DROUGHT, THE COLORADO RIVER, AND GRAND CANYON RESOURCES

Robert H. Webb [1]
Gregory McCabe
Richard Hereford

[1] U.S. Geological Survey
520 N. Park Avenue
Tucson, Arizona 85745
rhwebb@usgs.gov

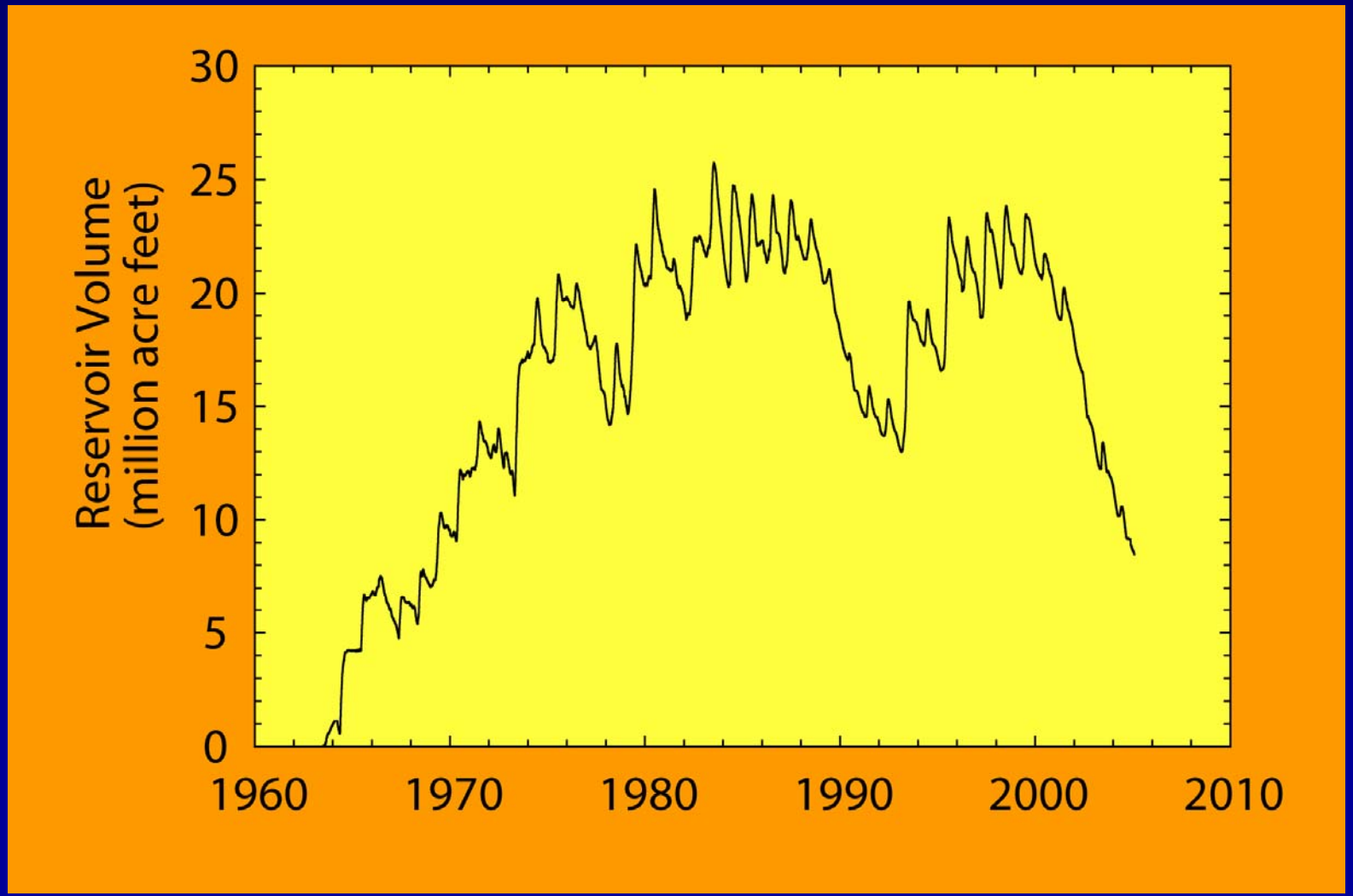
CURRENT CONDITIONS IN LAKE POWELL

- On January 27, the level of Lake Powell was at 3,562.5 feet (full pool capacity is 3,700 feet)
- The reservoir held 8.51 maf of storage (35% of capacity)
- That reservoir capacity represents 1.03 years of normal annual flow releases

Lake Powell Delta

Declines in lake level created an emergent delta. Many marinas on Lake Powell are now unusable. Large amounts of deltaic sediments are either mobilized or rearranged in the emergent reaches.

CURRENT CONDITIONS IN LAKE POWELL



CURRENT CONDITIONS IN THE LOWER BASIN

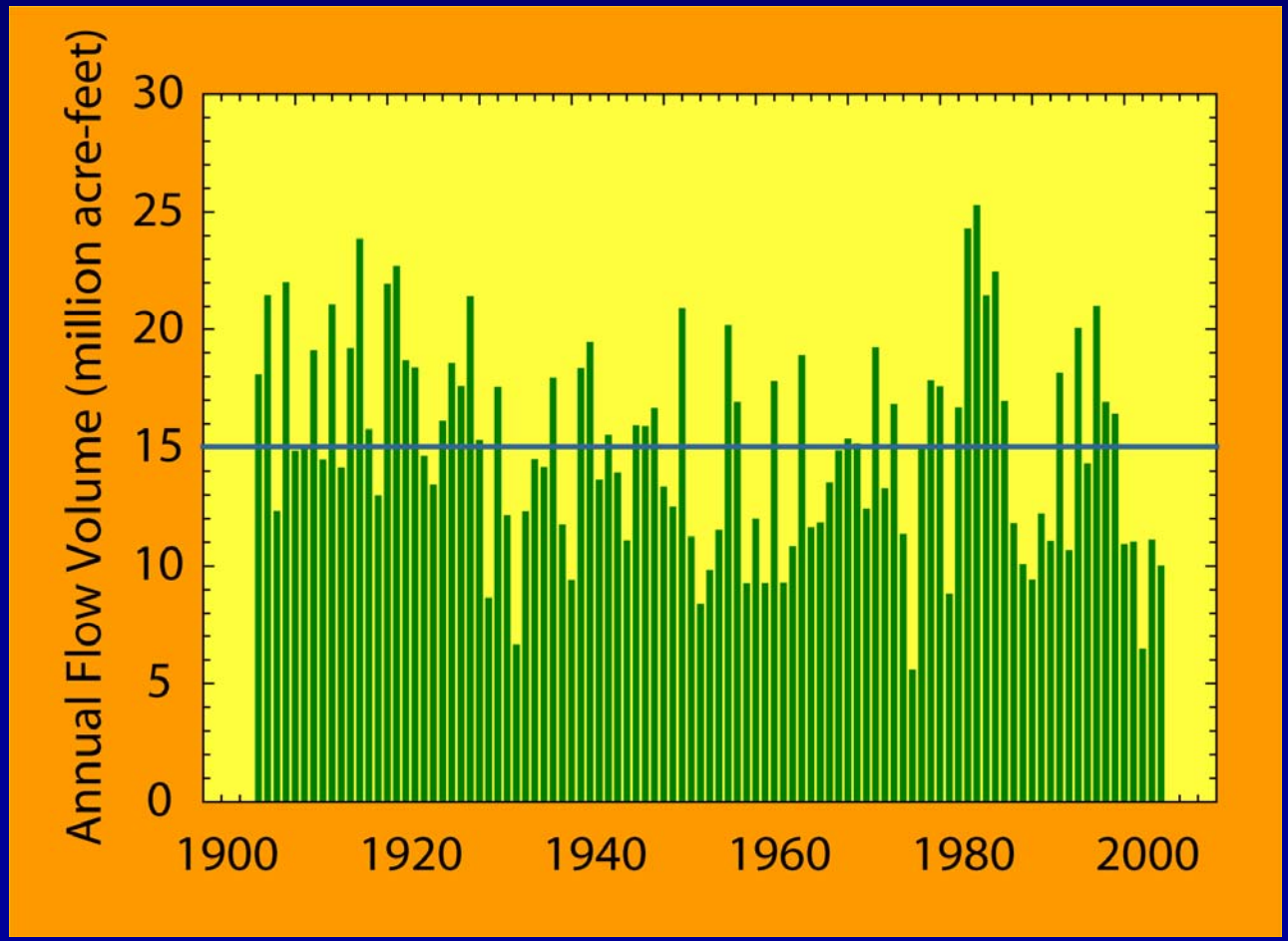
- Lake Mead is at its lowest level since the 1960s.
- Lower-basin states are being forced to consider or enact water conservation measures (*e.g.*, Las Vegas).
- Department of Interior negotiates the Colorado River Water Delivery Agreement (October 16, 2003) requiring California to stay within its 4.4 MAF allocation originally negotiated in 1929.

CONDITIONS IN THE COLORADO RIVER DRAINAGE

- Inflows to Lake Powell between about 2000 and 2004 were low and unprecedented in the 20th century
- Whether "natural flow" – corrected for consumptive uses upstream – or actual flows are used, the recent drought is the most severe in the 20th century

COLORADO RIVER FLOWS

"Natural" flow – corrected for consumptive uses (Reclamation)



Average annual flow volume: 15.03 MAF

HOW SEVERE WERE 2001-2004 CONDITIONS? (“Natural flow”)

Lowest Flow Years

Year	Volume (MAF)
1977	5.57
2002	6.44
1934	6.63
1954	8.37
1931	8.63

3-Year Average

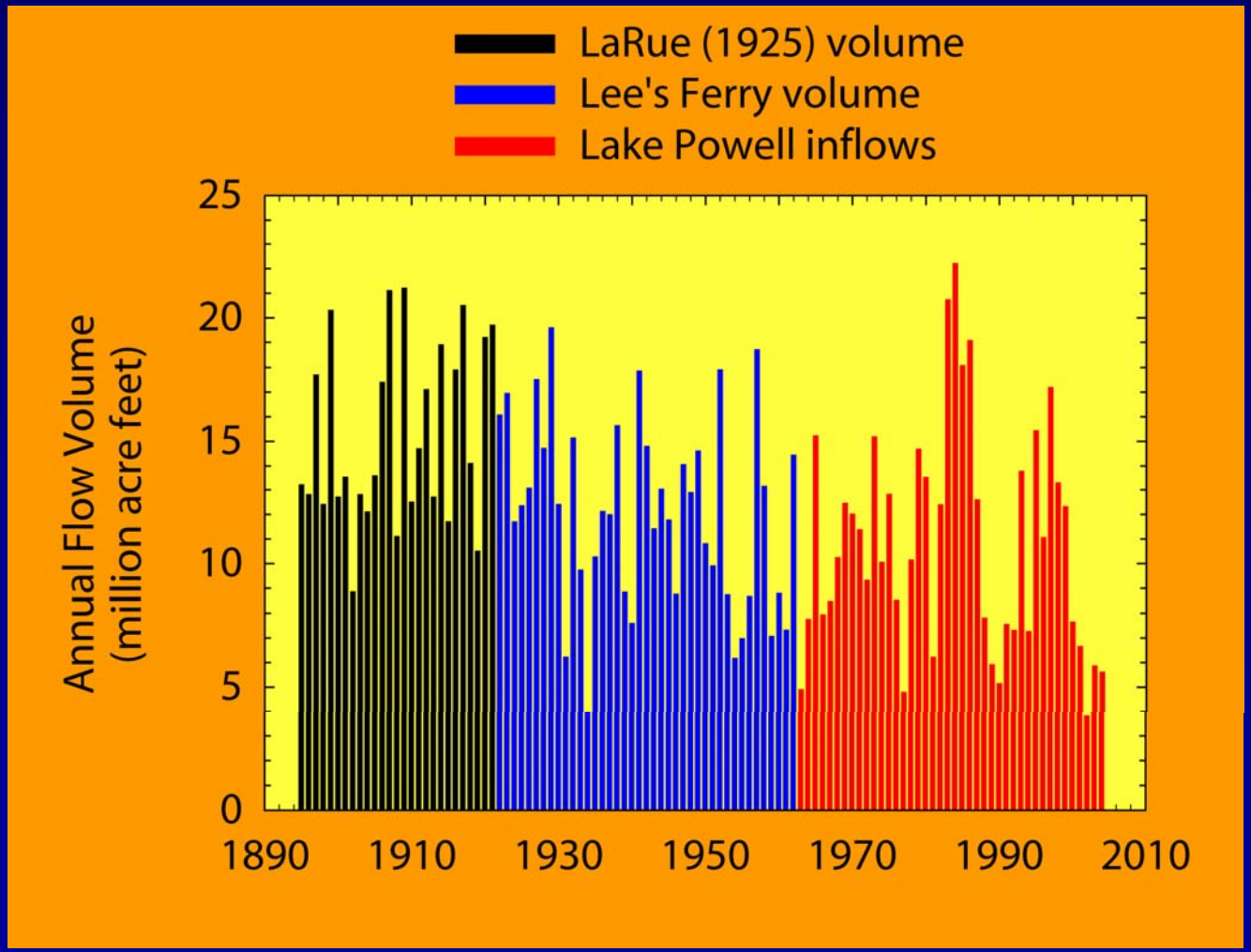
Year	Volume (MAF)
2003	9.18
2001	9.45
2002	9.51
1954	9.79
1955	9.89

5-Year Average

Year	Volume (MAF)
2002	9.89
1990	10.89
2001	11.17
1933	11.44
1961	11.50

COLORADO RIVER FLOWS

Actual flow – not corrected for consumptive uses



Average annual flow volume: 12.34 MAF

HOW SEVERE WERE 2001-2004 CONDITIONS? (actual flow)

Lowest Flow Years

Year	Volume (MAF)
2002	3.80
1934	3.95
1977	4.79
1963	4.89
1990	5.14

3-Year Average

Year	Volume (MAF)
2003	5.08
2002	5.44
2001	6.03
1990	6.20
1989	6.28

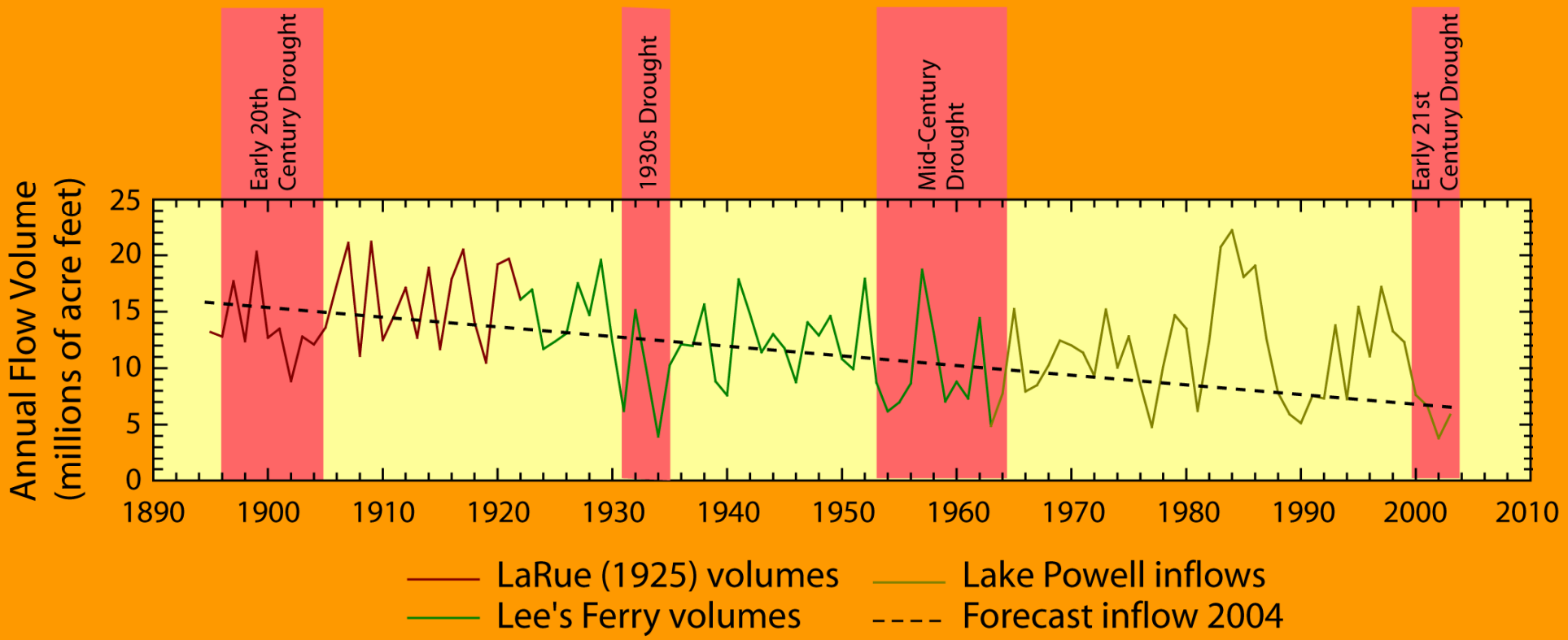
5-Year Average

Year	Volume (MAF)
2002	5.91
1990	6.74
2001	7.25
1989	7.80
1991	7.94

TRENDS IN RIVER FLOWS

- Regressions of volume versus time are poor for both “natural” and actual flows
- Trend in “natural” flow is a decrease of 0.35 MAF per decade, 1905-2004
- Trend in actual flows is a decrease of 0.5 MAF per decade, 1895-2004
- Both records are highly affected by the wet period from 1906 through 1920

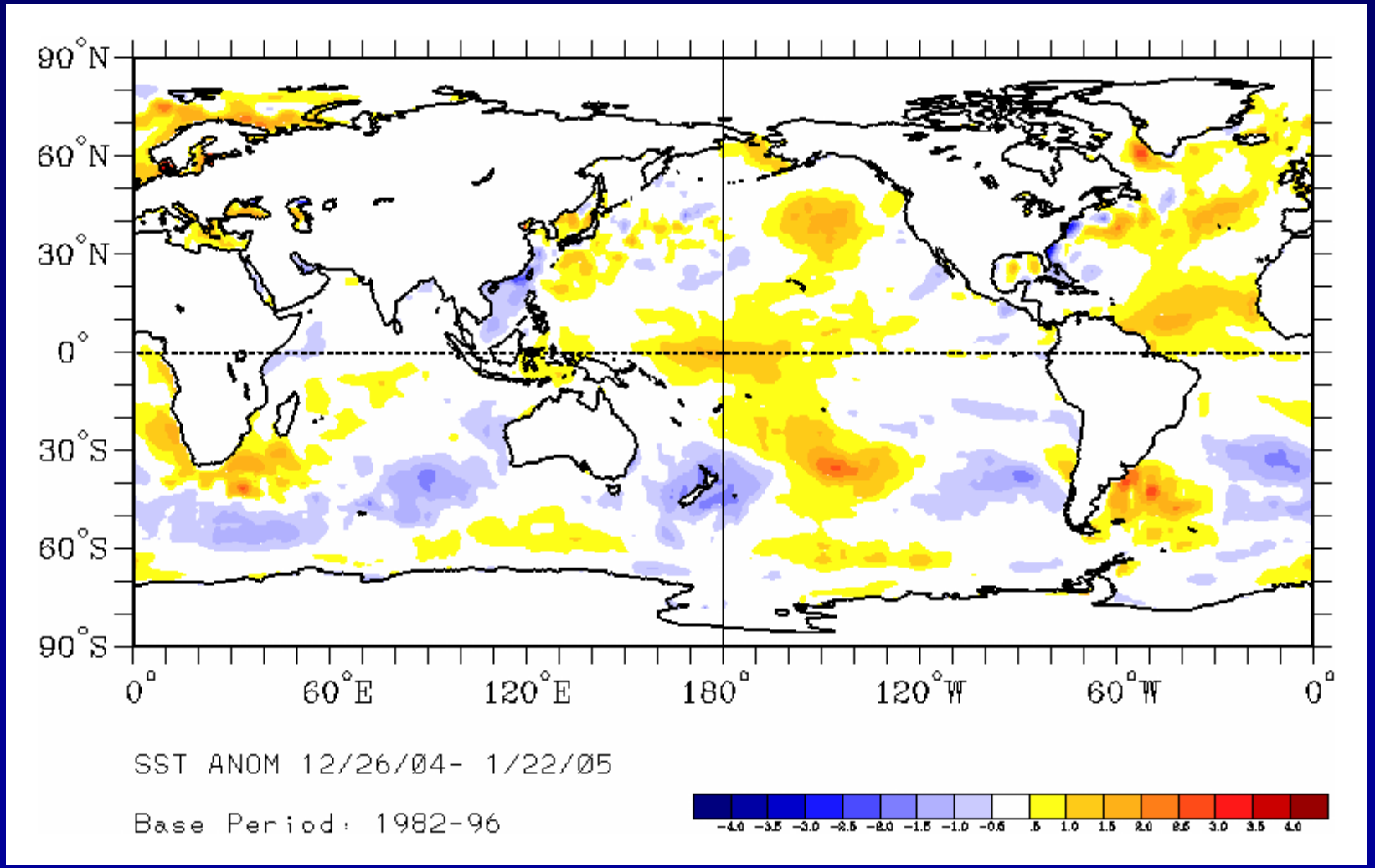
TRENDS IN ACTUAL FLOW RECORD



CURRENT WATERSHED CONDITIONS IN THE COLORADO RIVER DRAINAGE

- At the end of January, the snowpack averaged over the watershed was 125% of normal.
- The snowpack was higher in the southern and western parts of the watershed.
- Once again, initial inflow estimates (78% of normal) appear to be seriously off.

EL NINO IN THE PACIFIC OCEAN



MOISTURE SOURCES TO THE COLORADO RIVER DRAINAGE

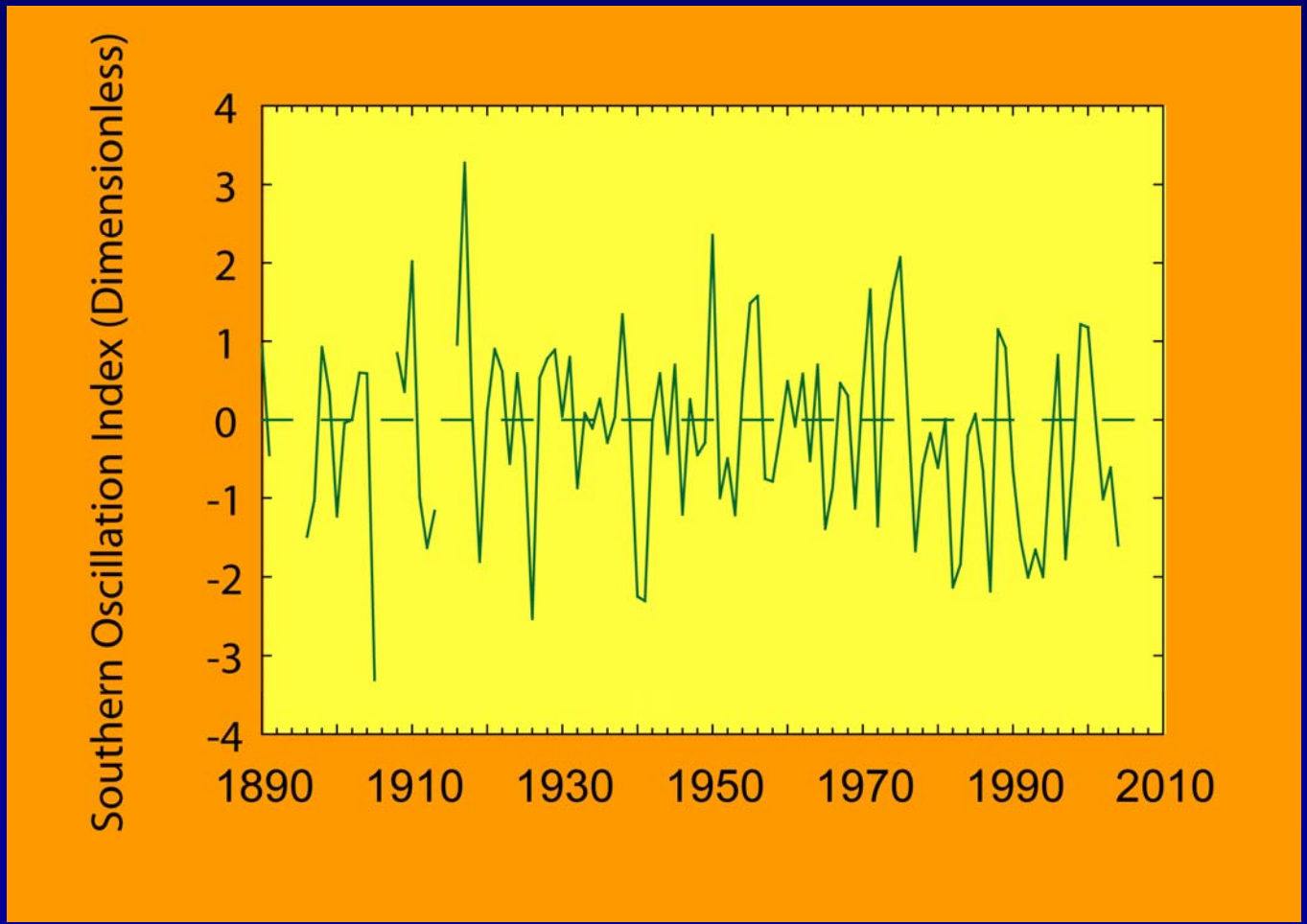
HYDROCLIMATOLOGY OF THE COLORADO RIVER

- Because of its large size and geographic position, the Colorado River defies simple hydroclimatic analysis
- This basin integrates a large variety of climatic signals

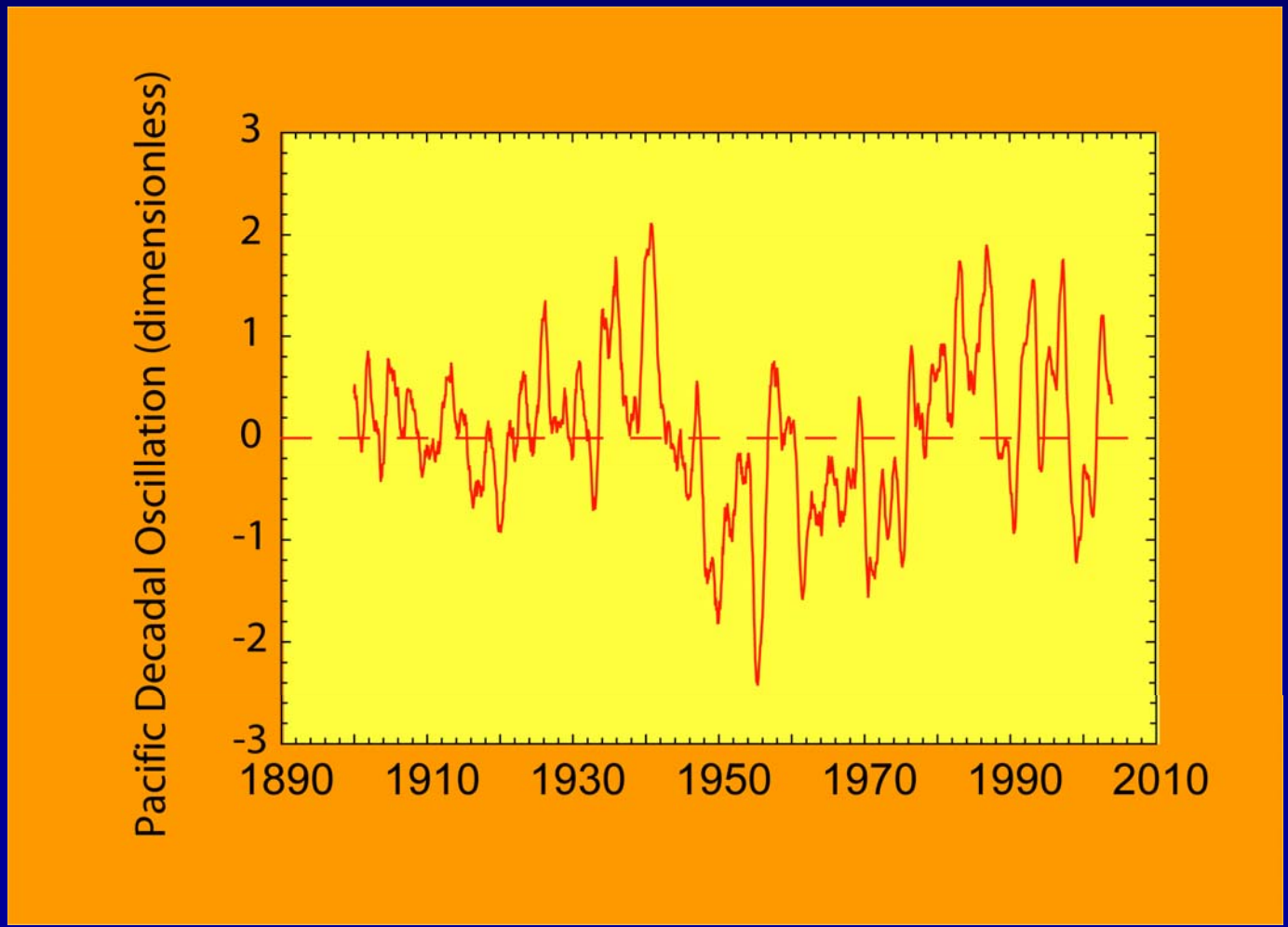
HYDROCLIMATOLOGY OF THE COLORADO RIVER

- Monthly influences: Madden-Julian Oscillation (MJO)
- Interannual influences: El Nino – Southern Oscillation (ENSO)
- Corollaries: Multivariate ENSO Index (MEI)
- Interdecadal influences: Pacific Decadal Oscillation (PDO)
- Long-term: Atlantic Multidecadal Oscillation (AMO)

EL NINO AND THE SOUTHERN OSCILLATION (ENSO)



PACIFIC DECADAL OSCILLATION



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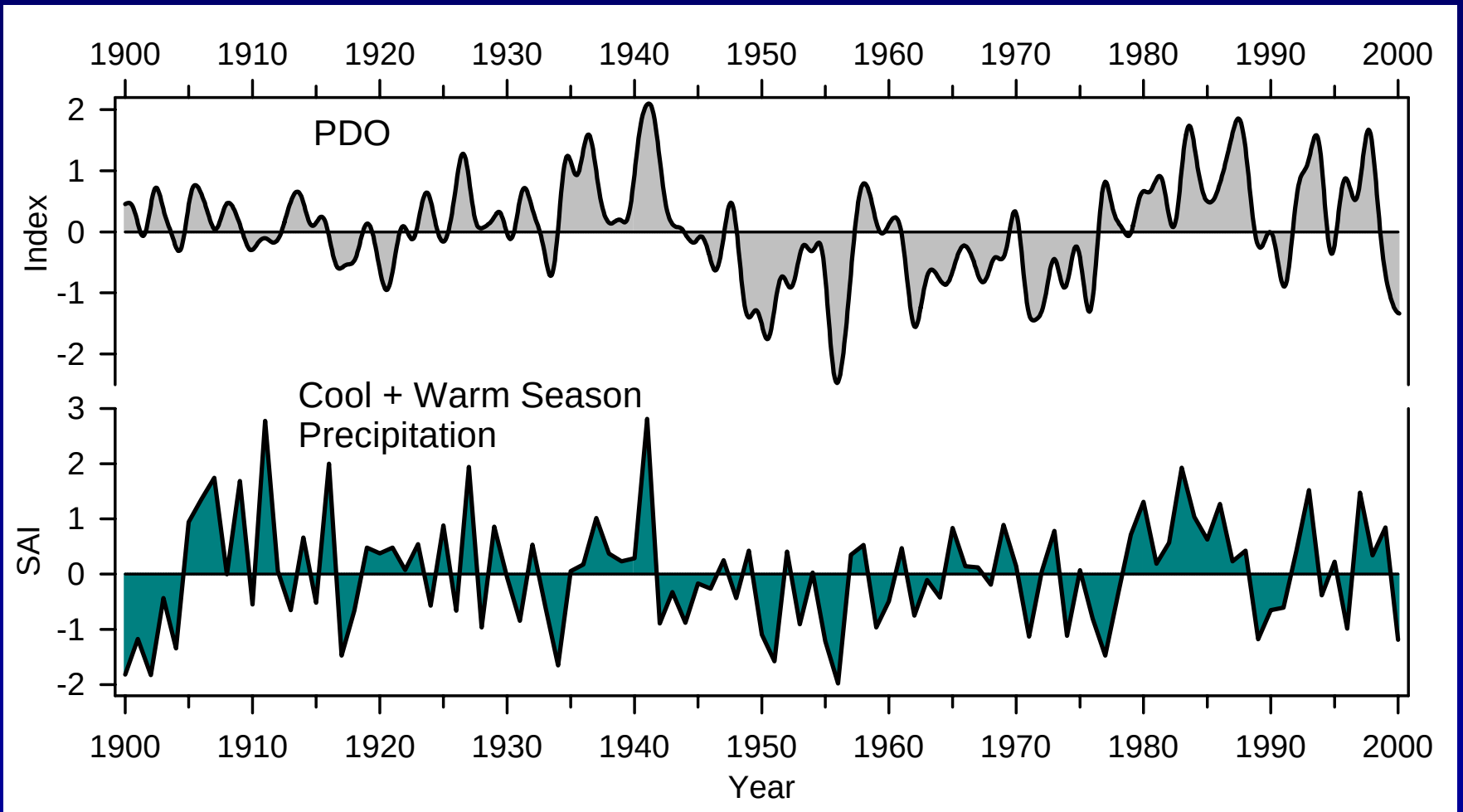
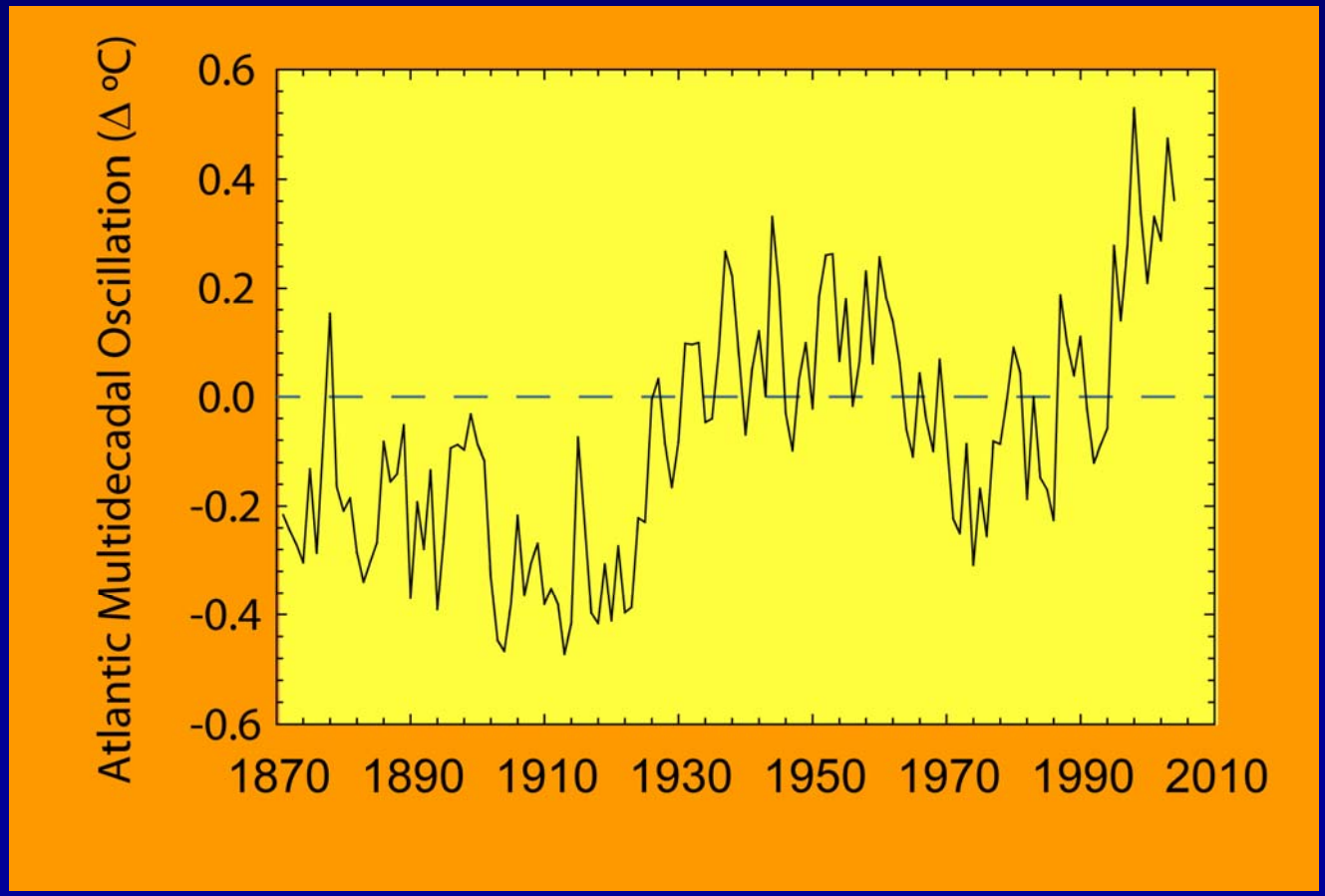
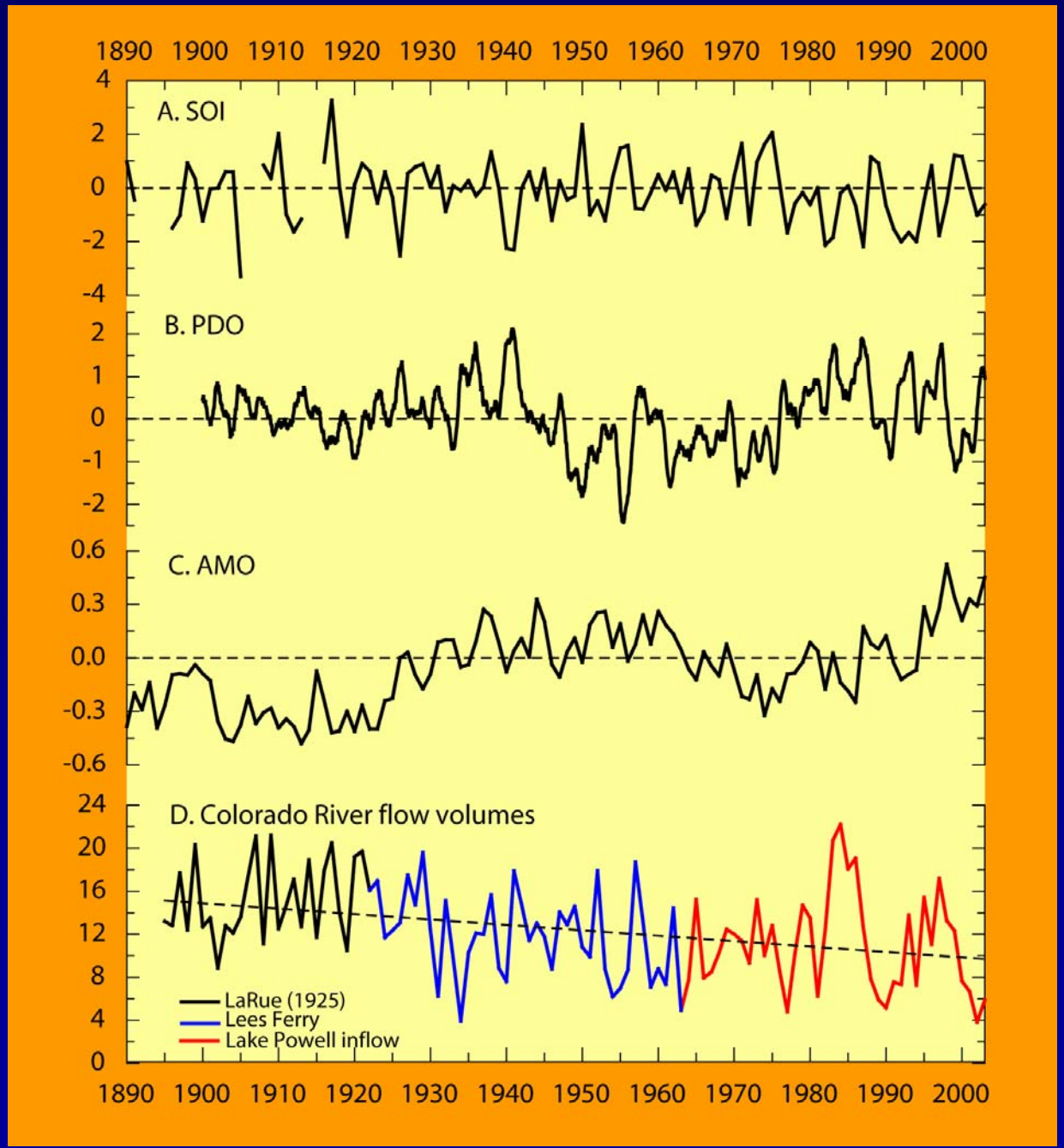


Ref: Hereford et al. (2002)

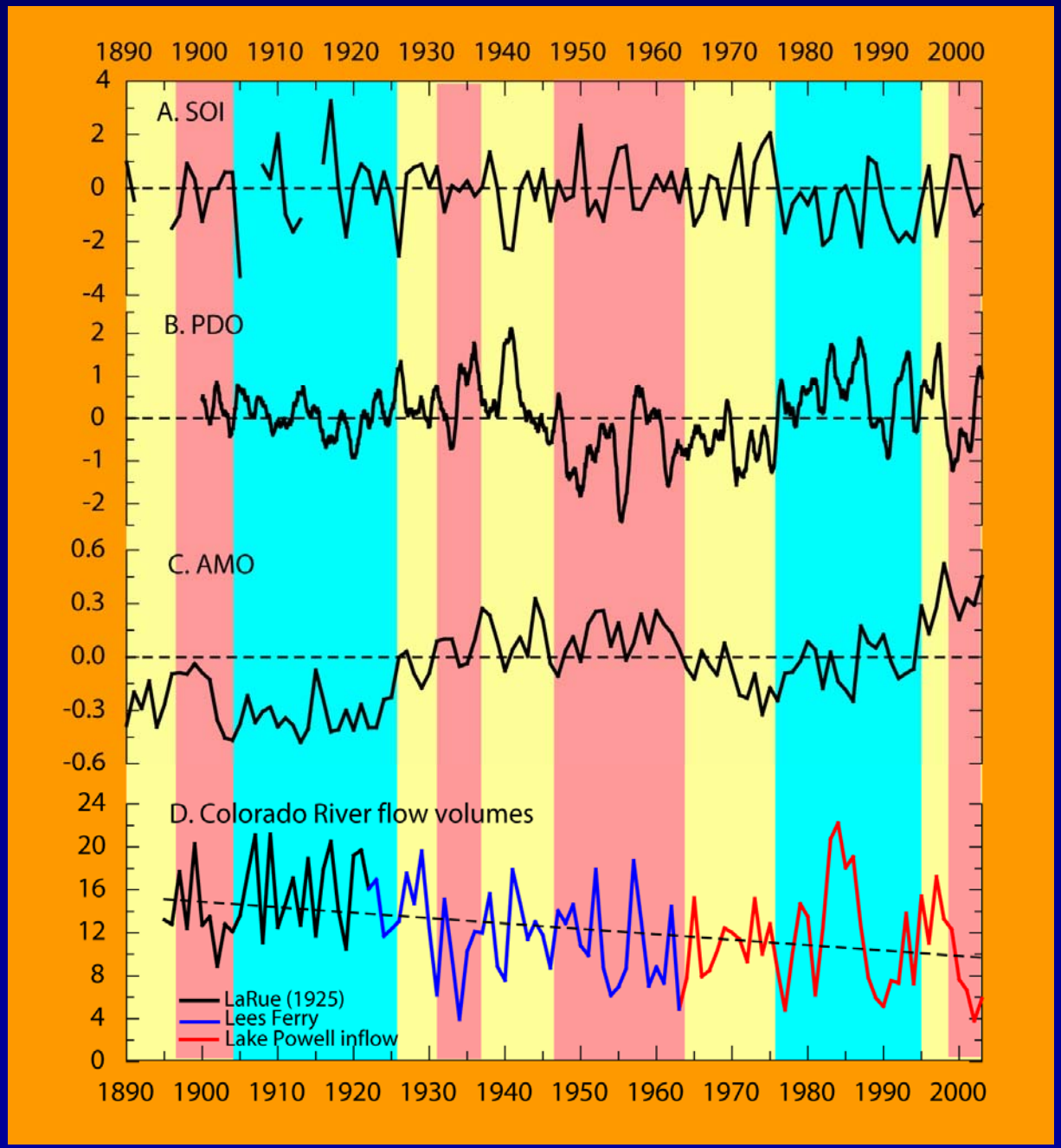
ATLANTIC MULTIDECADAL OSCILLATION





CLIMATIC VARIABILITY AND RIVER FLOW

There is no significant statistical relation among indices of climatic variability and Colorado River at Lee's Ferry or entering Lake Powell.



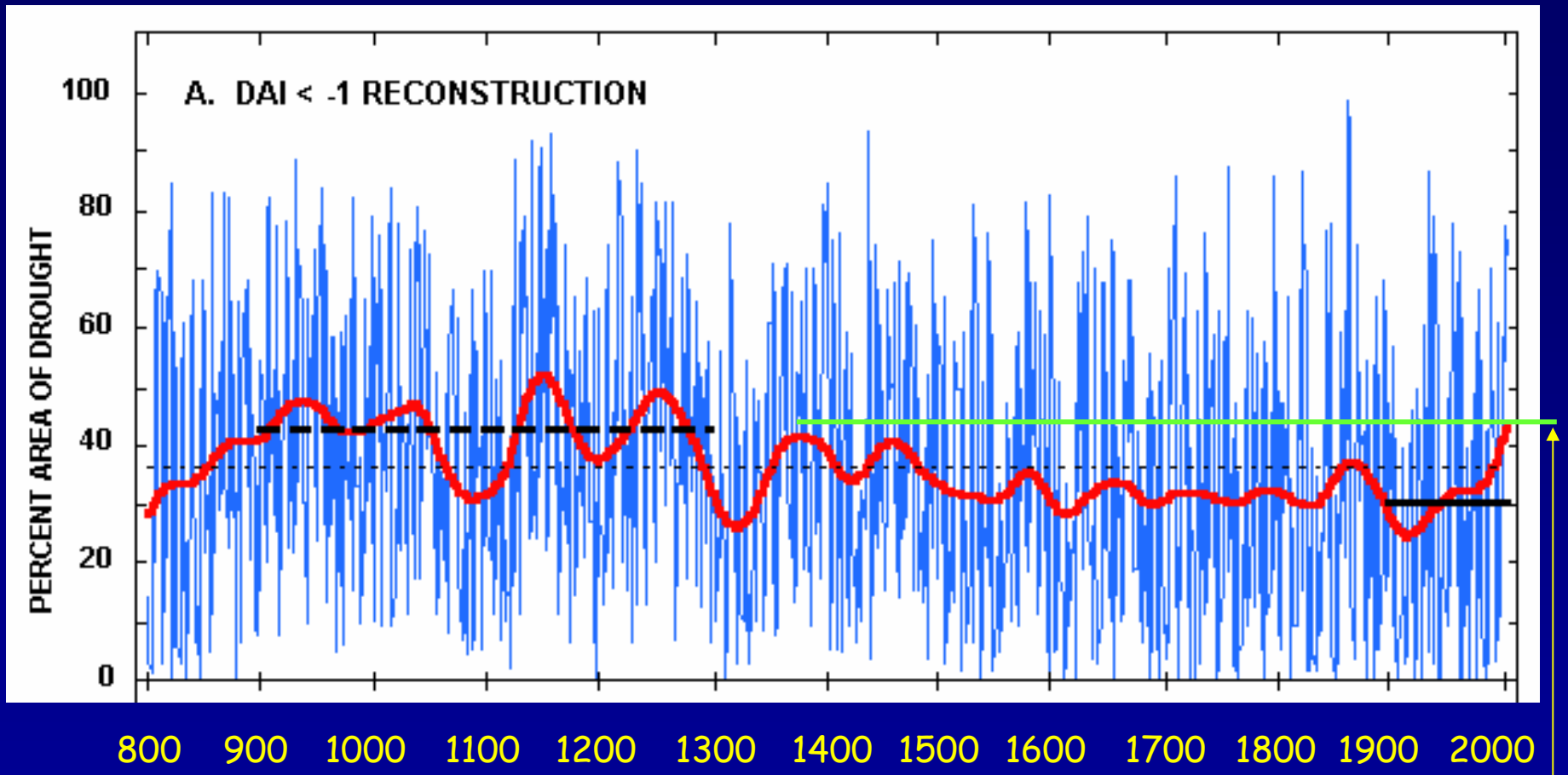
CLIMATIC VARIABILITY AND RIVER FLOW

BUT there are compelling patterns of long-term climatic variability. The lag effects and integration of climatic signal over the watershed may defy an easy statistical model.

TREE RINGS AND DROUGHT FREQUENCY

- Dendrochronology of headwaters trees has been used to reconstruct Colorado River flow, precipitation variability, AMO variability, etc, etc.
- Comparison of current and reconstructed conditions is an apples and oranges problem.
- However, one possibility is that the early 21st century drought is the most severe 5-year low flow since AD 1590.

Western US Summer Drought Area Index



Cook et al. (2004)

green line indicates most recent period

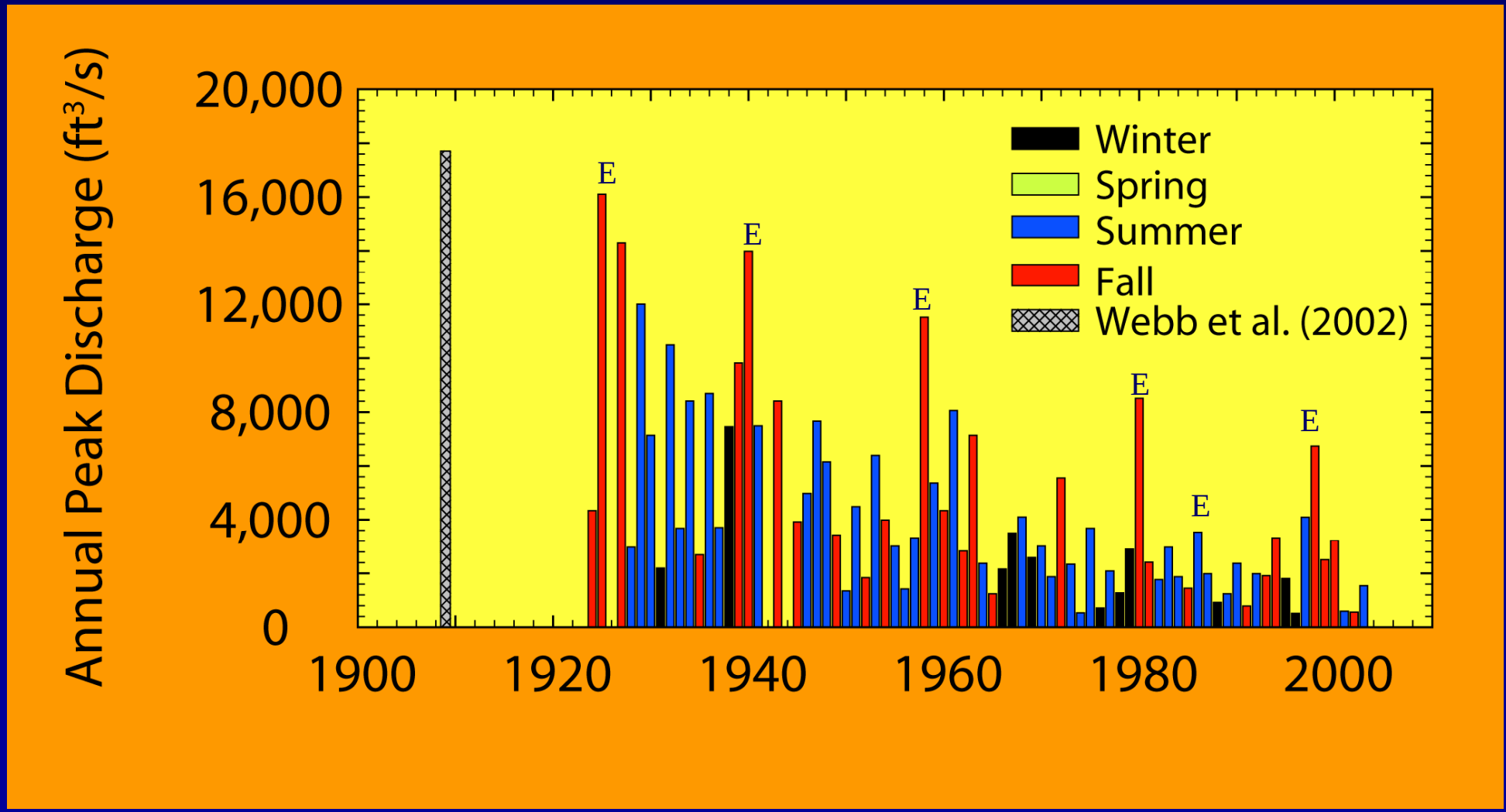
TREE RINGS AND DROUGHT FREQUENCY

- Drought reconstructions indicate that the most severe droughts can last 30 years.
- One possibility is that the current El Nino merely is interrupting an extended drought period.
- Tree-ring analyses indicate that the most unusual part of the 20th century was above-average conditions, not droughts.
- We’re left with no long-term prognosis.

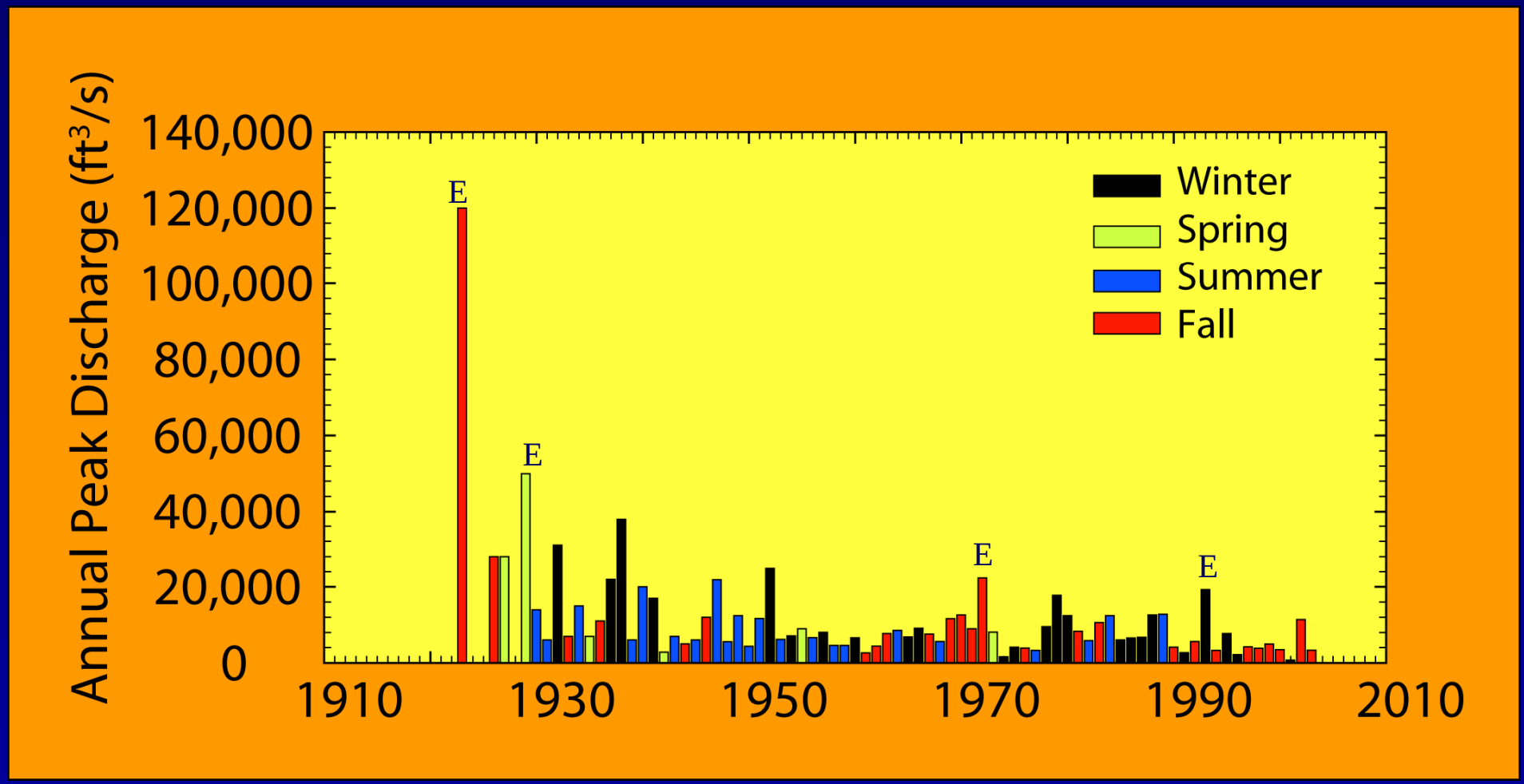
CLIMATE VARIABILITY AND TRIBUTARY STREAMFLOW

- El Nino conditions increase the probability of floods on rivers in Arizona.
- The effects of El Nino decrease with increasing latitude.
- La Nina conditions reliably indicate drought.
- PDO largely reflects ENSO.
- The influence of AMO is unknown.

PARIA RIVER AT LEE'S FERRY



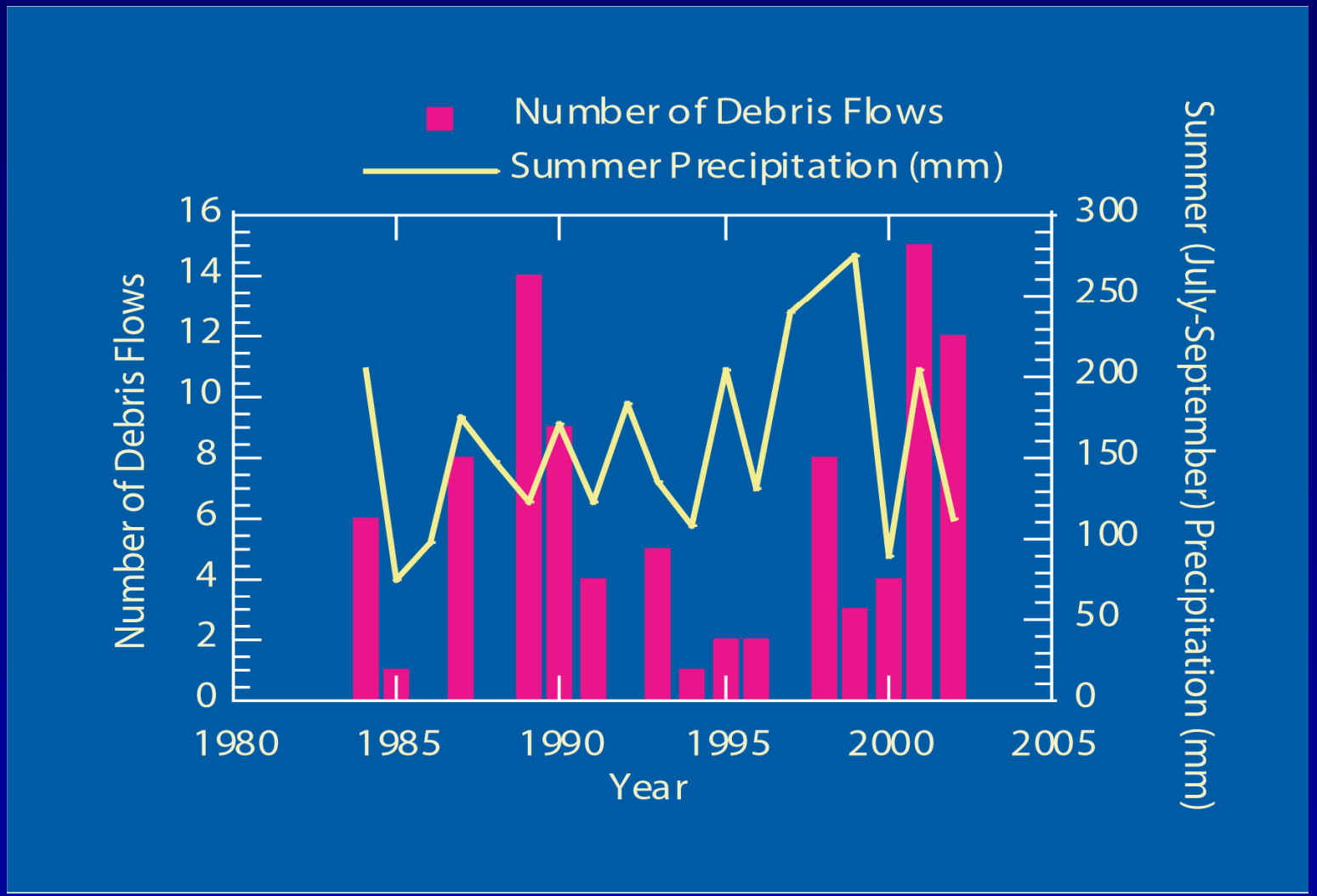
LITTLE COLORADO RIVER AT CAMERON AND GRAND FALLS



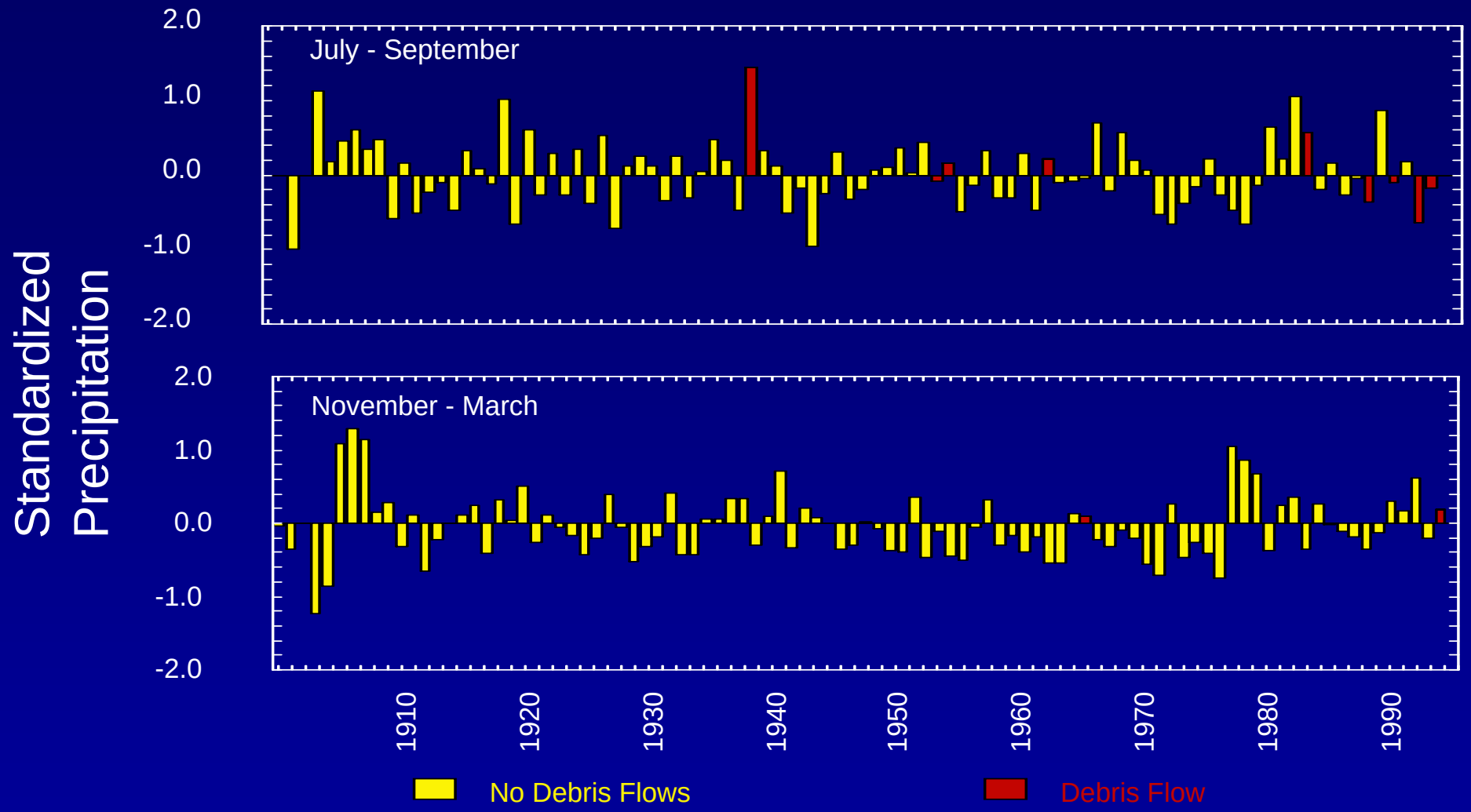
CLIMATE VARIABILITY AND DEBRIS FLOWS

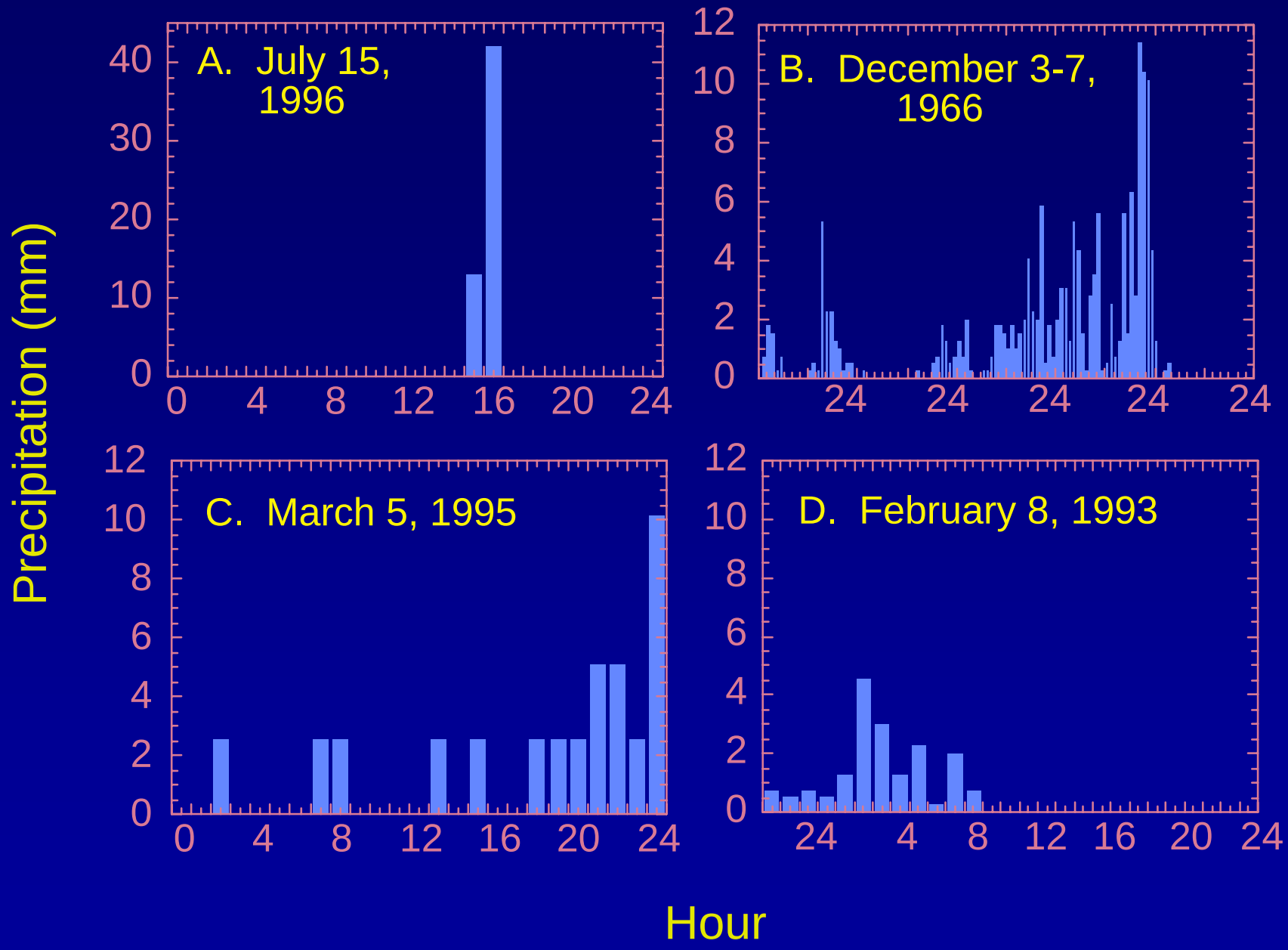
- Basically, there is no discernible relation

Observed Debris Flows, 1984-2002

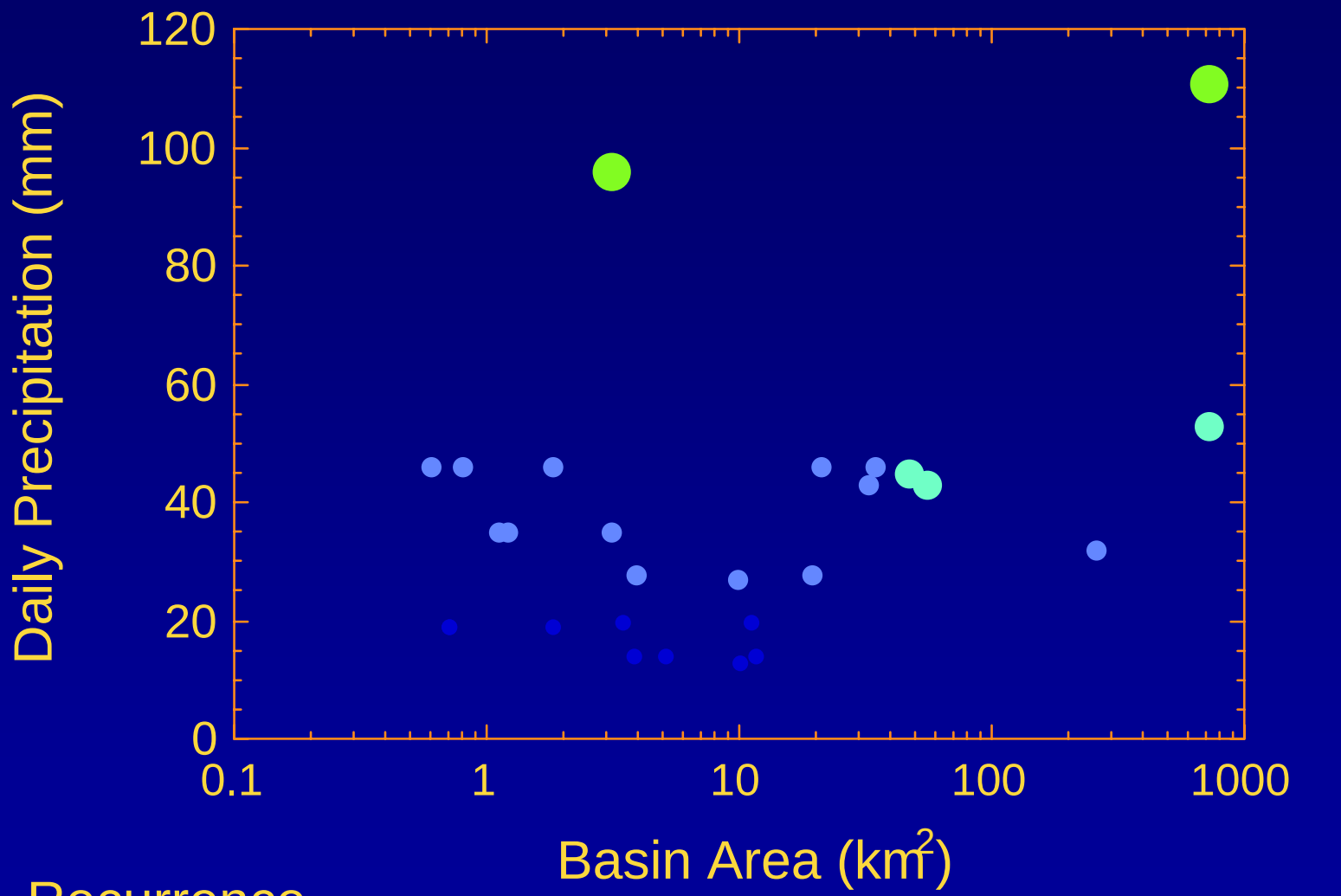


Ref: Griffiths et al. (2004)


Standardized Precipitation
July - September
November - March
2.0
1.0
0.0
-1.0
-2.0
1910
1920
1930
1940
1950
1960
1970
1980
1990
No Debris Flows
Debris Flow


A. July 15, 1996
B. December 3-7, 1966
C. March 5, 1995
D. February 8, 1993
Precipitation (mm)
Hour
0
10
20
30
40
2
4
6
8
12
16
20
24

Debris Flows and Daily Precipitation



CONCLUSIONS

- A drought unprecedented in >100 years affected the Colorado River upstream from Lake Powell from 2001 through 2004
- That drought also caused flow decreases on tributaries but did not affect debris-flow frequency in Grand Canyon
- Although above-average conditions are expected in 2005, the longer-term climatic future is uncertain – drought conditions could resume