Paleohydrology Workshop

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

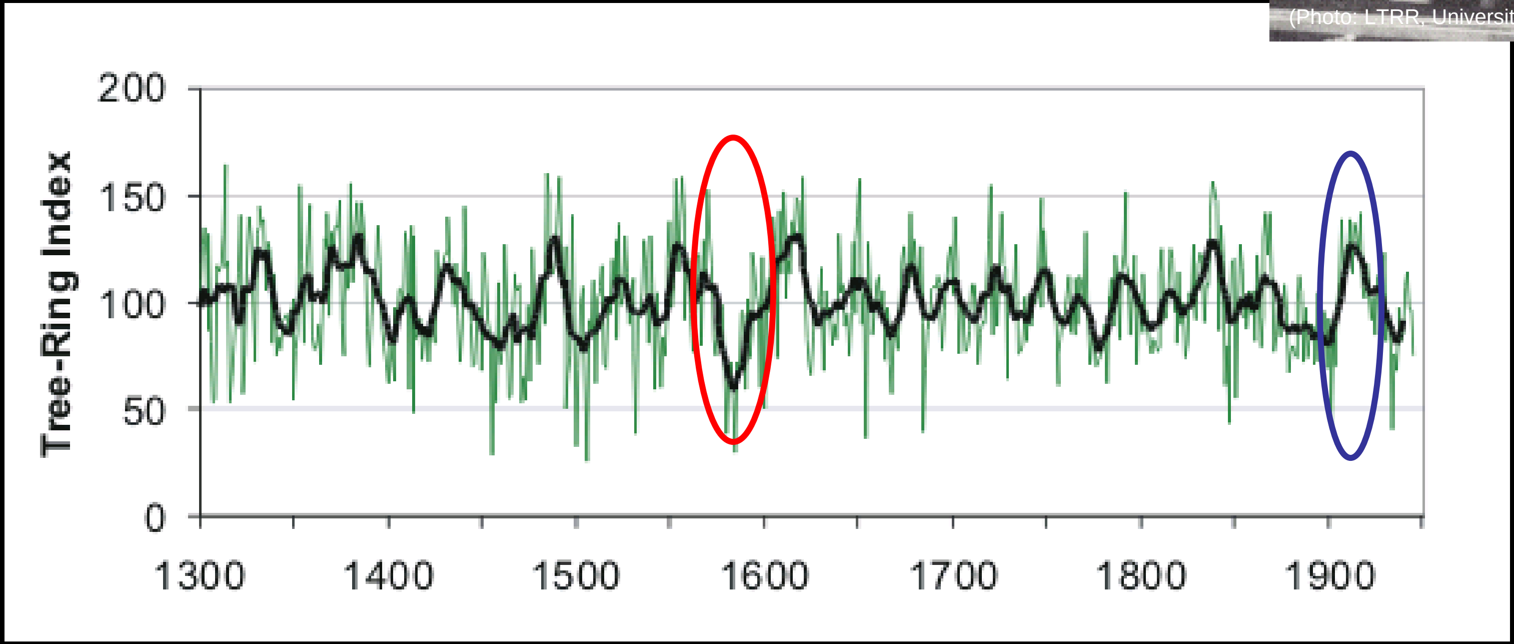
Reconstructions for the Colorado River Basin

- Upper Colorado *(C. Woodhouse)*
- Lower Colorado, and comparison with the Upper Colorado *(K. Morino)*
- Paleofloods *(K. Hirschboeck)*

Reconstructions of the Upper Colorado River Basin

Early Tree-Ring Records of Colorado River Flow

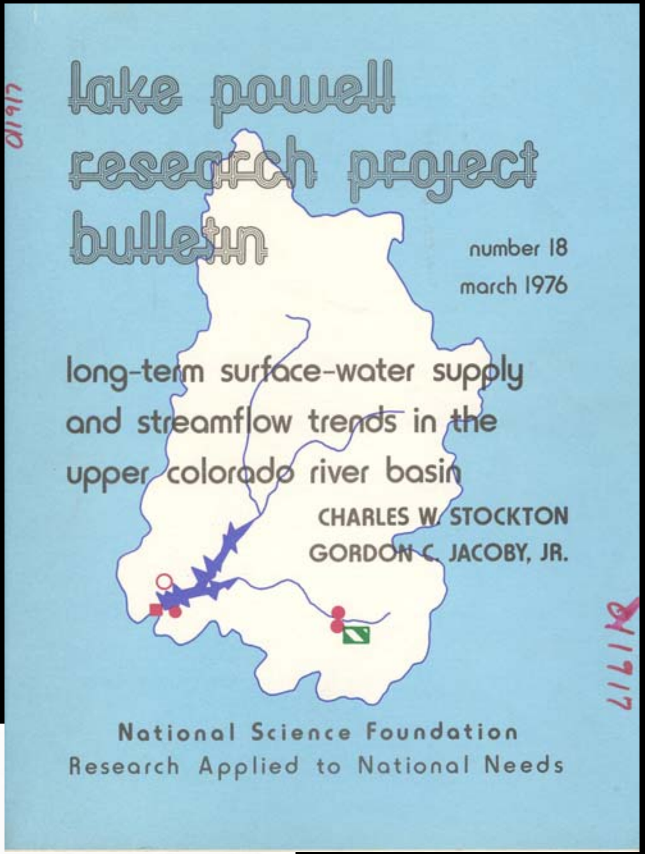
In the 1940s, Edmund Schulman found tree-rings reflected variations in moisture and could be used as a proxy for annual streamflow.

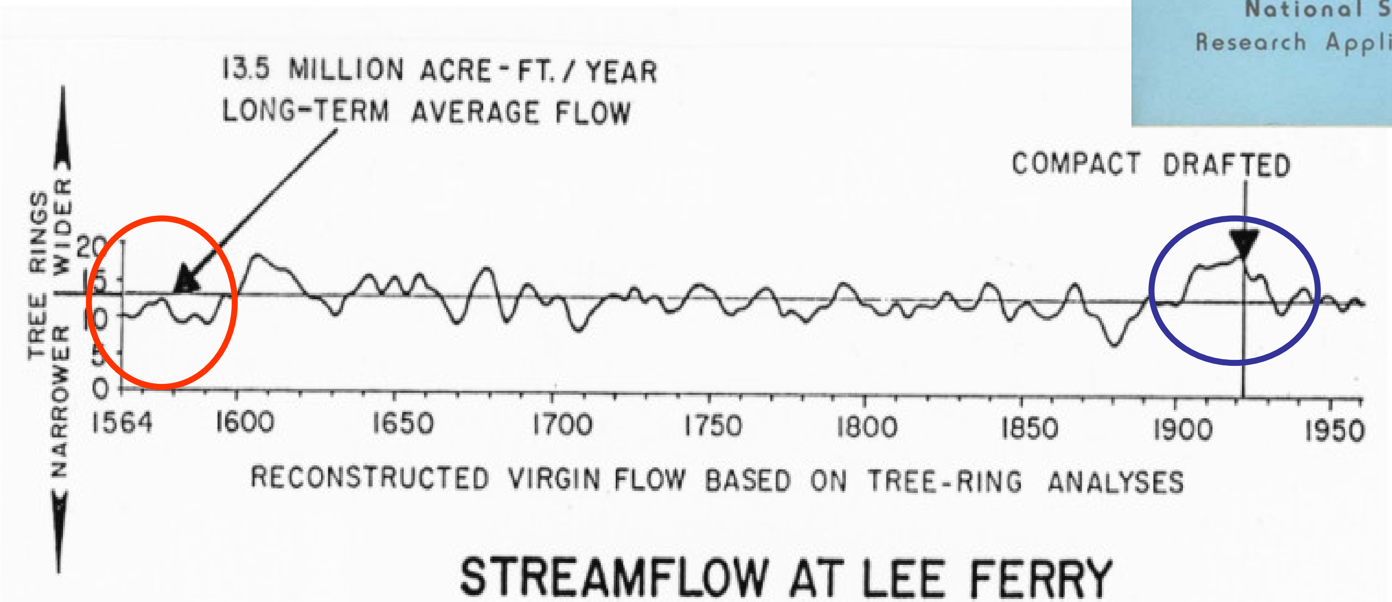


Schulman's Colorado River basin Douglas-fir tree-ring index (1300-1945) from "Tree-Ring Hydrology of the Colorado Basin", 1945.

The first Colorado River reconstruction was generated by Stockton and Jacoby in 1976.

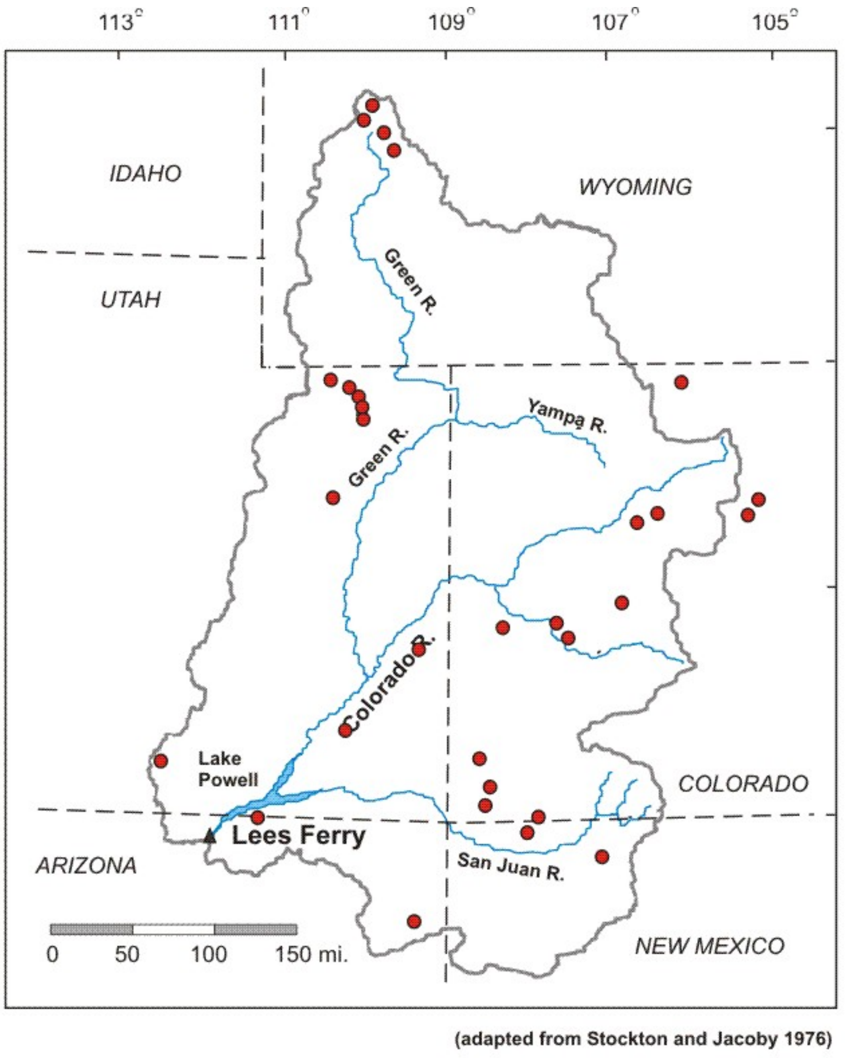
It supported Schulman's findings regarding high flows in the 20th century and droughts in past centuries.



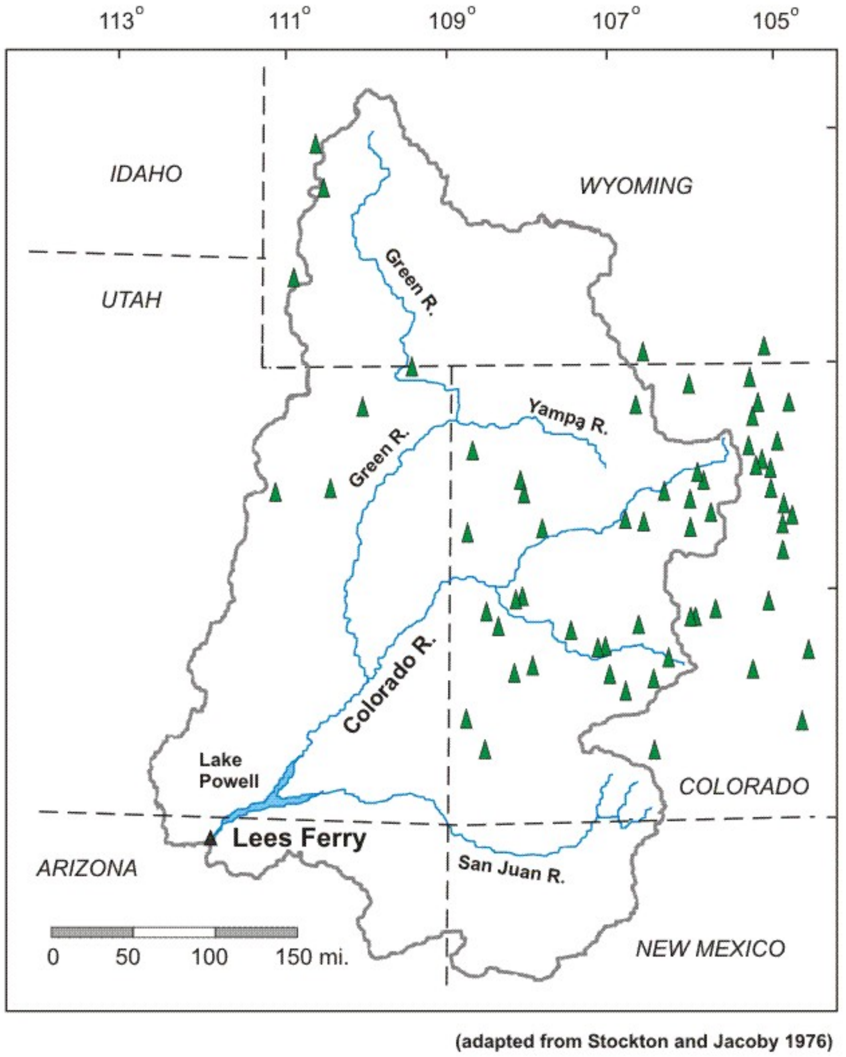


Stockton and Jacoby 1976

Stockton and Jacoby's reconstruction was updated in 2006 with new tree-ring collections



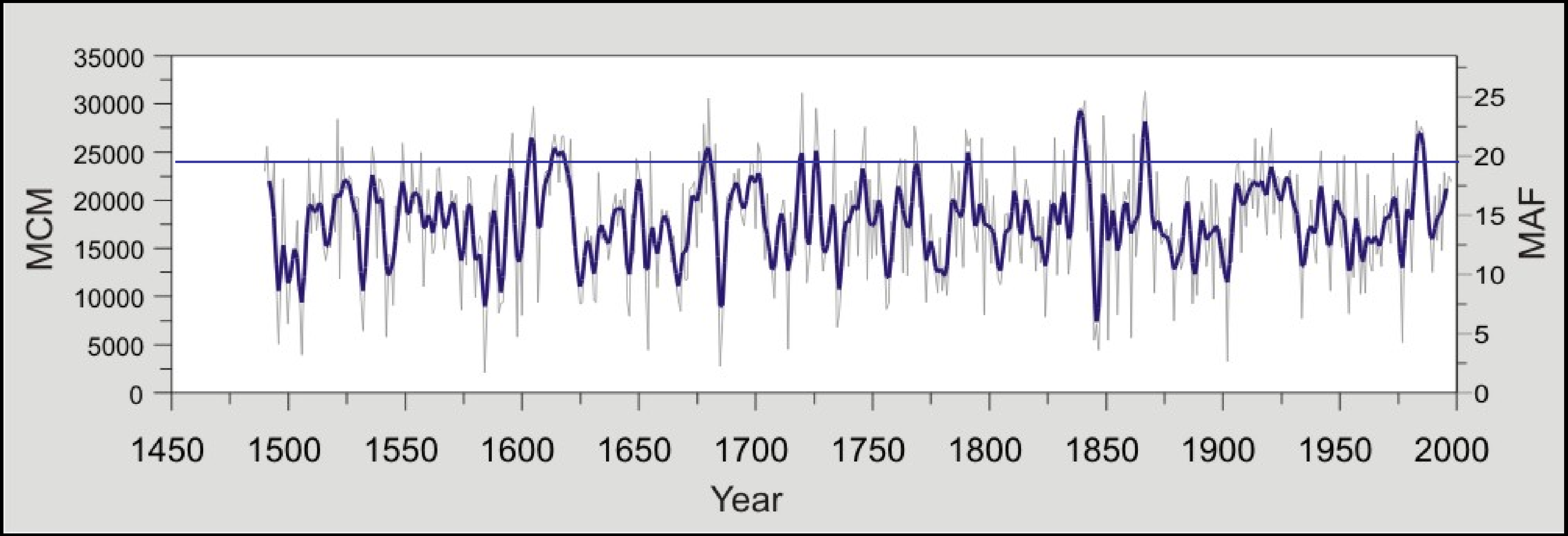
Stockton and Jacoby tree-ring sites



New network of tree-ring sites

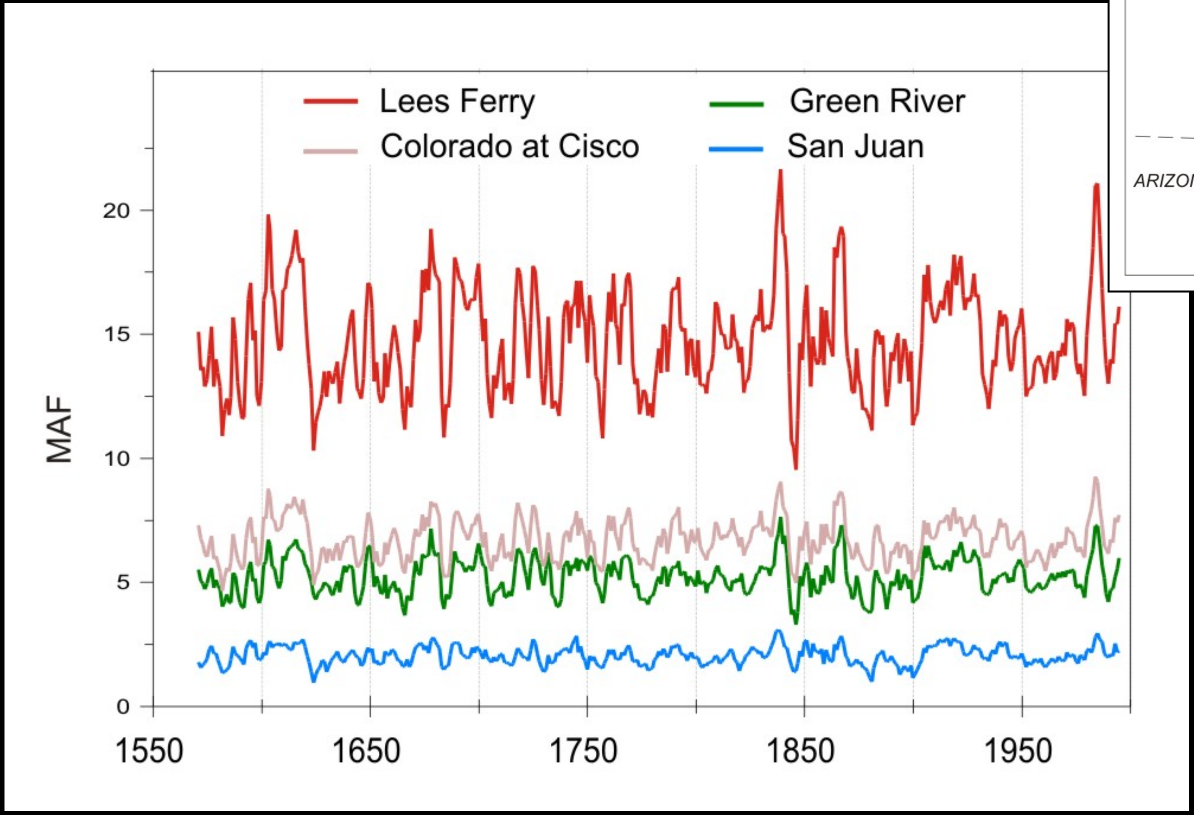
This work extended the Lees Ferry reconstruction to 1997 and back to 1490

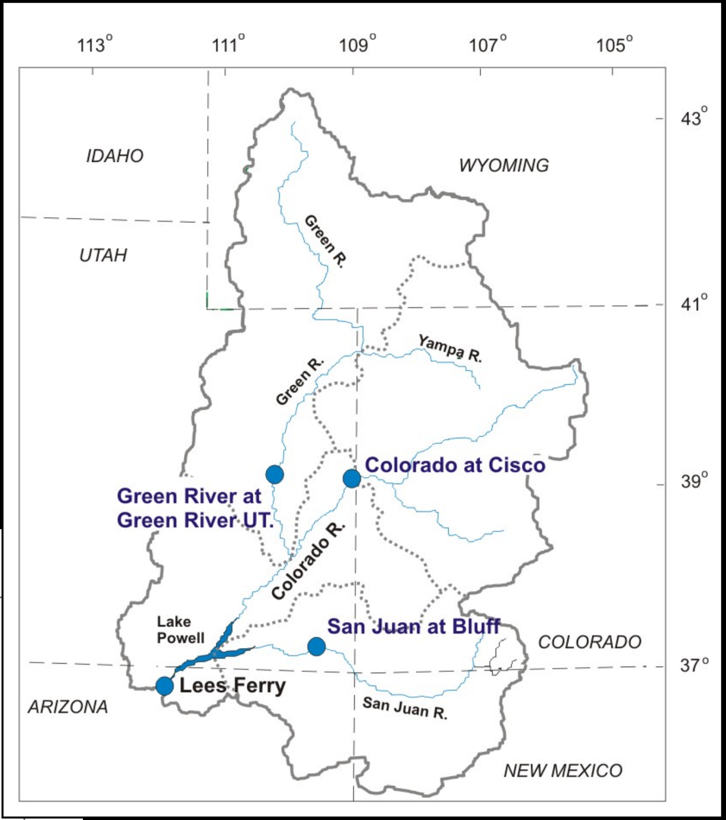
Reconstruction of Colorado River at Lees Ferry, 1490-1997

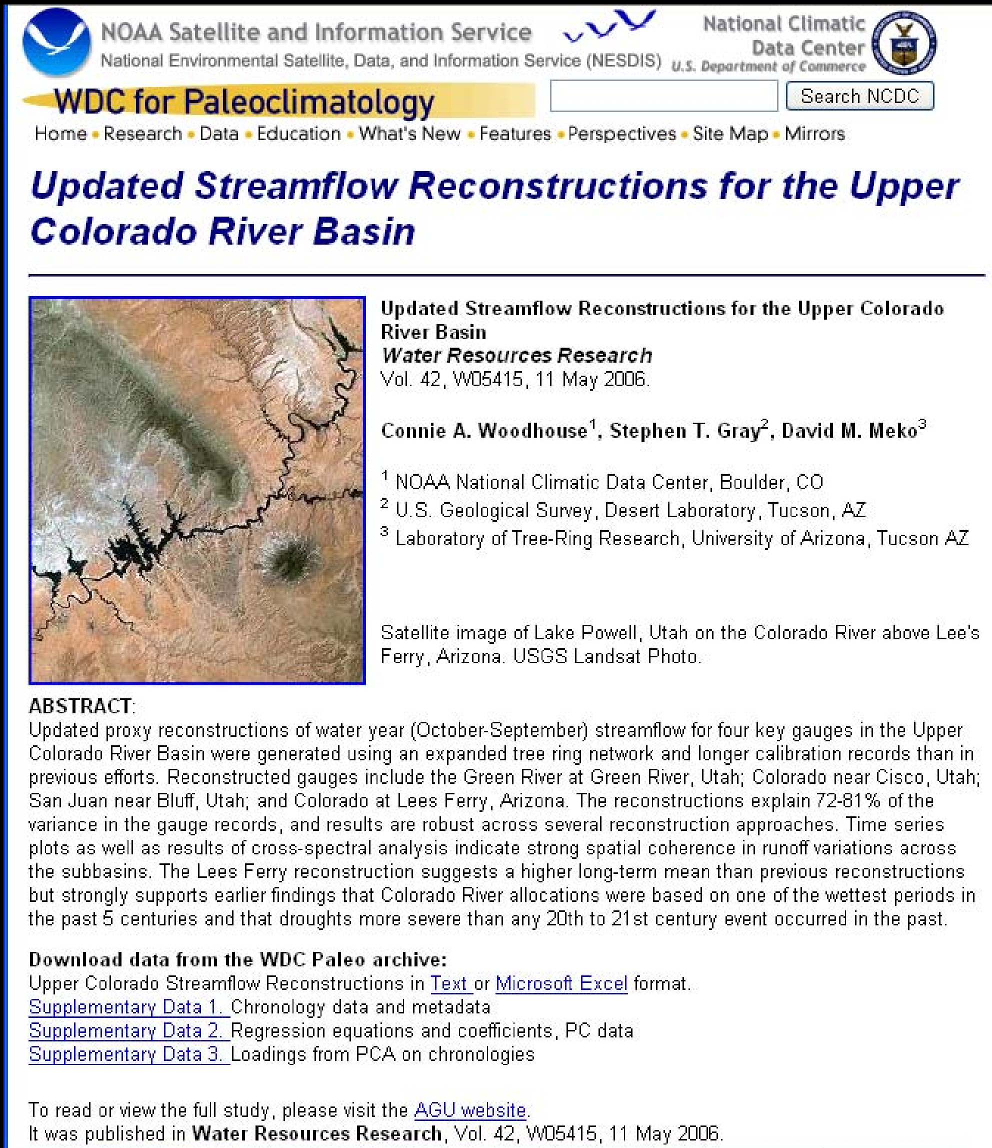


Woodhouse et al. 2006

Reconstructions were also generated for the major Upper Colorado tributaries, the Green and the San Juan Rivers, as well as for the Colorado mainstem.







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National Environmental Satellite, Data, and Information Service (NESDIS)
National Climatic Data Center
U.S. Department of Commerce

WDC for Paleoclimatology

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Updated Streamflow Reconstructions for the Upper Colorado River Basin

Updated Streamflow Reconstructions for the Upper Colorado River Basin
Water Resources Research
Vol. 42, W05415, 11 May 2006.

Connie A. Woodhouse[1], **Stephen T. Gray**[2], **David M. Meko**[3]

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[2] U.S. Geological Survey, Desert Laboratory, Tucson, AZ
[3] Laboratory of Tree-Ring Research, University of Arizona, Tucson AZ

Satellite image of Lake Powell, Utah on the Colorado River above Lee's Ferry, Arizona. USGS Landsat Photo.

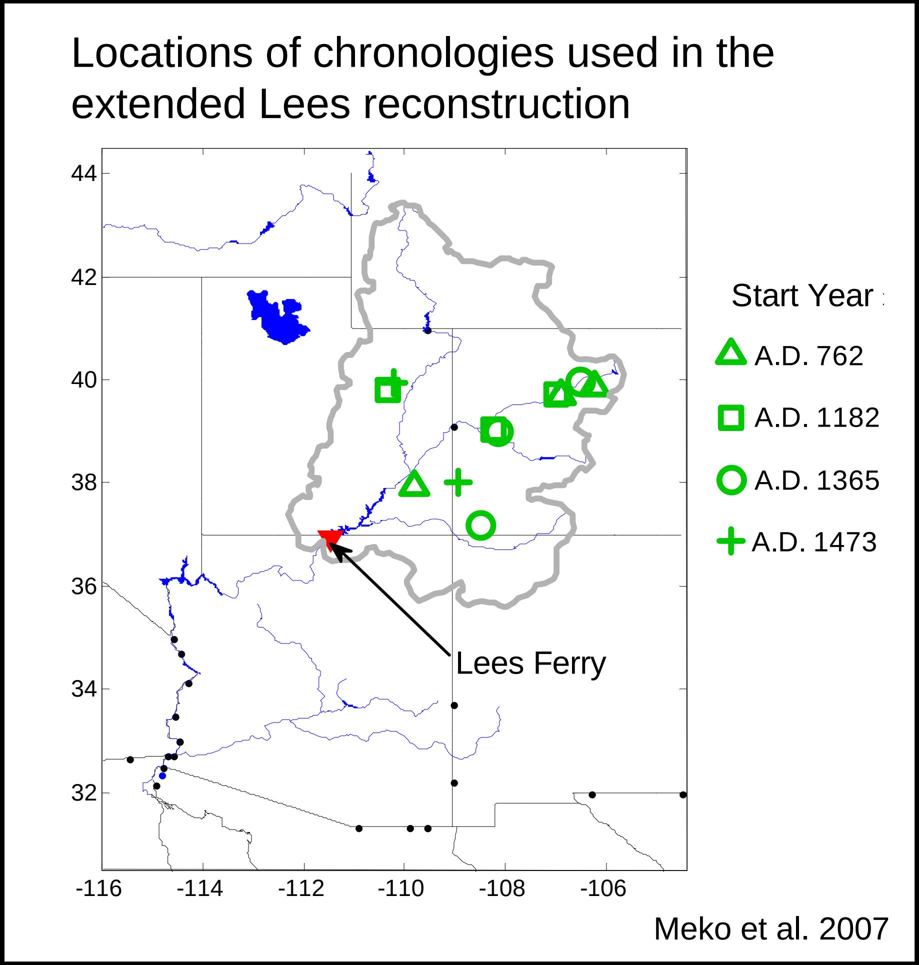
ABSTRACT:
Updated proxy reconstructions of water year (October-September) streamflow for four key gauges in the Upper Colorado River Basin were generated using an expanded tree ring network and longer calibration records than in previous efforts. Reconstructed gauges include the Green River at Green River, Utah; Colorado near Cisco, Utah; San Juan near Bluff, Utah; and Colorado at Lees Ferry, Arizona. The reconstructions explain 72-81% of the variance in the gauge records, and results are robust across several reconstruction approaches. Time series plots as well as results of cross-spectral analysis indicate strong spatial coherence in runoff variations across the subbasins. The Lees Ferry reconstruction suggests a higher long-term mean than previous reconstructions but strongly supports earlier findings that Colorado River allocations were based on one of the wettest periods in the past 5 centuries and that droughts more severe than any 20th to 21st century event occurred in the past.

Download data from the WDC Paleo archive:
Upper Colorado Streamflow Reconstructions in Text or Microsoft Excel format.
Supplementary Data 1. Chronology data and metadata
Supplementary Data 2. Regression equations and coefficients, PC data
Supplementary Data 3. Loadings from PCA on chronologies

To read or view the full study, please visit the AGU website.
It was published in **Water Resources Research**, Vol. 42, W05415, 11 May 2006.

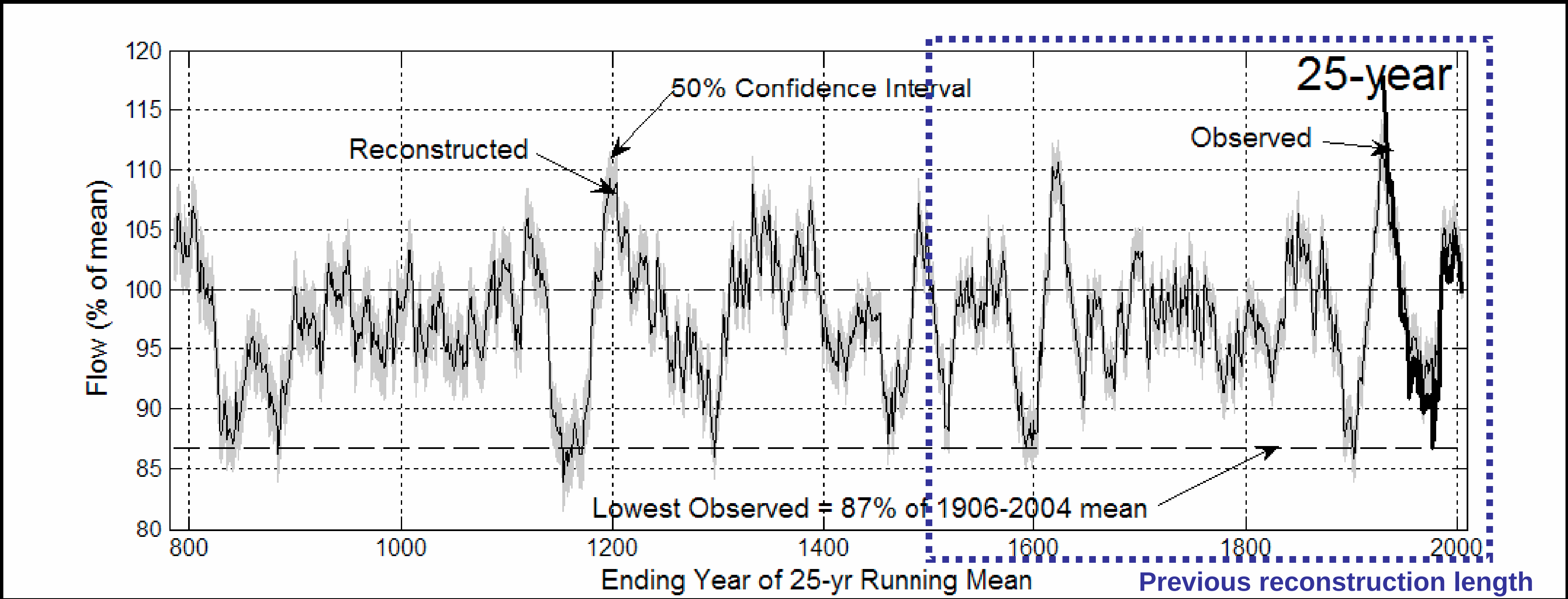
- Colorado R. at Glenwood Spgs, CO
- Colorado R. nr Cisco, UT
- Colorado R, at Lees Ferry, AZ
- Green R. nr Green River, WY
- Green R. at Green River, UT
- Gunnison R. at Crystal Reservoir
- Gunnison R. nr Grand Junction, CO
- San Juan R. nr Archuleta, NM
- San Juan R. nr Bluff, UT
- Dolores R. nr Cisco, UT

The Lees Ferry reconstruction has now been extended even further back in time using stumps, logs, and remnants of wood



Explained variance in the reconstruction ranges from 60% (762-1180) to 77% (by 1365)

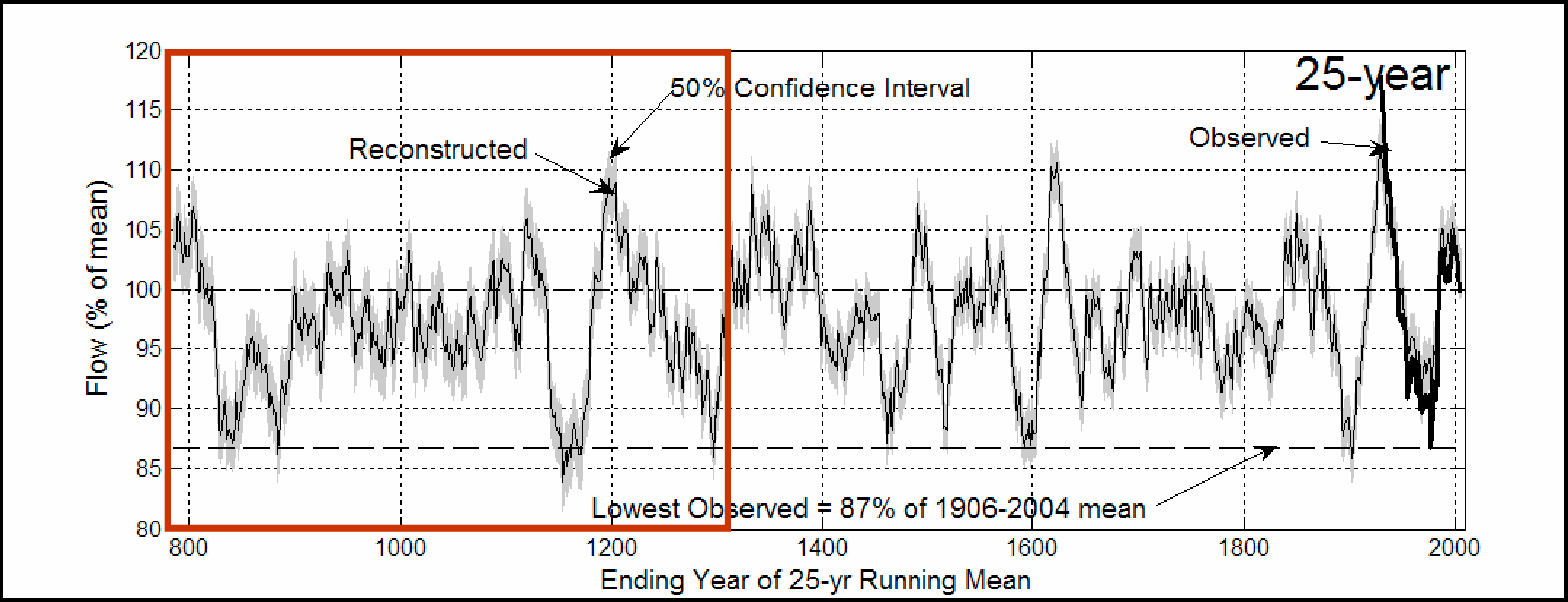
Reconstruction of Colorado River at Lees Ferry, AD 762 - 2005



25-yr running means of reconstructed and observed annual flow of the Colorado River at Lees Ferry, expressed as percentage of the 1906-2004 observed mean (Meko et al. 2007).

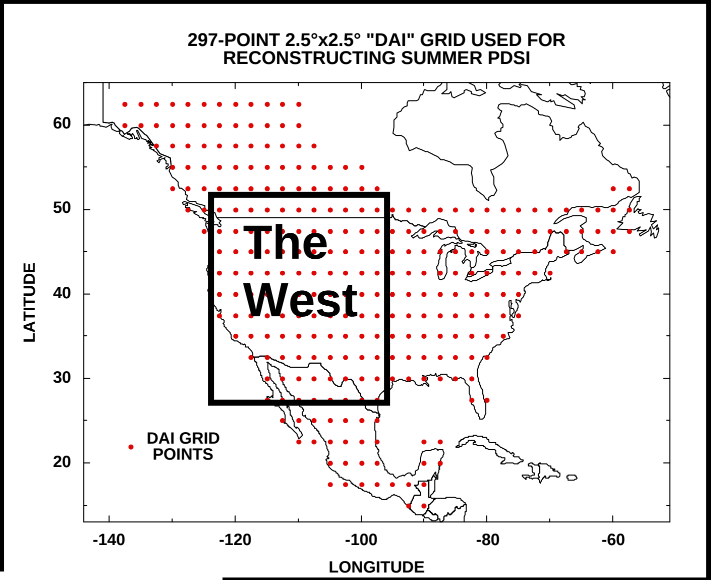
Low-frequency variability and persistent periods of low flow

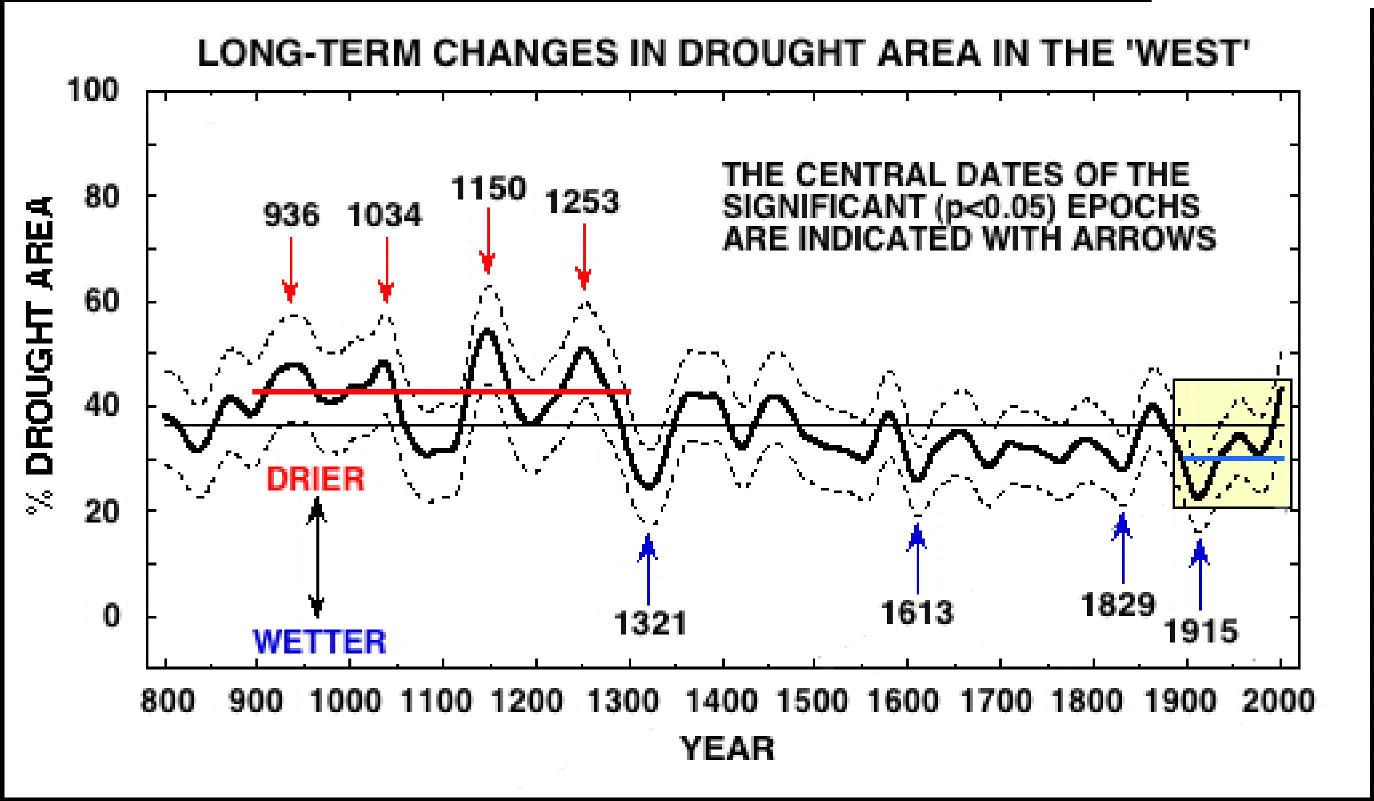
Colorado River at Lees Ferry, AD 762 - 2002



25-yr running means of reconstructed and observed annual flow of the Colorado River at Lees Ferry, expressed as percentage of the 1906-2004 observed mean (Meko et al. 2007).

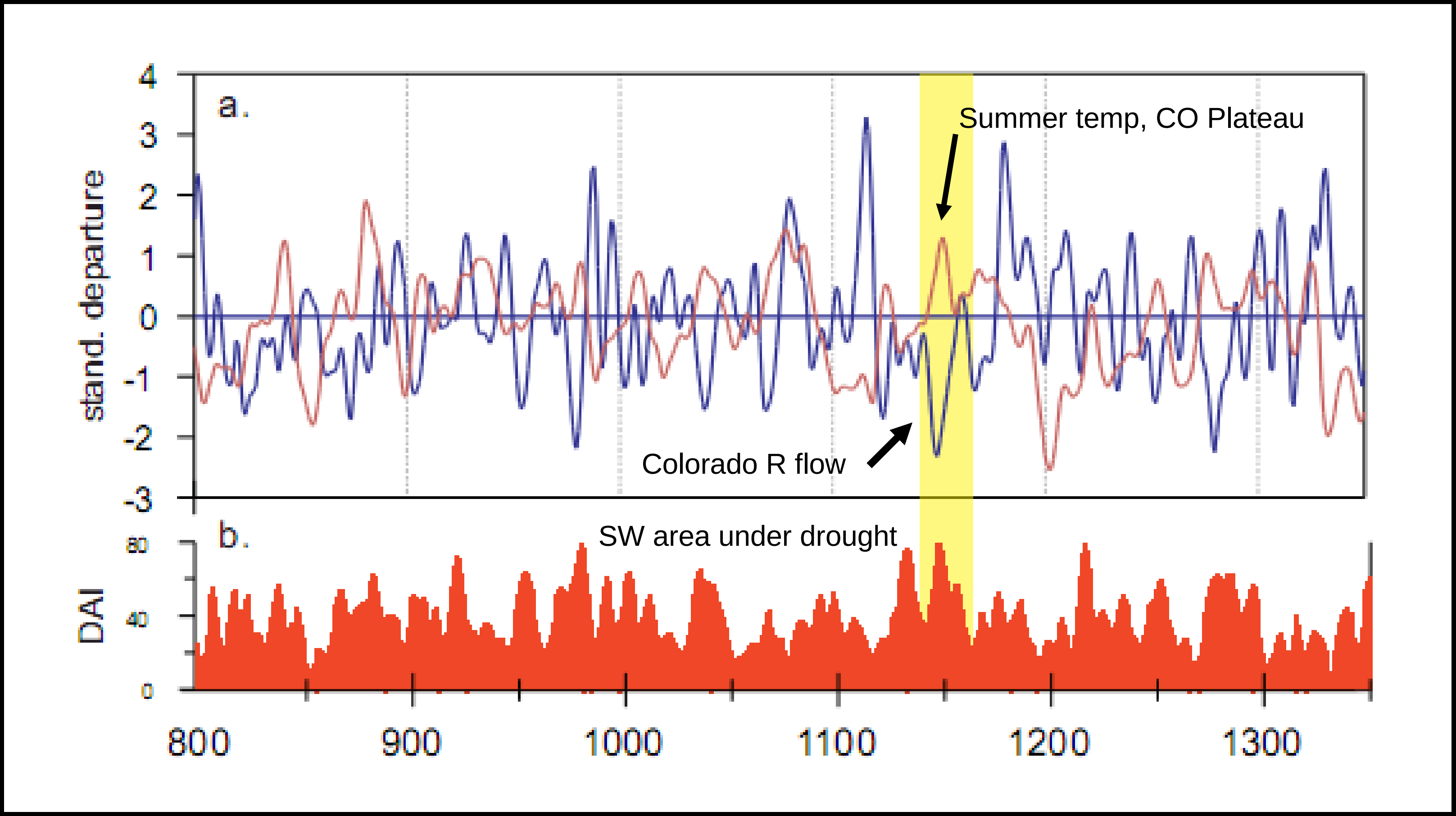
Periods of persistent low flow during the medieval period correspond to an expanded area experiencing in the western US, ~850-1300



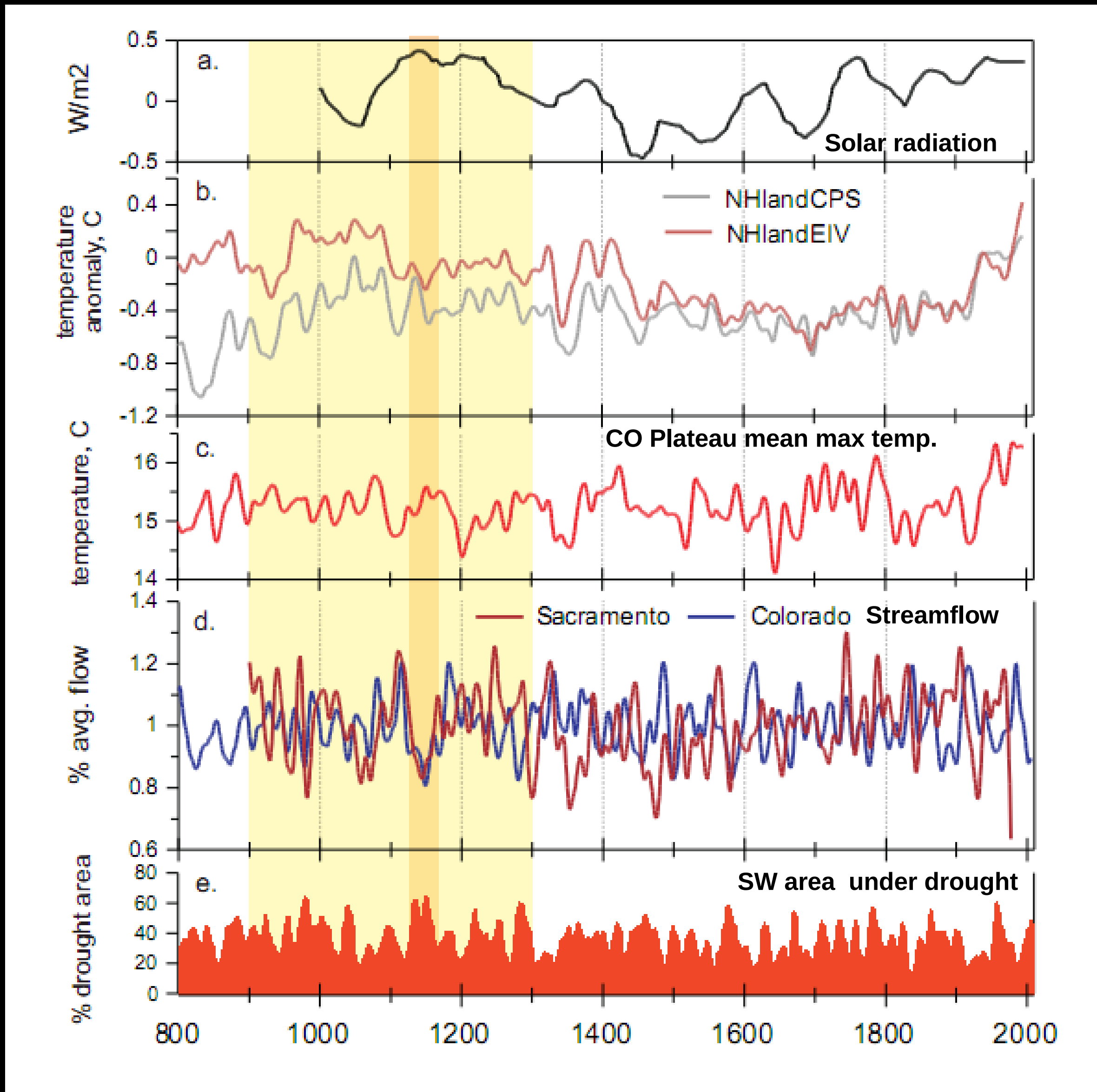


From Cook et al. 2004, *Science*

“Heart” of the Medieval Drought in the Colorado R. Basin



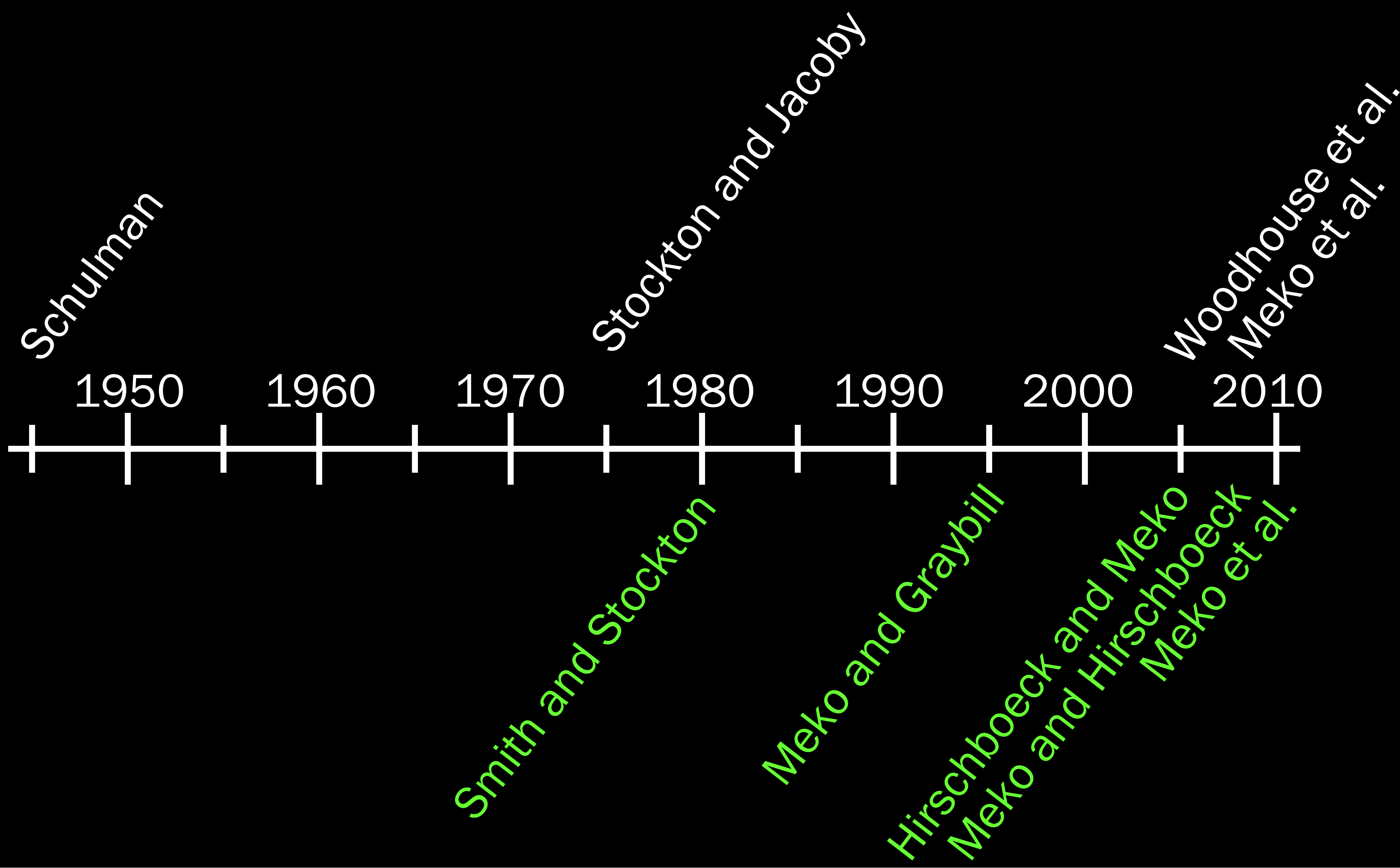
The 21st Century Drought in the Southwestern United States and Mexico: A 1000-year Perspective



Is the medieval period drought a possible analogue for a future warm droughts?

Reconstructions of the Lower Colorado River Basin

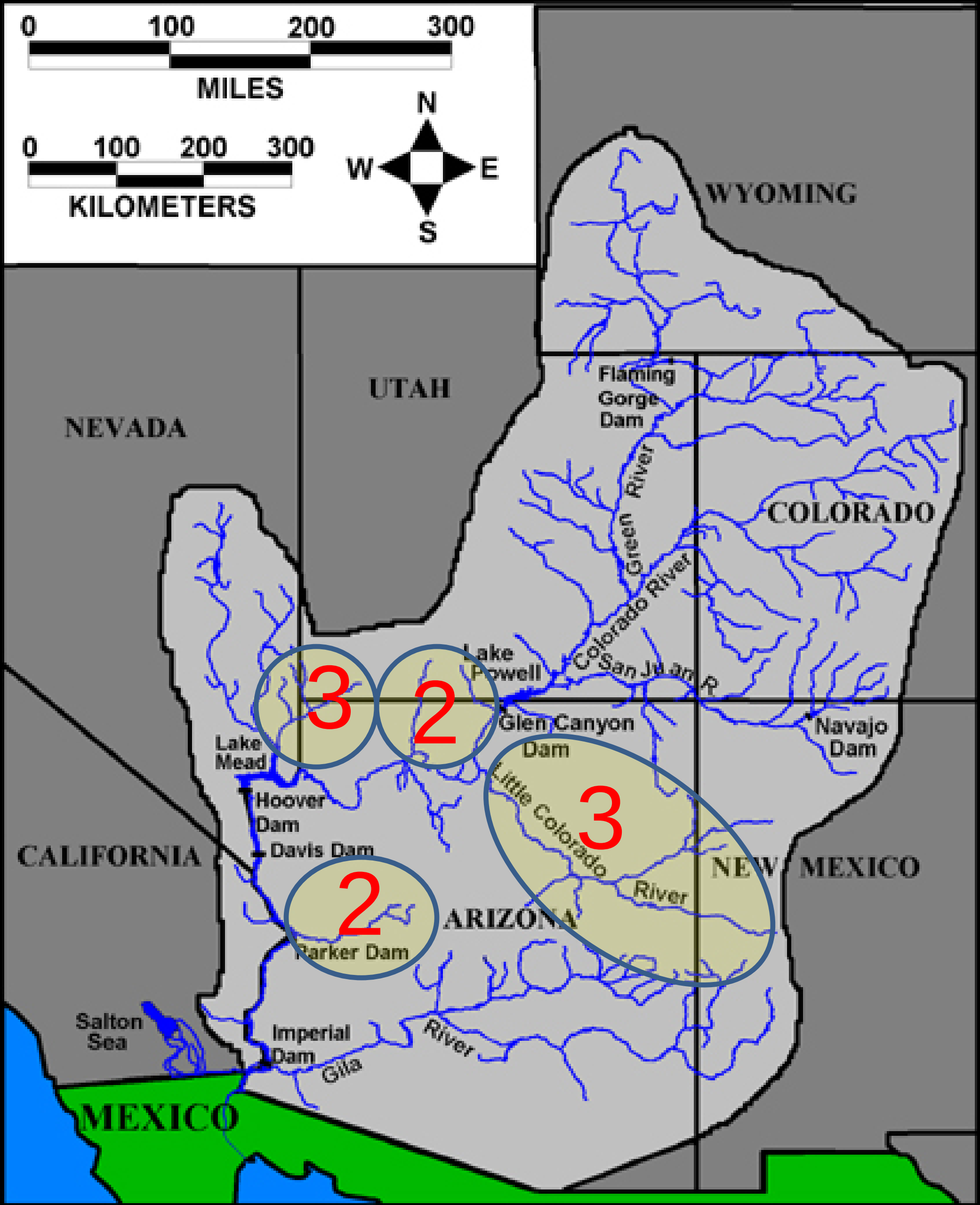
LOWER COLORADO RIVER BASIN
STREAMFLOW RECONSTRUCTIONS



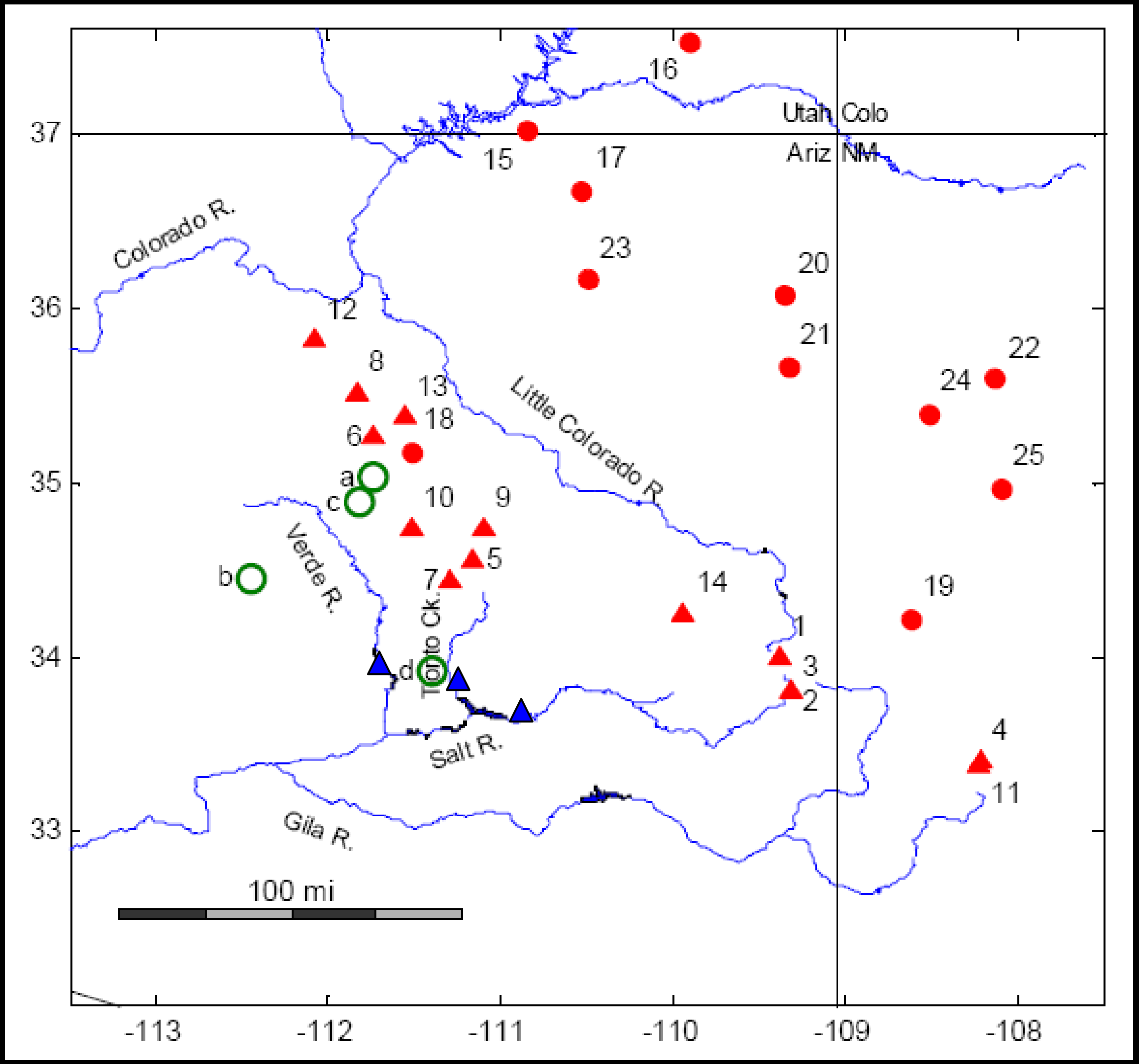
	Salt & Tonto	Verde	SVT	Gila	L'il Col
Smith & Stockton 1981	1580-1979 *	1580-1979			
Meko & Graybill 1995				1663-1985	
Hirschboeck & Meko 2005	1199-1988	1202-1988	1199-1988	1200-1988	
Meko & Hirschboeck 2008	1361-2005	1330-2005	1330-2005	1332-2005	
Meko et al. In progress					1420 - 2005

* Salt R. only

Near-Future Collections

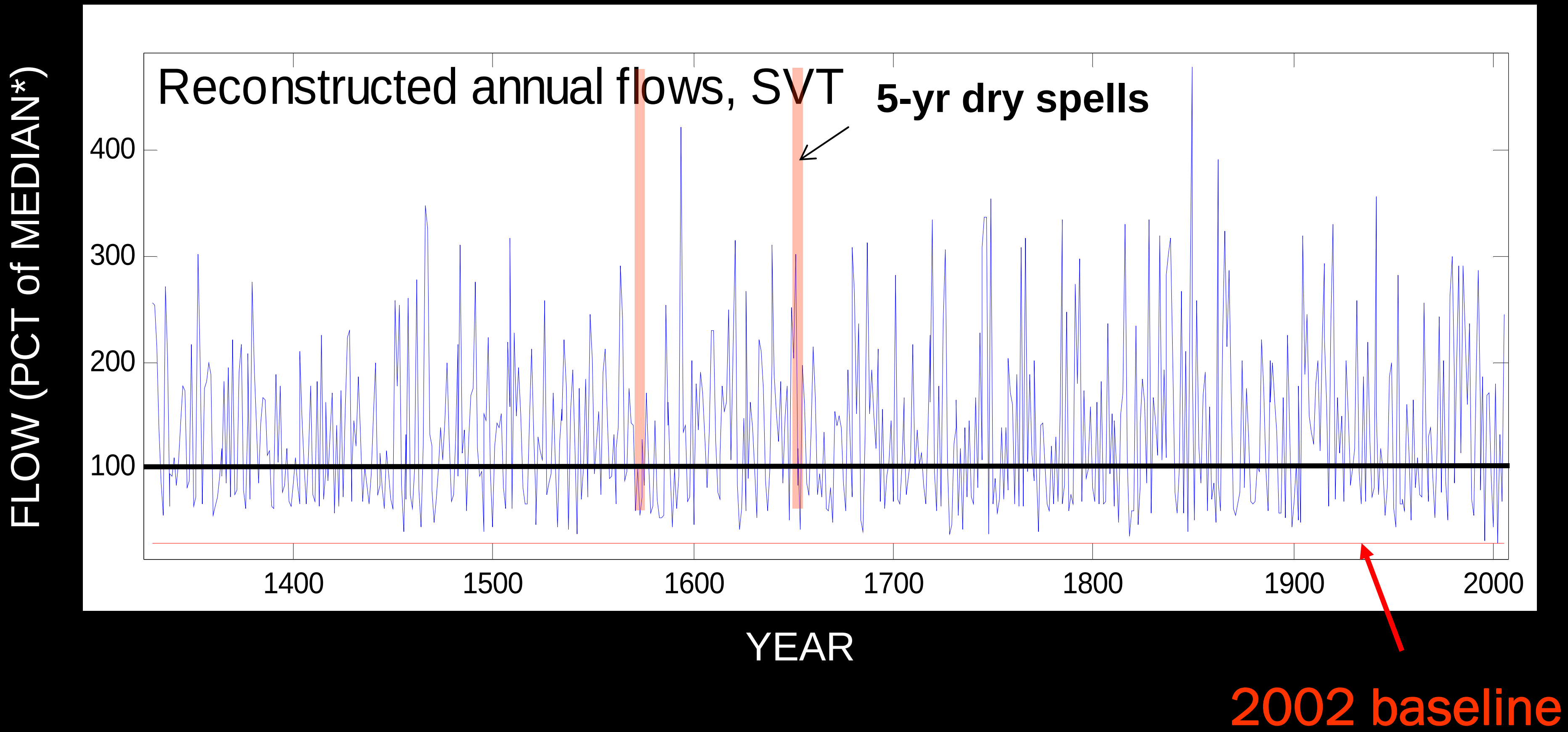


2005 tree-ring collections for SVT

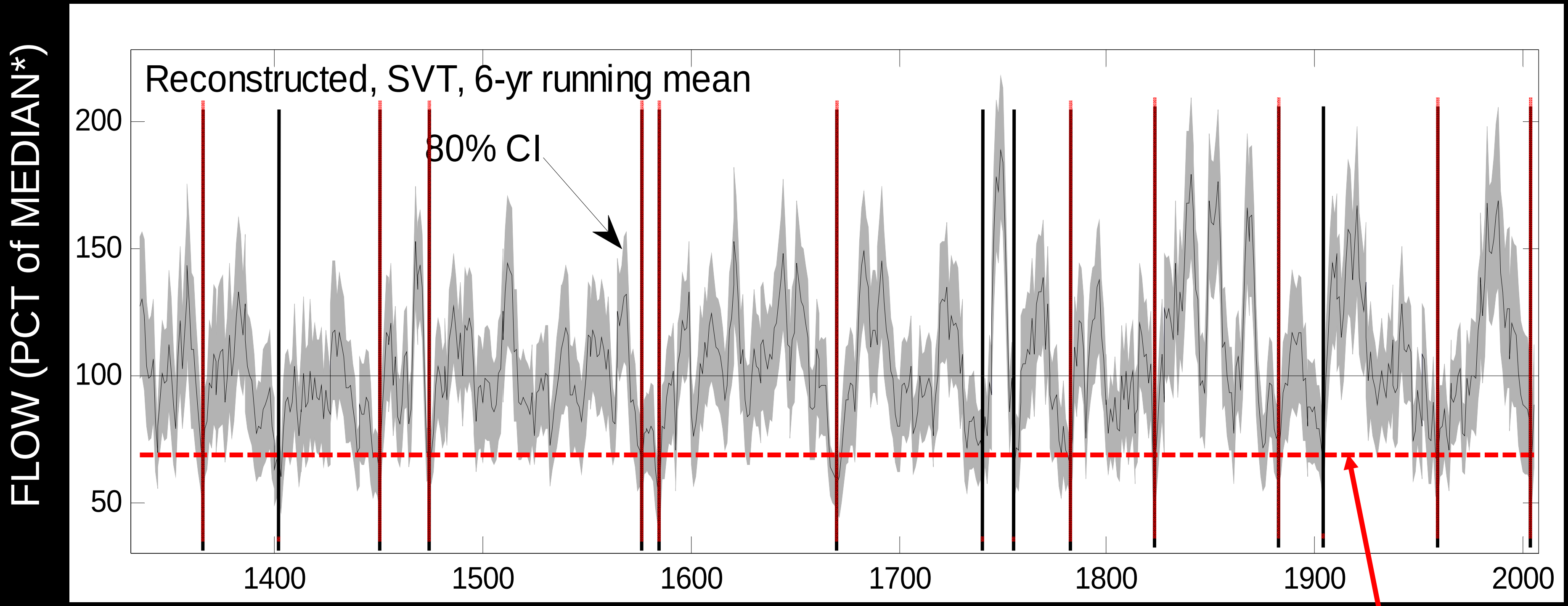


Existing = circles (11)
New = triangles (14)
Explored = circles (4)
Gages = triangles (3)

Model	No. Sites	R^2
1330-1989	4	0.53
1451-1982	10	0.69
1736-2004	10	0.49



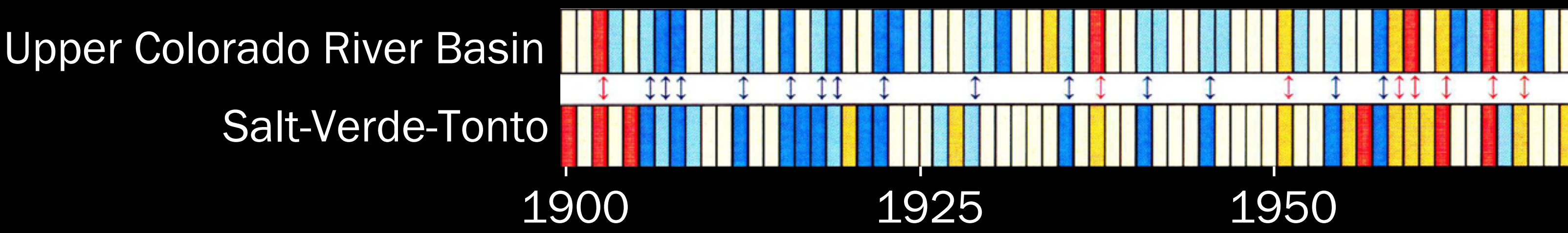
*MEDIAN of 1914 – 2006 Observed Flows



1999-2004 Baseline

*MEDIAN of All 6-YR Running Means

Comparison I: Upper Colorado River Basin and Salt-Verde-Tonto



LL 8

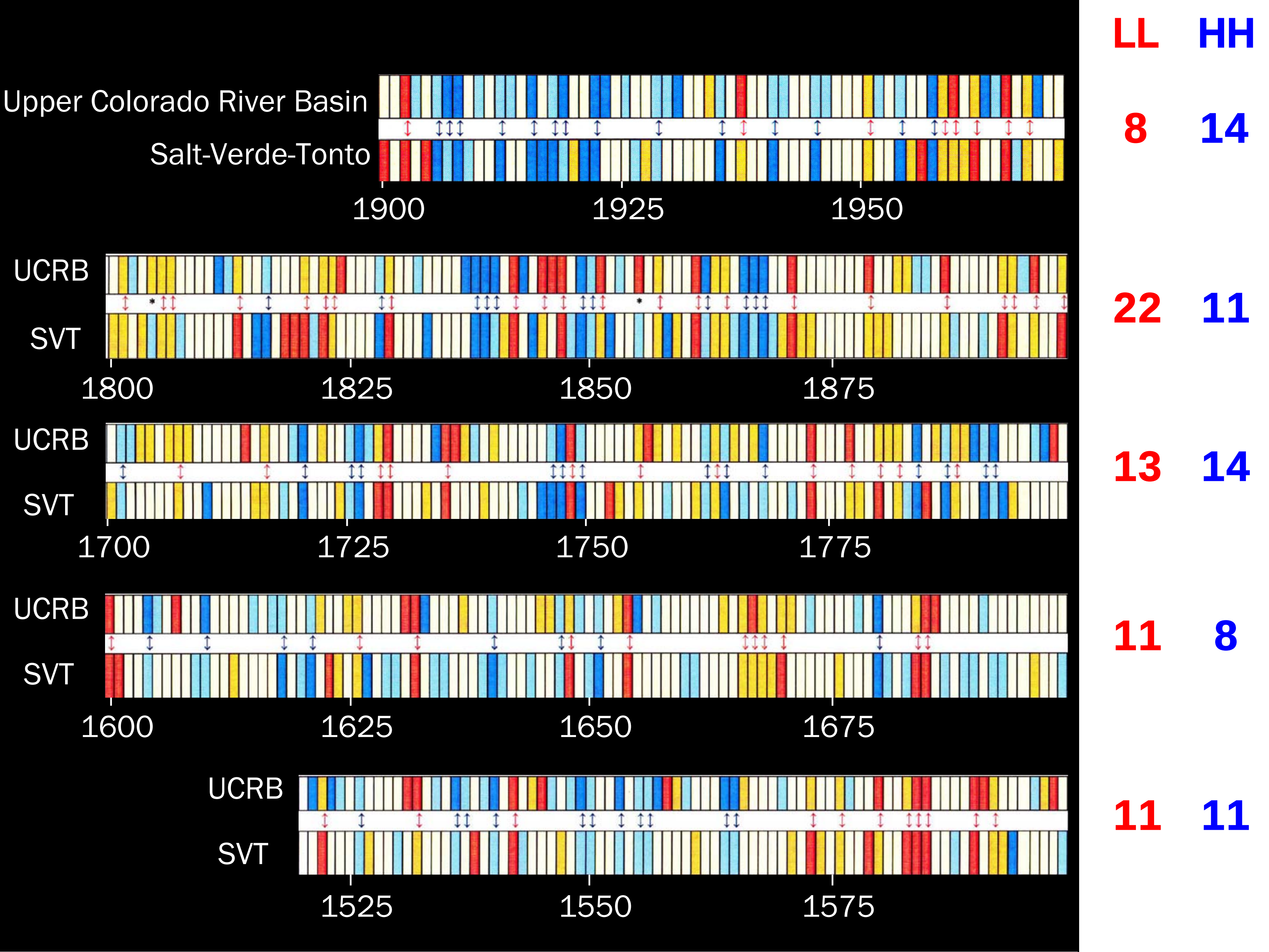
HH 14

- > 90^{th} percentile
- > 75^{th} & $\leq 90^{th}$ percentile
- $\geq 25^{th}$ & $\leq 75^{th}$ percentile
- $\geq 10^{th}$ & < 25^{th} percentile
- < 10^{th} percentile

H is >75^{th} quantile

L is <25^{th} quantile

Period of Analysis: 1521 – 1964

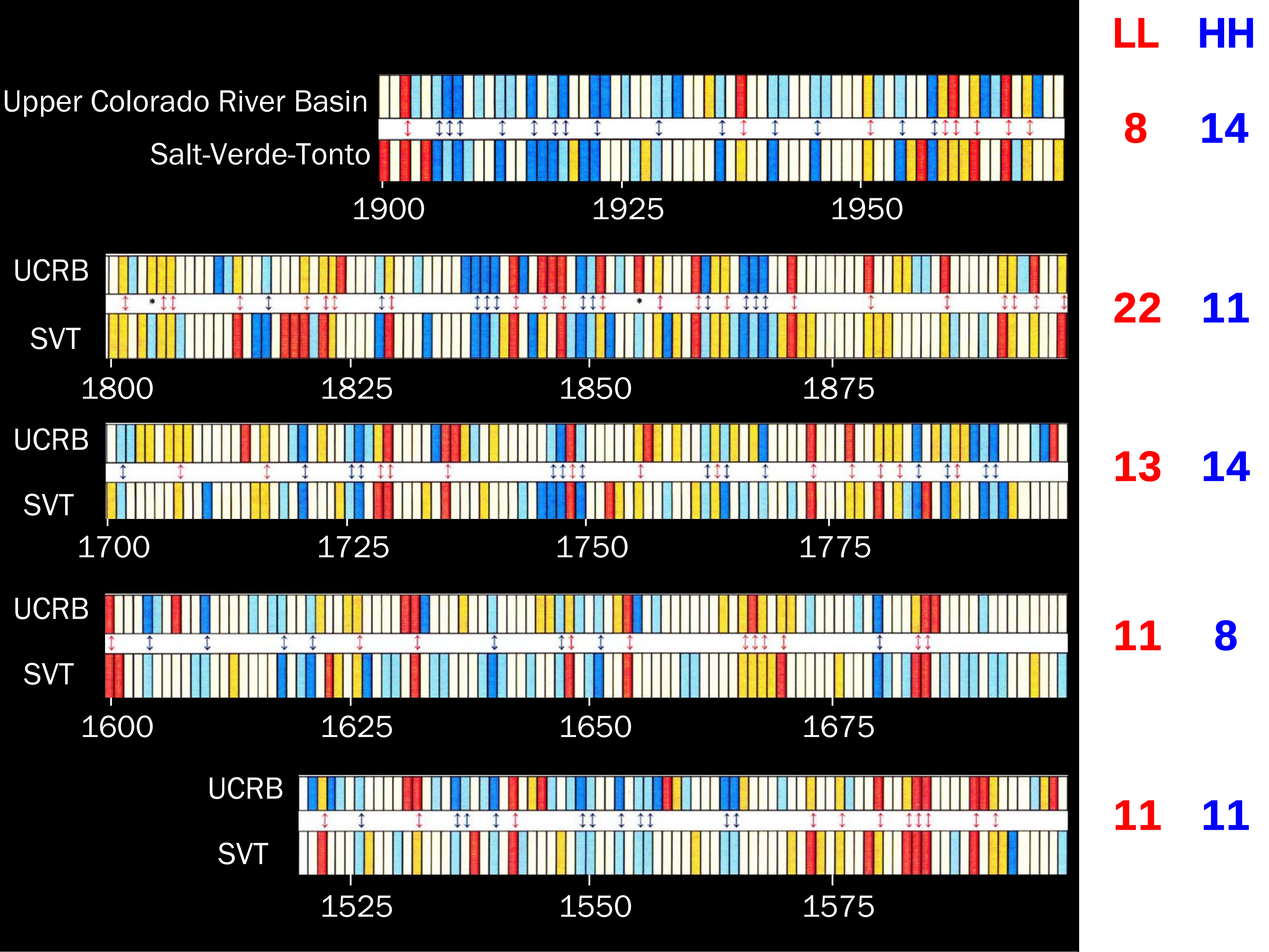

LL
HH
Upper Colorado River Basin
Salt-Verde-Tonto
1900
1925
1950
8
14
UCRB
SVT
1800
1825
1850
1875
22
11
UCRB
SVT
1700
1725
1750
1775
13
14
UCRB
SVT
1600
1625
1650
1675
11
8
UCRB
SVT
1525
1550
1575
11
11

$$LL = 65/444 = 0.15$$

$$HH = 58/444 = 0.13$$

$$H_{UPCO}L_{SVT} = 0/444 = 0.00$$

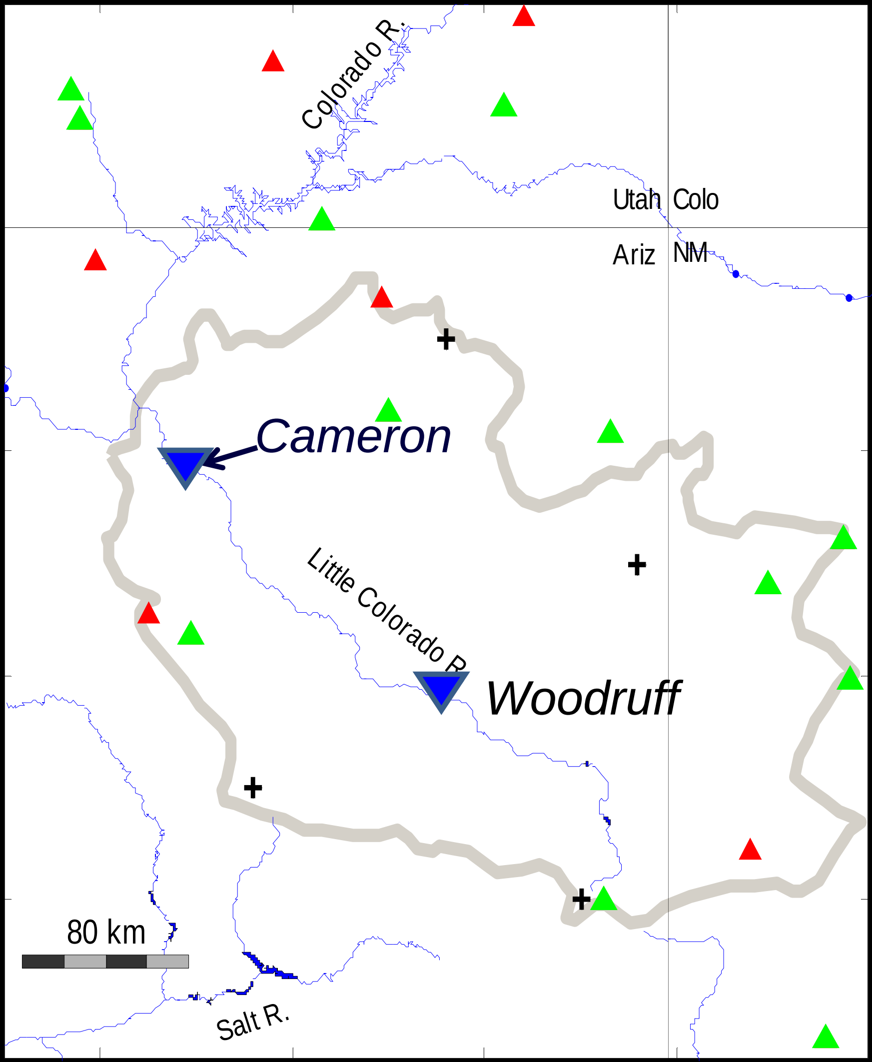
$$H_{SVT}L_{UPCO} = 2/444 = 0.0045$$



Upper Colorado River Basin
Salt-Verde-Tonto
1900
1925
1950
UCRB
SVT
1800
1825
1850
1875
UCRB
SVT
1700
1725
1750
1775
UCRB
SVT
1600
1625
1650
1675
UCRB
SVT
1525
1550
1575
LL
HH
8
14
22
11
13
14
11
8
11
11

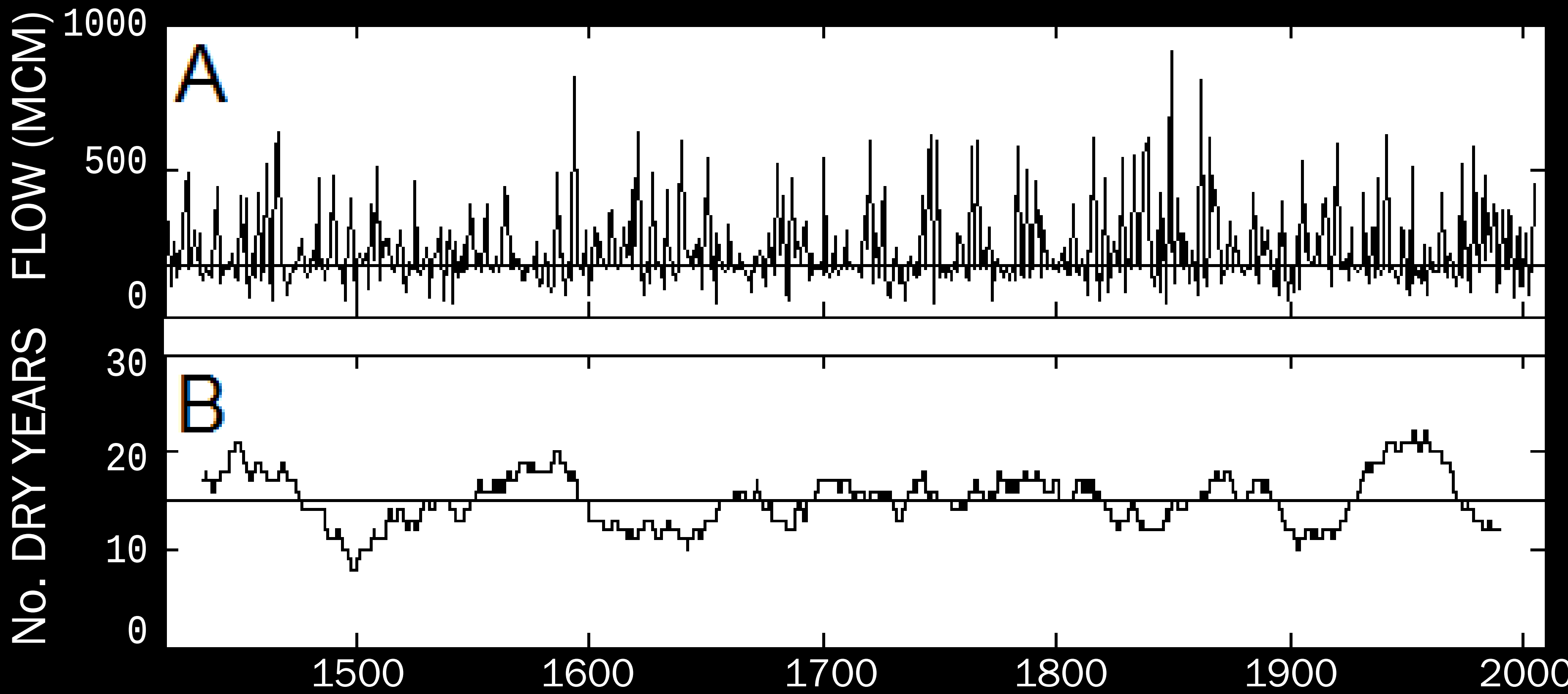
Period of Analysis 1521 – 1964	LL # events/# possible (probability)	HH # events/# possible (probability)
Individual 1-yr events	65/444 (0.15)	58/444 (0.13)
2 consecutive years	10/443 (0.023)	14/443 (0.032)
2 yrs (3-yr window)	22/442 (0.05)	29/442 (0.07)
2 yrs (4-yr window)	45/441 (0.10)	47/441 (0.11)

Little Colorado Streamflow Reconstruction



Accepted = Green (13)
Rejected = Red (6)

Model	No. Sites	R^2
1420-1983	8	0.55
1451-1982	5	0.57
1736-2004	1	0.26



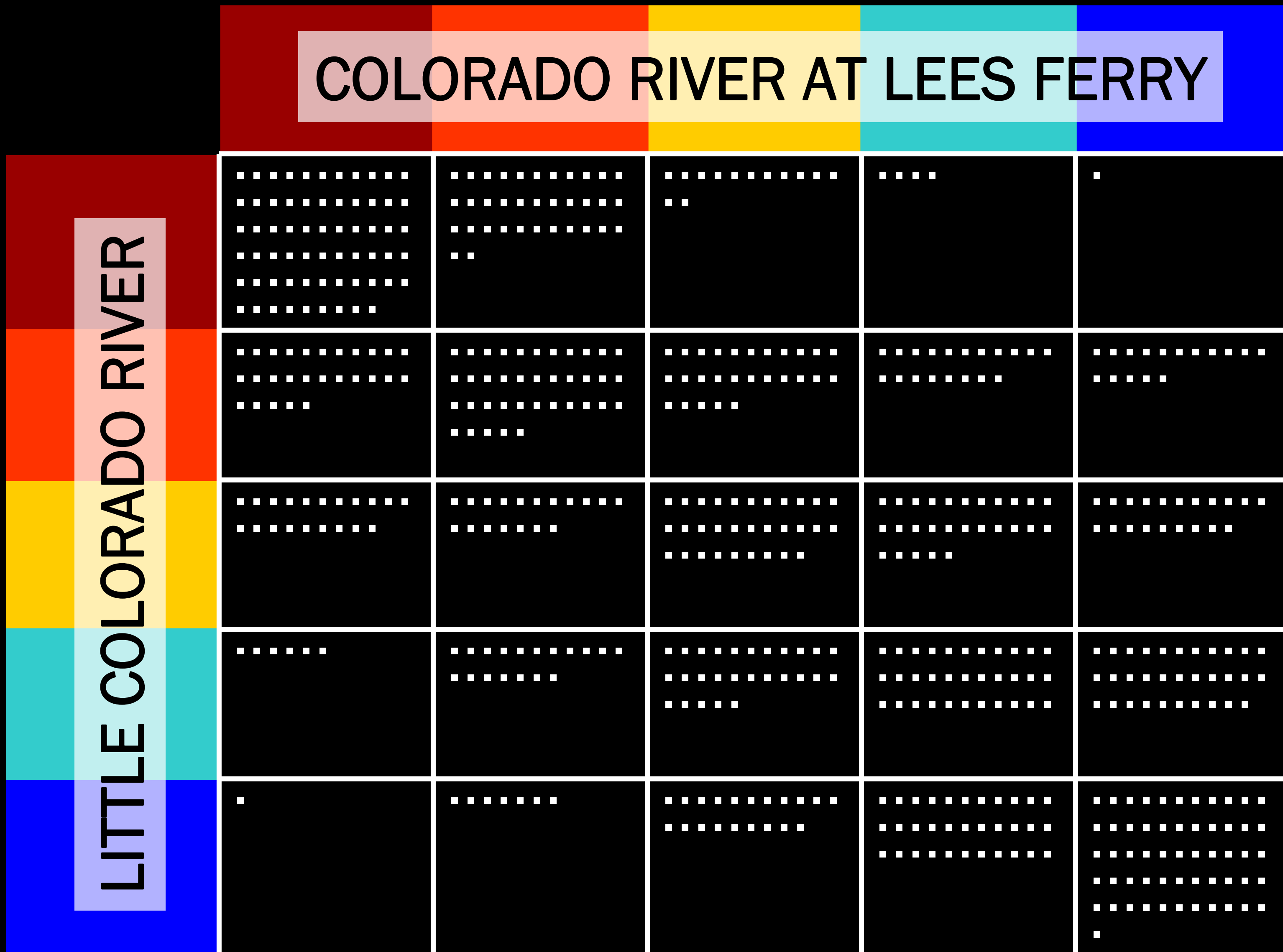
FLOW (MCM)
1000
500
0
A
No. DRY YEARS
30
20
10
0
B
1500
1600
1700
1800
1900
2000

Comparison II: Upper Colorado River Basin and Little Colorado

COLORADO RIVER AT LEES FERRY

LITTLE COLORADO RIVER

1420 - 2005

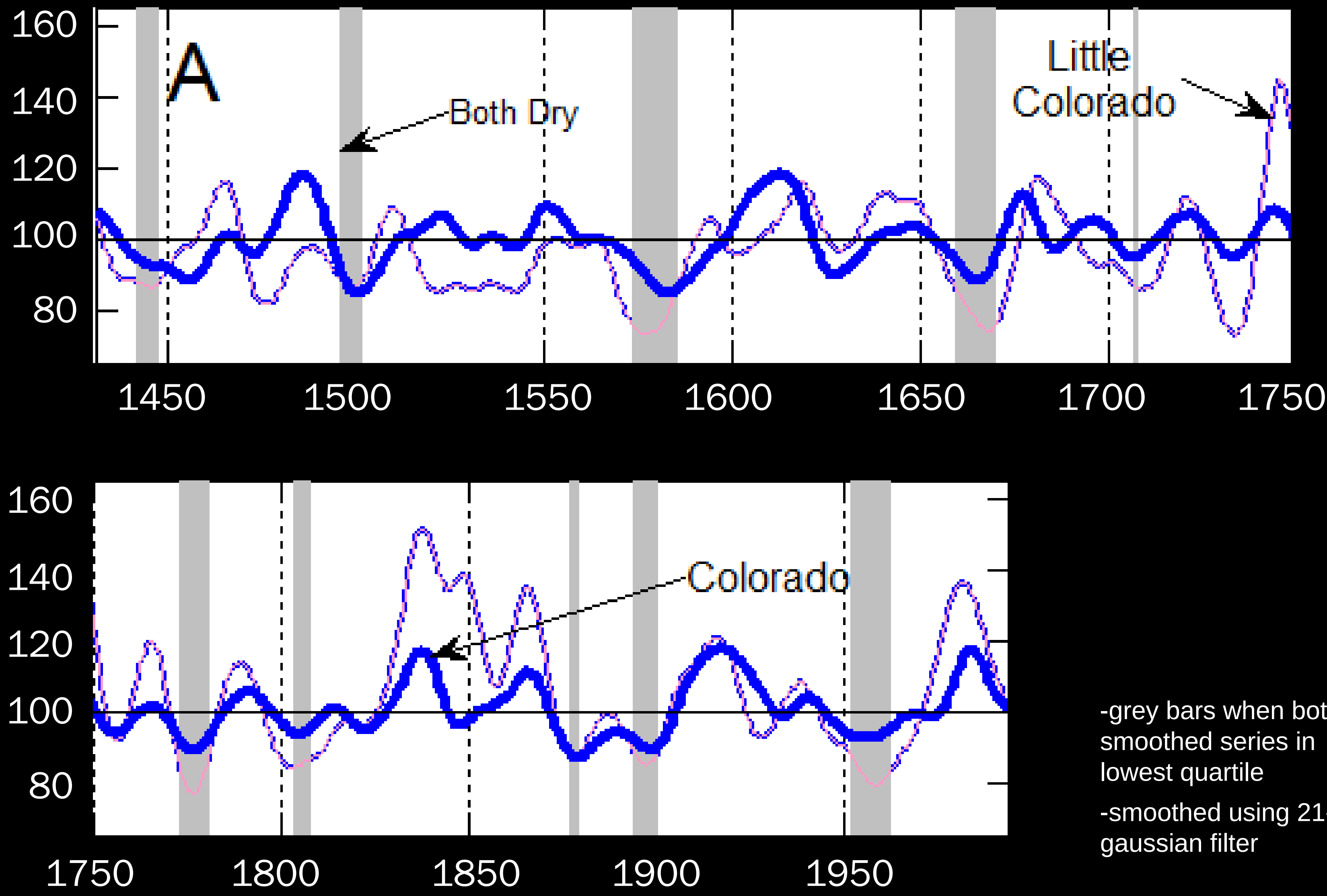

COLORADO RIVER AT LEES FERRY
LITTLE COLORADO RIVER

$LL = 64/586 = 0.11$

$HH = 56/586 = 0.10$

$H_{UPCO}L_{LiIC} = 1/586 = 0.0017$

$H_{LiIC}L_{UPCO} = 1/586 = 0.0017$



-grey bars when both smoothed series in lowest quartile

-smoothed using 21-yr gaussian filter

THE POTENTIAL OF PALEOFLOOD INFORMATION

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ADVANTAGES OF EXPLORING HOW FLOODS ARE REPRESENTED IN THE PALEORECORD

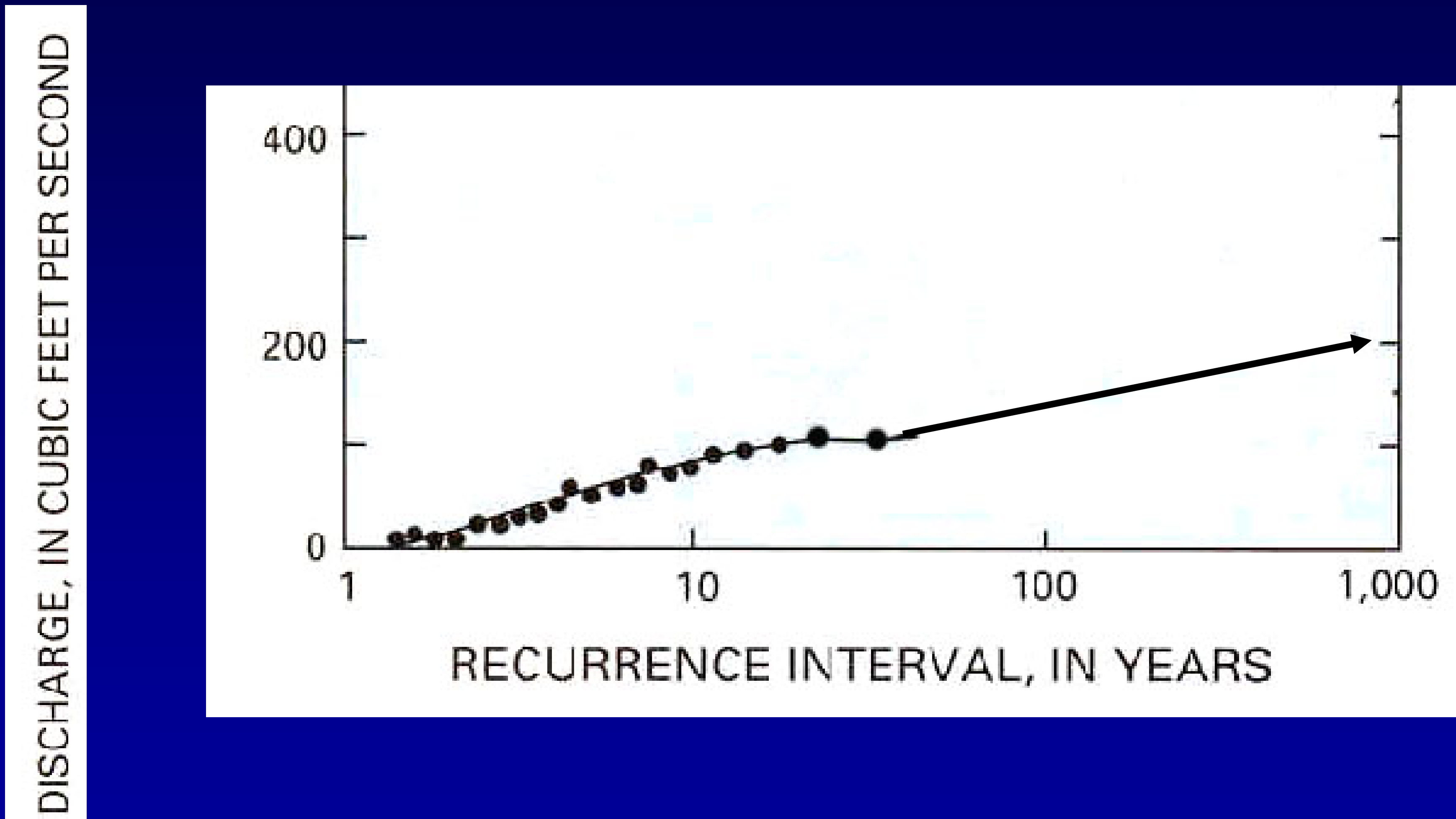
To fully understand flood variability, the longest record possible is the ideal . . .

<u>especially</u> to understand and evaluate <u>extreme</u> flooding!

By definition extreme events are rare . . .
hence gaged streamflow records capture only a recent sample of the full range of extremes that have been experienced by a given watershed.

Flood Frequency Analysis:

Straightforward extrapolation . . . .

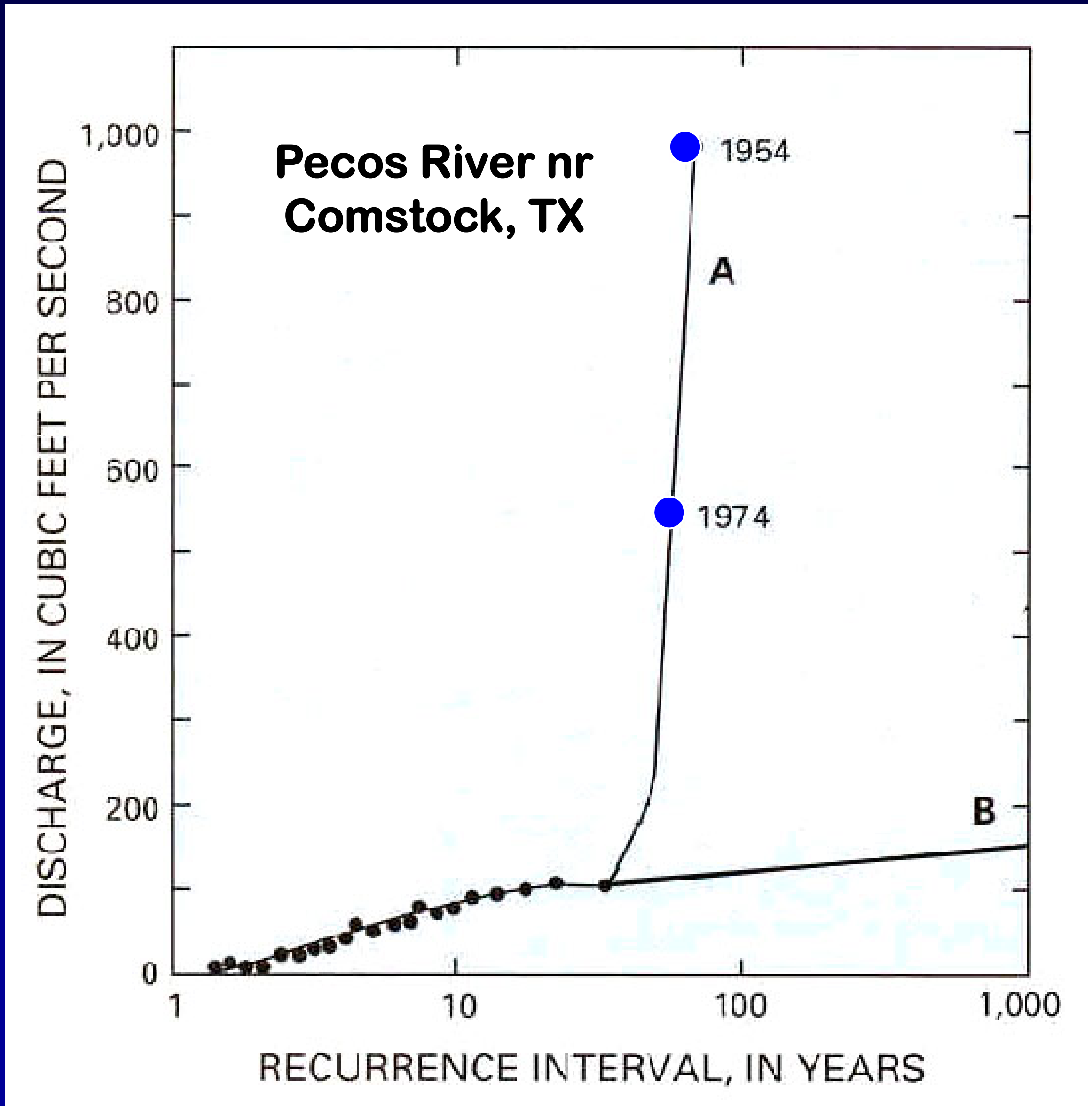


(SOURCE: modified from Jarrett, 1991 after Patton & Baker, 1977)

The Challenge of the "Upper Tails"

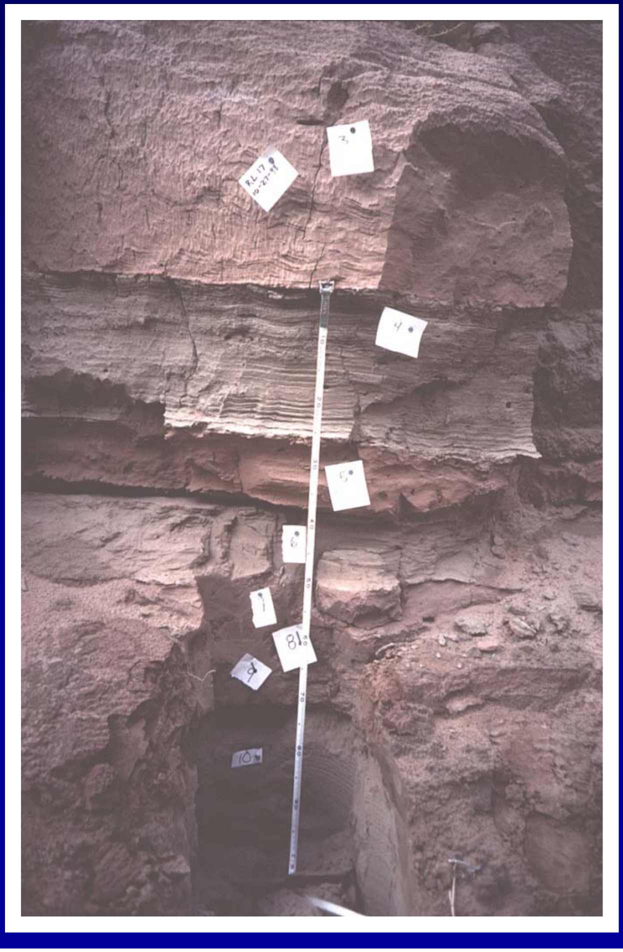
. . . can fail when "outlier" floods occur !

Curves A & B indicate the range (uncertainty) of results obtained by using conventional analysis of outliers for 1954 & 1974 floods.



SOURCE: modified from Jarrett, 1991, after Patton & Baker, 1977

Using Paleo-stage Indicators & Paleoflood Deposits . . .



-- ***direct*** physical evidence of extreme hydrologic events

-- selectively preserve evidence of only the <u>largest</u> floods . . .

. . . this is precisely the information that is lacking in the short gaged discharge records of the observational period

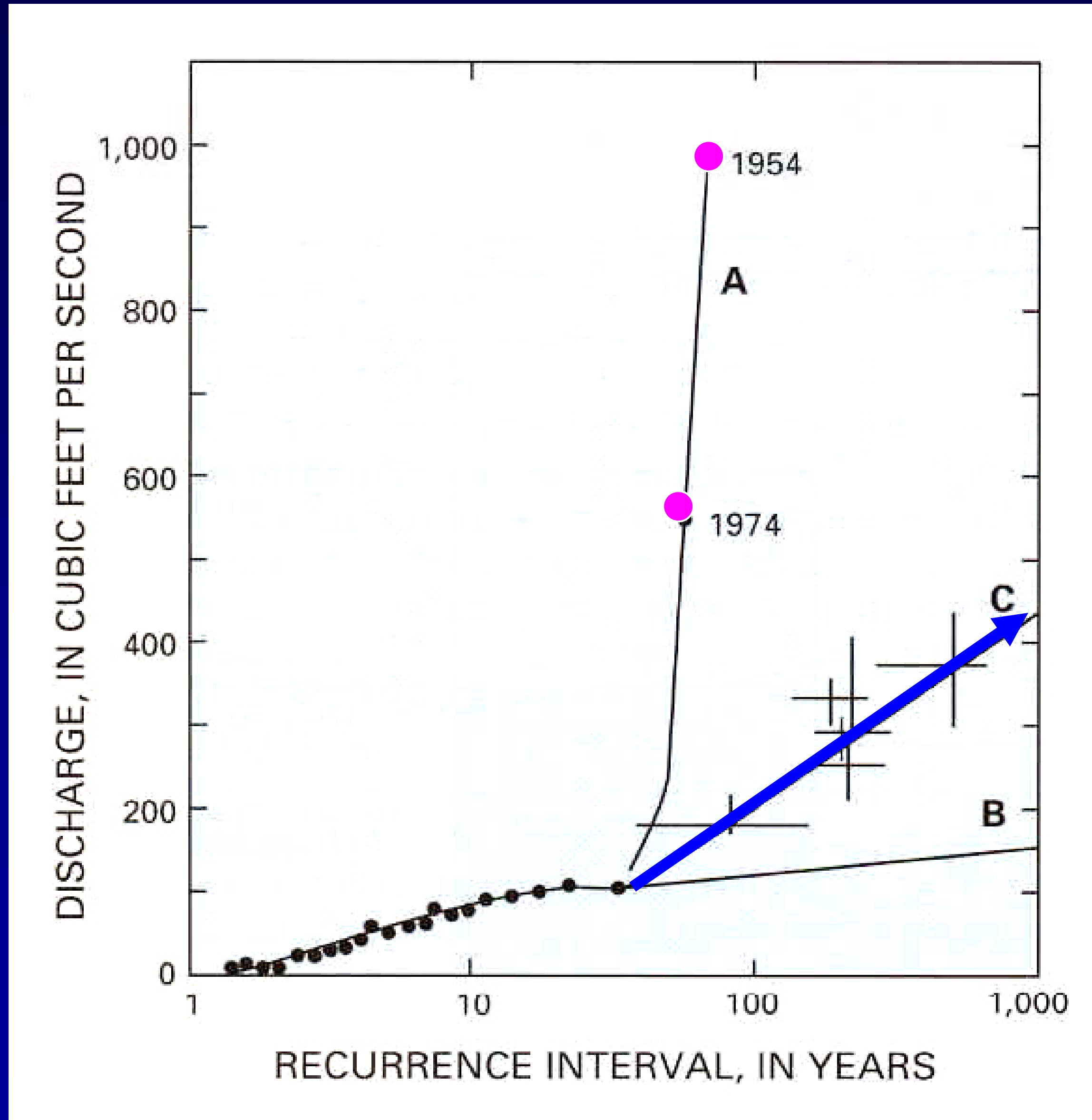
- Paleoflood evidence provides information about the upper discharge and stage limits of the most extreme floods (and by inference, the flood-generating precipitation) and their likely return periods.
- this type of information is not available in any other source of paleoenvironmental data.

(SOURCE: Jarrett, 1991 after Patton & Baker, 1977)

Flood Frequency Analysis

Curves A & B indicate range (uncertainty) of results obtained by using conventional analysis of outliers for 1954 & 1974 floods.

Curve C is from analyses of paleoflood data.

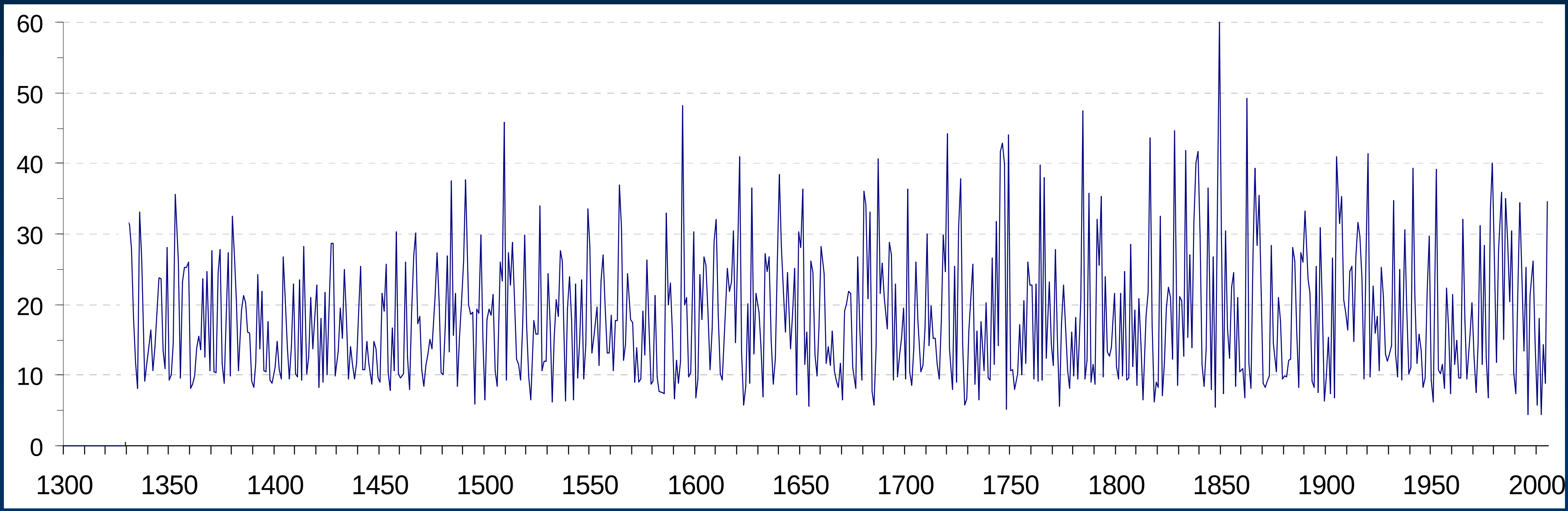


| Q (discharge) uncertainty

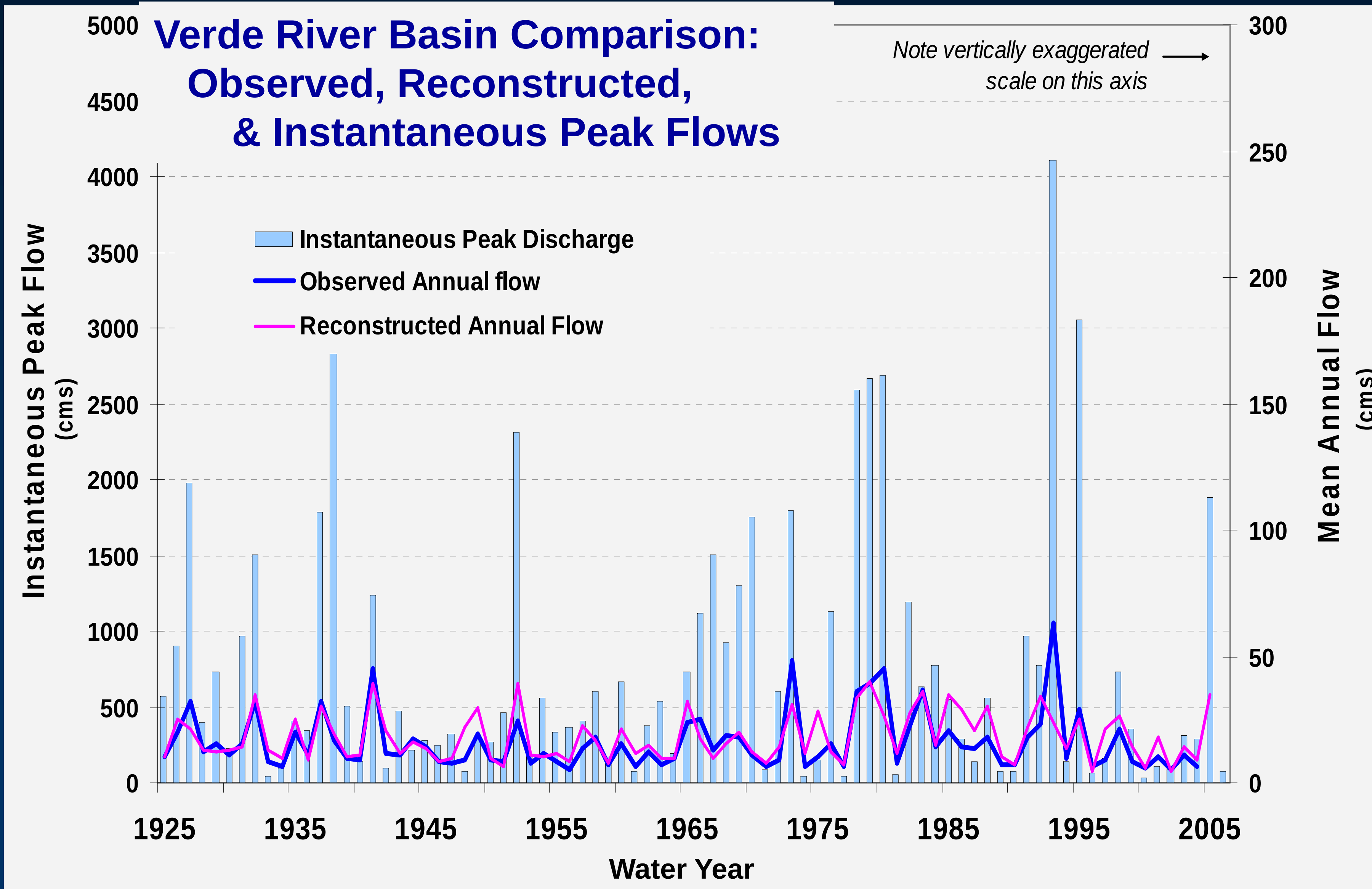
— R.I. uncertainty

Key question:

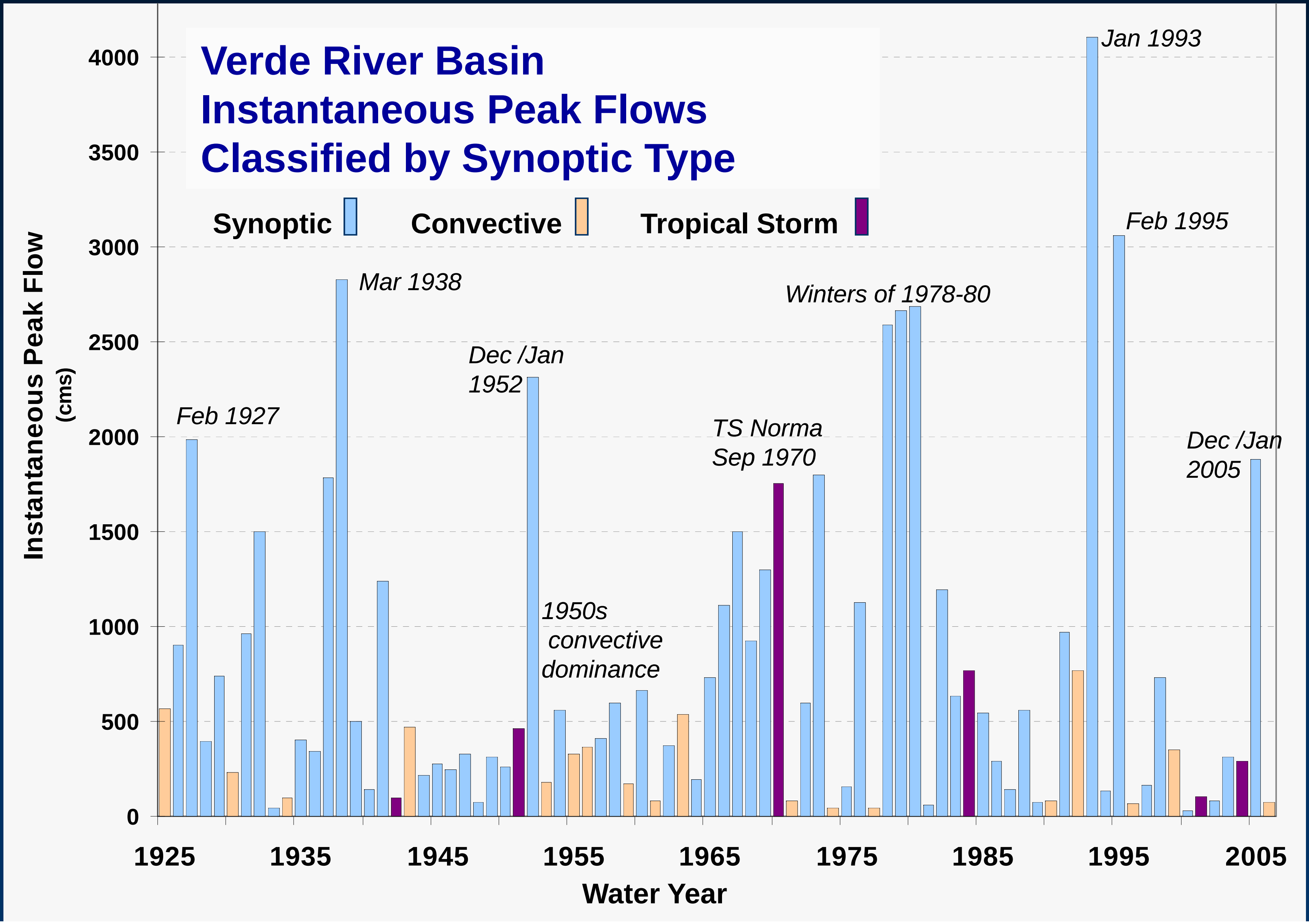
Are extreme floods and peak flows identifiable in a Tree-Ring Reconstruction?



Process-based evaluation of relationship between mean annual flow & instantaneous peaks

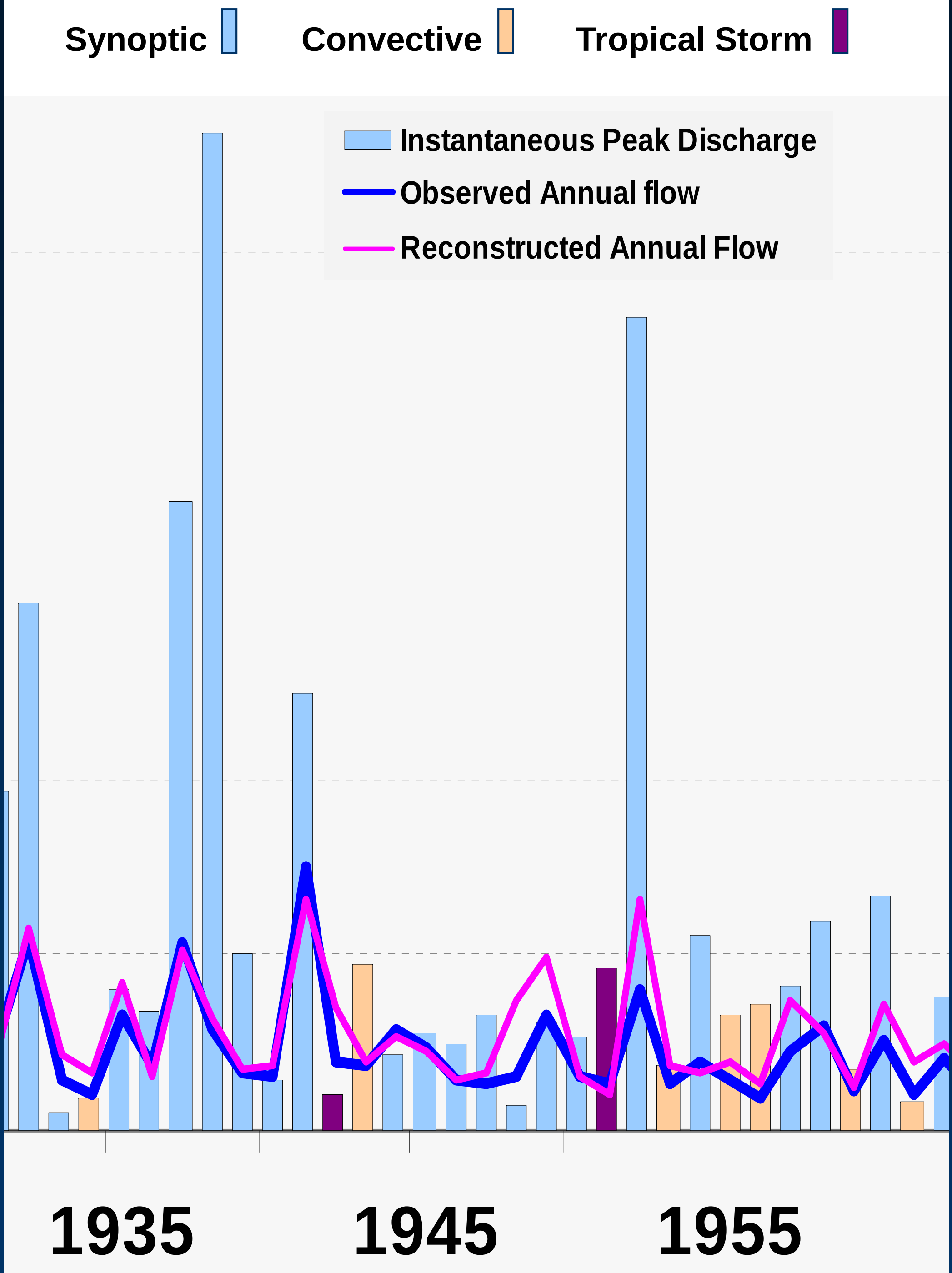


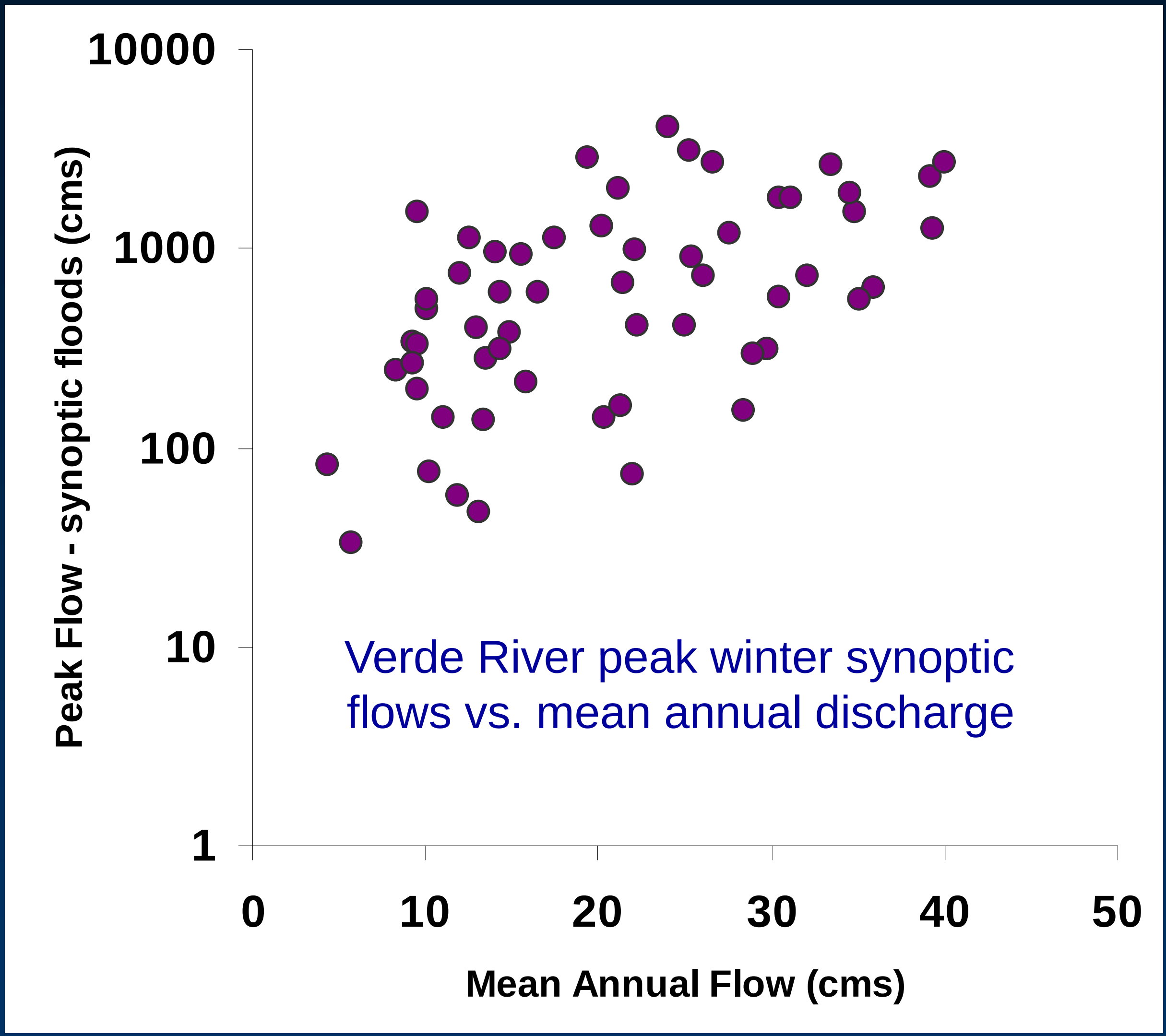
Flood Hydroclimatology Approach



. . . analyzing the reconstruction mechanistically

Both reconstructed & observed annual flows track the magnitude of the instantaneous peak better during synoptic (winter) events





10000
1000
100
10
1
0
10
20
30
40
50
Peak Flow - synoptic floods (cms)
Mean Annual Flow (cms)
Verde River peak winter synoptic
flows vs. mean annual discharge

Not all Paleofloods are“Paleo” . . .

- PALEOFLOOD

A past or ancient flood event which occurred prior to the time of human observation or direct measurement by modern hydrological procedures.

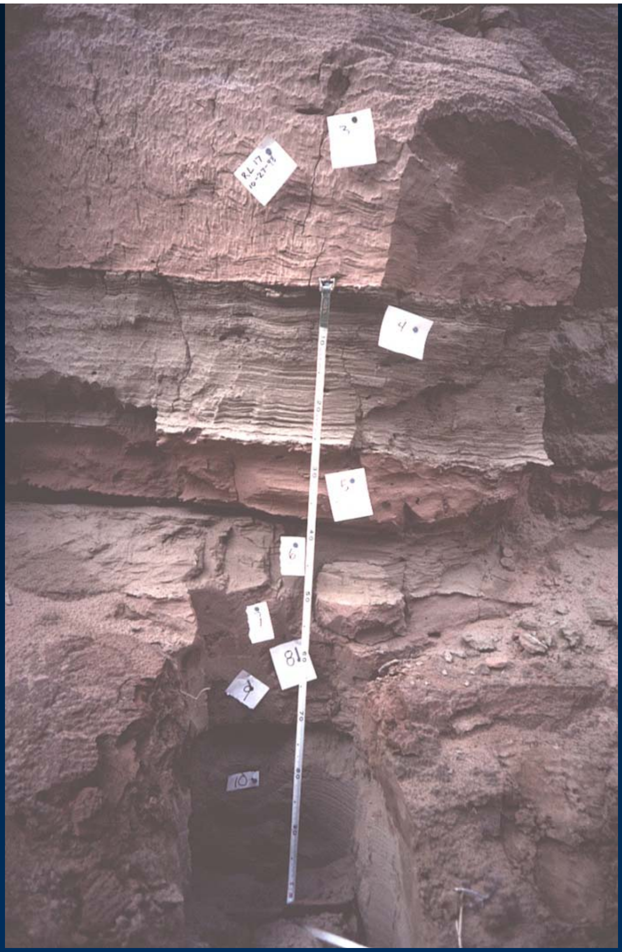
- HISTORICAL FLOOD

Flood events documented by human observation and recorded prior to the development of systematic streamflow measurements

- EXTREME FLOODS IN UNGAGED WATERSHEDS

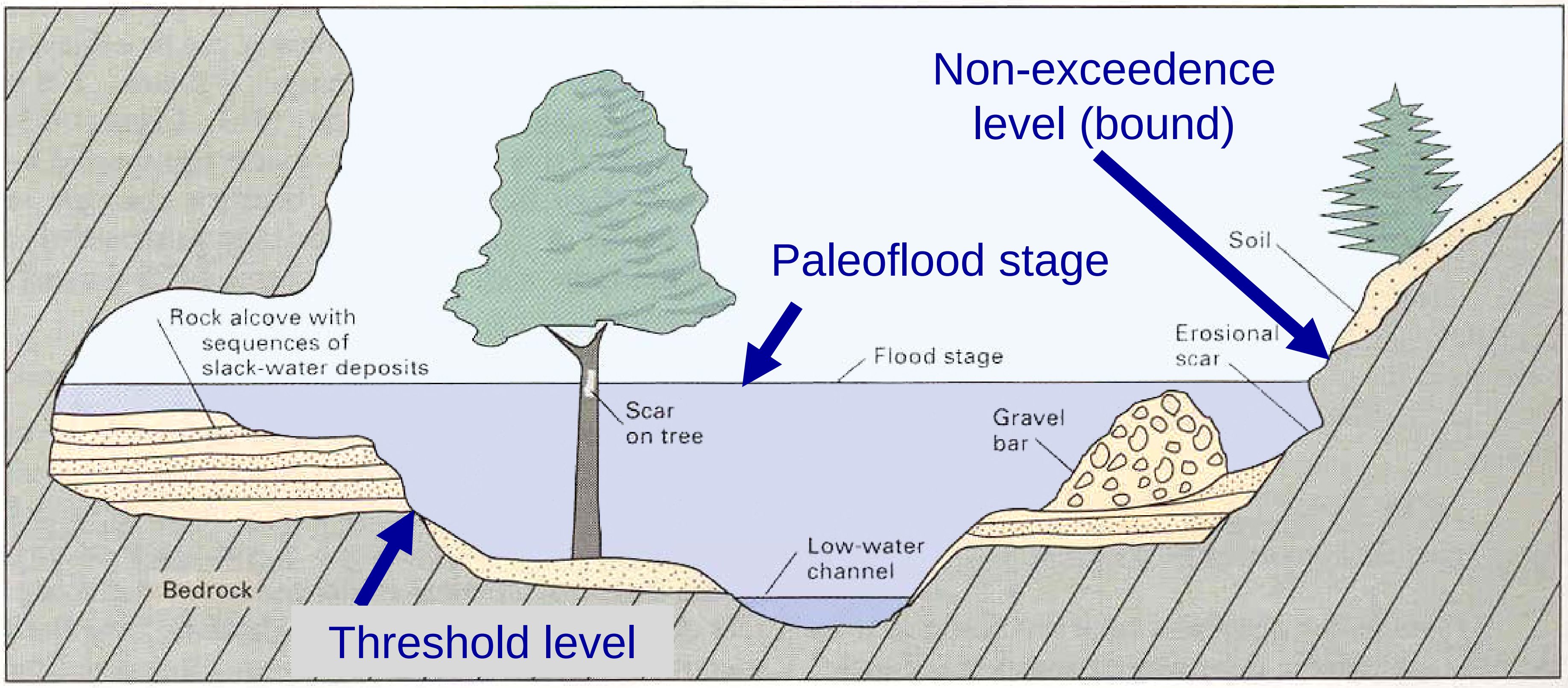
For comparison & benchmarks:
GAGED HYDROLOGICAL RECORDS *are also included*

Unlike systematic gaged data, paleoflood information is collected and reported in different ways, leading to different "data types" . . .



- Paleofloods (w/ stage +/or discharge)
- Thresholds
- Non-exceedence bounds

Paleoflood data types:



Diagrammatic section across a stream channel showing a flood stage and various features

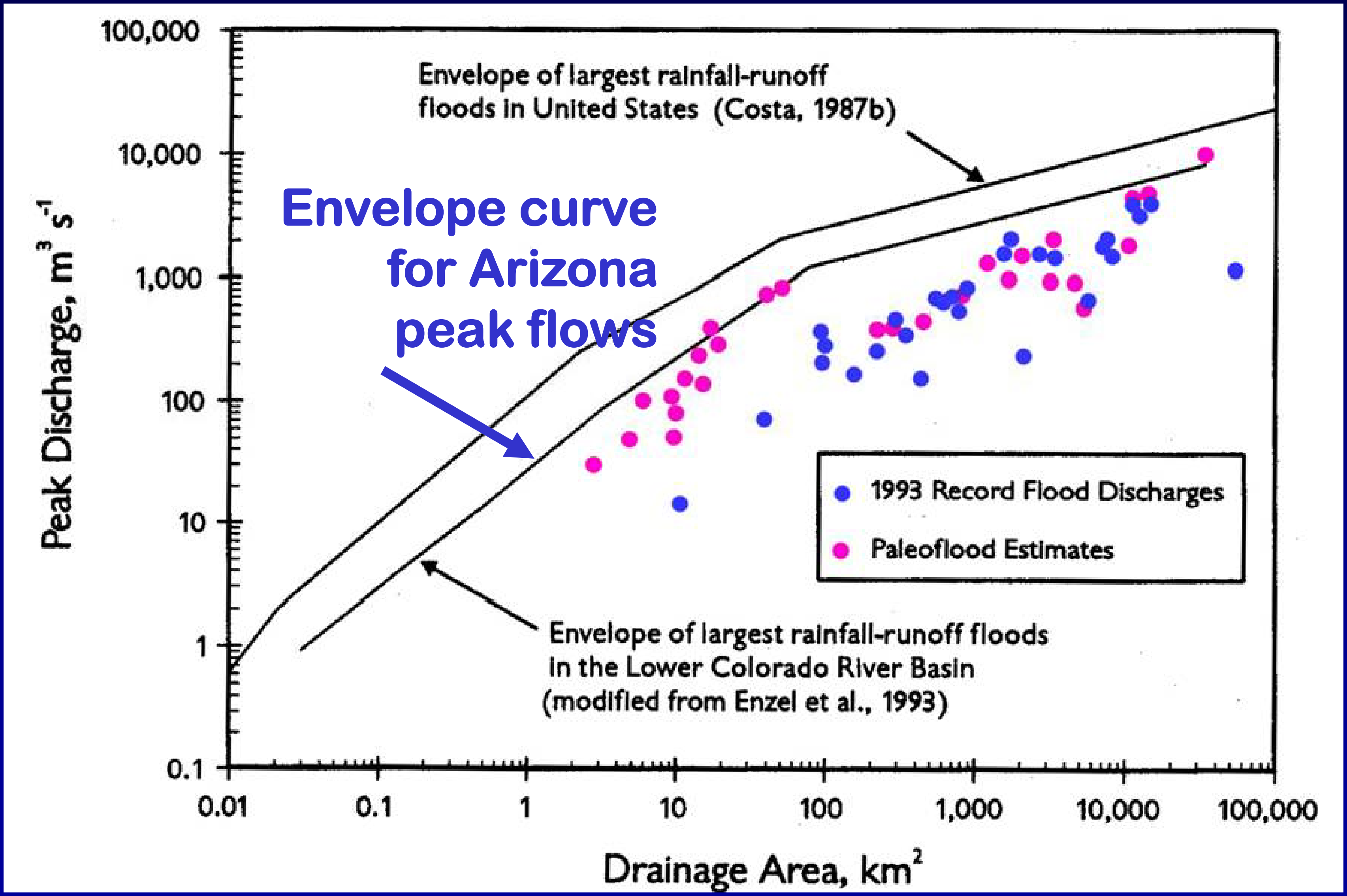
(Source: Jarrett 1991, modified from Baker 1987)

Paleoflood = discrete flood / paleoflood stage or discharge estimate

Threshold = a stage or discharge level below which floods are not preserved; only floods which overtop the threshold level leave evidence; smaller events not preserved (over specific time interval)

Non-exceedence bound = a stage or discharge level which has either never been exceeded, or has not been exceeded during a specific time interval

Compilations of paleoflood records combined with gaged records suggest there is a natural, upper physical limit to the magnitude of floods in a given region --- will this change?



- **Are paleoflood data useful for water management planning?**

- **What format would be the most useful?**

- **Intriguing question is how much peak events influence the annual (or seasonal) flow reconstructed through tree rings.**