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Droughts and Reservoir Yield
Listen to the Trees!

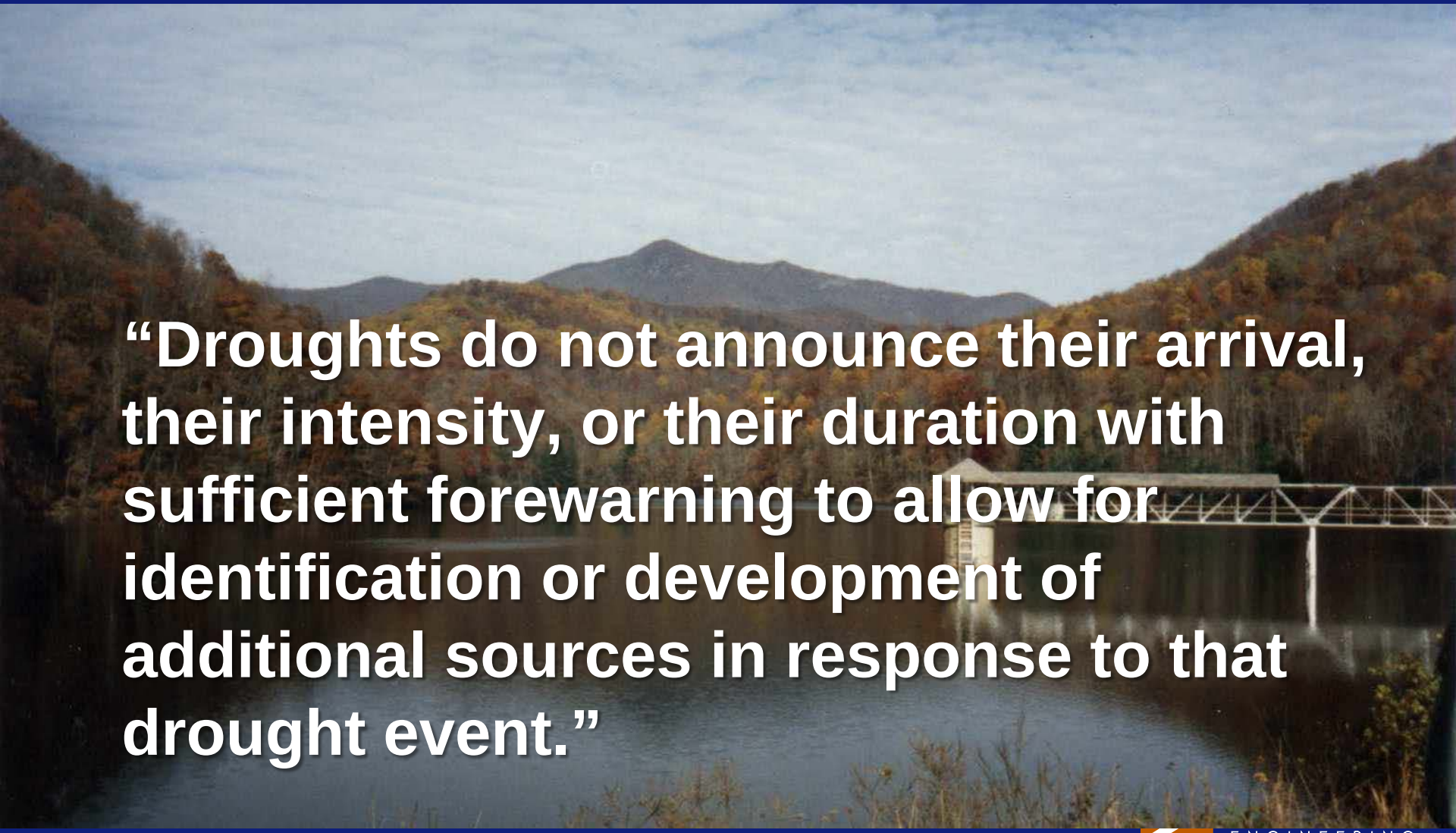
John Harrison, PE

PA AWWA 2013 Conference

Hershey, PA

April 24, 2013

Water Supply Planning



“Droughts do not announce their arrival, their intensity, or their duration with sufficient forewarning to allow for identification or development of additional sources in response to that drought event.”

Unrecognized Uncertainty

- The process of estimating reservoir safe yield assumes that climate is unchanging:
  - “the past 50 years provides a supportable basis for forecasting the next 50 years”
- But we know it isn’t

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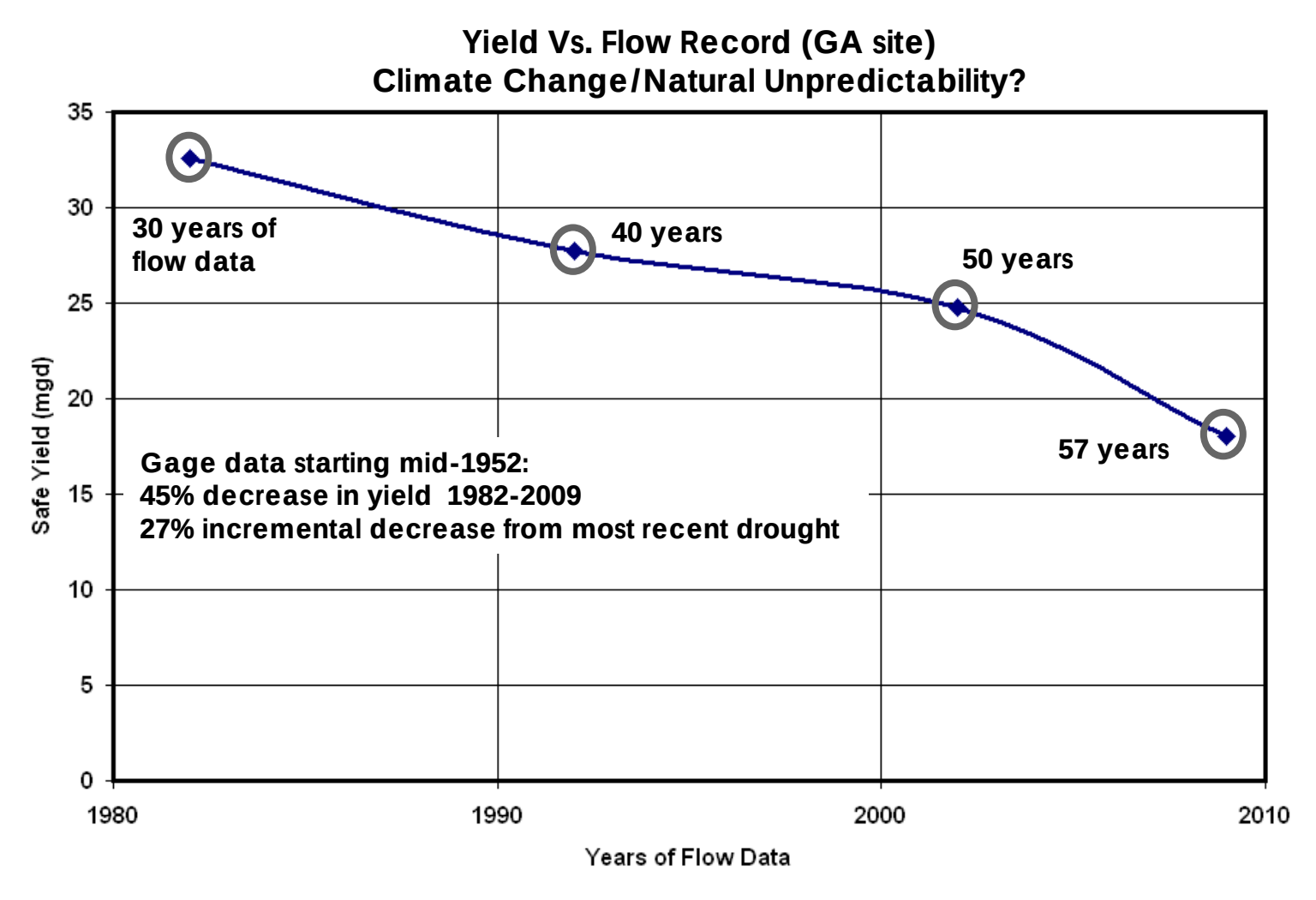
Climate Change/Natural Unpredictability?



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Planning to Fail

- Spillways for dams that present a risk of loss of life or significant economic damage are designed for 10,000 year + event
- Water supplies sources which are vital to health, fire protection and economic well being of a community are often designed for a 50 to 100 year event
- Does this make sense?

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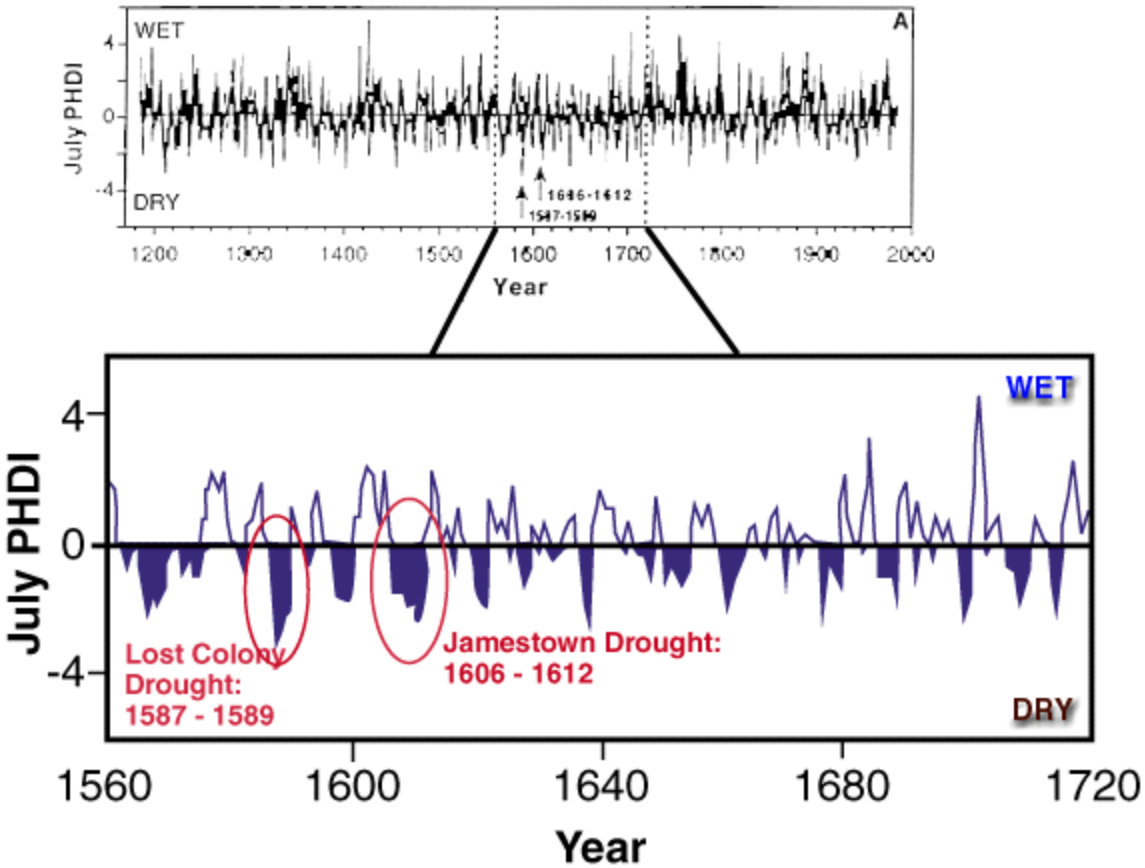
Palmer Hydrological Drought Index



Tree-ring Reconstruction: July PHDI
Tidewater region of Virginia & N. Carolina
from 1185 to 1984 (top), and
early colonial period 1560 to 1720 (bottom).

Ref: NOAA Paleoclimatology website

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Dendrochronology:

the science that deals with the dating and study of annual growth layers in wood

Fritts 1976

Main products:

- Reconstructions of past conditions; continuous time-series of environmental variables (e.g., climate, hydrology)

- Dates of environmental and human events (e.g., fires, infestations, prehistoric settlement)

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Coring a Tree

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Tree Core - Section

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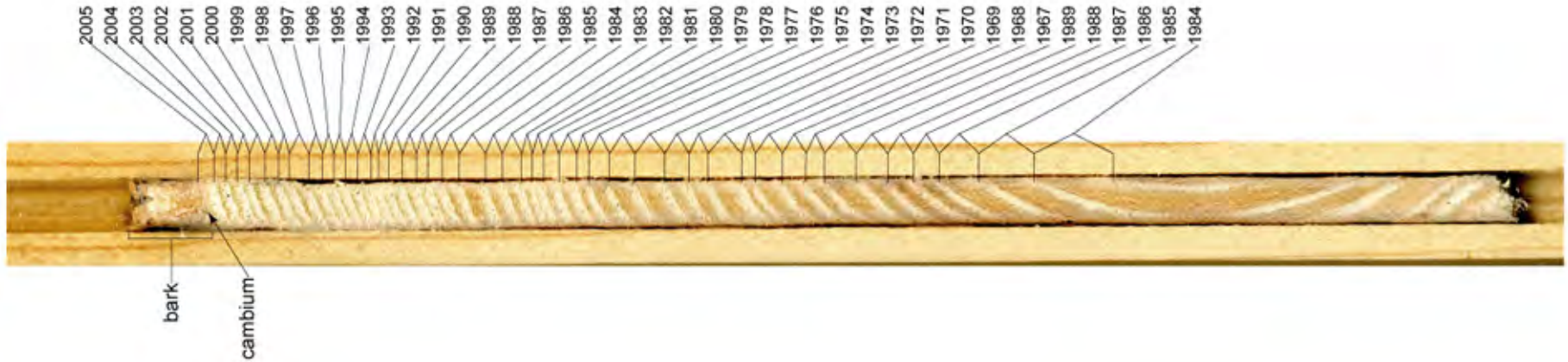
Tree Core - Section



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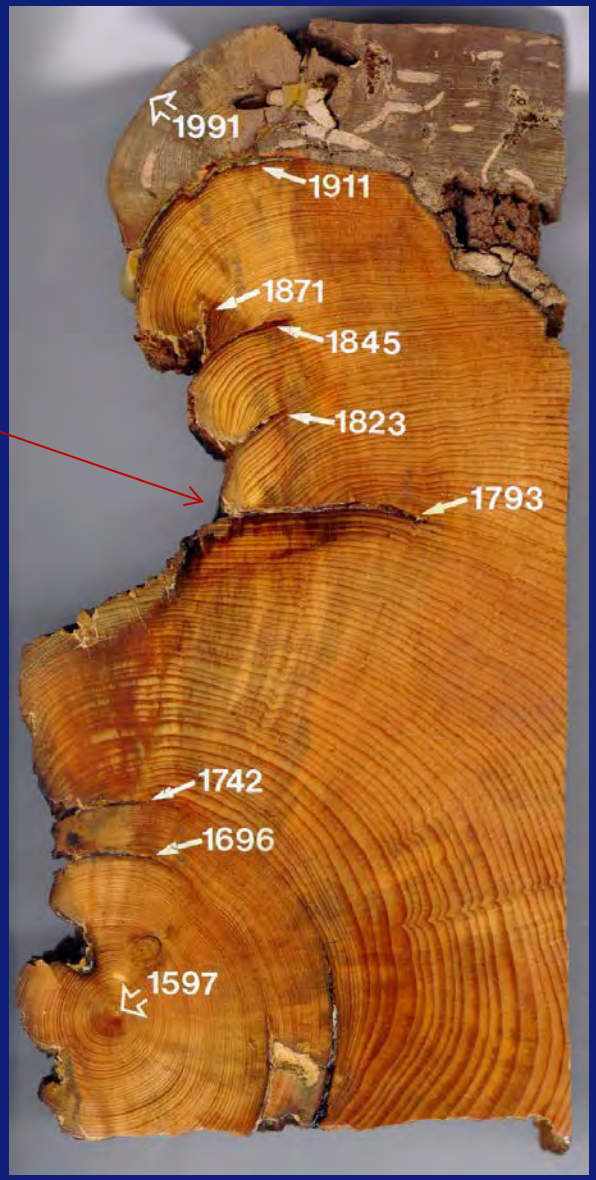
Tree Rings Tell a Story

Fire scars



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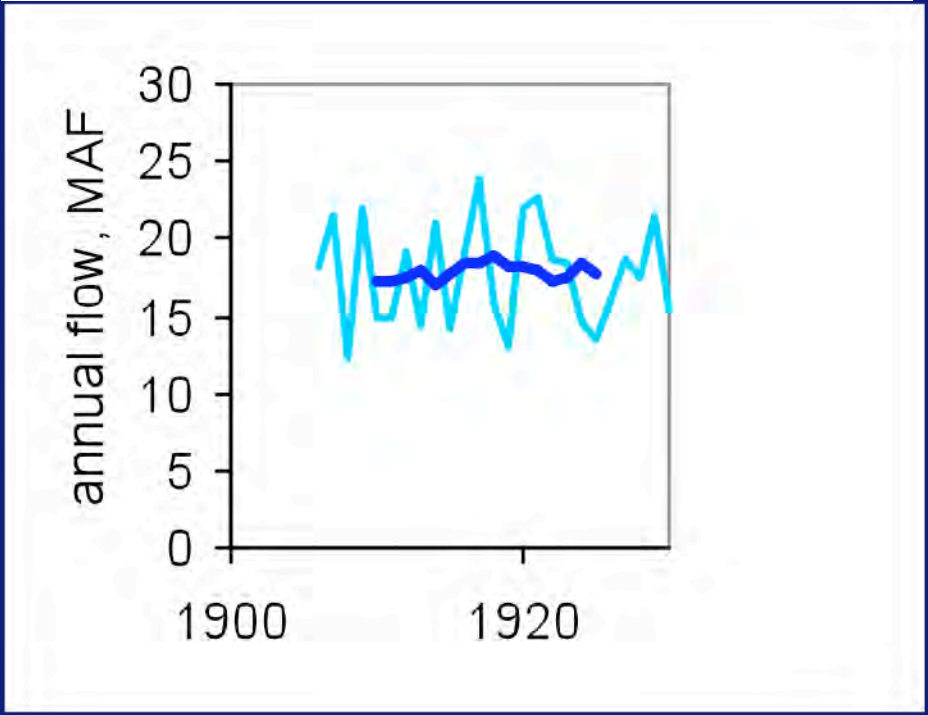
Learning from experience in water management

Colorado at Lees Ferry

Gaged (natural flow) record, 1906-1930



With Permission:
Jeff Lukas
Western Water Assessment, University of Colorado
Connie Woodhouse
University of Arizona & Climate Assessment for the Southwest (CLIMAS)

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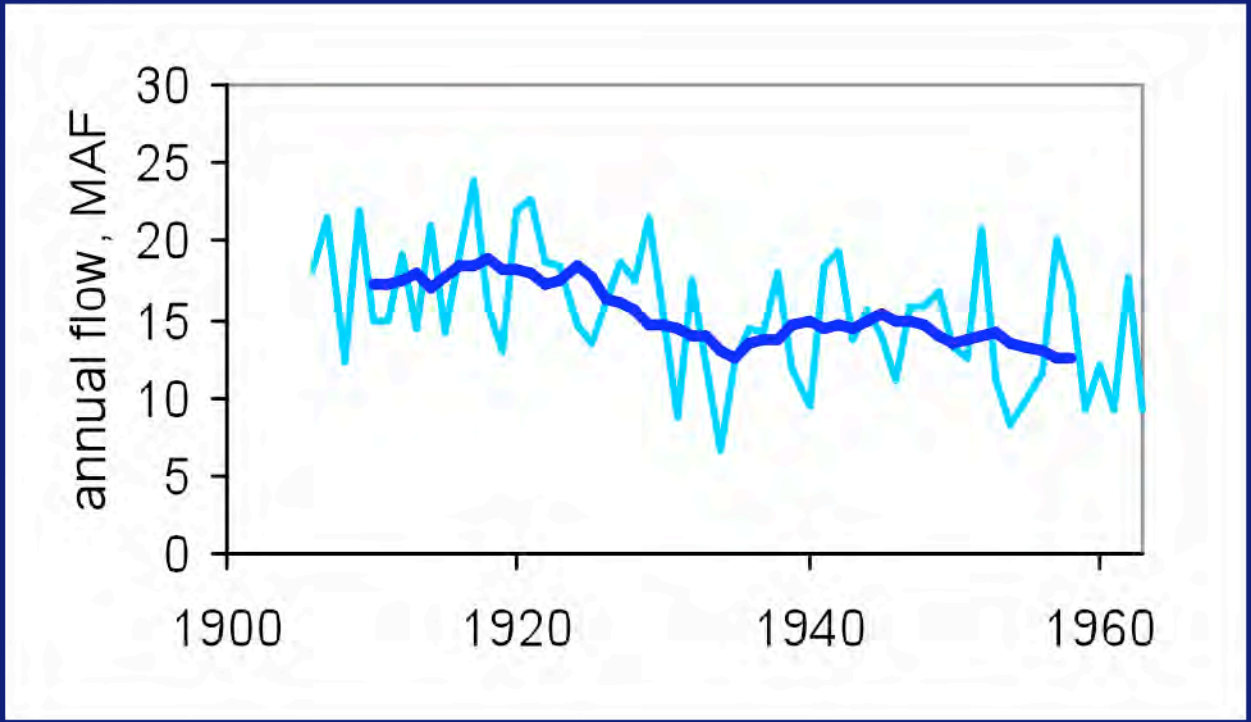
Learning from experience (cont'd)

Colorado at Lees Ferry

Gaged (natural flow) record, 1906-1963



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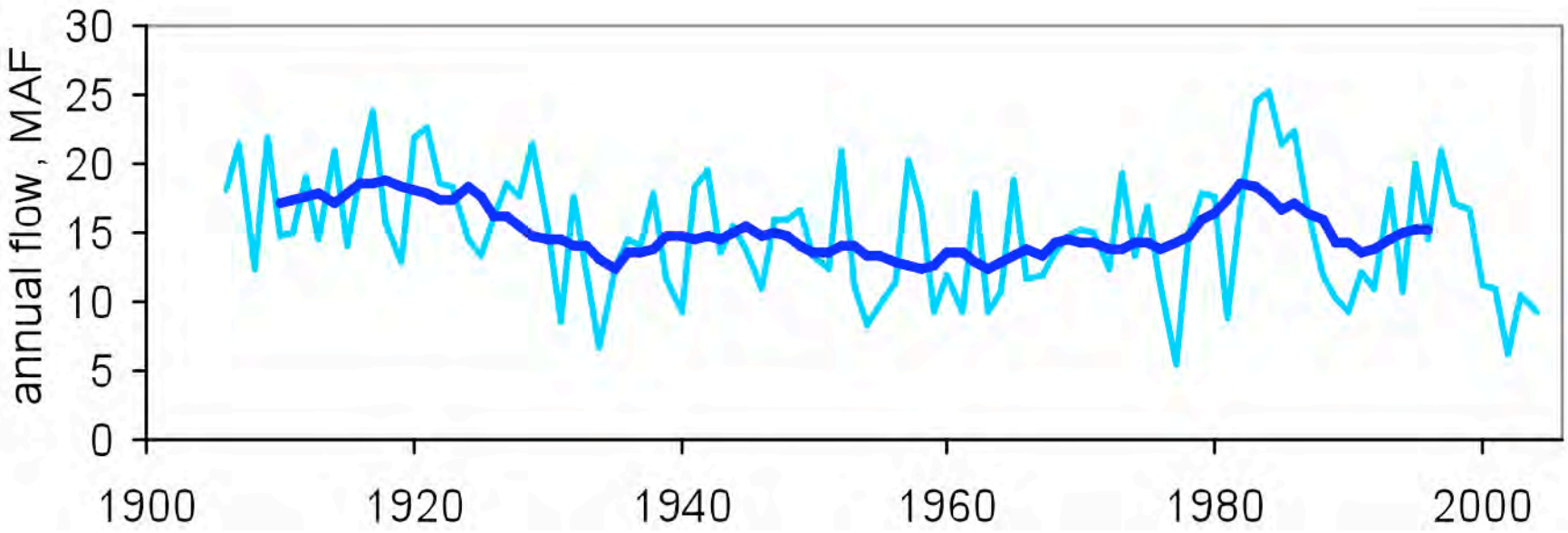
Learning from experience (cont'd)

Colorado at Lees Ferry

Gaged (natural flow) record, 1906-2004



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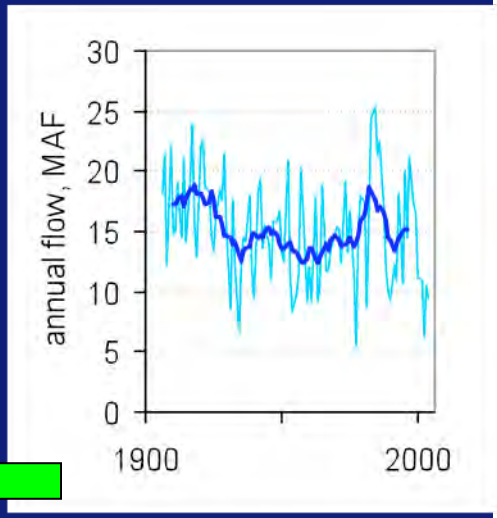
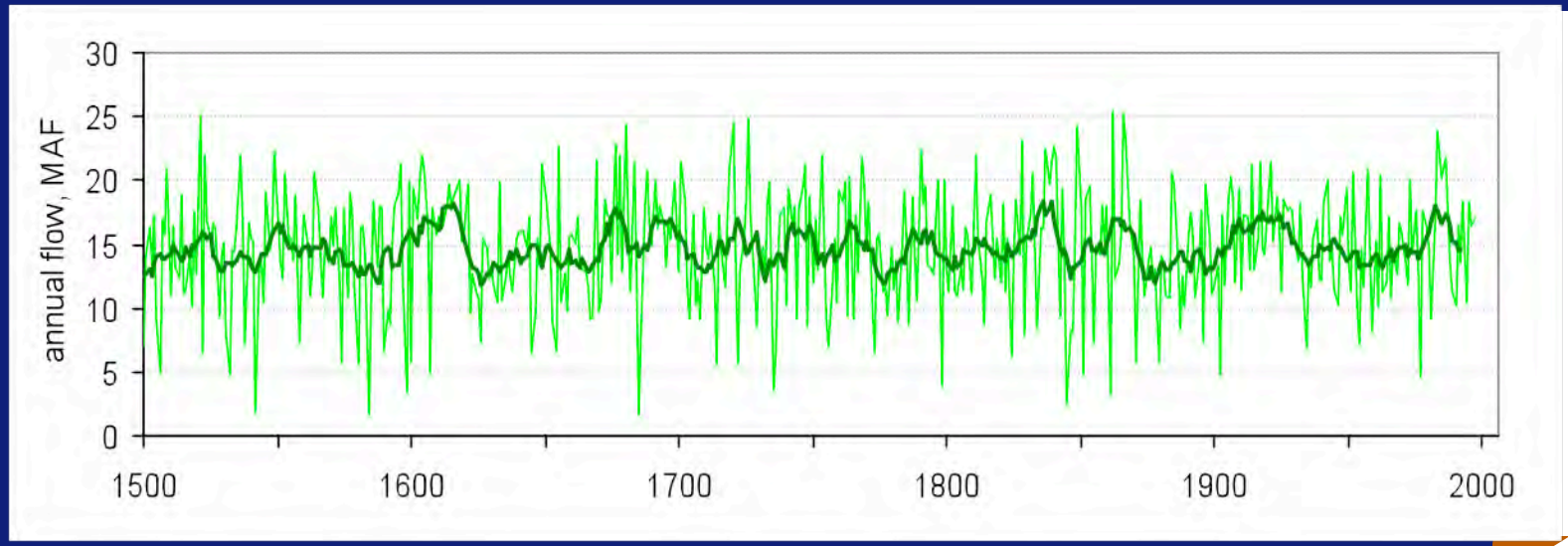
Tree-ring reconstructions – a surrogate for experience



Colorado at Lees Ferry

Gaged (natural flow) record

1906-2004



Tree-ring reconstruction

1490-1997

With Permission: Connie Woodhouse

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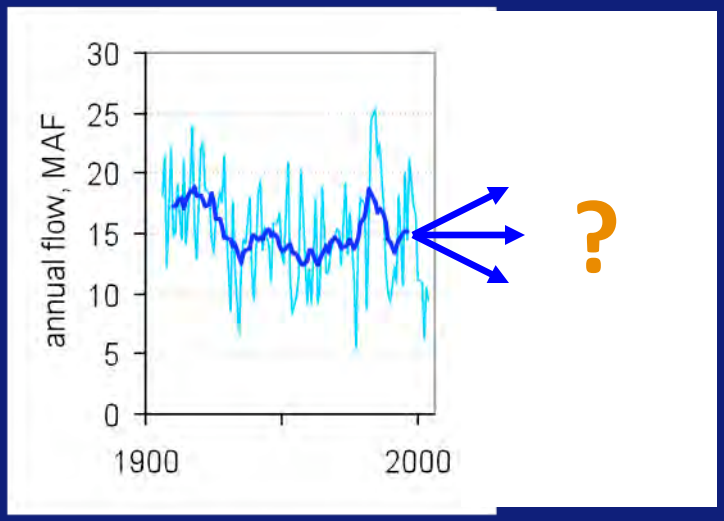
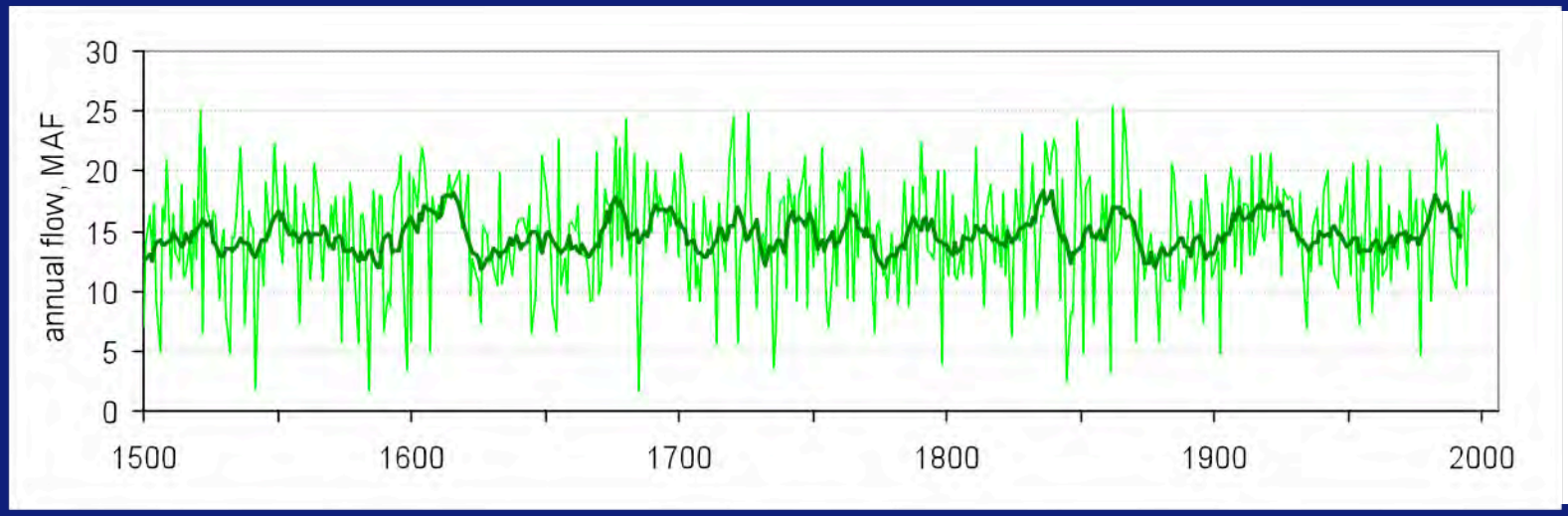
Tree-ring reconstructions – a surrogate for experience

Benefits:

- Improved *anticipation* (not prediction) of future conditions

- Improved assessment of *risk*





Tree-ring reconstruction

1490-1997

With Permission: **Connie Woodhouse**

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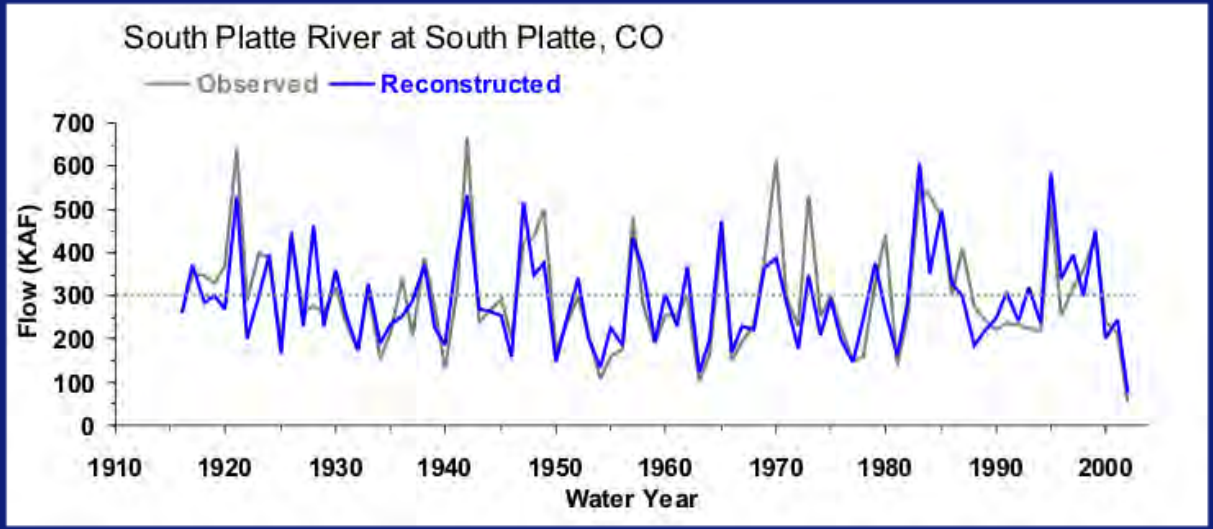
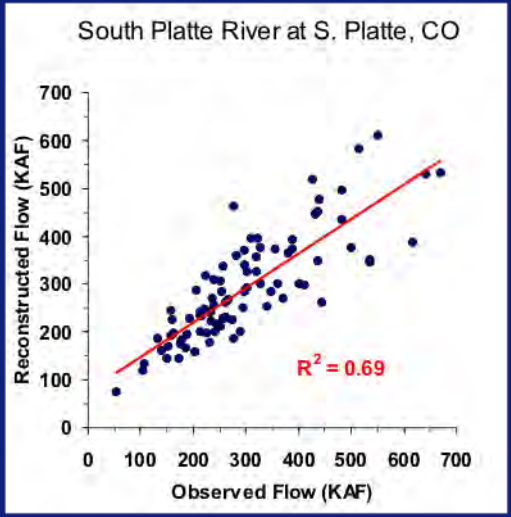
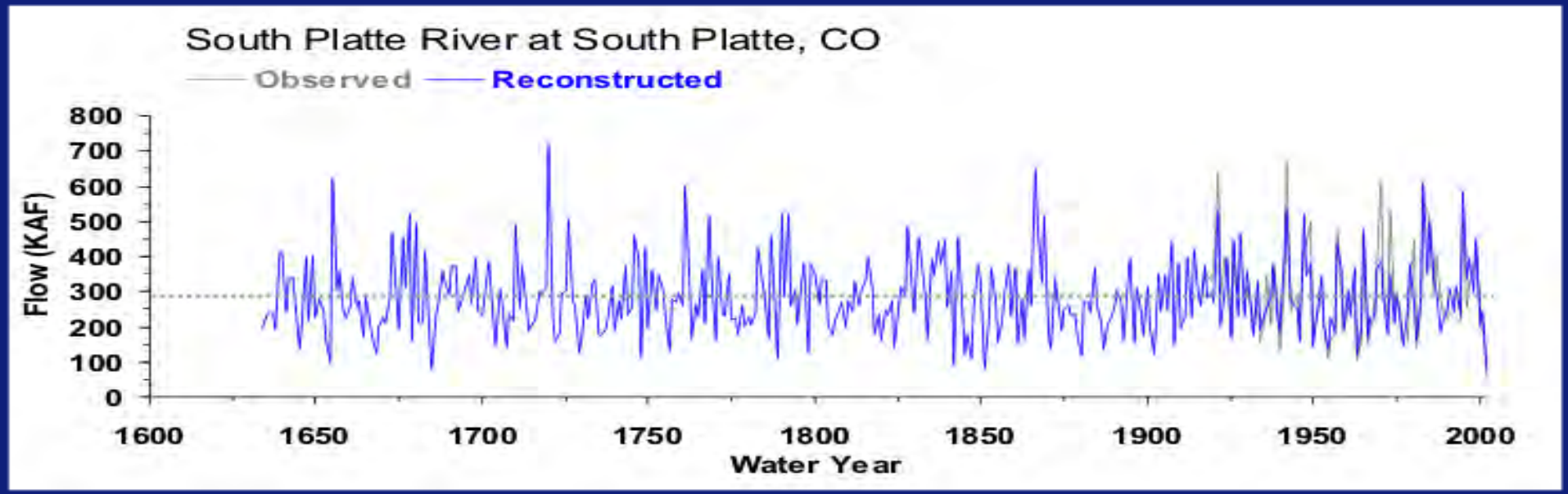
Sample Reconstruction

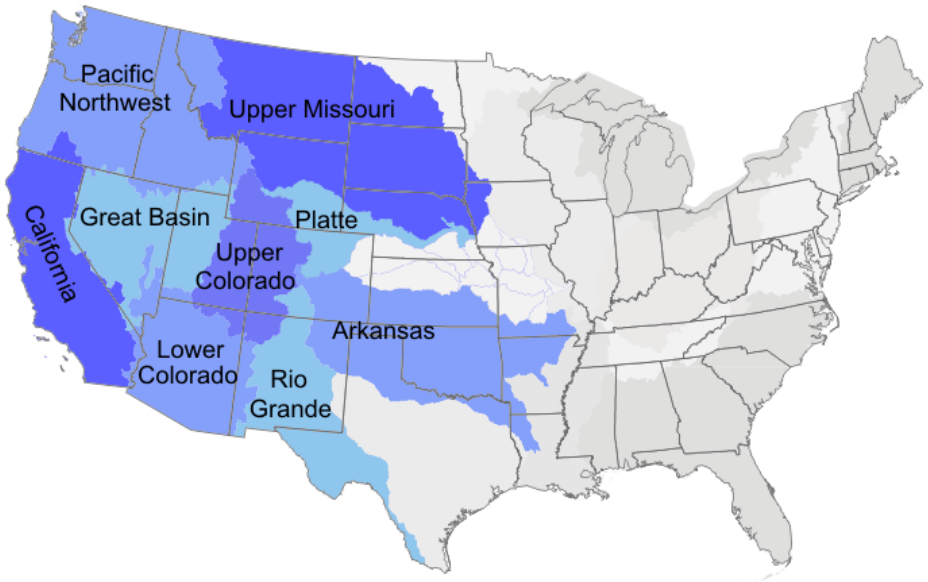
Reference: http://treeflow.info







Available Streamflow Reconstructions



Source: treeflow.info

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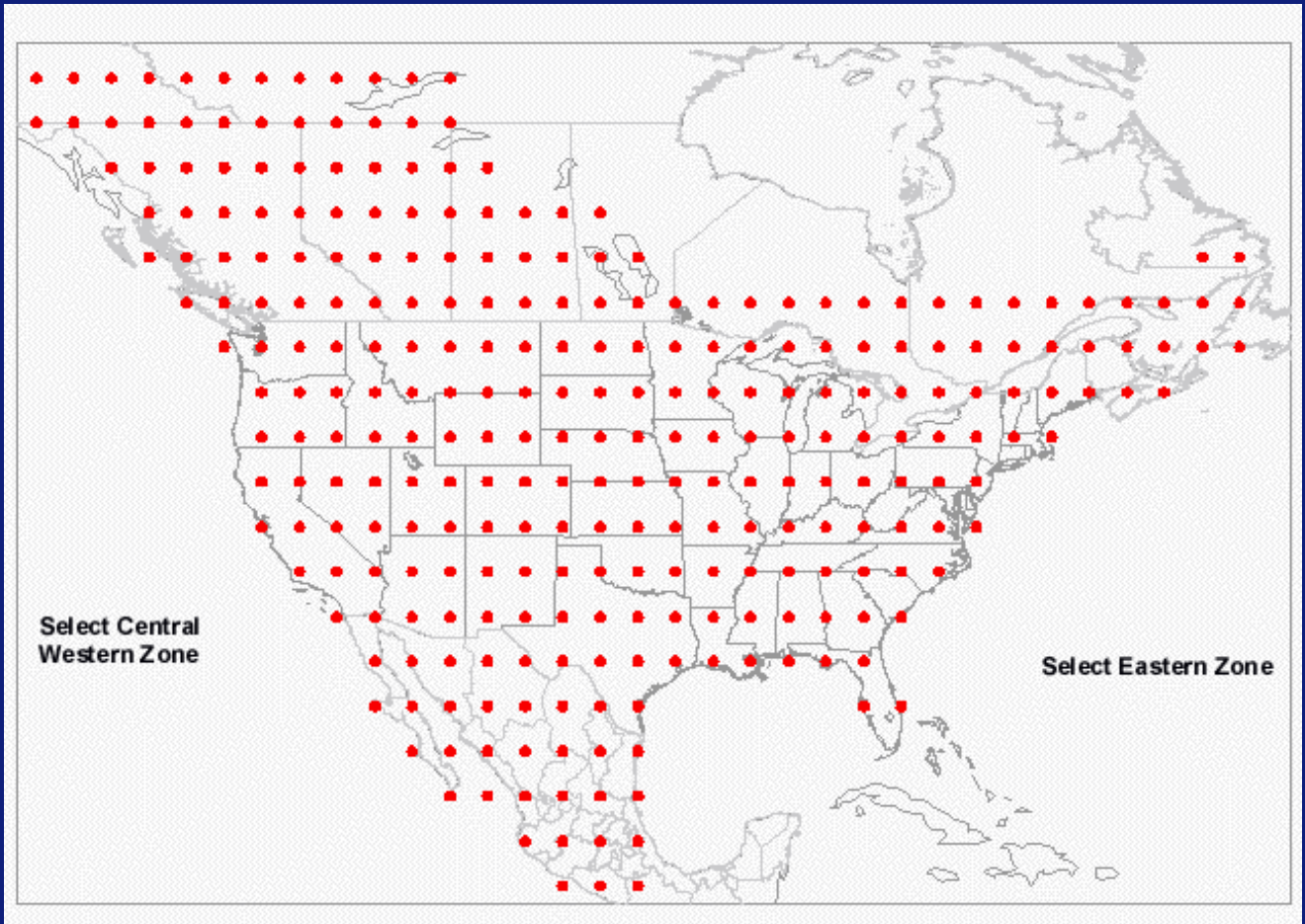
North American Drought Atlas PDSI Reconstructions, Cook et al.(2004)- Time Series Plots



Source: ww.ncdc.noaa.gov/paleo/pdsi.html

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Annual tree growth is limited by moisture availability

So:

– a dry year leads to a *narrow* growth ring

– a wet year leads to a *wide* growth ring

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Crossdating allows the extension of tree-ring records back in time using living and dead wood

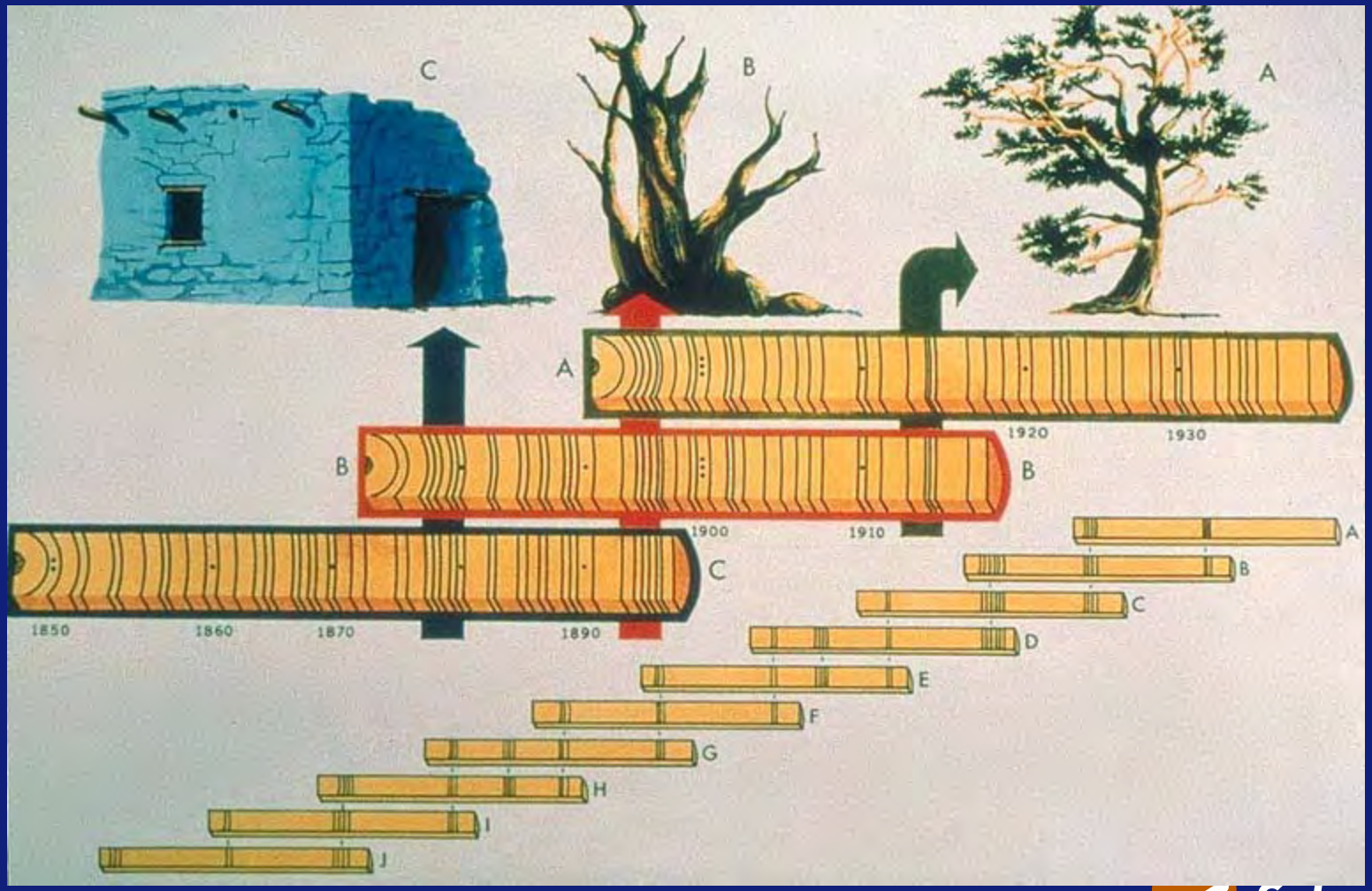

Image courtesy of LTRR (U. AZ)

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10 States Standards – Water Quantity

- "The quantity of water at the source shall be adequate to meet the maximum projected water demand of the service area as shown by calculations based on a one in fifty year drought or the extreme drought of record, and should include consideration of multiple year droughts."

Recommended Standards for Water Works – 2012 Ed.

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Safe Yield Defined

- Safe Yield is the quantity of water that can be taken from a source of supply at a constant rate for a period of years without depleting the source permanently, i.e., beyond its ability to be replenished naturally in “wet years.”

- Sufficient supply is considered to be available if the lowest flow or yield exceeds the maximum demand of all uses.

Source: PADEP Drinking Water Operator Certification Training

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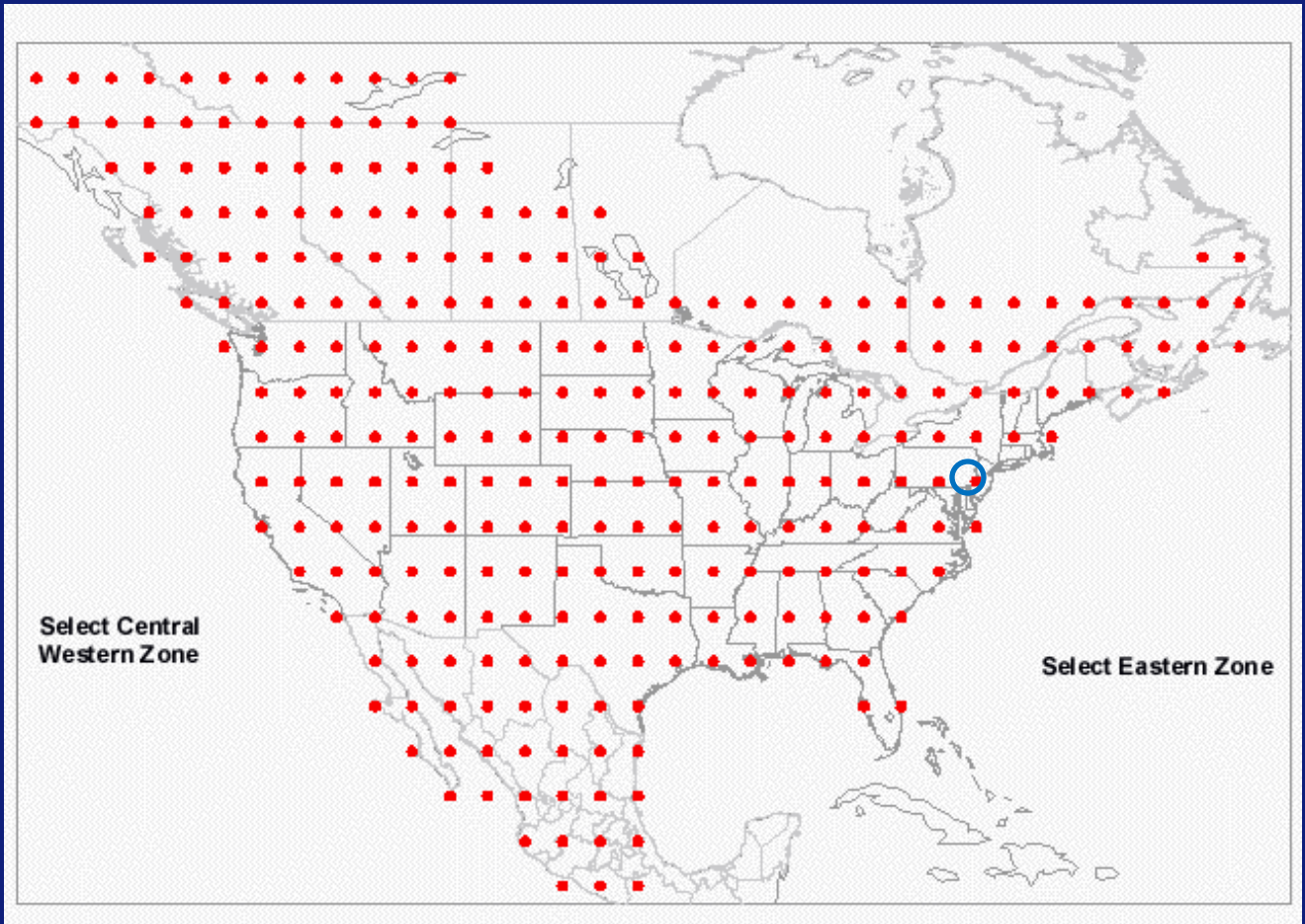
North American Drought Atlas PDSI Reconstructions, Cook et al.(2004)- Time Series Plots



Source: ww.ncdc.noaa.gov/paleo/pdsi.html

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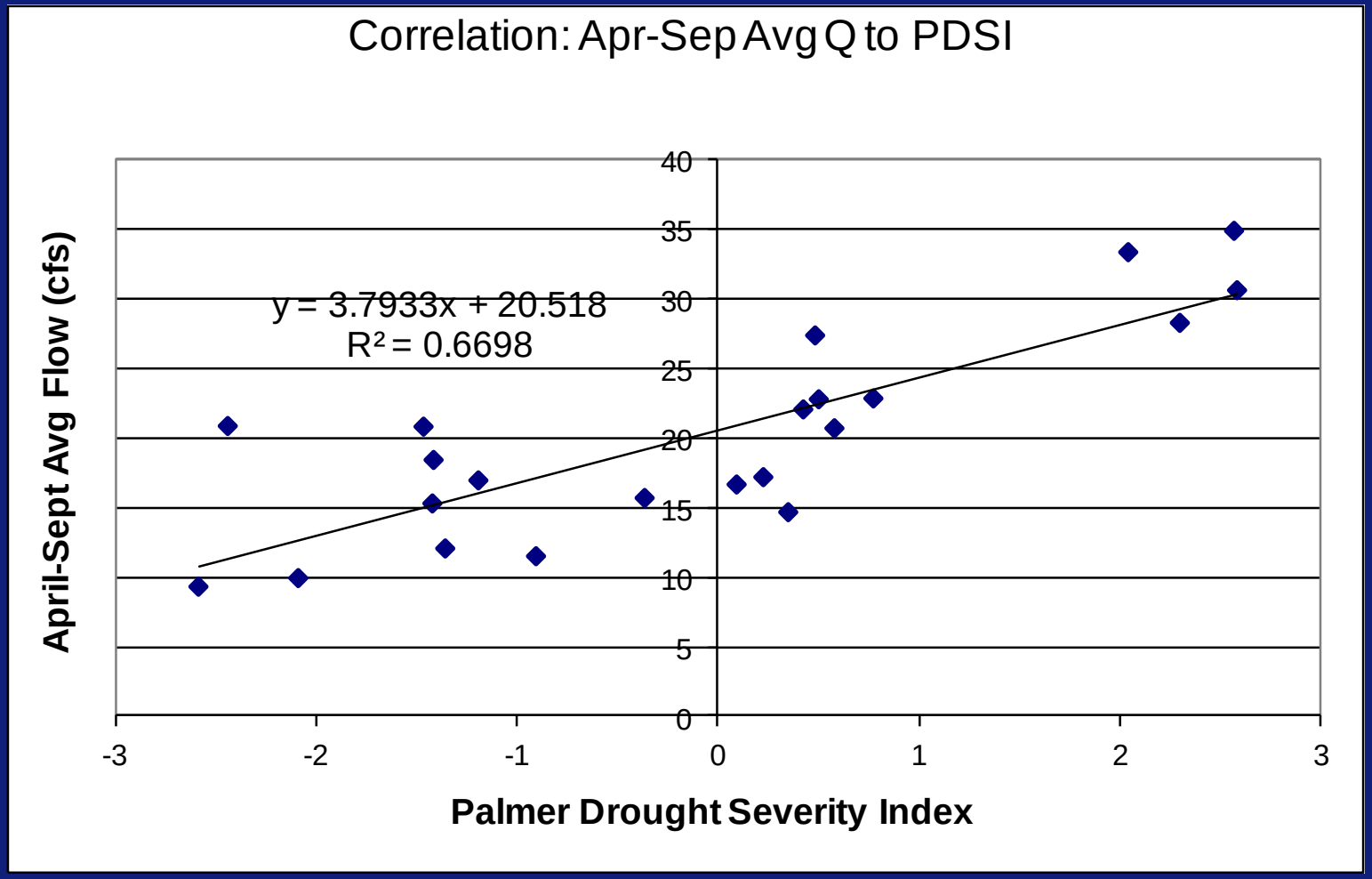
Estimate April-Sept Avg Stream Flow (Q)

Southeastern PA Stream



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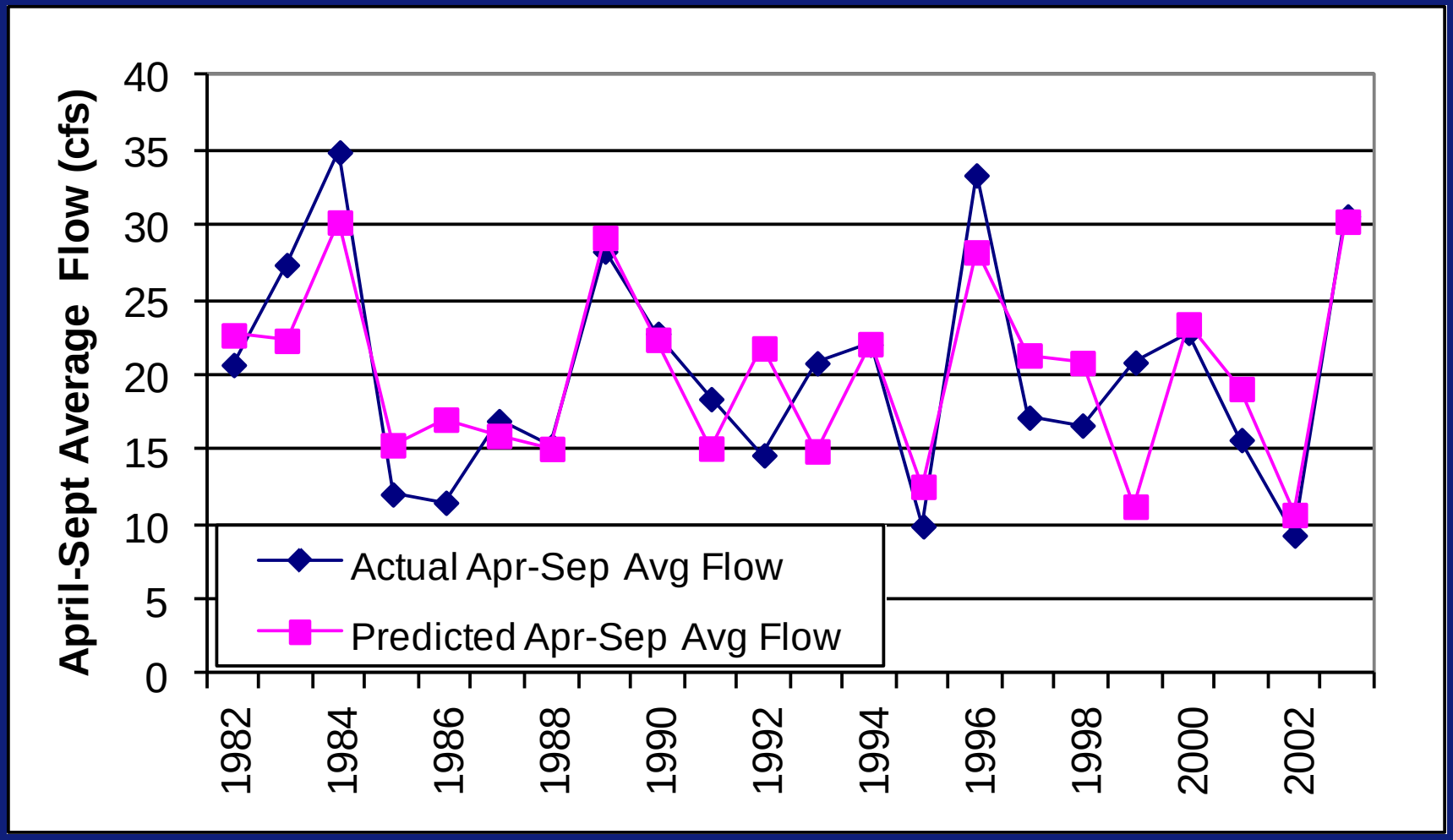
Predicted vs Actual Flow (Apr-Sep Q)

Southeastern PA Stream



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Streamflow Reconstruction Results

Southeastern PA Stream

Period	1982-2003	1982-2003	367-2003
Number of Years	22	22	1636
Source	Actual	Reconstructed	Reconstructed
Min PDSI	-2.6	-2.6	-4.7
Min Apr-Sep Q (cfs)	9.3	10.7 (15% high)	2.7
100-Yr Apr-Sep Low Q (cfs)	7.5	8.8 (17% high)	7.3 (6.2)

100-Yr Drought: 20% Lower Q

Drought of Record: 70% Lower Q

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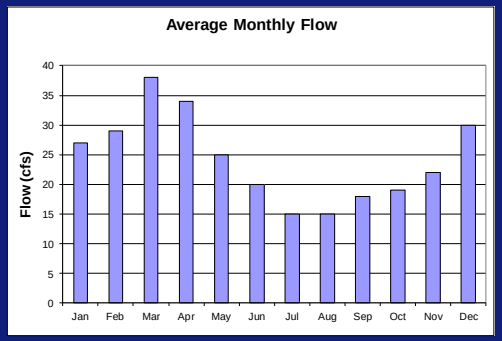
Reconstructing Monthly Flow

- April-Sept Flows
  - Distribute total according to normal monthly variation



- Oct-Mar Flows:
  - Assume average monthly flow

X

- Simplistic approach – and does not capture multi-year drought!

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Reservoir Safe Yield Analysis

- Hypothetical Reservoir
  - Usable Storage = 400 MG
  - D.A. = 20 mi^2
  - MIF = 2 cfs (1.3 mgd)
  - Evaporation

Period/Source	Safe Yield	Drought
1982-2003 Actual Data	5.7 mgd	DOR
367-2003 Reconstructed Data	2.8 mgd	DOR
367-2003 Reconstructed Data	5.4 mgd (4.9 mgd)	100-Yr

100-Yr Drought: SY ~15% Lower

Drought of Record: SY~ 50% Lower

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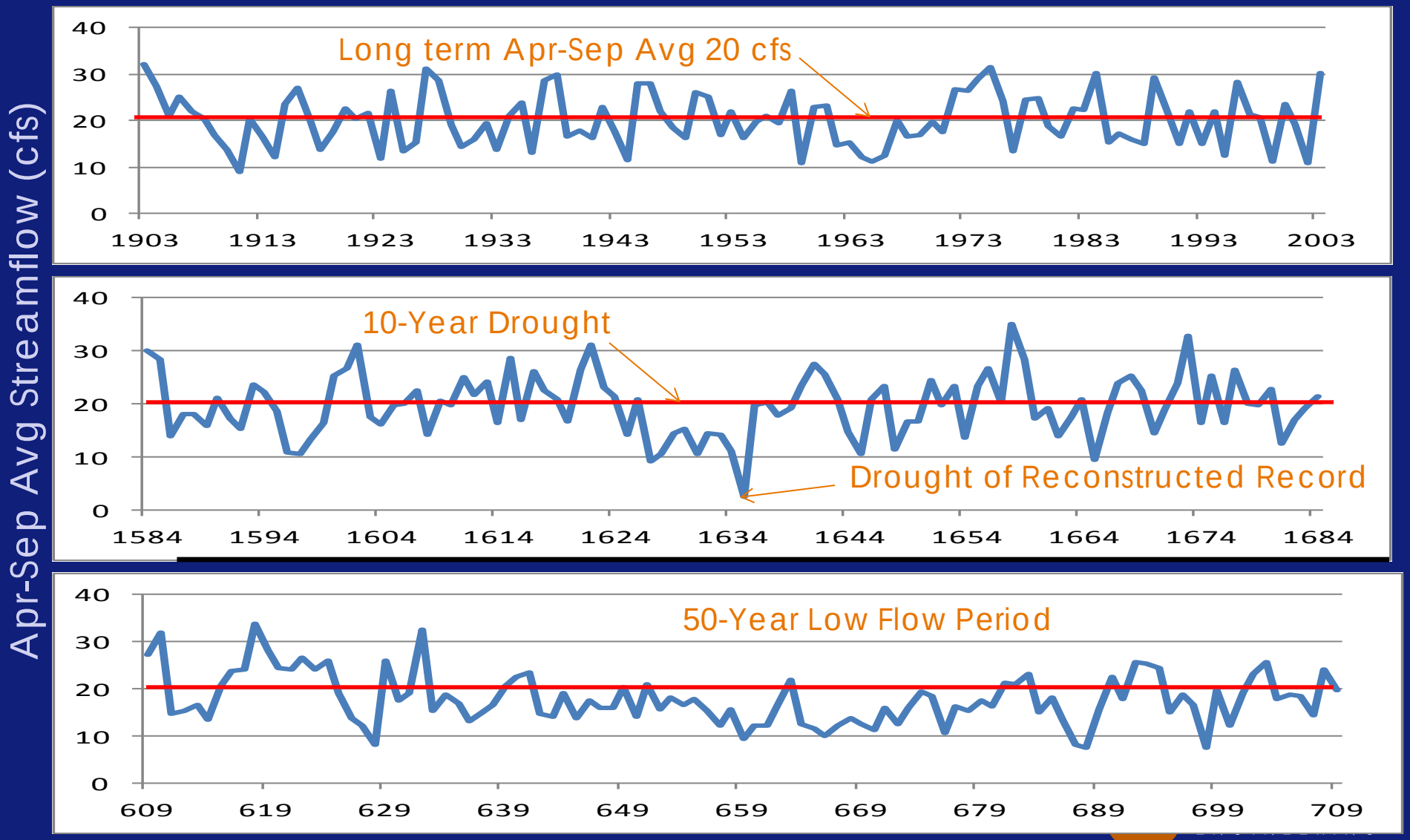
Comparison of Three 100-Yr Periods

Southeastern PA Stream



Conclusions

- Knowledge of past drought events is important for water resource management
- The instrumented record does not represent the full range of variability
- Dry periods exceeding instrumented record have occurred:
  - 10-year droughts
  - 50-year period of below-median flow

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Conclusions (cont'd)

- Plan ahead!
  - Within-system interconnections
  - Interconnections with neighboring suppliers
  - Add pump station on nearby stream/river
  - Add storage

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Questions & Discussion