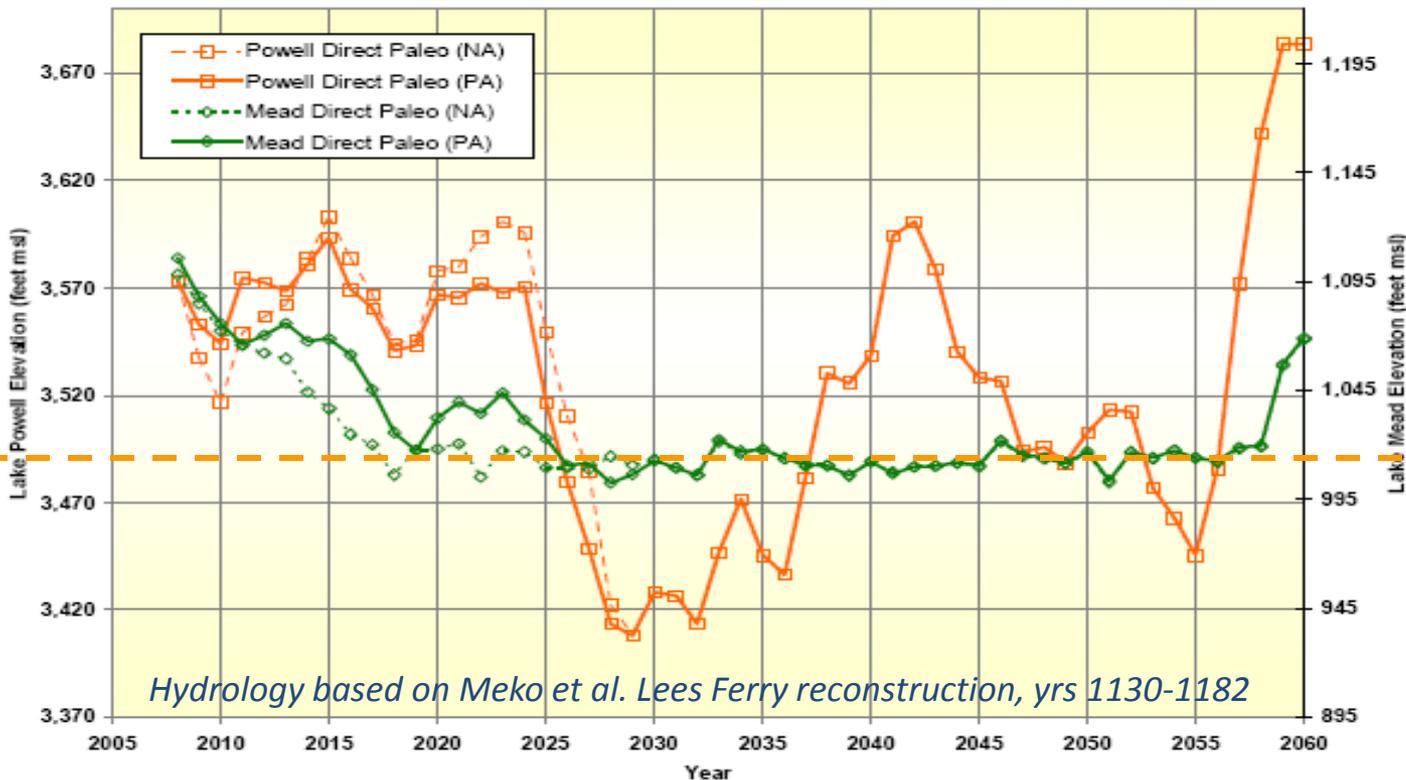
Includes 30,000 af Strategic Water Reserve and Drought Restrictions



## 4. Alternative hydrologies and water supply assessments

Bureau of Reclamation Shortage EIS (2007):

Analysis of hydrologic sensitivity to different management alternatives proposed using sequences of inflows into Lakes Powell and Mead from Lees Ferry reconstruction data



Minimum power pool for Powell

Modeled Powell (orange) and Mead (green) year-end elevations, under No Action (dashed) and Preferred Alternative (solid), using trace starting in AD 1130.

# SB 07-122 Colorado River Water Availability Study

**How much water from the Colorado River Basin System is available to meet Colorado's current and future water needs?**

Until recently, state water managers estimated that Colorado still had up to **1.5 million acre-feet** left to develop. Other estimates put this number at closer to **150,000 acre feet**.

The CRWAS will assess the **observed flow records and history of depletions to project future water availability as well as projections from climate models and "alternative historical hydrology" --from tree-ring data--** to account for past hydrologic variability more extreme than that seen in the observed record.

## Colorado River Basin Water Supply and Demand Study Plan of Study

**Table 2. Overview of Study Phases**

**Phase 1. Water Supply Assessment.** Assess the quantity and location of current and future water supplies throughout the Basin, including the potential effects of climate variability and climate change. Major tasks and sub-tasks include:

1.1 Review & Select Methods to Estimate Current Supply

1.1.1 Historic Observed Record

1.1.2 Paleo Record

1.2 Review & Select Methods to Project Future Supply

1.3 Conduct Assessment of Current Supply

1.4 Conduct Assessment of Future Supply

1.5 Enhance Modeling Capability as Needed to Incorporate Methods to Project Future Supply

1.6 Conduct Sensitivity Analysis of Selected Methods to Project Future Supply

1.7 Prepare Draft Interim Report

1.8 Peer Review Report

1.9 Prepare & Publish Interim Report

## 5. Scenarios for future planning

### Given that:

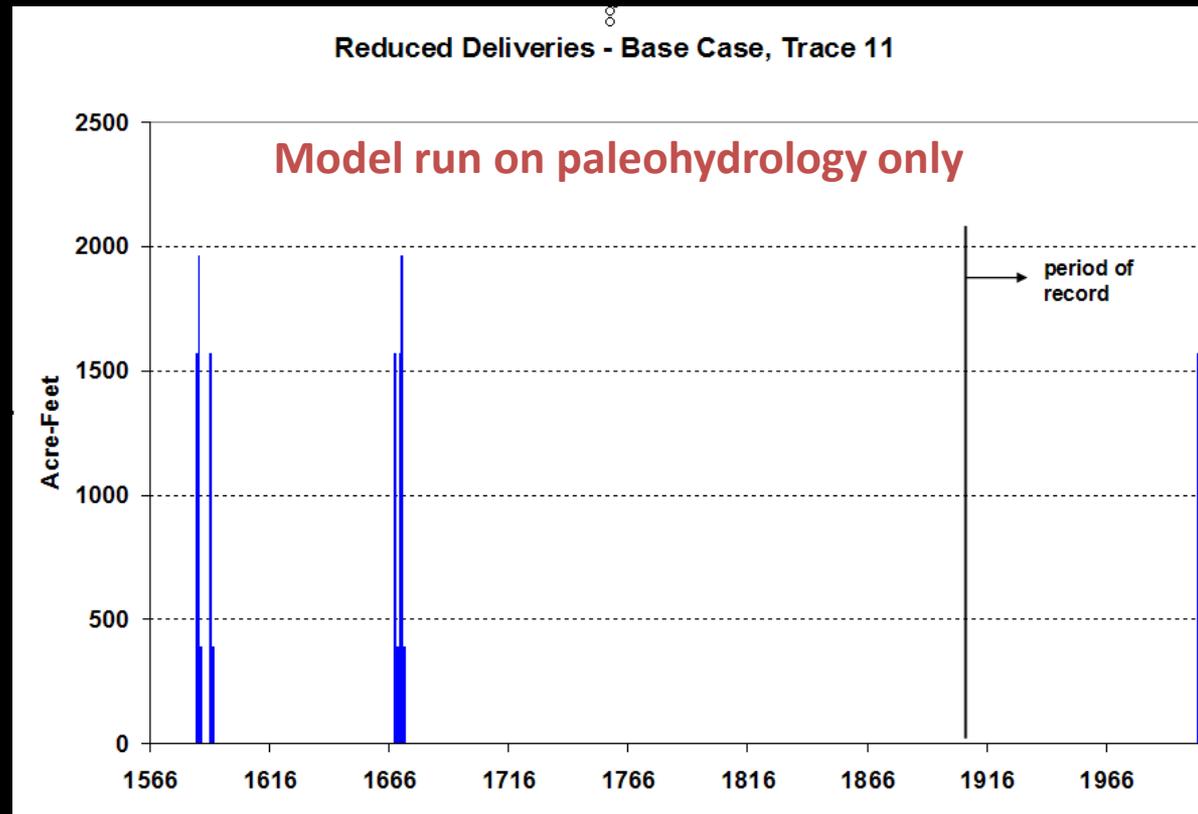
- A reconstruction is a plausible estimate of flows using a given set of data and modeling decisions, and
- The past will not be an exact analogue for the future, but
- GCM and regional models are still far from perfect predictors of the future,

Many water managers are now focusing on the plausible range of conditions that could be expected in the future, given both natural variability and anthropogenic climate change

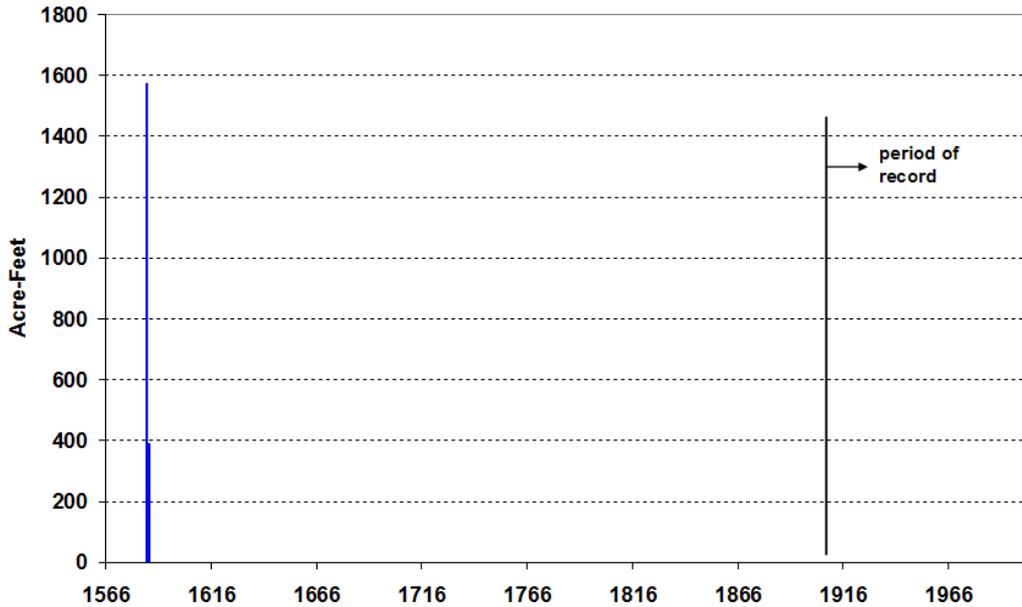
***This range is often represented by a set of scenarios.***

# Combining Paleo and GCMs: Stratus and AMEC Consultants for the City of Boulder

- A1, A1b, and B1 scenarios, two 20-yr periods centered on 2030 and 2070.
- Boulder Creek flow reconstruction
- Analogue method was used to develop temperature and precipitation inputs for a hydrologic model



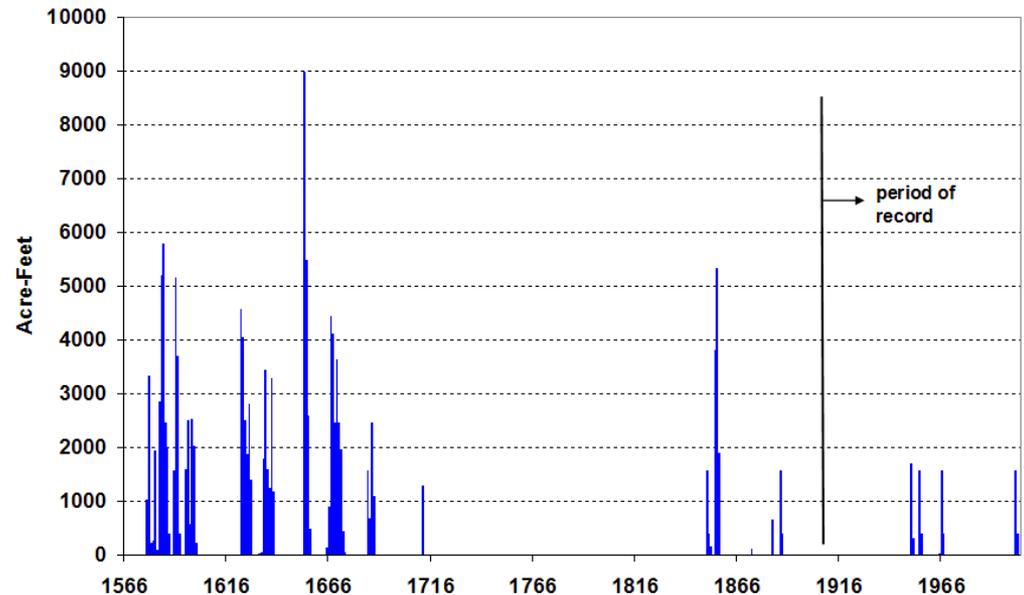
Reduced Deliveries - B1 Wet 2070, Trace 24



Best case scenario: A “wet” model imposed on the paleohydrology

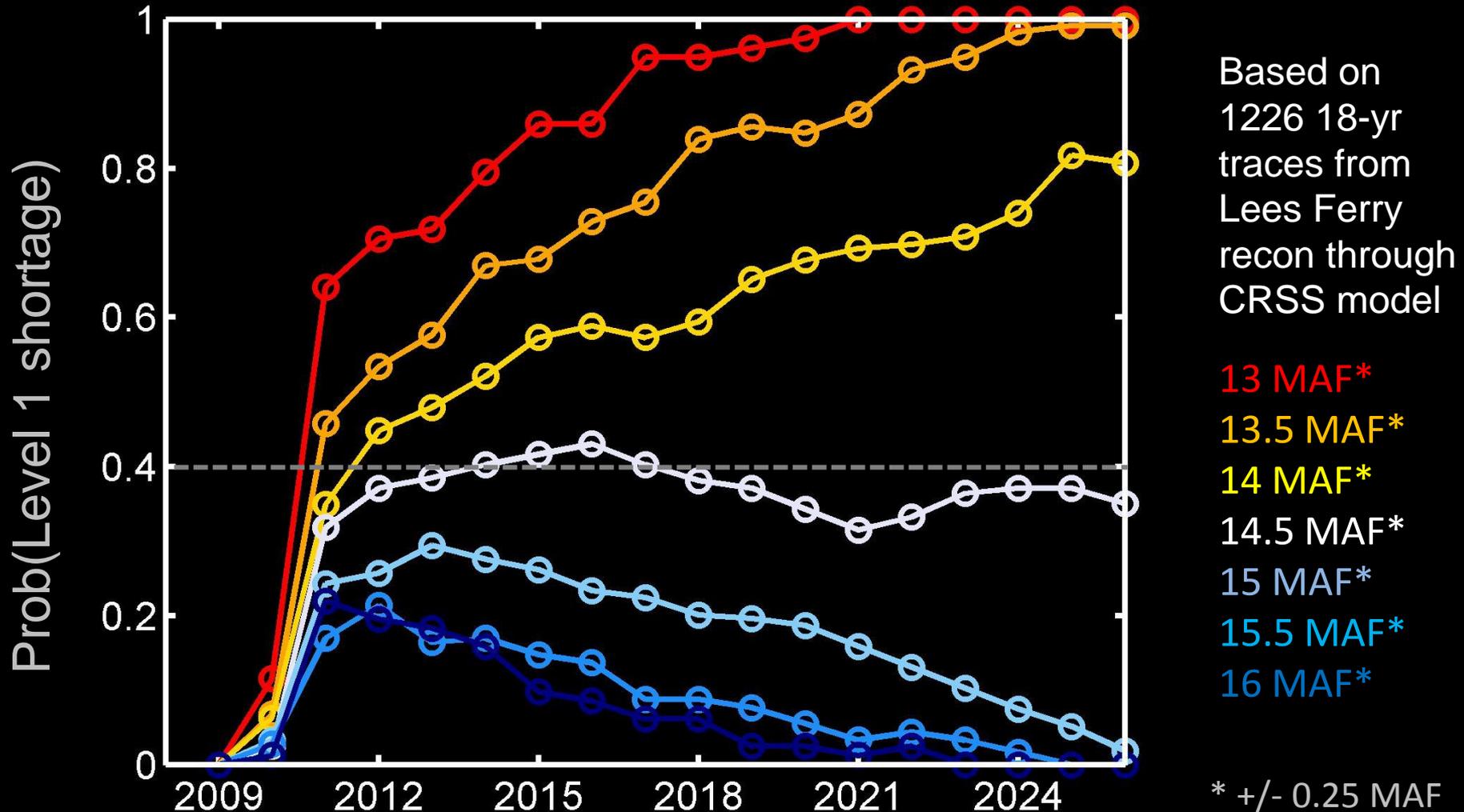
Worst case scenario: A “dry” model imposed on the paleohydrology

Reduced Deliveries - A2 Dry 2070, Trace 257



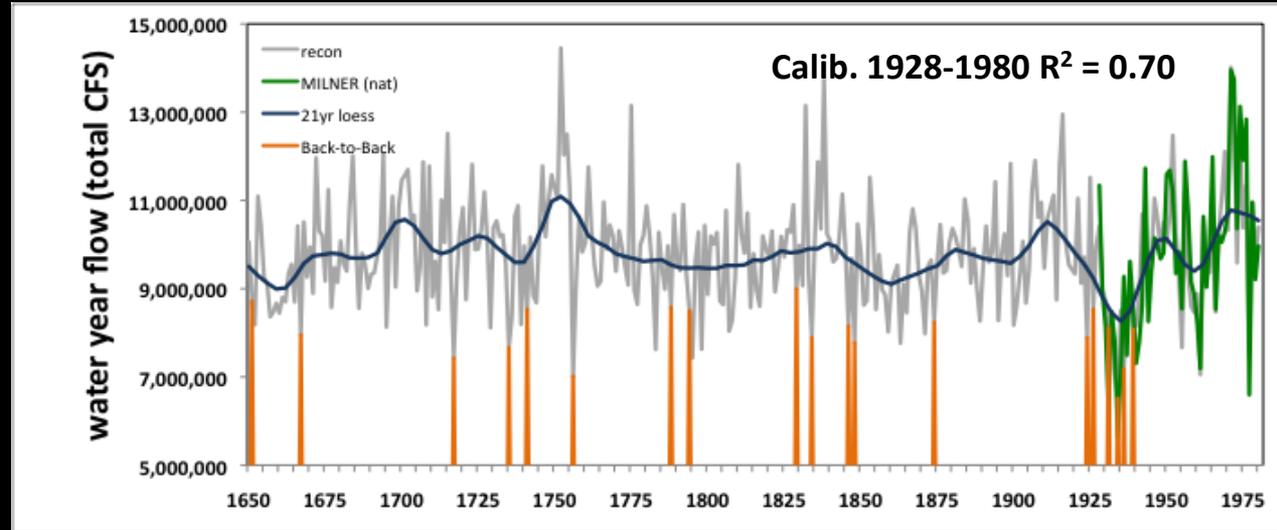
# Bureau of Reclamation Shortage EIS: Trigger Elevations

1<sup>st</sup> trigger: Lake Mead at <1075 ft = involuntary shortage of 333kaf

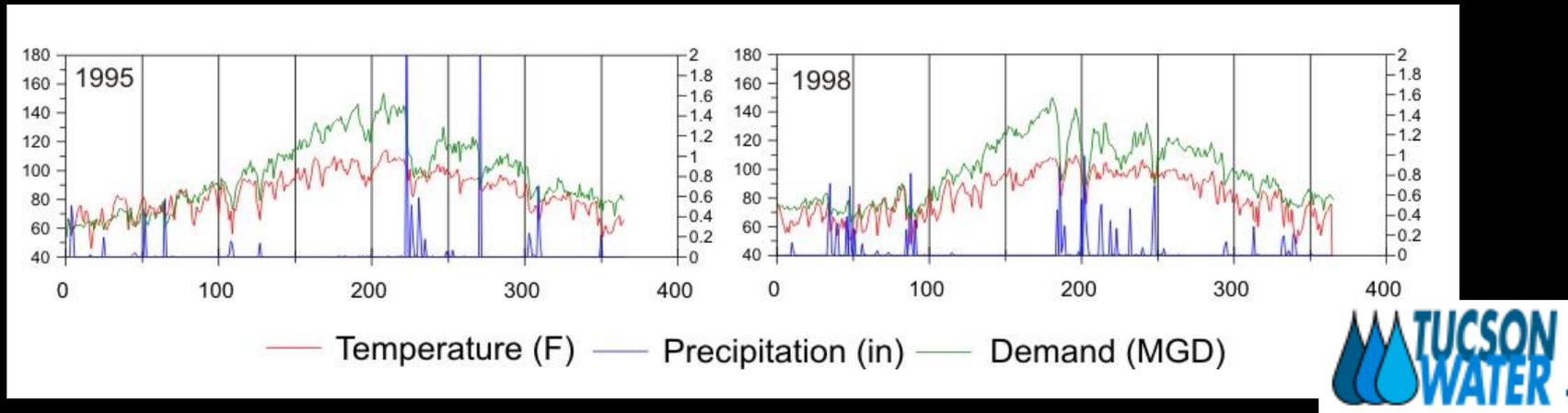


# Broadening the Scope

Geographically: reconstructions for the Columbia/Snake River basins under development (Jeremy Littell, U. WA)



Demand side: N. American monsoon onset work with Tucson Water



# How are streamflow reconstructions being used by water providers and other decision makers?

- To provide an awareness of a broader range of hydrologic variability than contained in the gage record
- As the basis for determining a drought “worst-case scenarios”
- To test system reliability under a broader range of conditions by incorporating reconstruction data into water supply models
- As alternative hydrologies for water supply assessments
- With climate change projections to assess a range of plausible future scenarios