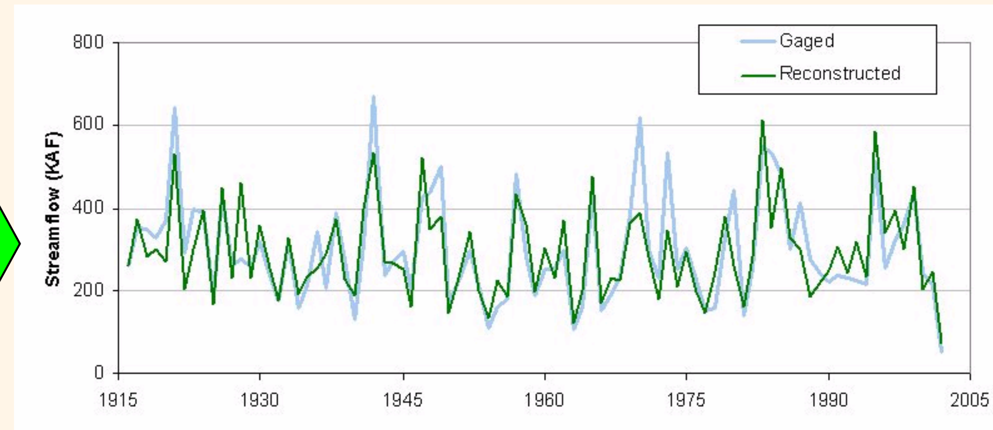
Tree-ring-based streamflow reconstructions for the Rio Grande basin



Connie Woodhouse, University of Arizona

Jeff Lukas, University of Colorado

Western Water Assessment

NM STATE

CLIMAS

Climate Assessment for the Southwest

Agenda

- Background and history of project
- How tree rings record climate information
- Building the tree-ring chronology
- Generating reconstructions of streamflow

Break

- Information about reconstructions on the Web
- How reconstructions are being used in water management
- Current and future applications in the Southwest

Lunch

- What reconstructions in the upper Rio Grande basin show
- Visualizing climate and reconstruction data
- Discussion of management issues and information needs for Rio Grande basin, and development of new streamflow reconstructions

Please ask questions!

Acknowledgements

PIs and Contributors for Rio Grande Project:

University of Arizona: Connie Woodhouse, Gregg Garfin, Holly Hartman, Ramzi Touchan, Dave Meko; *University of Colorado:* Jeff Lukas, Brad Udall; *New Mexico State University:* Deborah Bathke

Partners and Collaborators:

Denver Water, Hydrosphere Resource Consultants, Northern Colorado Water Conservancy District, Rio Grande Water Conservation District, CA Dept Water Resources, US Bureau of Reclamation, US Geological Survey, City of Westminster

Funding:

NOAA Climate Program Office (Coping with Drought program, Regional Integrated Science Assessments: CLIMAS and Western Water Assessment)

Thanks to all who suggested people to invite to this workshop!

About RISAs

- RISAs (Regional Integrated Sciences & Assessments) are NOAA-funded programs that conduct climate-related research that supports decisionmaking at a regional level

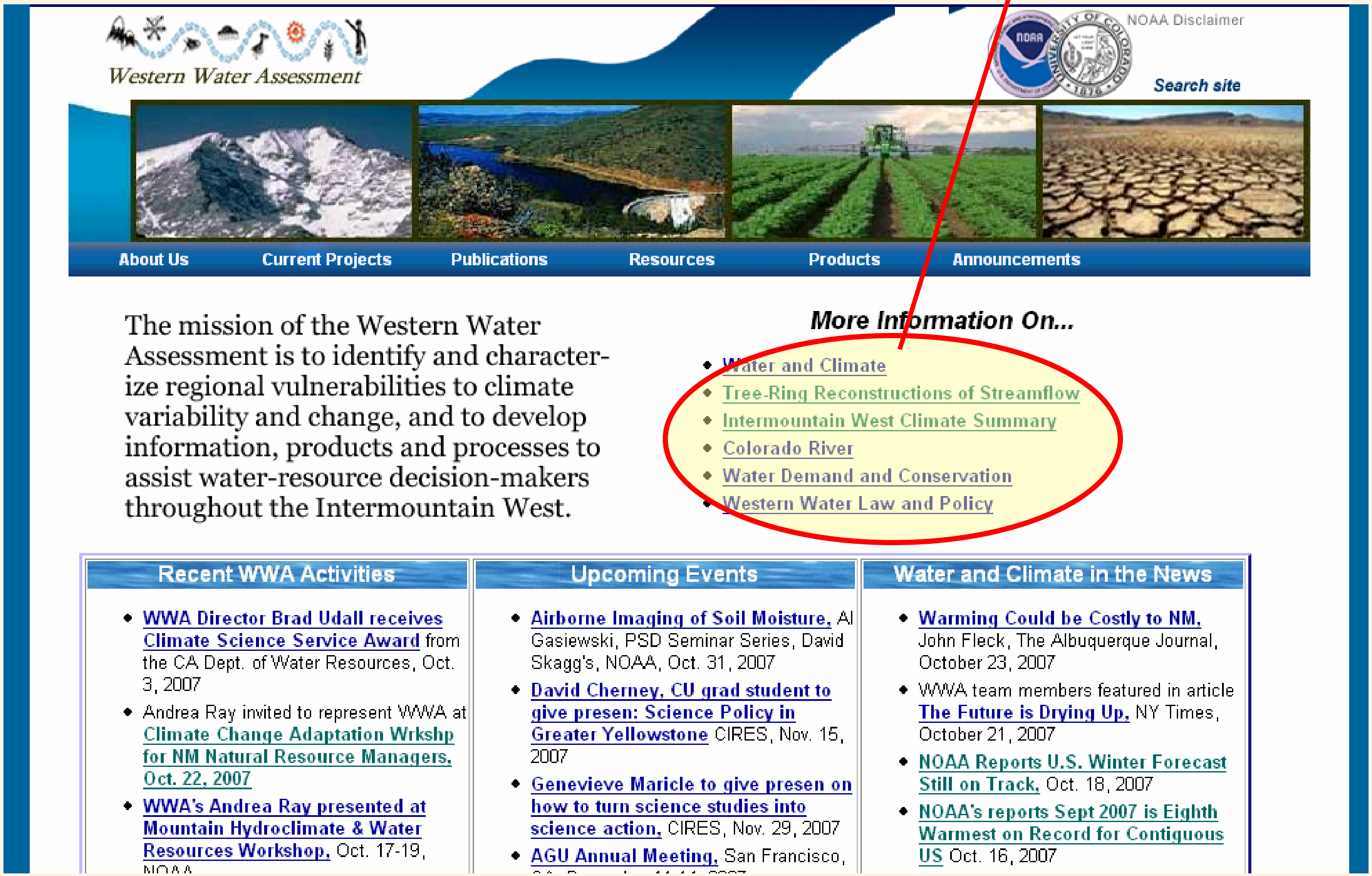
- **Western Water Assessment** - CO, UT, WY
- **CLIMAS** (Climate Assessment for the Southwest) – AZ, NM

For more information on the RISA programs, please see the brochures in your folder

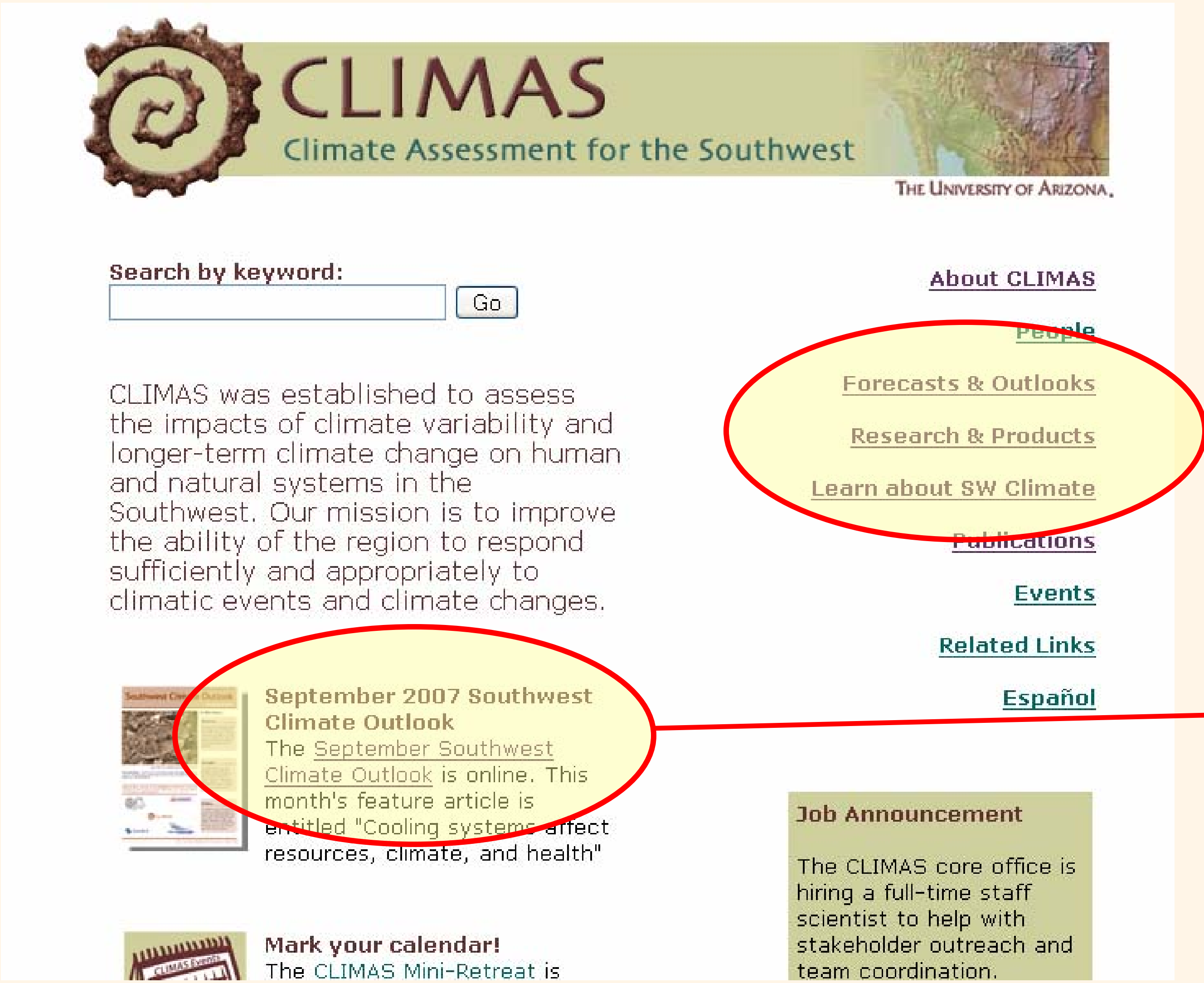
Western Water Assessment

http://wwa.colorado.edu

Quick links to main projects and resources



CLIMAS http://www.ispe.arizona.edu/climas/



Other projects and resources

Southwest Climate Outlook

History behind this workshop

2005 - *Planning Workshop to Develop Hydroclimatic Reconstructions for Decision Support in the Colorado River Basin* - Tucson - 30 climate and water scientists and 30 water managers

2006 - One-day technical workshops on streamflow reconstructions for water managers in Alamosa, Boulder, and Tucson

2006-2007 – New publications: *Updated Streamflow Reconstructions for the Upper Colorado River Basin,* NRC report on the Colorado River, including tree-ring reconstructions

2007 - More workshops, greater focus on applications

New Cross-RISA project:
Tree-Ring Reconstructions of Hydroclimatic Variability in the Rio Grande Basin, New Mexico

1) *TODAY* - Workshop to introduce the use of tree-ring reconstructions of streamflow, and identify gages of interest

2) Develop a set of reconstructions from existing tree-ring data based on gages identified above

3) Follow-up workshop (spring 2008?) to deliver new reconstructions, explore applications, and plan future collaborative work

4) Develop web page to feature Rio Grande reconstructions

Objectives for today (and beyond)

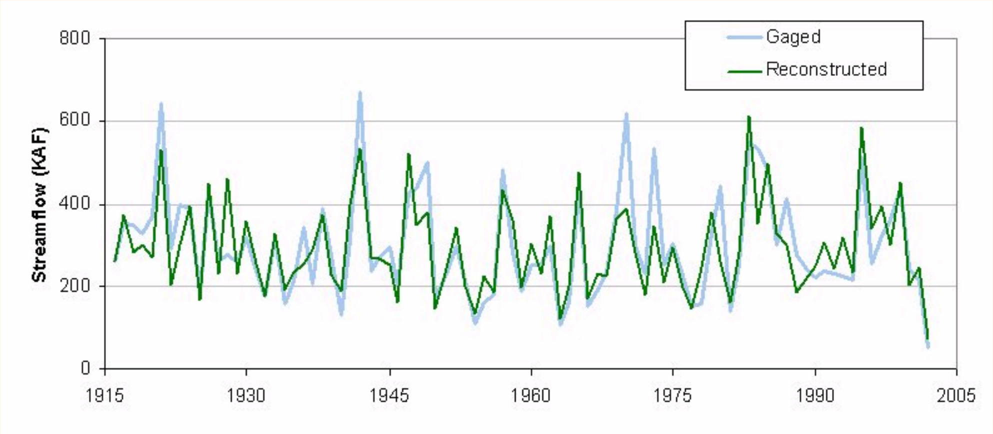
1) Describe how tree-ring reconstructions are developed and are being used
2) Get input on issues Rio Grande basin and what new reconstructions would be useful

In other words, we'll show you what's possible, you let us know what's desirable

- The follow-up workshop next year will showcase the results and solicit further feedback
- We'll be a long-term partner in assisting with application of the data

Part 1:

Context and Background



The conundrum of (water) management

We need to make decisions about the future, but we don't know much about it.

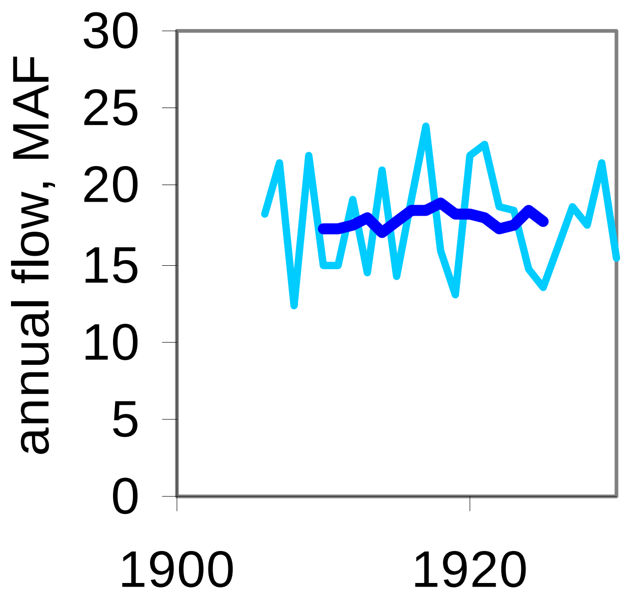
So how do we generally make decisions?

Based on past experience.

Learning from experience in water management

Colorado River at Lees Ferry

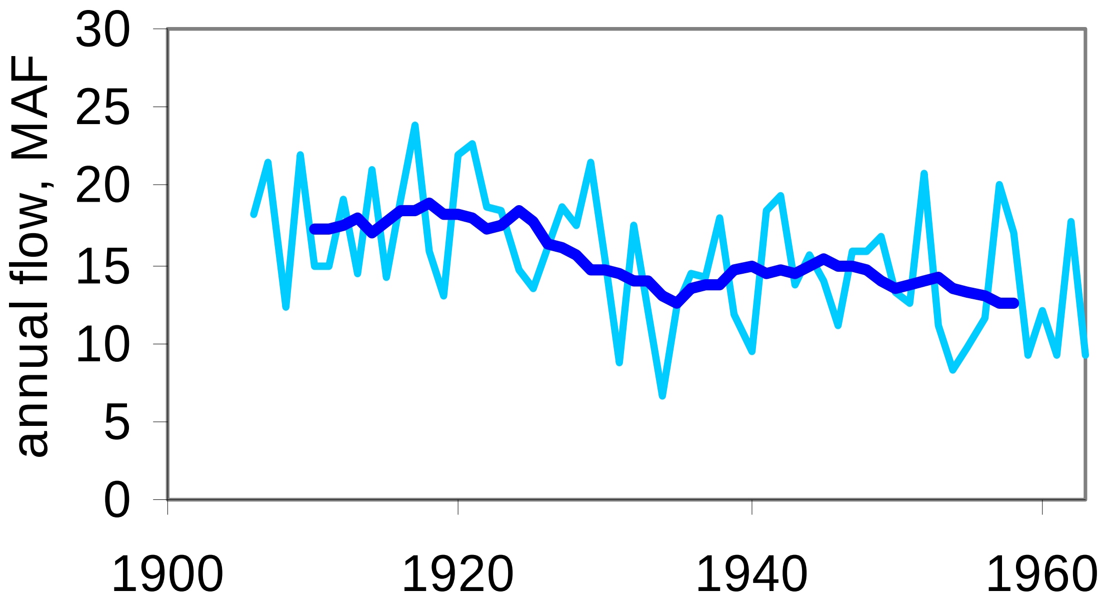
Gaged (natural flow) record, 1906-1930



Learning from experience in water management

Colorado River at Lees Ferry

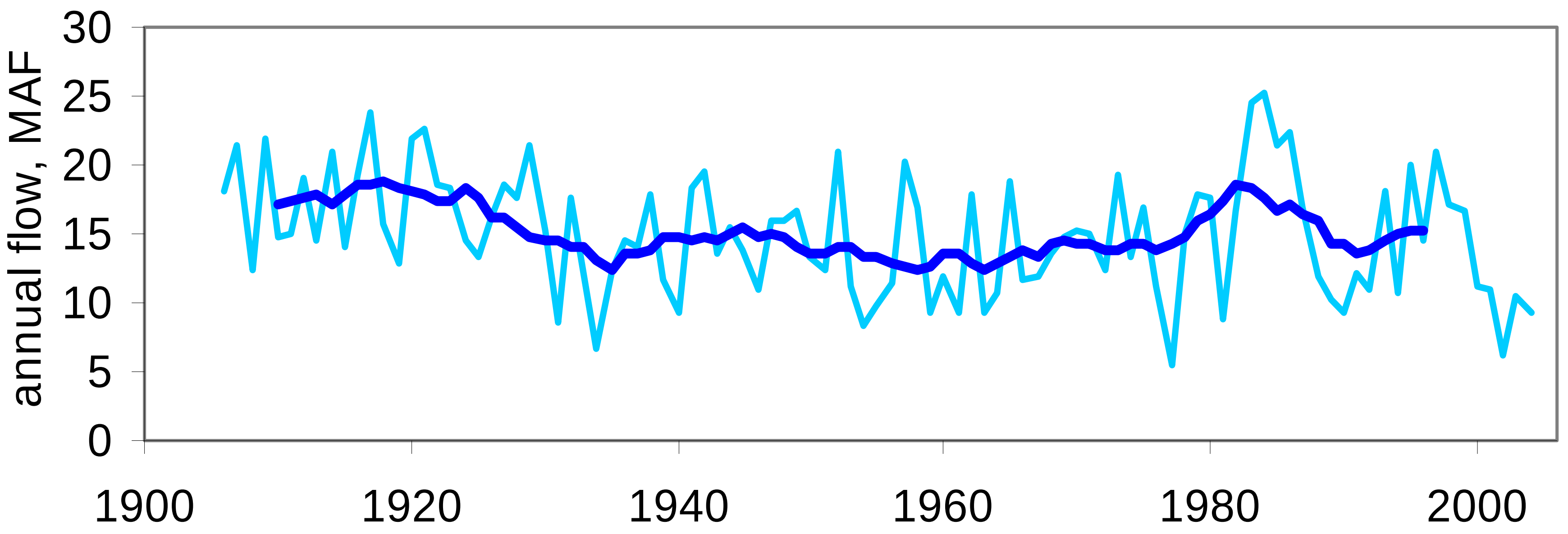
Gaged (natural flow) record, 1906-1963



Learning from experience in water management

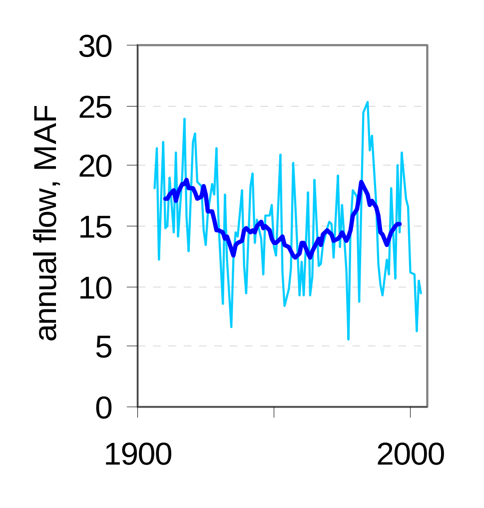
Colorado River at Lees Ferry

Gaged (natural flow) record, 1906-2004



Even 100 years of experience may be inadequate

Tree-ring reconstructions - a surrogate for experience



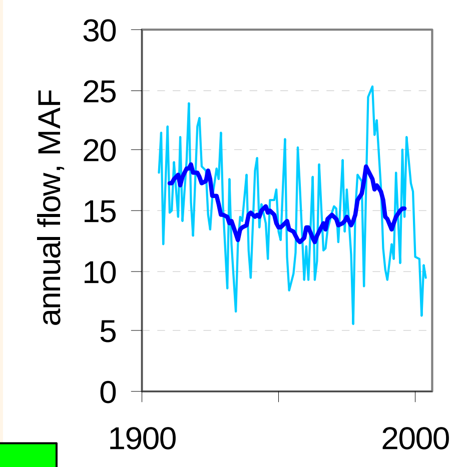
Colorado at Lees Ferry

Gaged (natural flow) record

1906-2004

Tree-ring reconstructions - a surrogate for experience

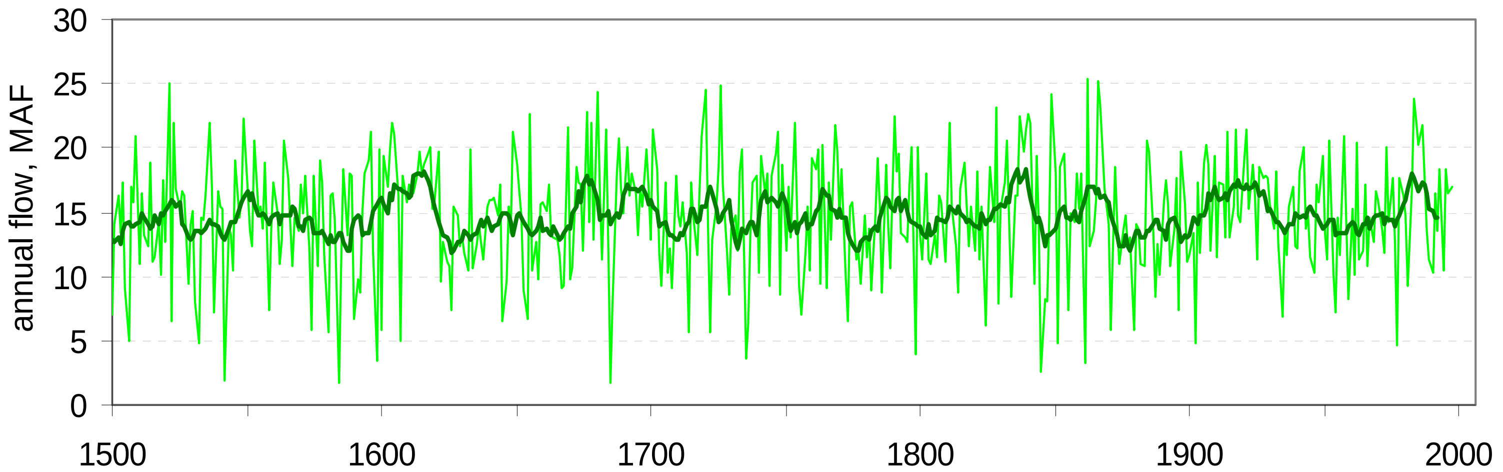
By extending the gaged hydrology by hundreds of years into the past, the reconstructions provide a more complete picture of hydrologic variability



Colorado River at Lees Ferry

Gaged (natural flow) record

1906-2004

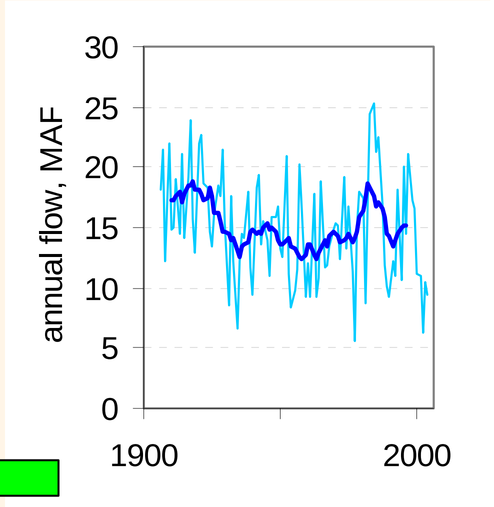


Tree-ring reconstruction

1490-1997

Tree-ring reconstructions - a surrogate for experience

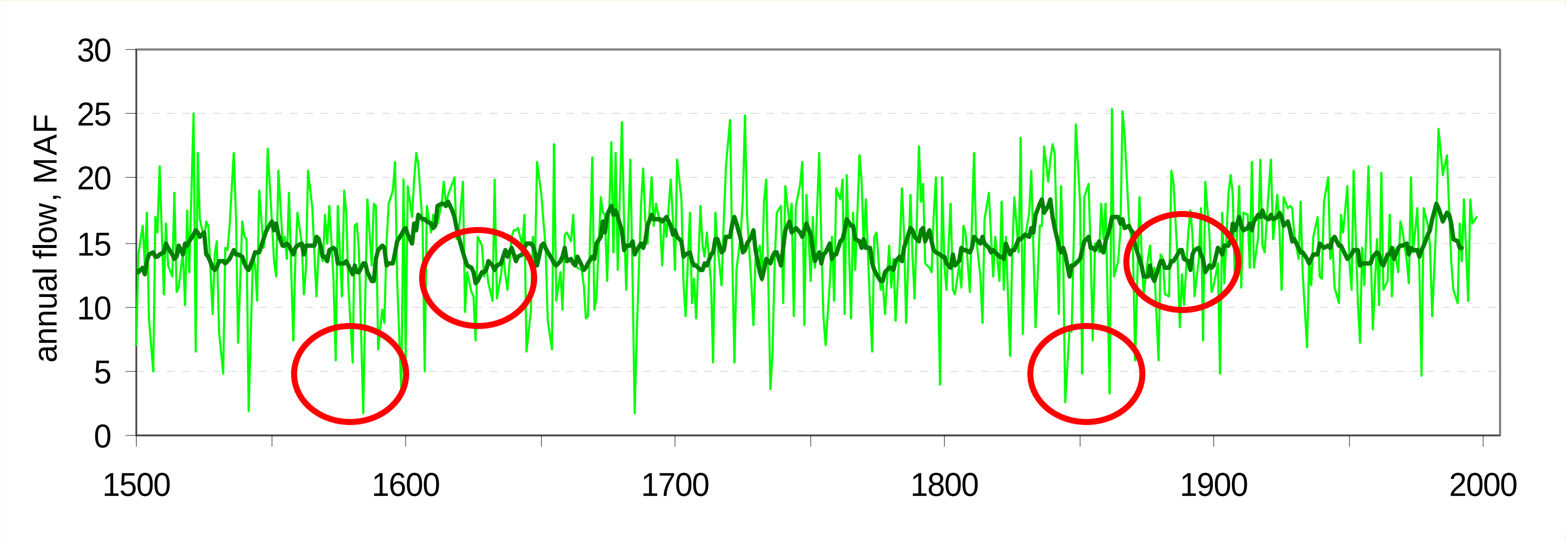
By extending the gaged hydrology by hundreds of years into the past, the reconstructions provide a more complete picture of hydrologic variability



Colorado River at Lees Ferry

Gaged (natural flow) record

1906-2004



Tree-ring reconstruction

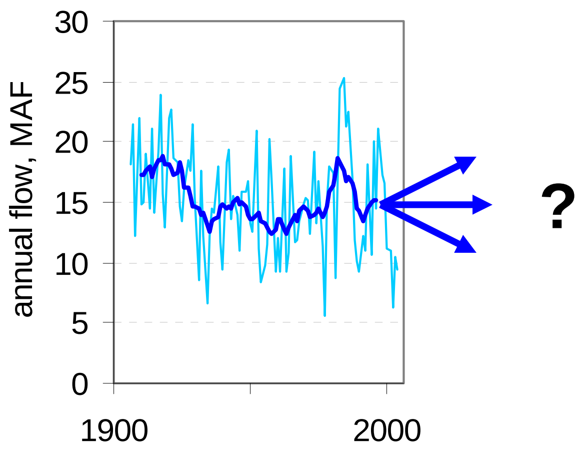
1490-1997

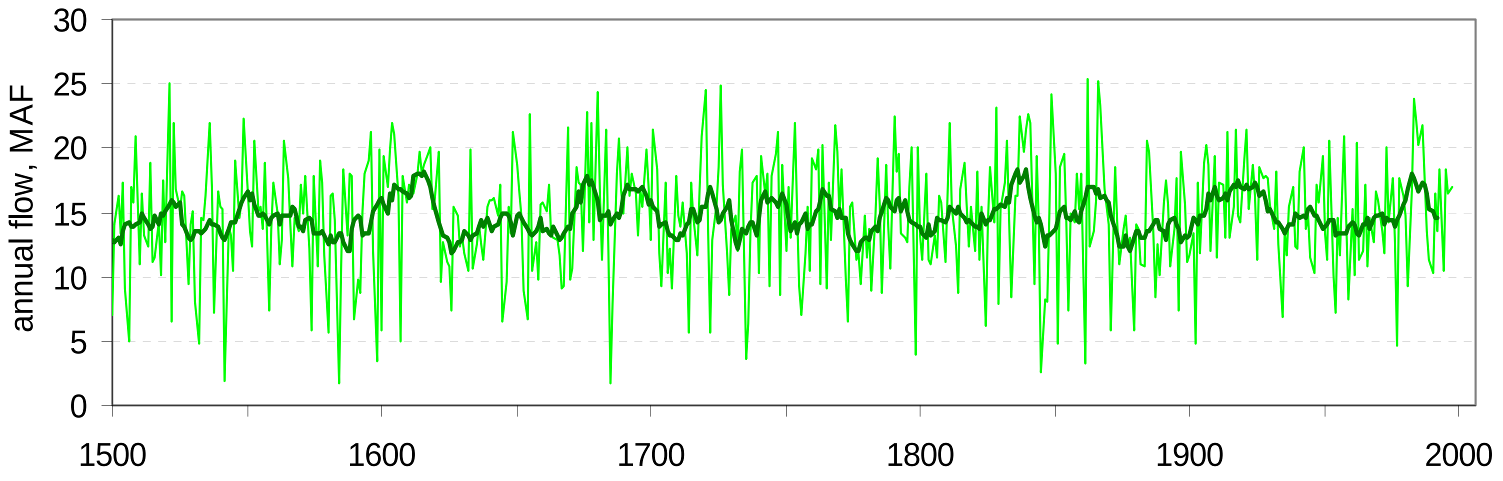
Tree-ring reconstructions - a surrogate for experience

Benefits:

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

- Better assessment of *risk*





Tree-ring reconstruction

1490-1997

Attributes of tree rings useful for climate and streamflow reconstruction

- Annual resolution
- Continuous records (100-10,000 yrs)
- High sensitivity and fidelity to climate variability
- Widespread distribution

Dendrochronology

The science that deals with the dating and study of tree rings

Dendroarchaeology

Dendroecology

Dendrogeomorphology

etc.

Dendroclimatology

The science that uses tree rings to study present climate and reconstruct past climate

Dendrohydrology

The science that uses tree rings to study changes in river flow, surface runoff, and lake levels

Key advances in dendrochronology, dendroclimatology, and dendrohydrology

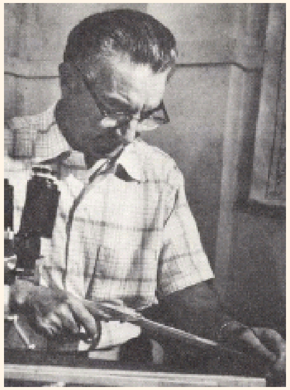
1905-1920 - Douglass establishes modern tree-ring science; links tree-growth and climate in Southwest

1930s - First studies relating tree growth to runoff in western US

1940s - Schulman investigates history of Colorado River flow using tree rings

1960s - Fritts models physiological basis of trees' sensitivity to climate; develops modern statistical methods for climate reconstruction

A.E. Douglass



E. Schulman

Key advances in dendrochronology, dendroclimatology, and dendrohydrology

1976 - Stockton and Jacoby reconstruction of Lees Ferry streamflow

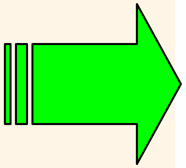
1980s - Cook and Meko refine statistical tools for chronology development and reconstructions

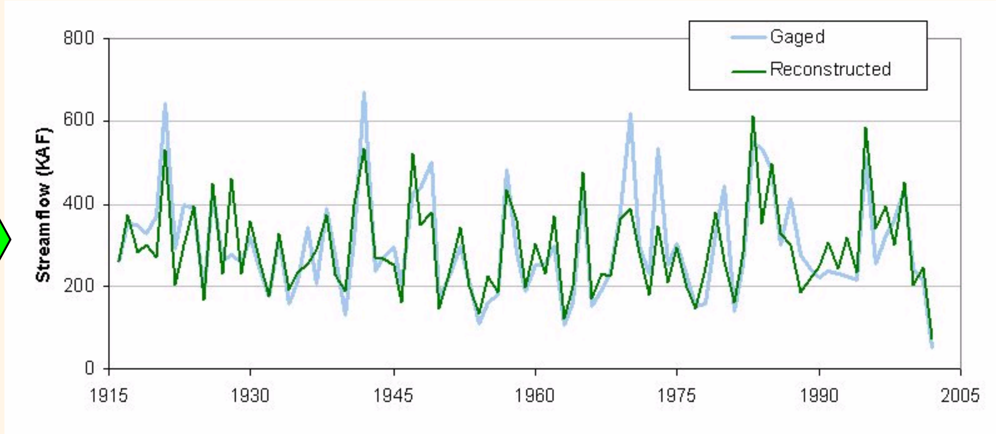
2000s - Many new flow reconstructions for western US and Colorado

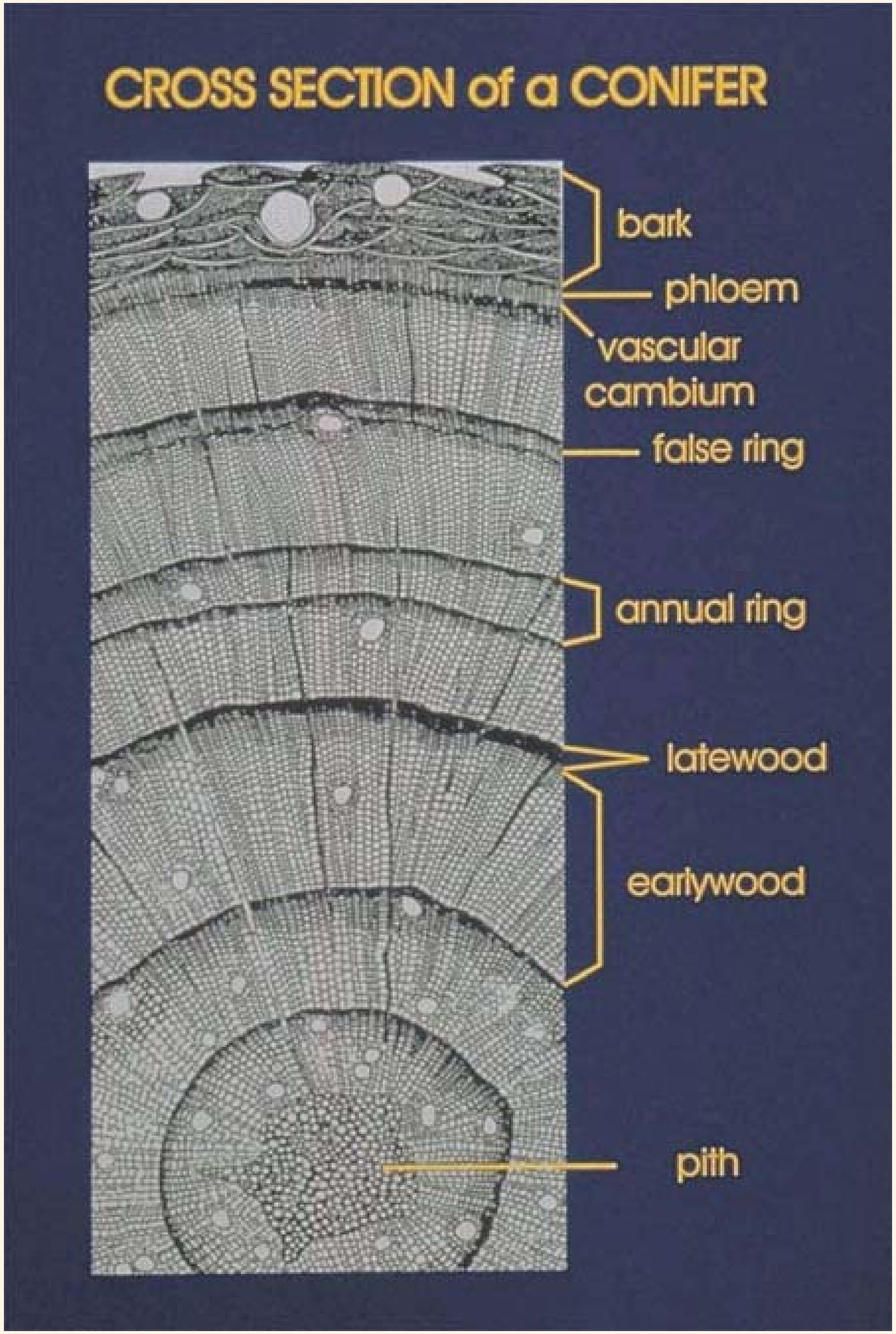
2006 - Woodhouse et al. reconstructions of Lees Ferry and other Colorado basin gages

Part 2:

How tree rings record climate information







The formation of annual growth rings

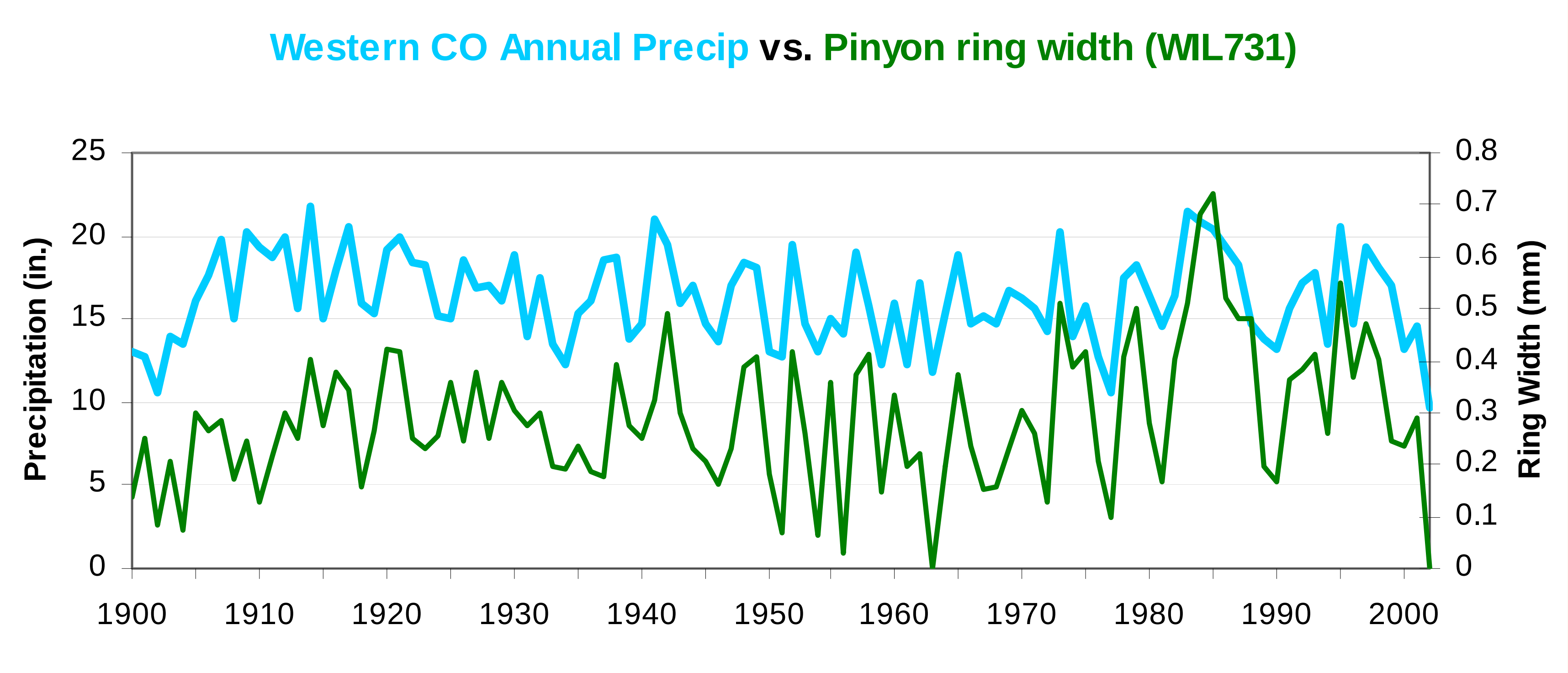
- New wood forms in the vascular cambium, underneath the bark
- Earlywood + latewood = growth ring
- In temperate climates, growth ring = *annual ring*
- Rings have varying widths when a *limiting factor* on growth varies in magnitude from year to year

Climate is typically the limiting factor for tree growth in the intermountain West

- At high elevations, growth is typically limited by summer warmth and length of the growing season

- At lower elevations, growth is typically limited by *moisture availability* (precipitation - evapotranspiration)

The moisture signal recorded by trees in this region is particularly strong



- Here, the “raw” ring widths from one tree are closely correlated to the annual basin precipitation (r = 0.7)
- Our job is to *capture* and *enhance* the moisture signal, and reduce noise, through careful sampling and data processing

This moisture signal in tree rings can be a proxy for multiple moisture-related variables

- Annual or seasonal precipitation
- Drought indices (e.g., PDSI)
- Snow-water equivalent (SWE)
- Annual streamflow

These variables are closely correlated in this region, and trees whose ring widths are a good proxy for one tend to be good proxies for all of them

Ring-width and streamflow - an indirect but robust relationship

- Like ring width, streamflow integrates the effects of precipitation and evapotranspiration, as mediated by the soil

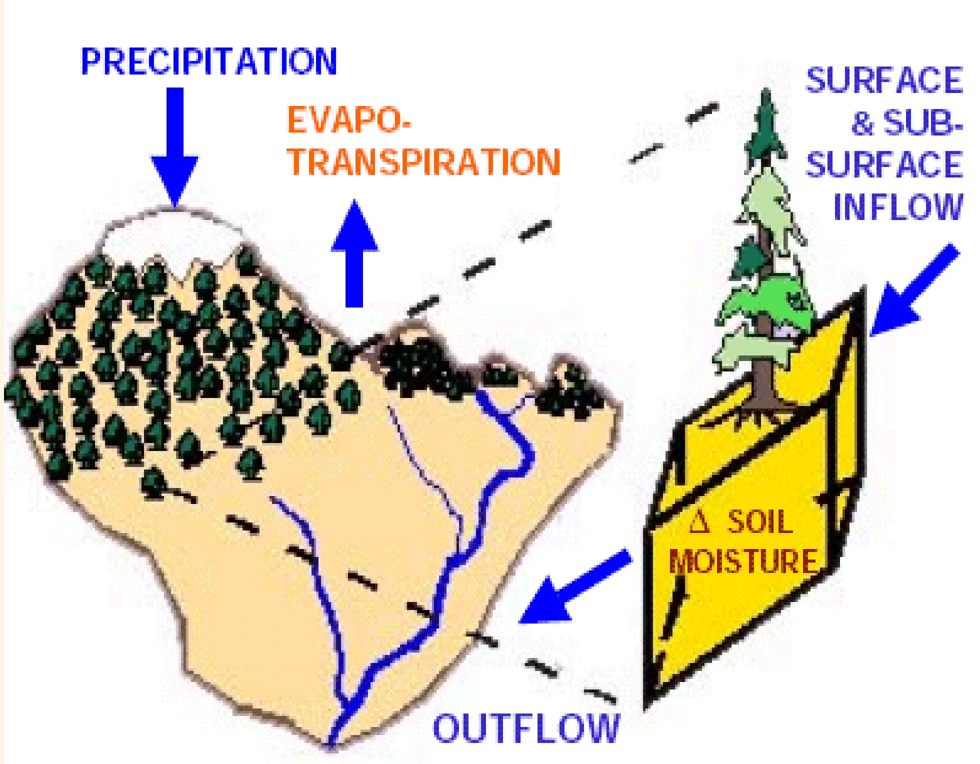
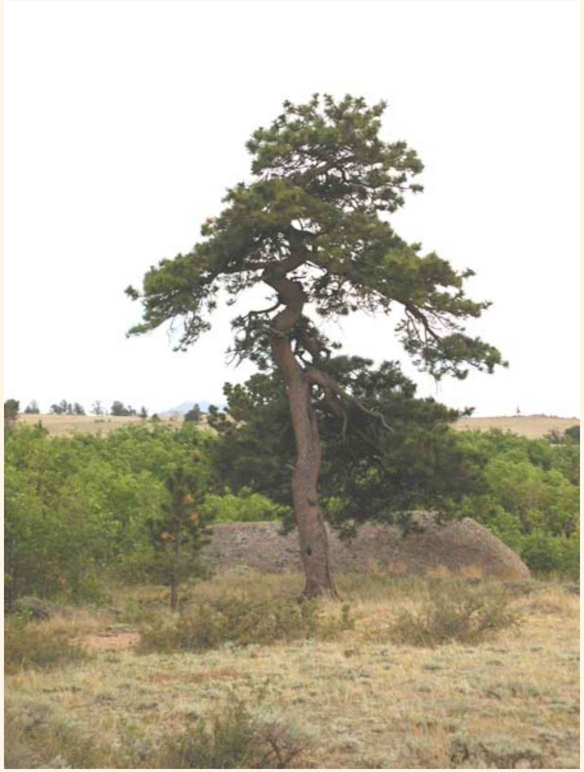


Image courtesy of D. Meko (U. AZ)

Main moisture-sensitive species in the Southwest

Douglas-fir

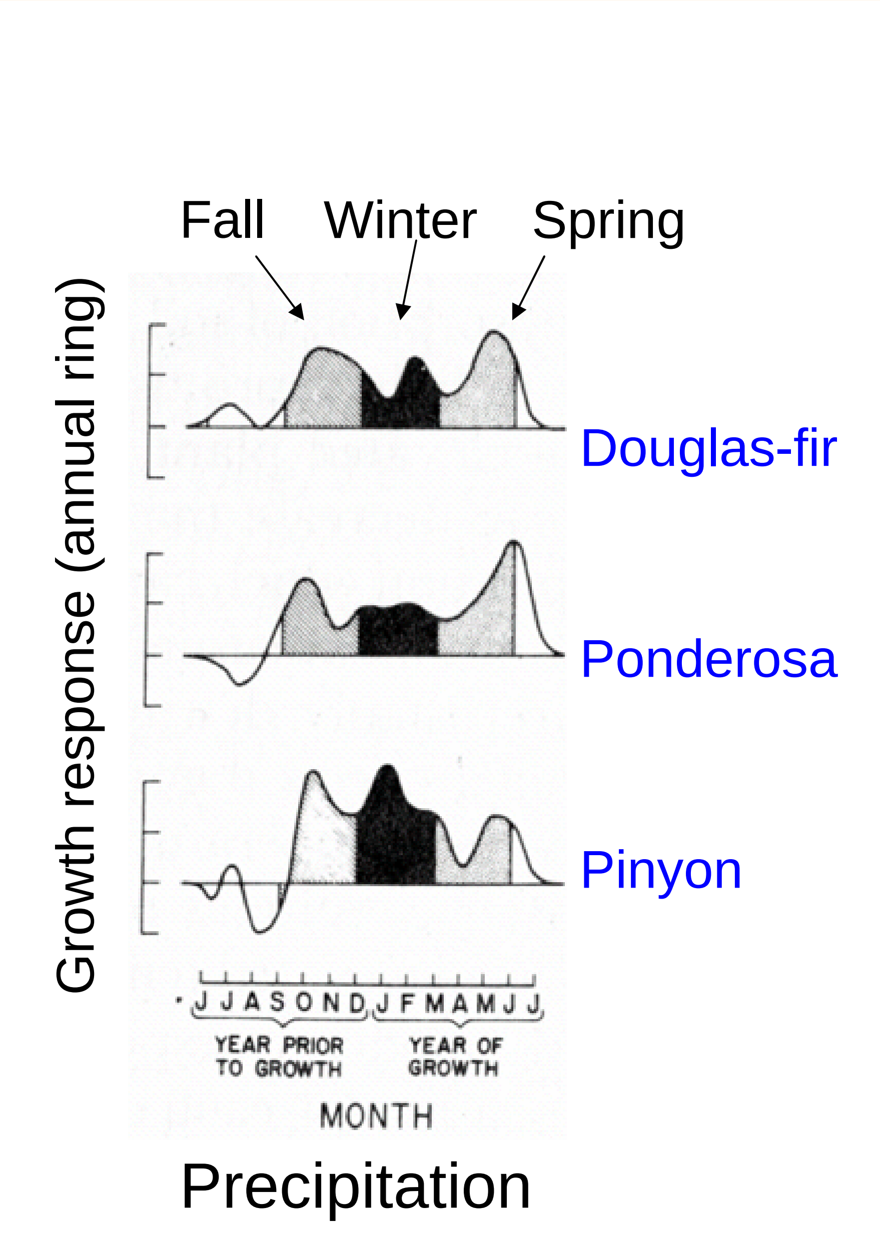


Ponderosa Pine

Pinyon Pine

- All have maximum ages of 800-1000 years; old trees are typically 400-700 years

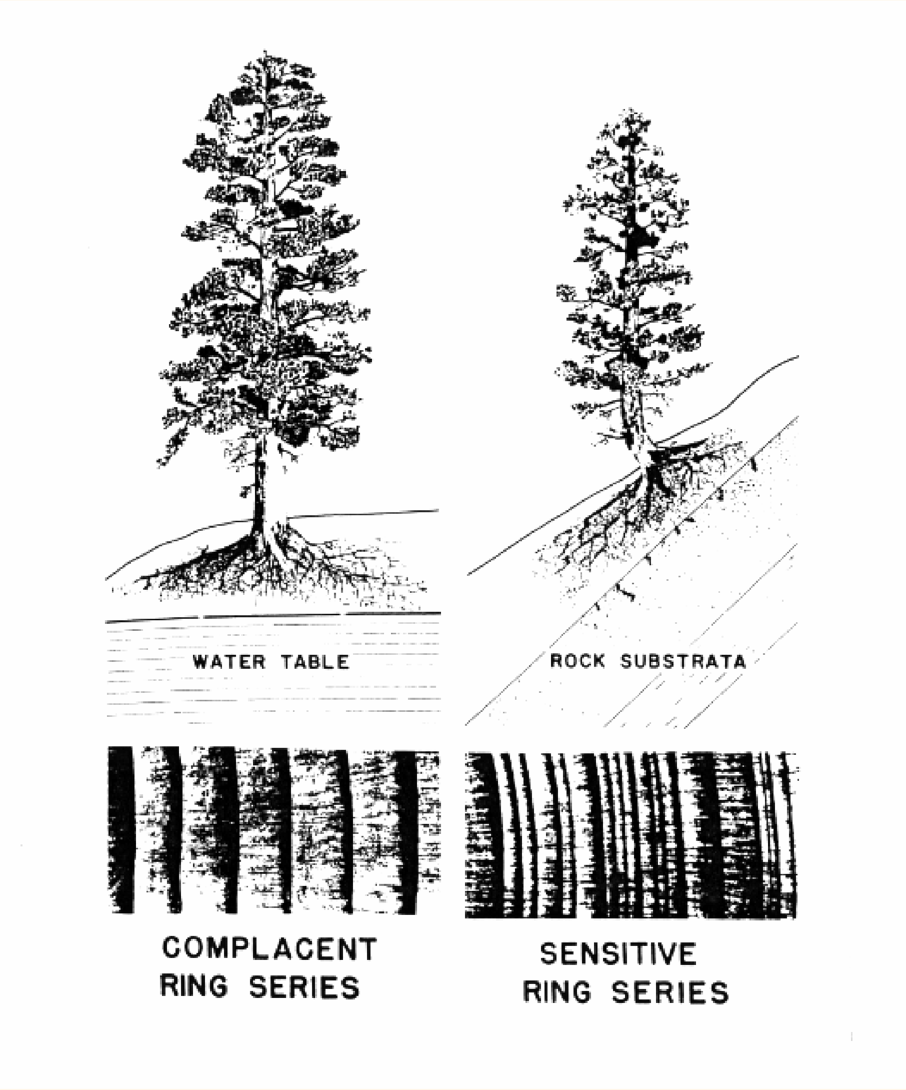
Seasonal precip. response by species - western US



- All species' growth responds mainly to precipitation in fall/winter/spring prior to growing season
- Some variation in shape of the seasonal response curve

from *Fritts 1976*

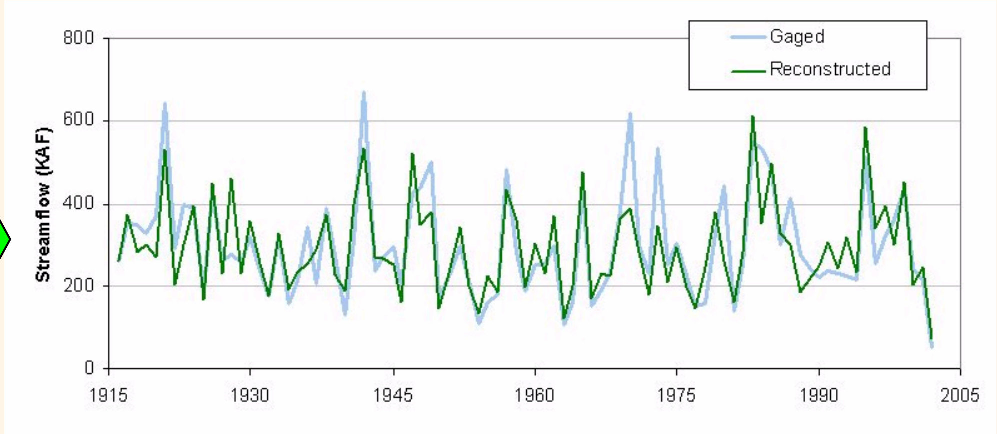
Stressful sites produce ring series with greater sensitivity (higher Signal:Noise ratio)



from *Fritts 1976*

Part 3:

Building a tree-ring chronology



Chronology = basic unit of tree-ring data, “building block” for the flow reconstruction

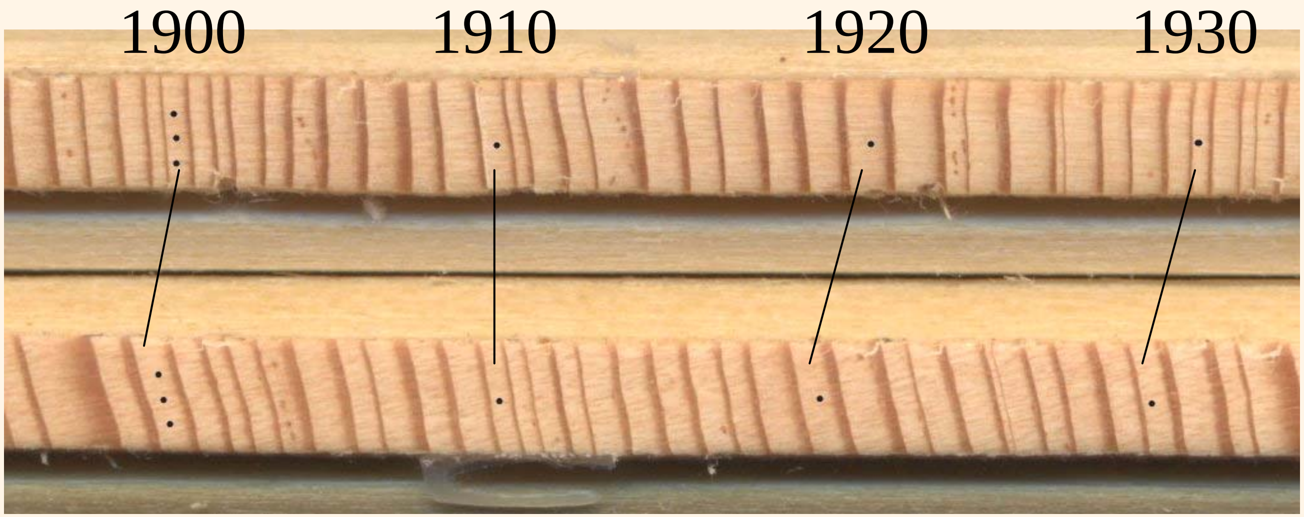
Sampling the trees

- Core 10-30+ trees at a site, same species
- Goal: maximize the number of samples throughout the chronology (300-800+ years)
- Can also core or cut cross-sections from dead trees

Crossdating the samples

- Because of the common climate signal, the pattern of wide and narrow rings is highly replicated between trees at a site, and between nearby sites

- This allows *crossdating:* the assignment of absolute dates to annual rings (not just ring-counting)



Two Douglas-fir trees south of Boulder, CO

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

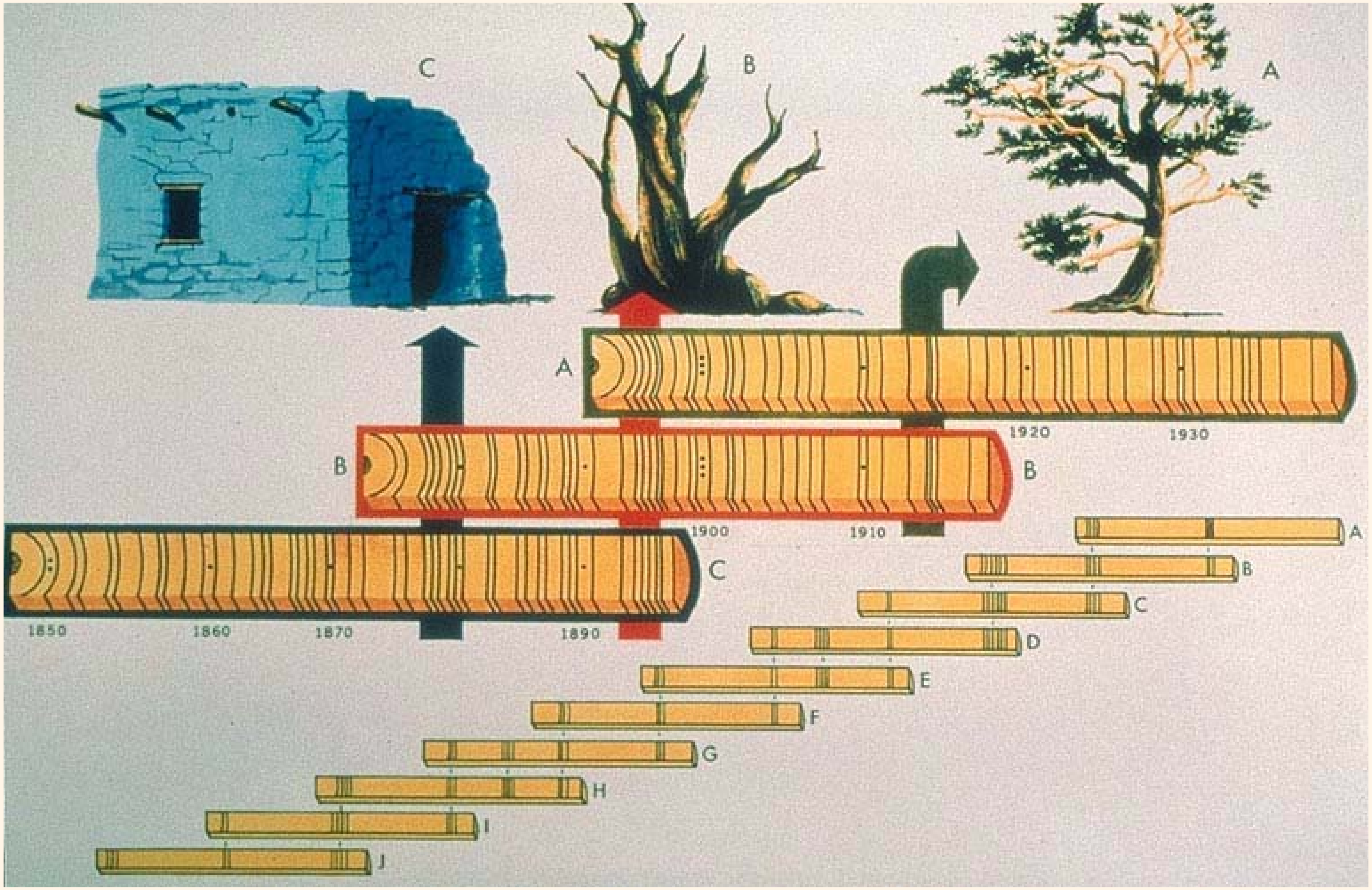
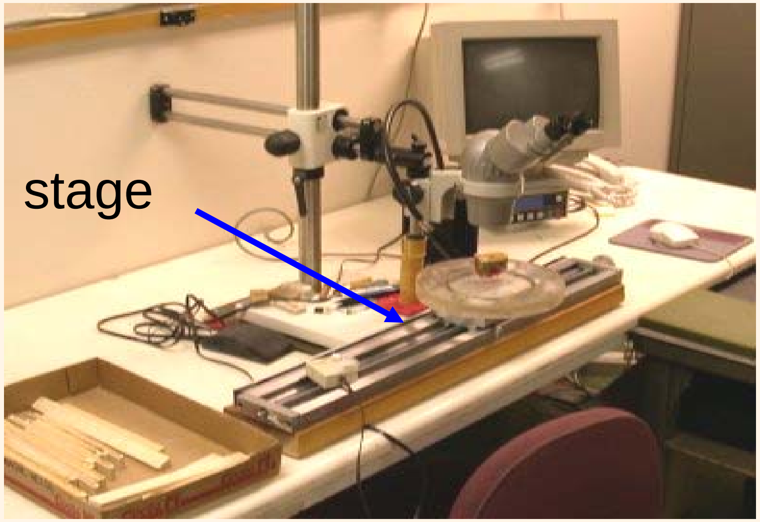
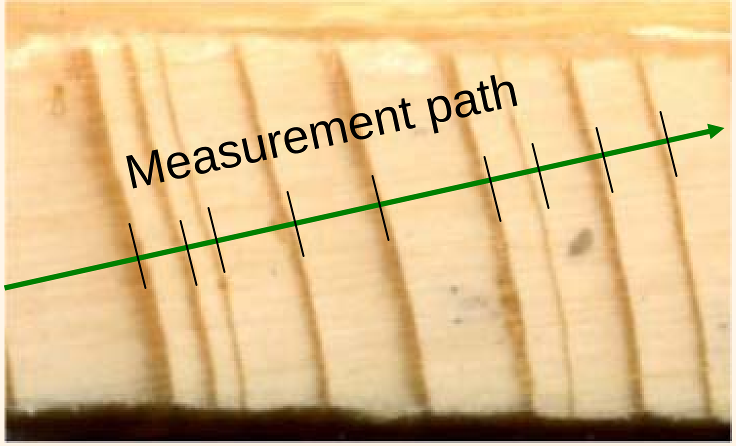


Image courtesy of LTRR (U. AZ)

Measuring the samples

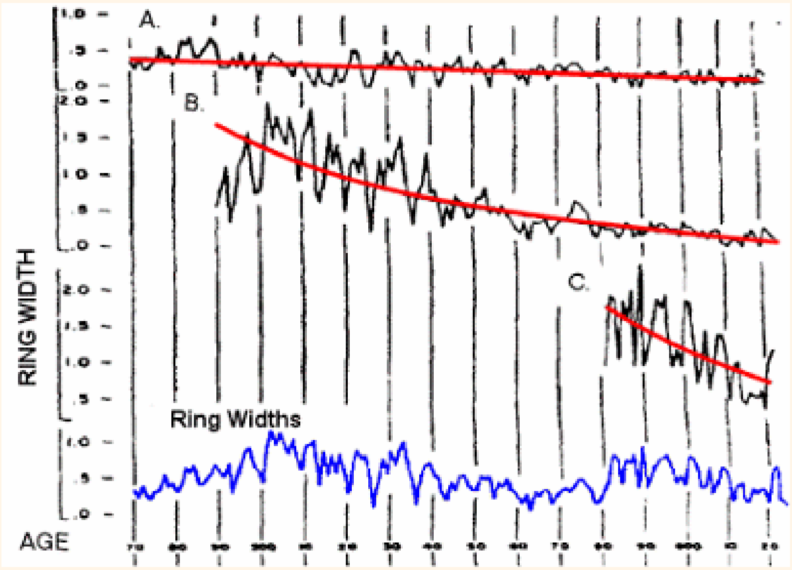


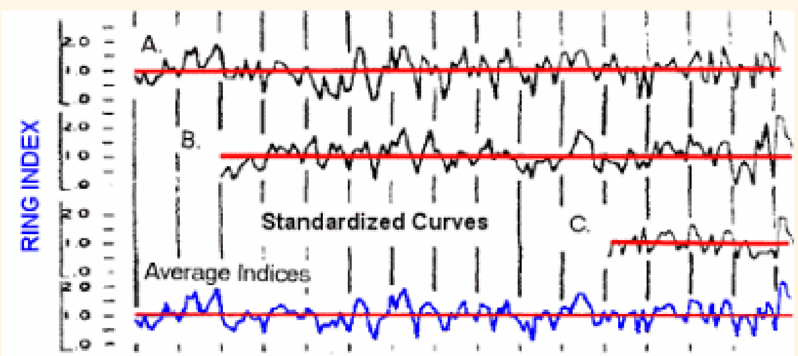
- Computer-assisted measurement system with sliding stage
  - captures position of core to nearest 0.001mm (1 micron)



- Measurement path is parallel to the rows of cells (and perpendicular to the ring boundaries)

Detrending the measured series



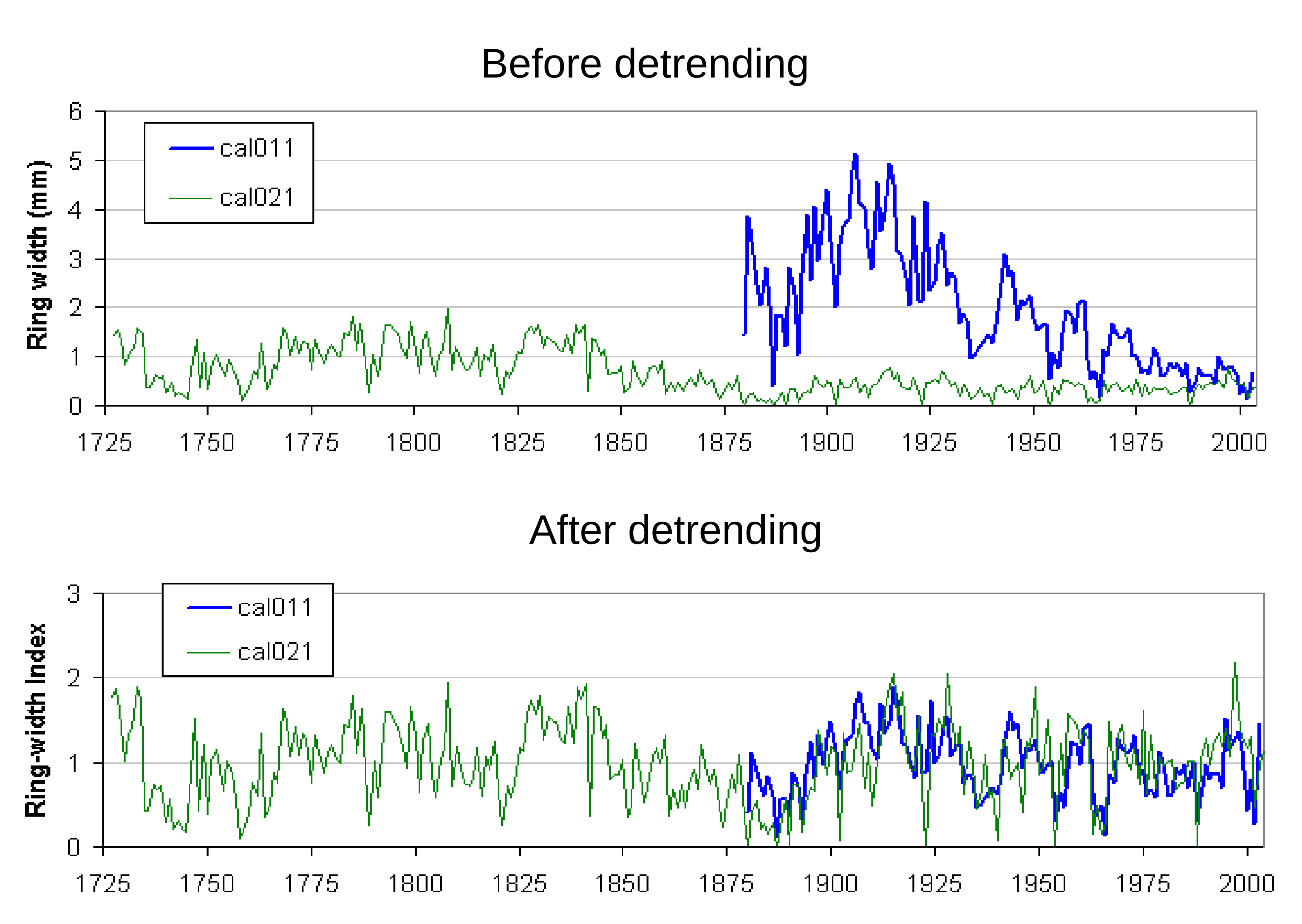


- Ring-width series typically have a declining trend with time because of tree geometry
- These are low-frequency *noise* (i.e. non-climatic)

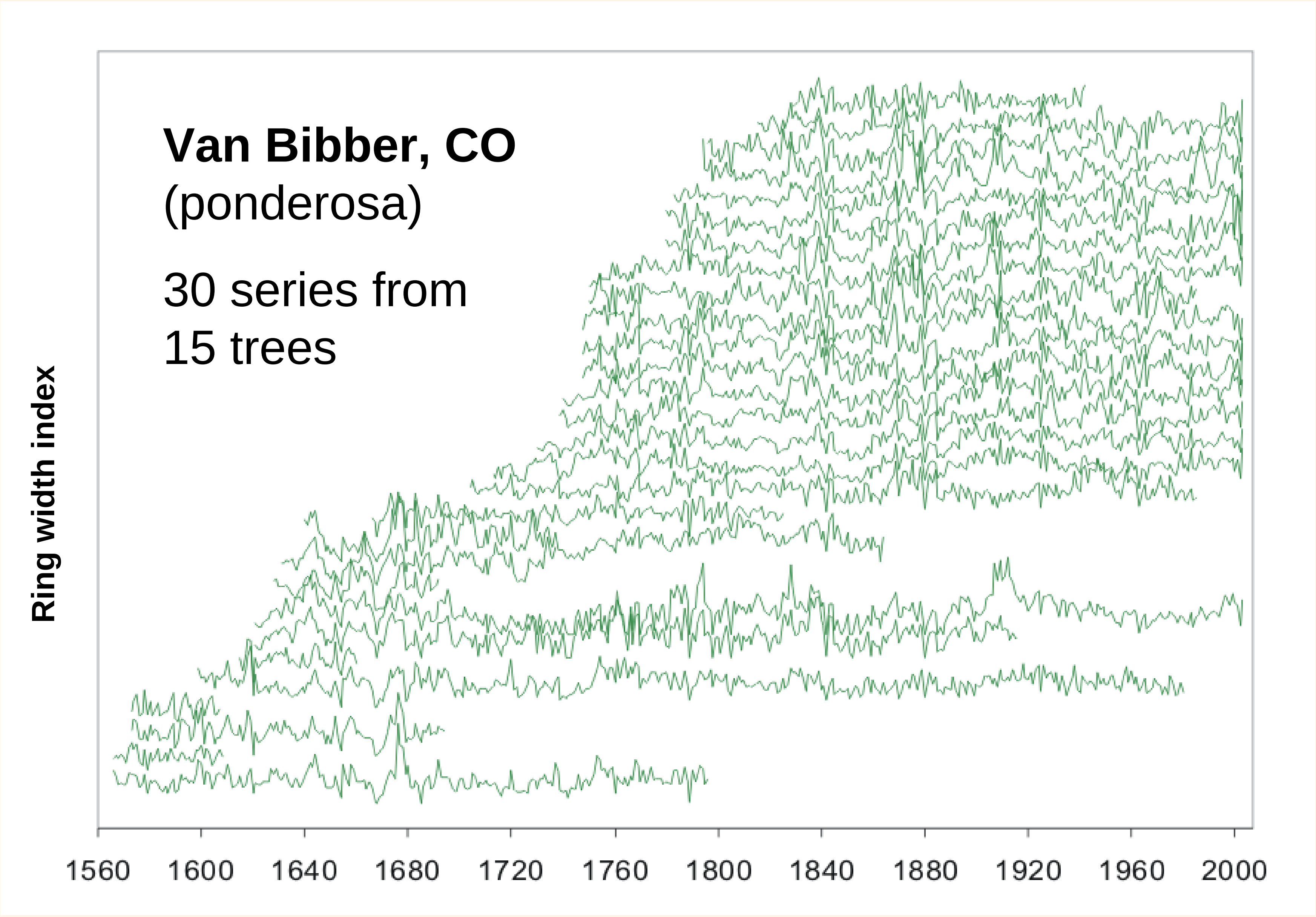
- Raw ring series are detrended with straight line, exponential curve, or spline

- These *standardized* series are compiled into the site chronology

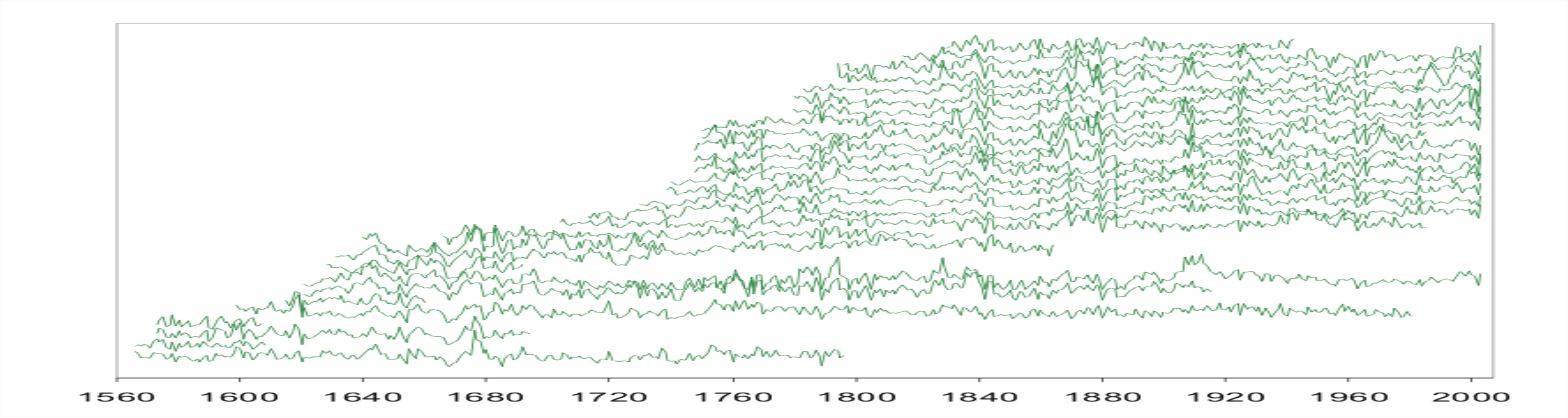
Example of detrending - 2 trees, same site

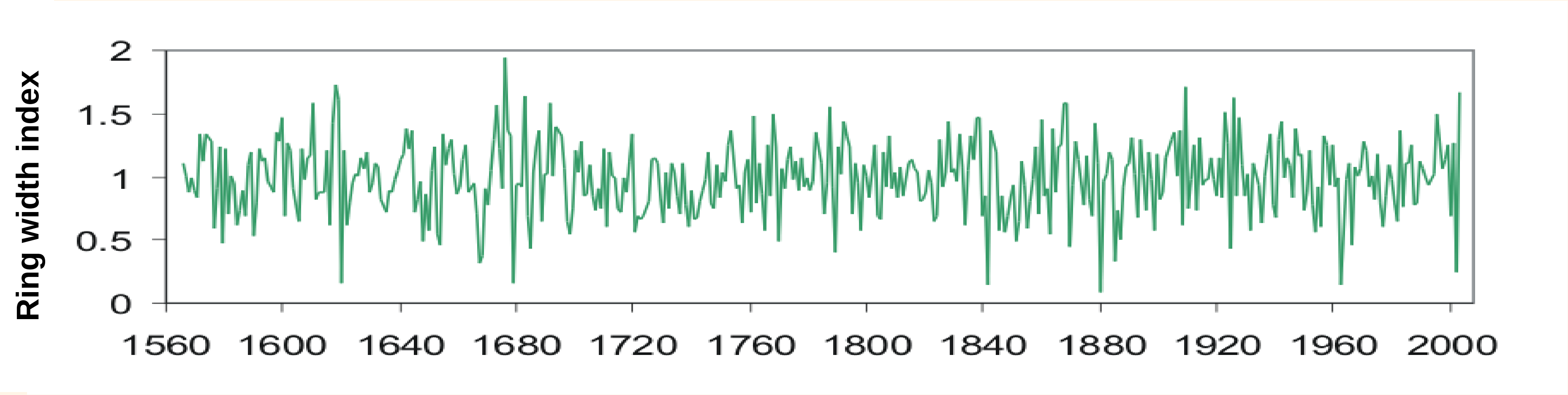


By compiling the measurements from many trees...

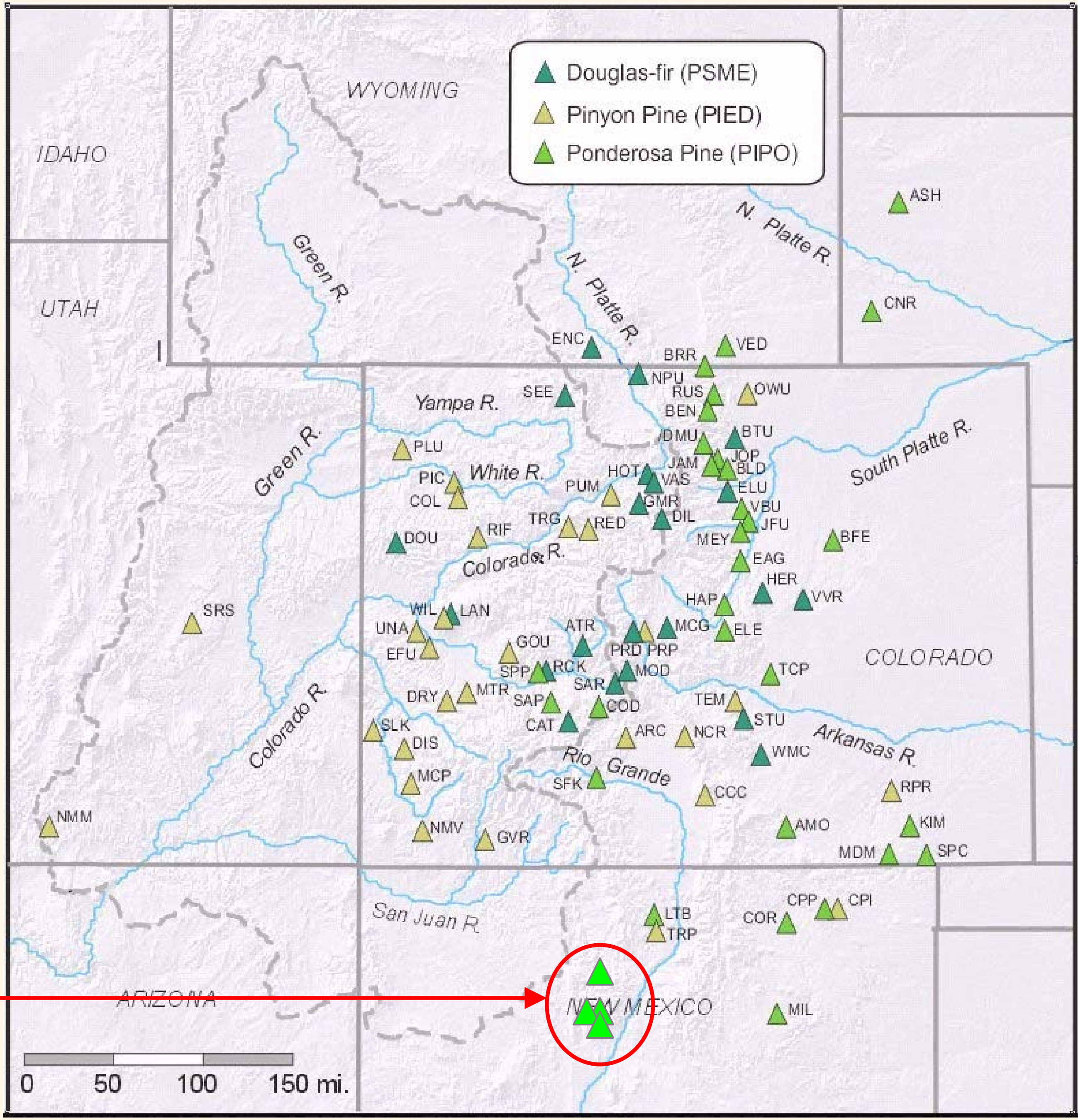


…we enhance the common (climate) signal in the resulting site *chronology*





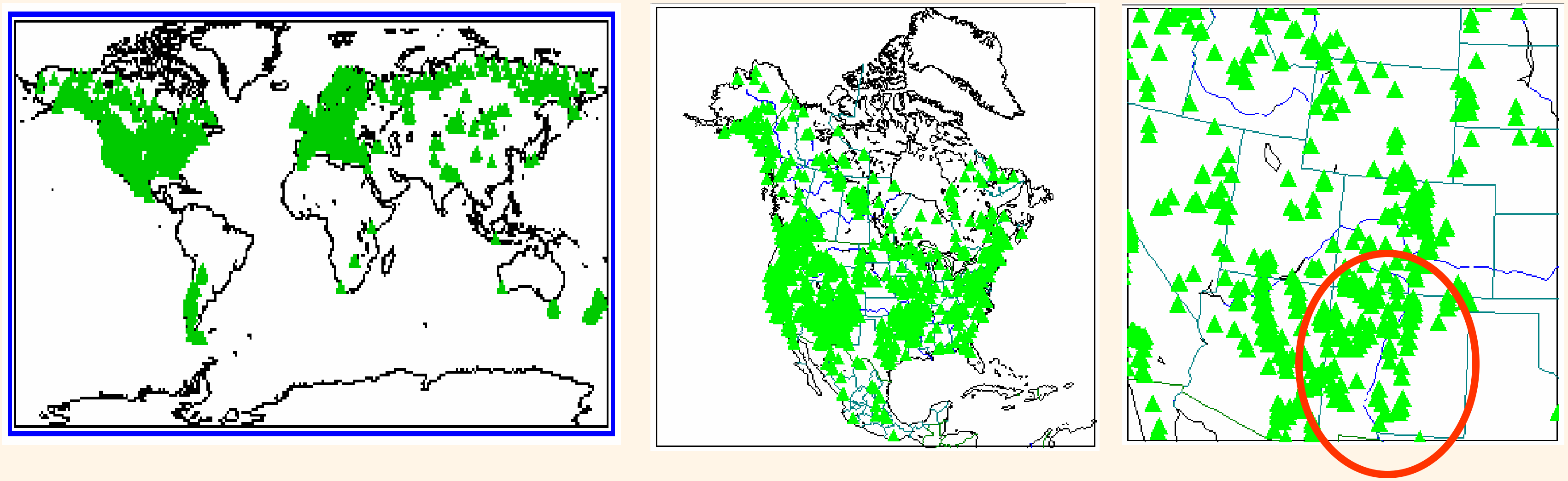
Moisture-sensitive chronologies developed 1999-2006 by CU-INSTAAR Dendro Lab



4 new collections Fall 2007, Univ. of Arizona LTRR

The larger world of tree-ring chronologies

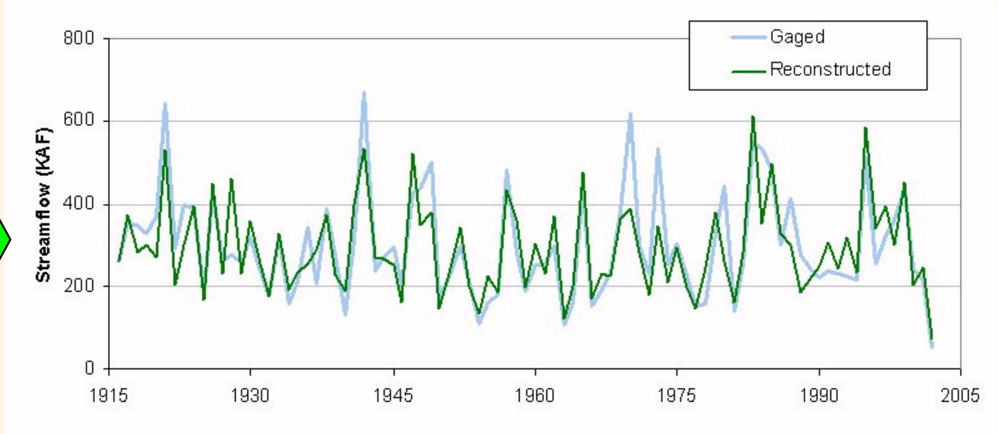
International Tree-Ring Data Bank (ITRDB)
http://www.ncdc.noaa.gov/paleo/treering.html



- 2500 chronologies contributed from all over the world
- 90 chronologies from New Mexico, nearly all are moisture-sensitive

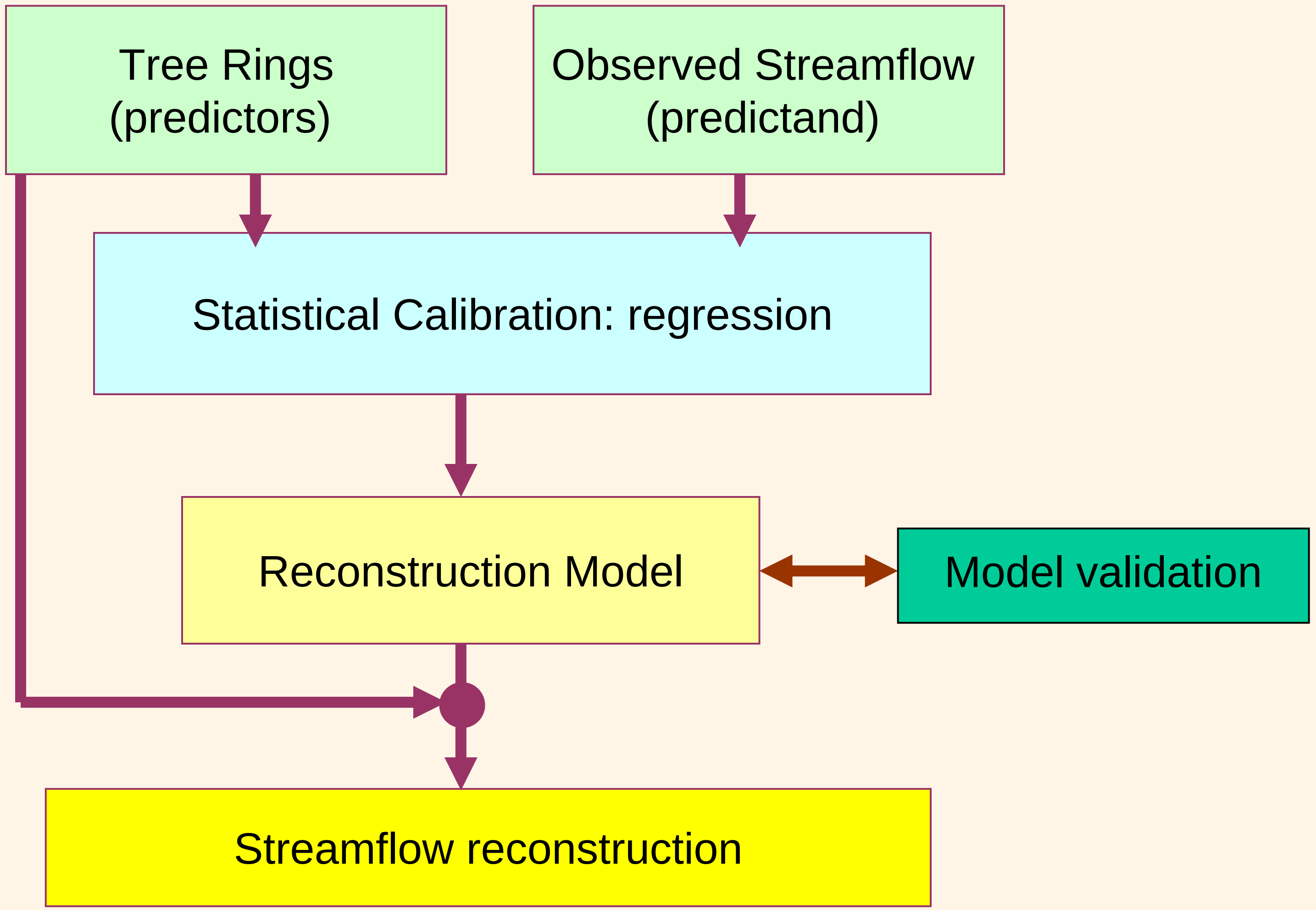
Part 4:

Generating the streamflow reconstruction



Reconstruction = best estimate of past flows, based on the relationship between a selected set of tree-ring data and gaged flows

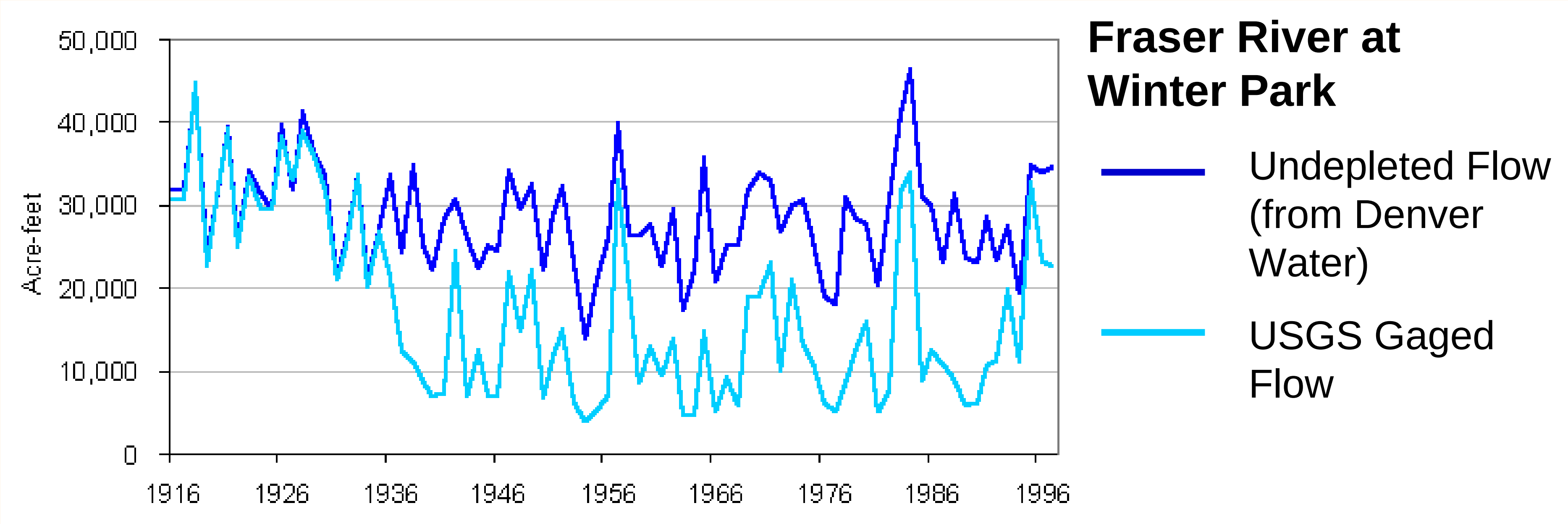
Overview of reconstruction methodology



based on Meko 2005

Requirements for observed streamflow record

- **Length** – minimum 50 years for robust calibration with tree-ring data
- **Natural/undepleted record** – must be corrected for depletions, diversions, evaporation, etc.



- *The reconstruction can only be as good as the flow record on which it is calibrated*

Requirements for tree-ring chronologies

- **Moisture sensitive species** - Douglas-fir, ponderosa pine, pinyon pine
- **Location** – from a region that is climatically linked to the gage of interest
  - *Because weather systems cross watershed divides, chronologies do not have to be in same basin as gage*
- **Years -**

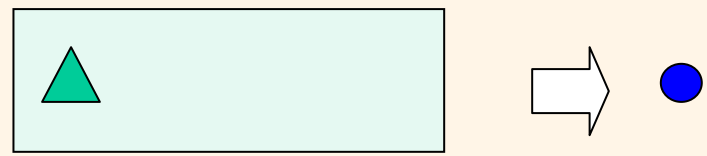
  Last year close to present for the longest calibration period possible

  First year as early as possible (>300 years) but in common with a number of chronologies

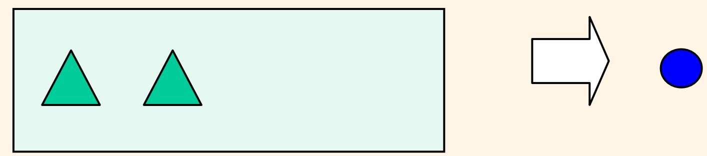
  - *reconstructions are usually limited by the shortest chronology*

Model calibration: Forward stepwise regression

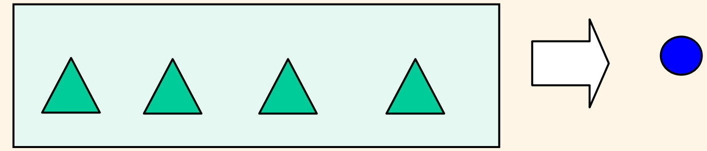
1) The chronology that explains the most variance in the flow record is selected as the first predictor in the regression



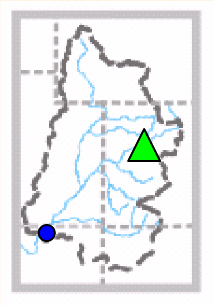
2) The chronology that explains the most *remaining unexplained* variance in the flow record is incorporated into the regression (repeat)



3) The process ends when no additional chronology significantly improves the fit of the regression to the flow record



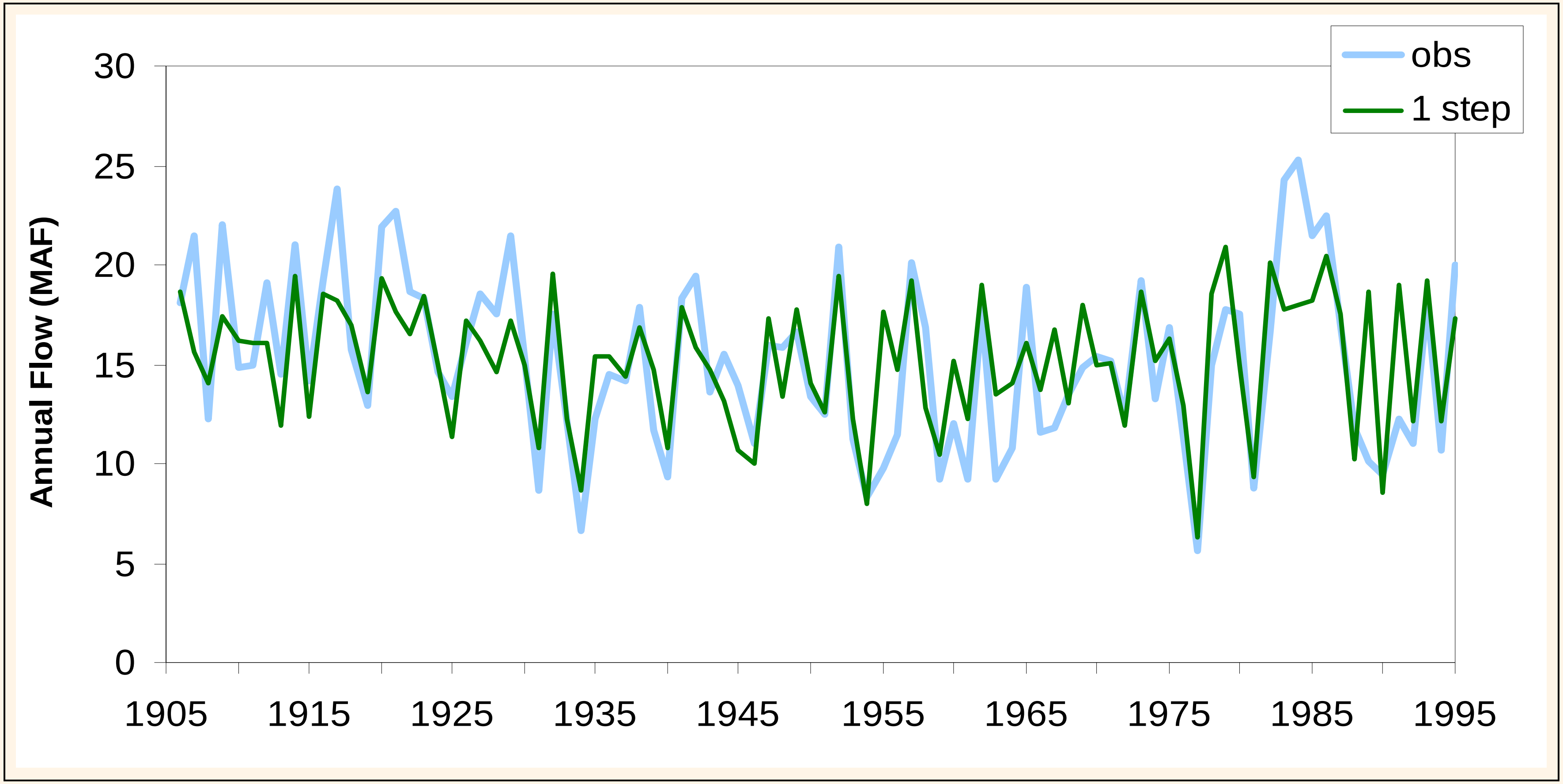
Colorado at Lees Ferry - forward stepwise regression



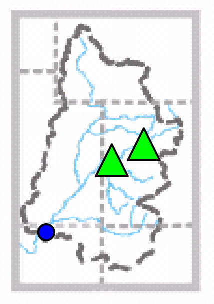
TRG

Variance Explained

55%



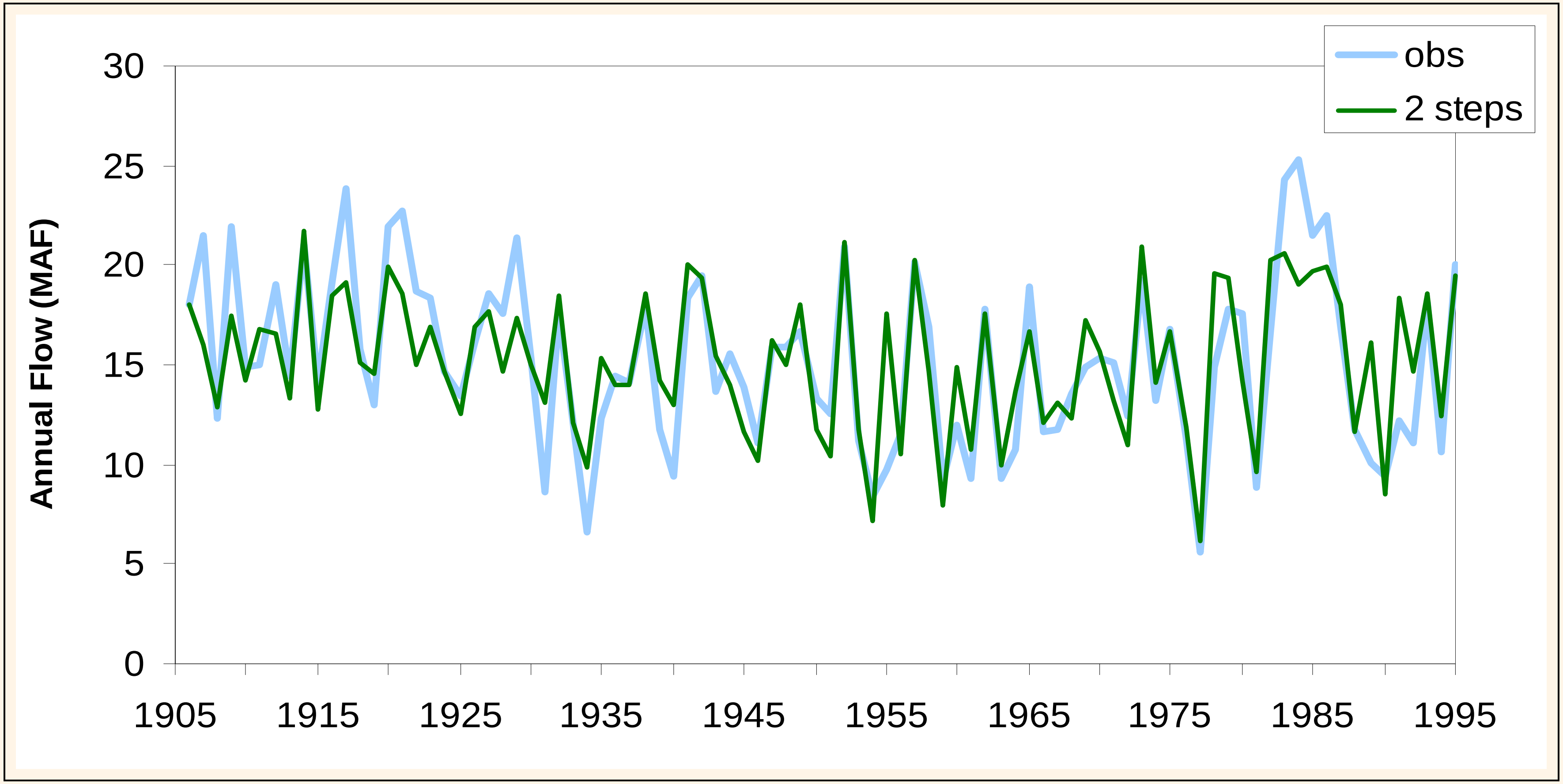
Colorado at Lees Ferry - forward stepwise regression



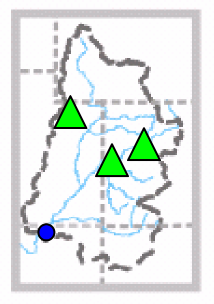
TRG + WIL

Variance Explained

67%



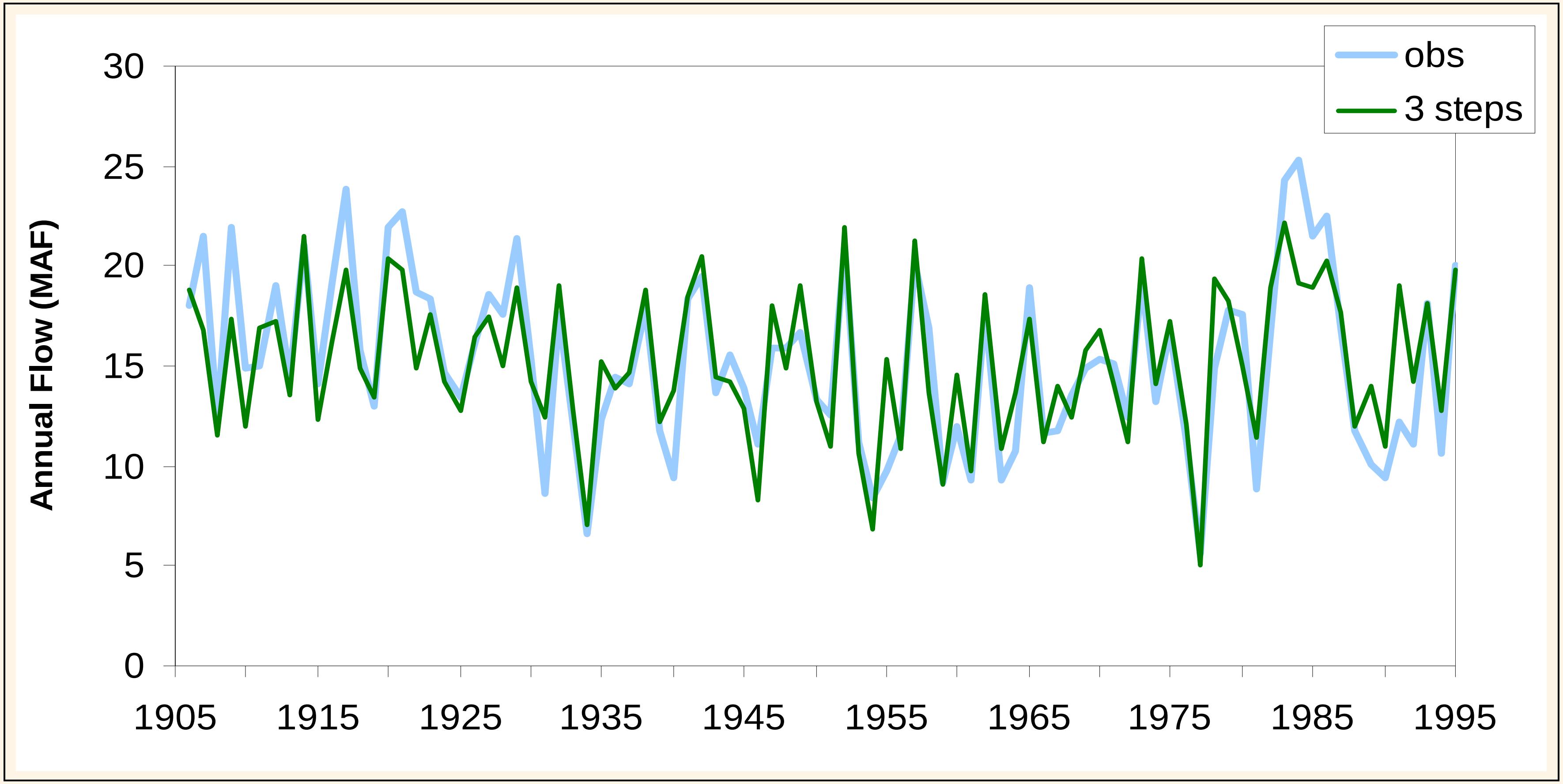
Colorado at Lees Ferry - forward stepwise regression



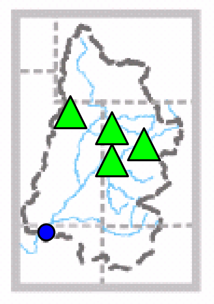
TRG + WIL + DJM

Variance Explained

72%



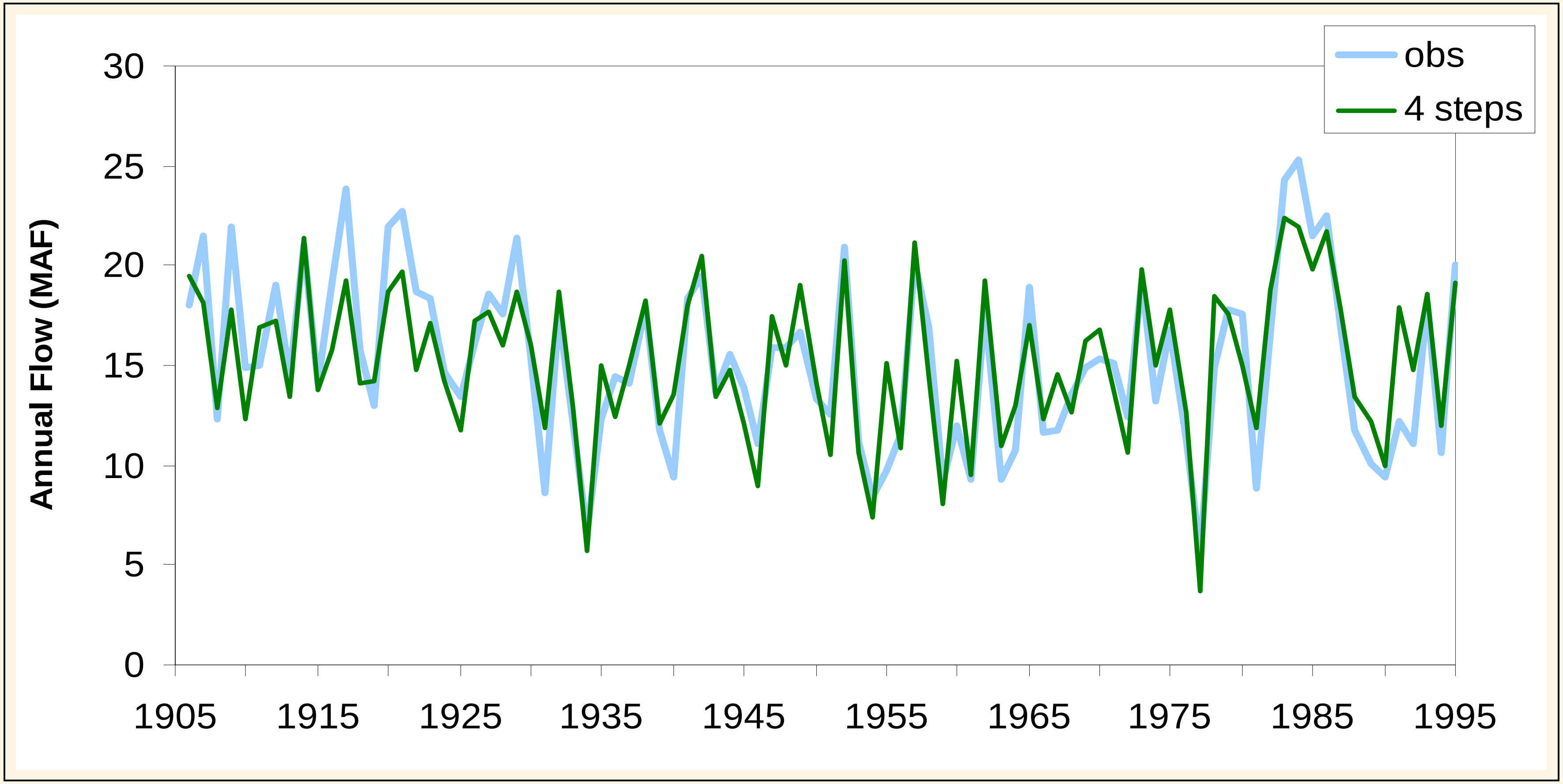
Colorado at Lees Ferry - forward stepwise regression



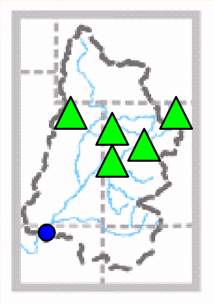
Variance Explained

75%

TRG + WIL + DJM + DOU



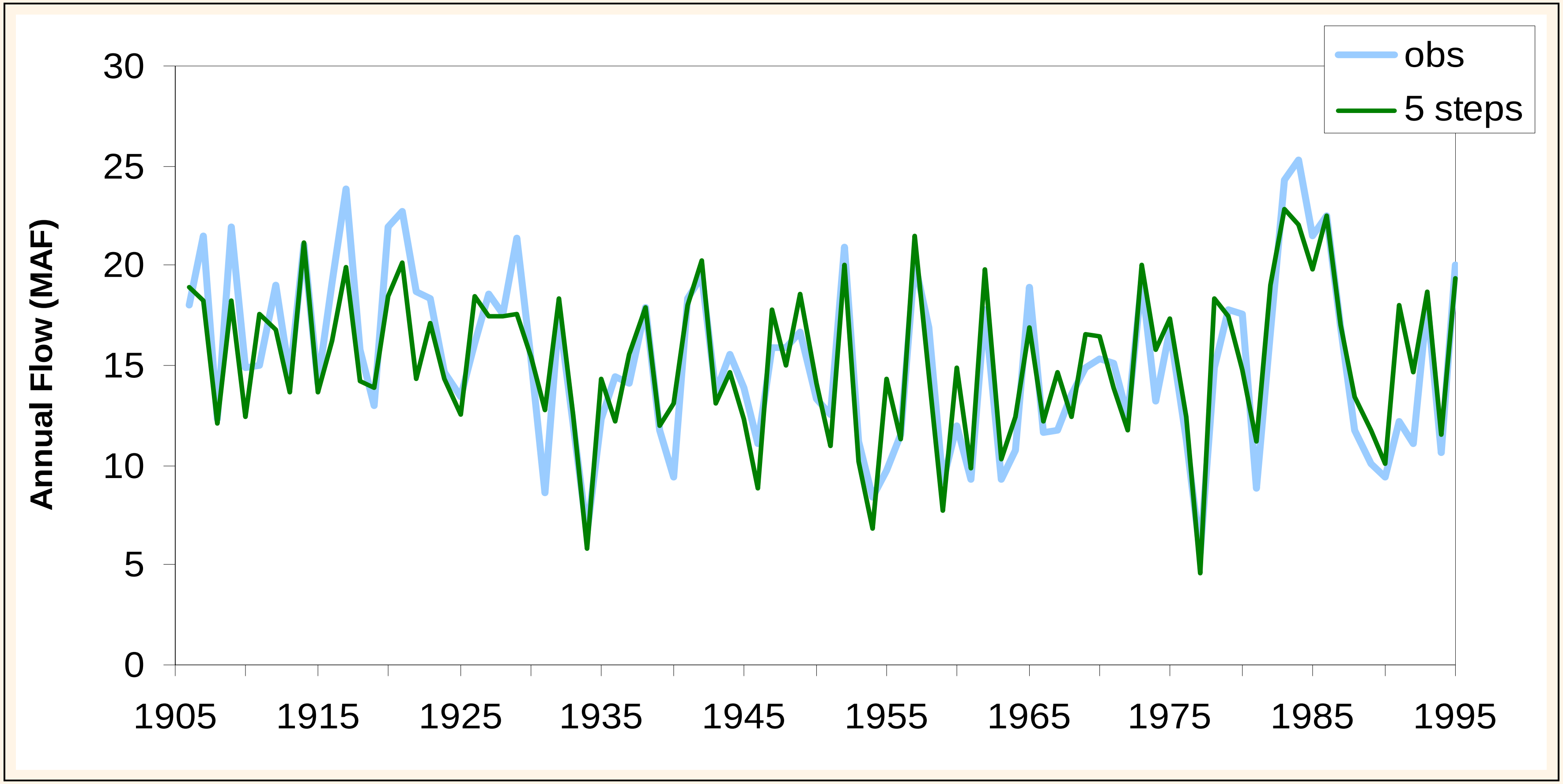
Colorado at Lees Ferry - forward stepwise regression



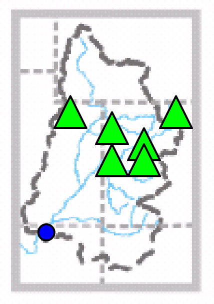
TRG + WIL + DJM + DOU + NPU

Variance Explained

77%



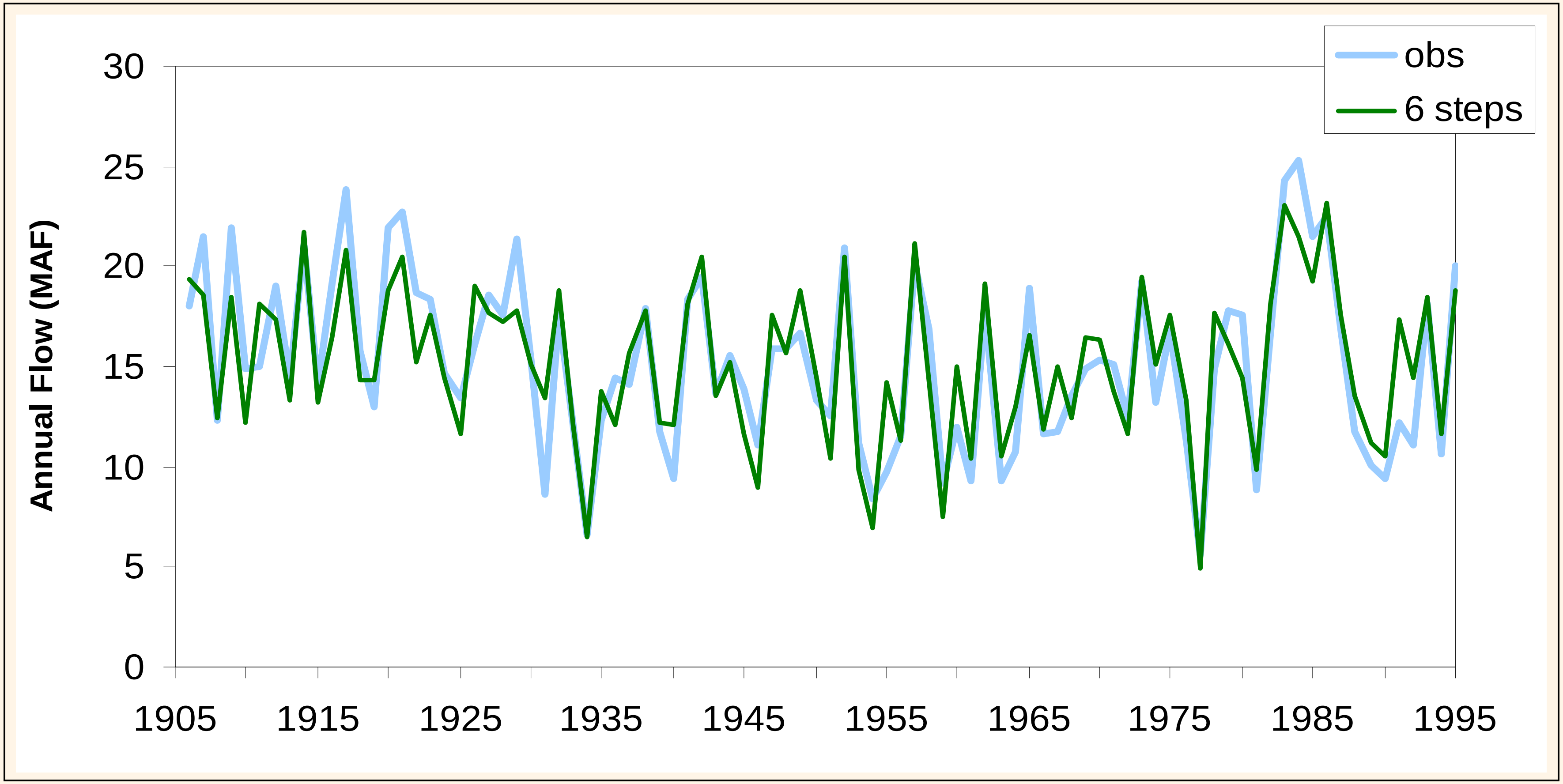
Colorado at Lees Ferry - forward stepwise regression



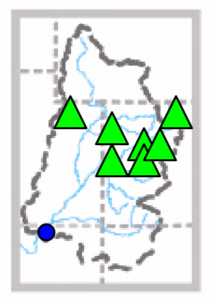
TRG + WIL + DJM + DOU + NPU + RED

Variance Explained

79%



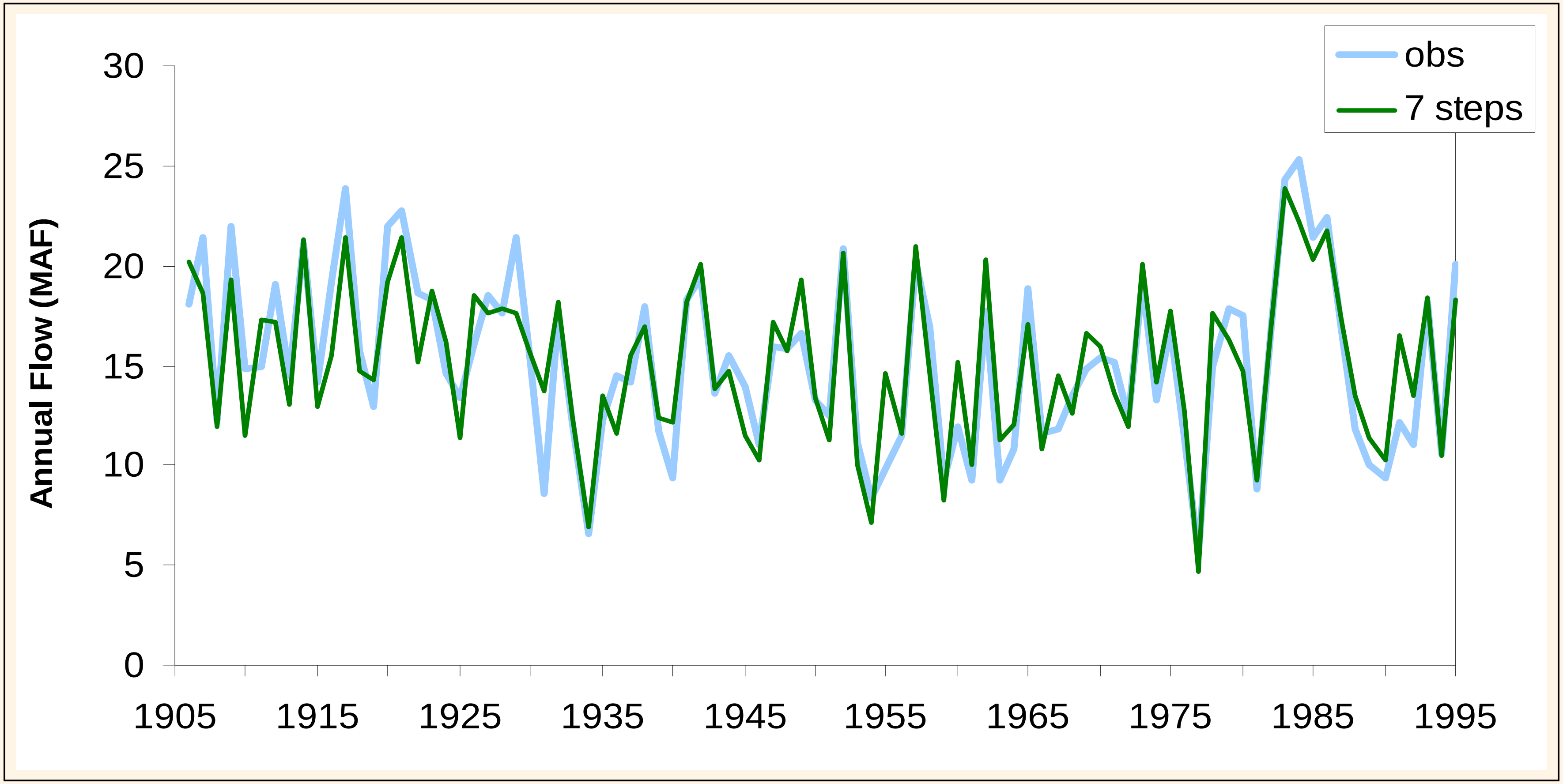
Colorado at Lees Ferry - forward stepwise regression



TRG + WIL + DJM + DOU + NPU + RED + PUM

Variance Explained

81%



Model validation and skill assessment

- Are regression assumptions satisfied?
- How does the model validate on data not used to calibrate the model?
- How does the reconstruction compare to the gage record?

How does the model validate on data not used to calibrate the model?

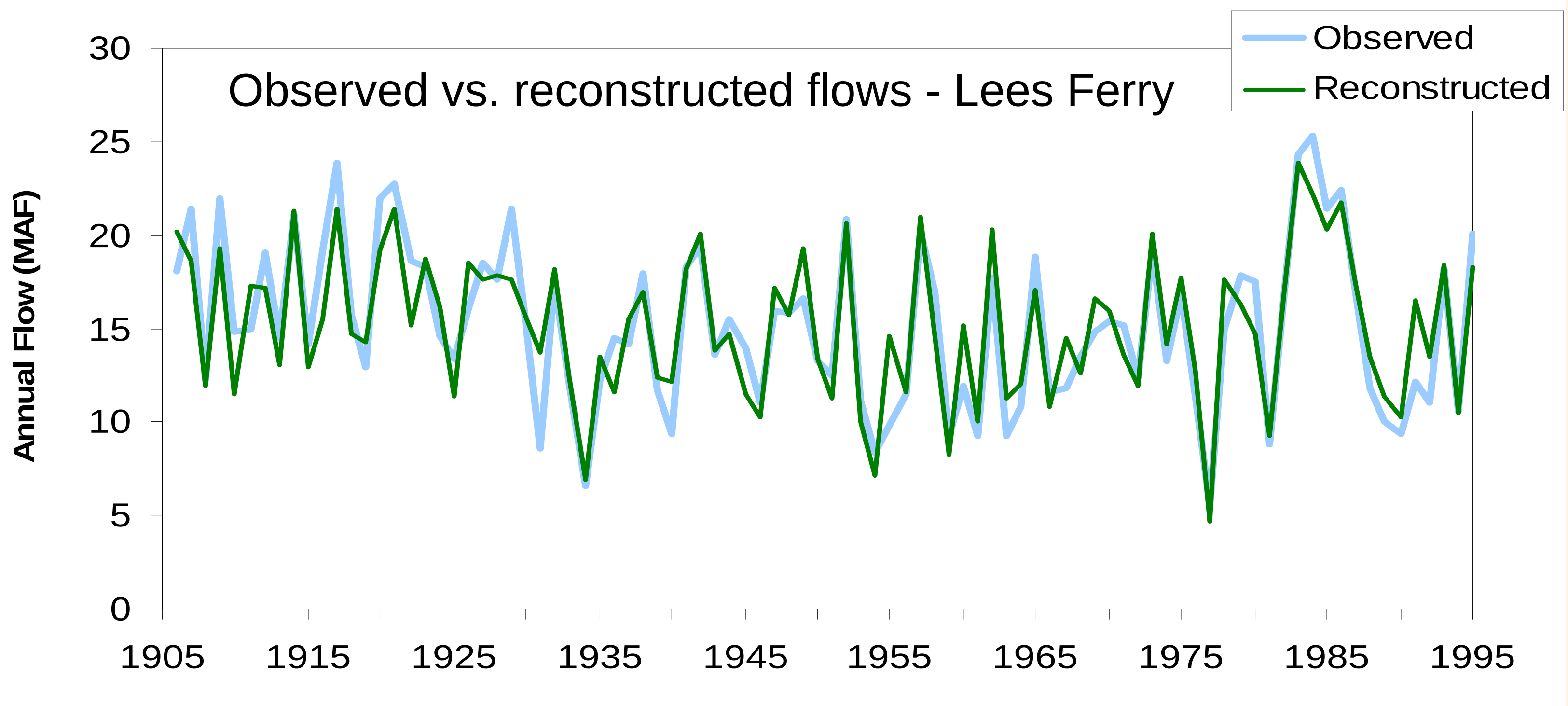
Validation statistics – based on withheld data or data generated in cross-validation process, compared to observed data

	Calibration	Validation
Gage	**R^2**	**RE***
Boulder Creek at Orodell	0.65	0.60
Rio Grande at Del Norte	0.76	0.72
Colorado R at Lees Ferry	0.81	0.76
Gila R. near Solomon	0.59	0.56
Sacramento R.	0.81	0.73

R^2 and RE should be similar, and ideally above 0.50, though much above 0.80 suggests overfitting

*RE is Reduction of Error statistic; tests model skill against “no knowledge”

How does the reconstruction compare to the gage record?

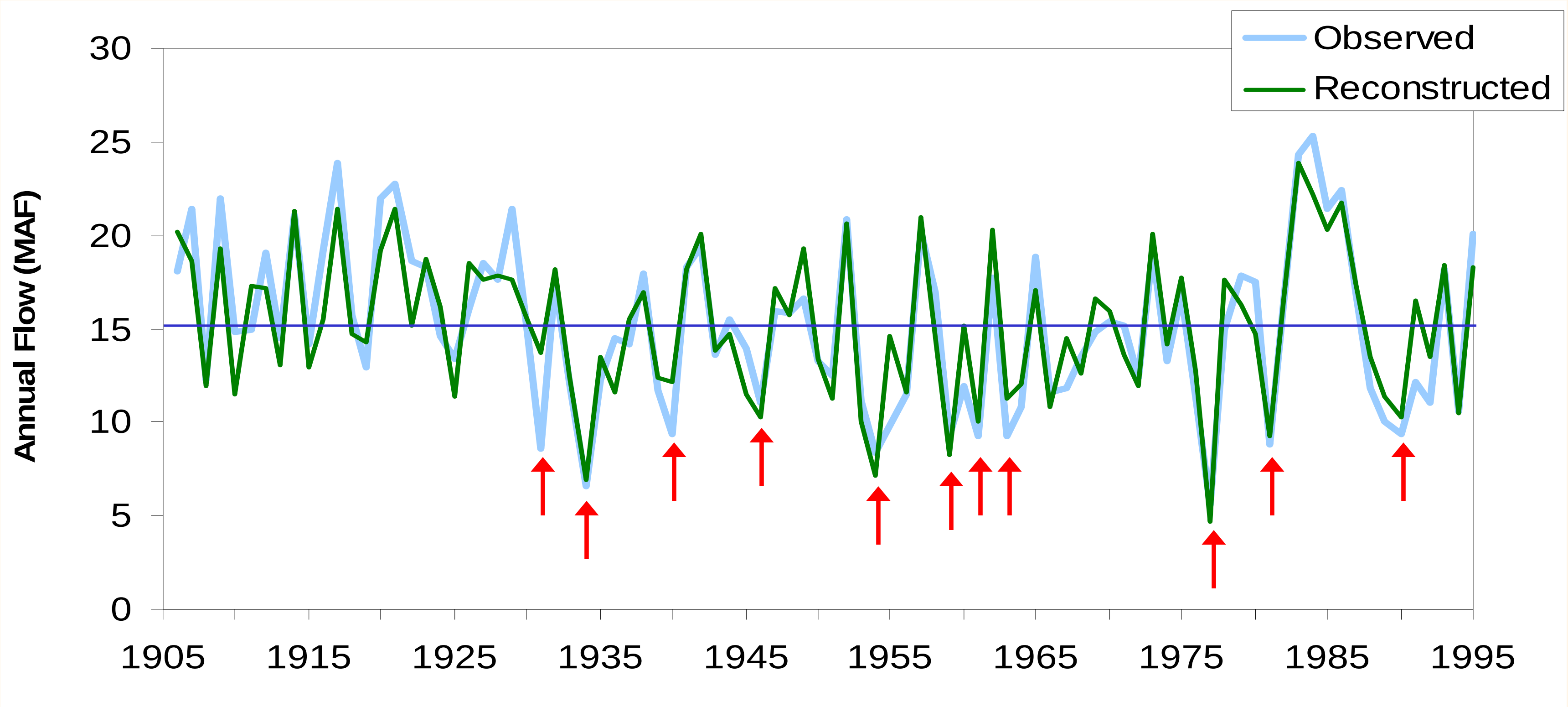


	Observed	Recon'd
Mean	15.22	15.22
Max	25.27	23.91
Min	5.57	4.71
StDev	4.32	3.88

The means are the same, as expected from the the linear regression

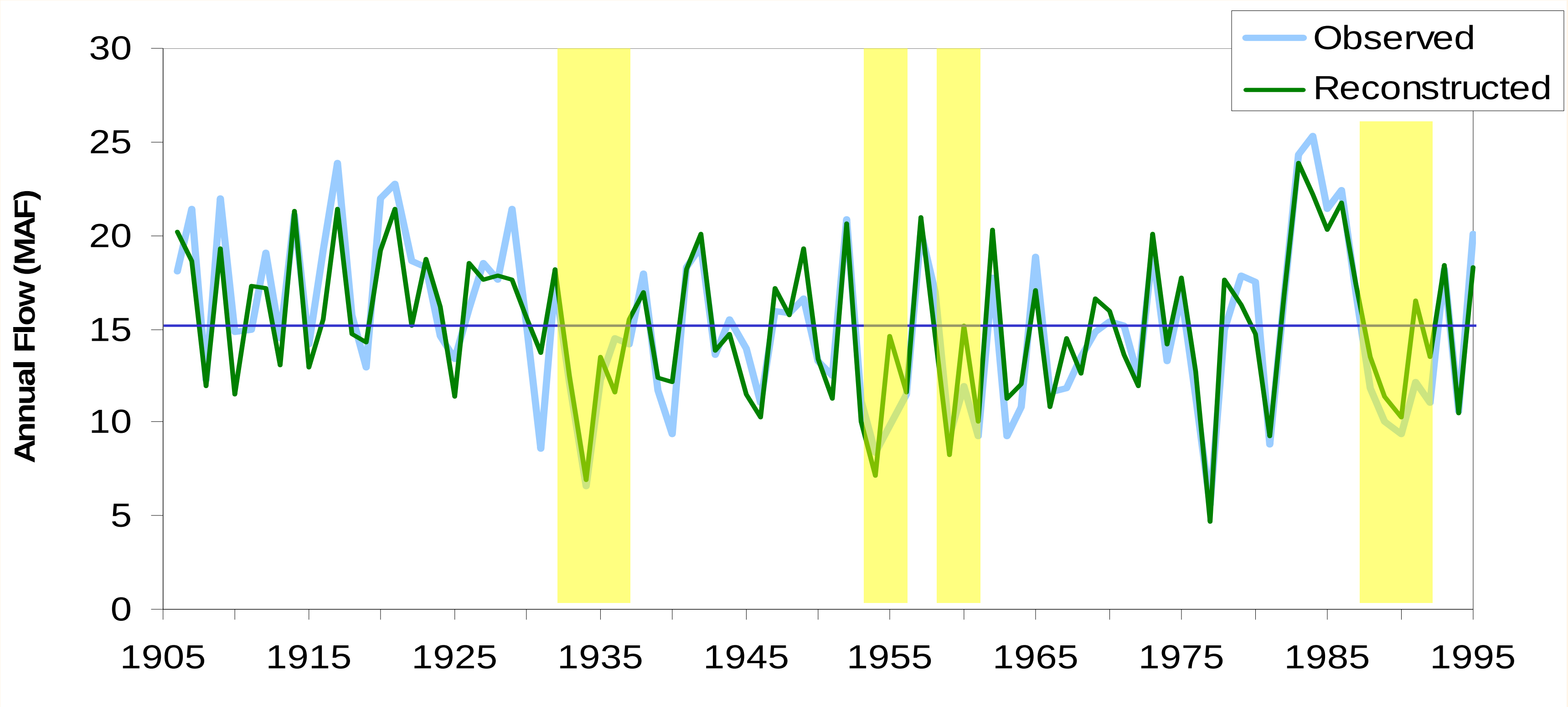
Also as expected, the standard deviation in the reconstruction is lower than in the gage record

Subjective assessment of model quality



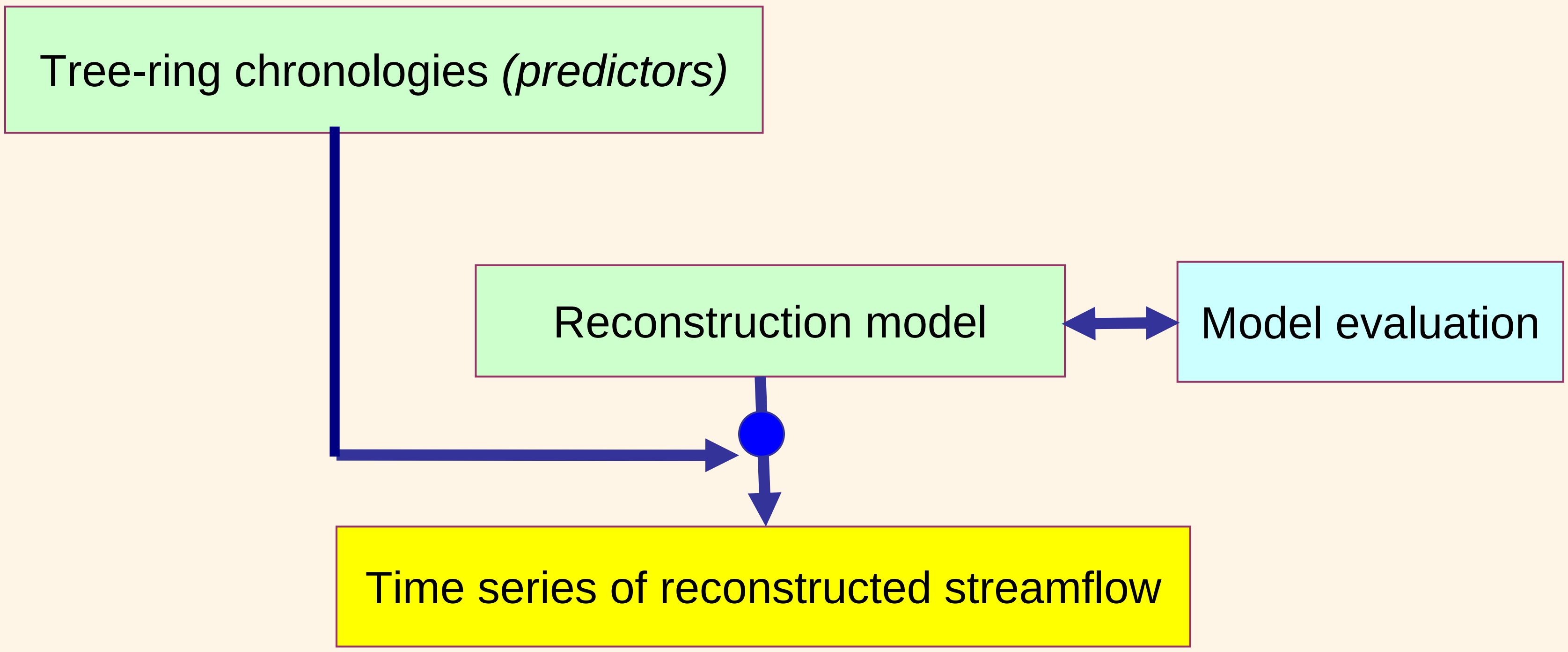
- Are severe drought years replicated well, or at least correctly classified as drought years?

Subjective assessment of model quality



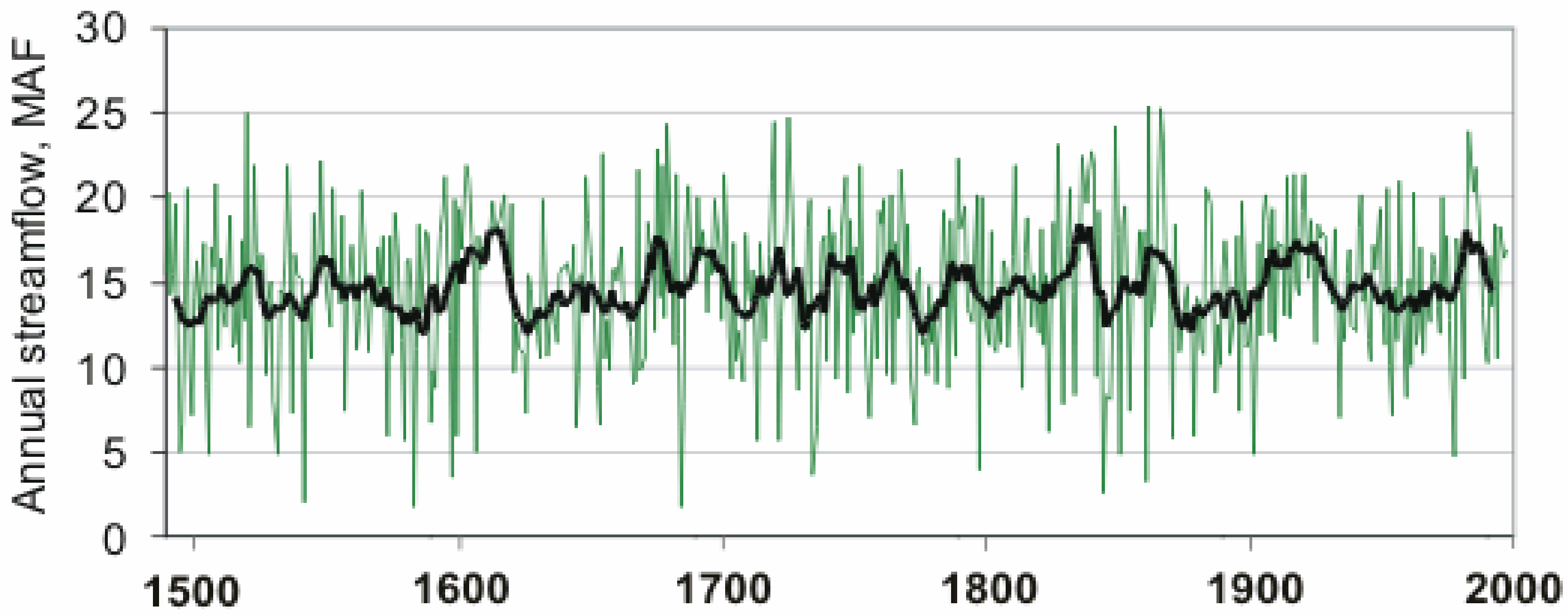
- Are the lengths and total deficits of multi-year droughts replicated reasonably well?

From model to full reconstruction



- When the regression model has been fully evaluated (residuals and validation statistics), then the model is applied to the full period of tree-ring data to generate the reconstruction

Full Colorado R. at Lees Ferry streamflow reconstruction, 1490-1997



- Green = annual values
- Black = 10-yr running mean

Uncertainty in the reconstructions

- Tree-ring data are imperfect recorders of climate and streamflow, so there will always be uncertainty in the reconstructed values

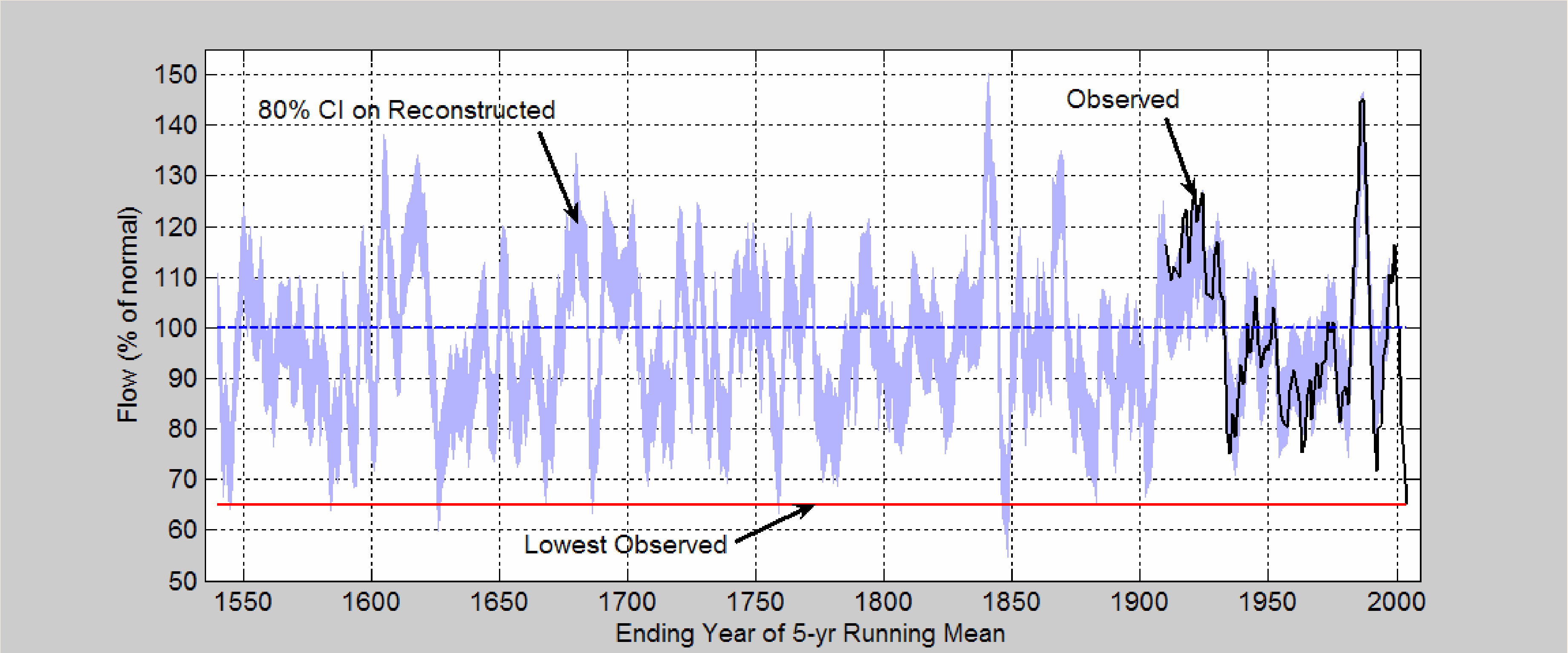
- The statistical uncertainty in the reconstruction model can be estimated from the validation errors (RMSE)

- RMSE only summarizes the uncertainty associated with a specific model; the reconstructed flows are also sensitive to the decsions made in the data selection and modeling

- *A reconstruction is a plausible estimate of flows using a given set of data and modeling decisions; there is no one "right" reconstruction (though higher RE values usually indicate a better one)*

Application of model uncertainty: using RMSE-derived confidence interval in drought analysis

Lees Ferry Reconstruction, 1536-1997
5-Year Running Mean
Assessing the 2000-2004 drought in a multi-century context

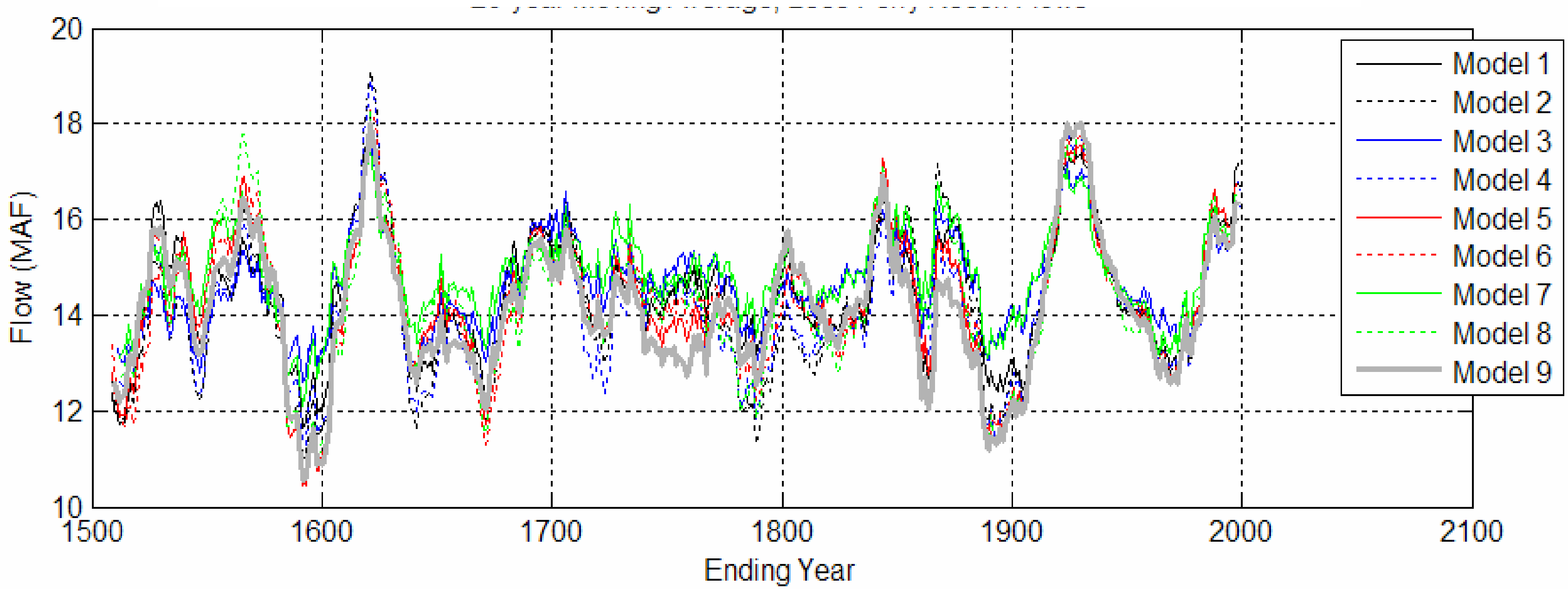


Data analysis: Dave Meko

Sensitivity to other choices made in modeling process

Lees Ferry reconstructions from 9 different models that vary according to data treatment, chronologies used, model choice

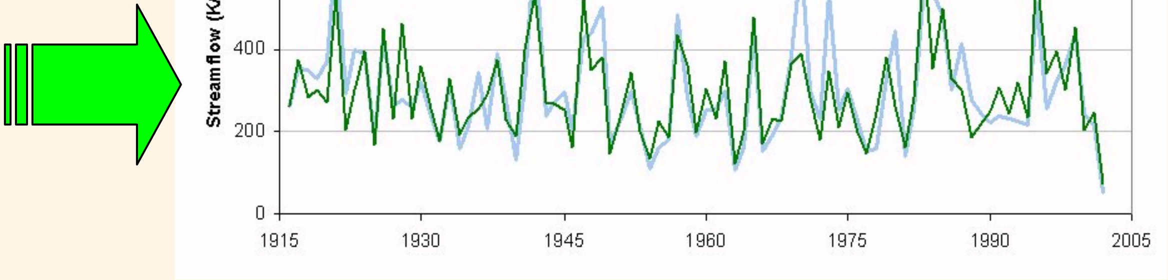
Lees Ferry Reconstructions, 20-yr moving averages



Analysis from D. Meko

Part 5:

Information about streamflow and climate reconstructions for the Southwest



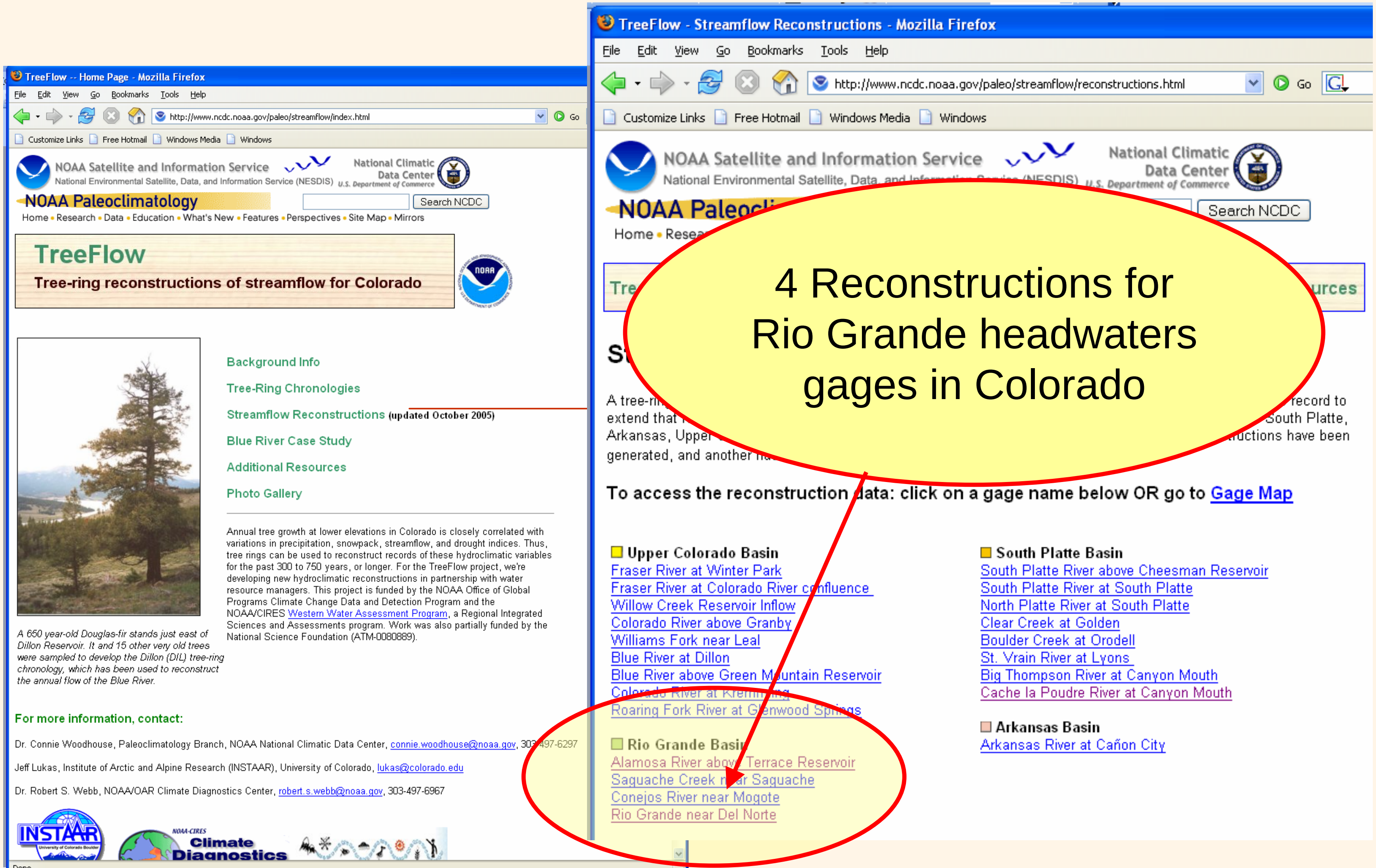
One-stop resource for the western US

Tree-Ring Reconstructions of Streamflow for Water Management in the West

http://wwa.colorado.edu/resources/paleo/

- Introduction to streamflow reconstructions
- Other workshops we've held, including presentations
- Applications of reconstructions to resource management
- Links to data: streamflow and precipitation reconstructions for the West
- Colorado River Streamflow: A Paleo Perspective
- Other useful web sites and references

Links to data: **Colorado TreeFlow (streamflow reconstructions)**



http://www.ncdc.noaa.gov/paleo/streamflow

Links to data: **Woodhouse et al. 2006 - Upper Colorado River Basin streamflow**

NOAA Satellite and Information Service
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]

[1] NOAA National Climatic Data Center, Boulder, CO
[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.

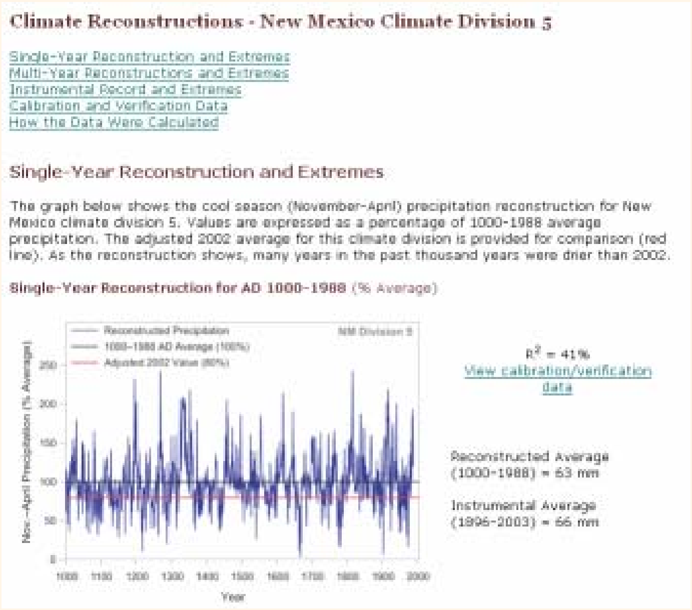
Download data from the WDC Paleo archive:
Upper Colorado Streamflow Reconstructions in Text or Microsoft Excel format.
Supplementary Data 1. Chronology data and metadata
Supplementary Data 2. Regression equations and coefficients, PC data
Supplementary Data 3. Loadings from PCA on chronologies

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

http://www.ncdc.noaa.gov/paleo/pubs/woodhouse2006/woodhouse2006.html

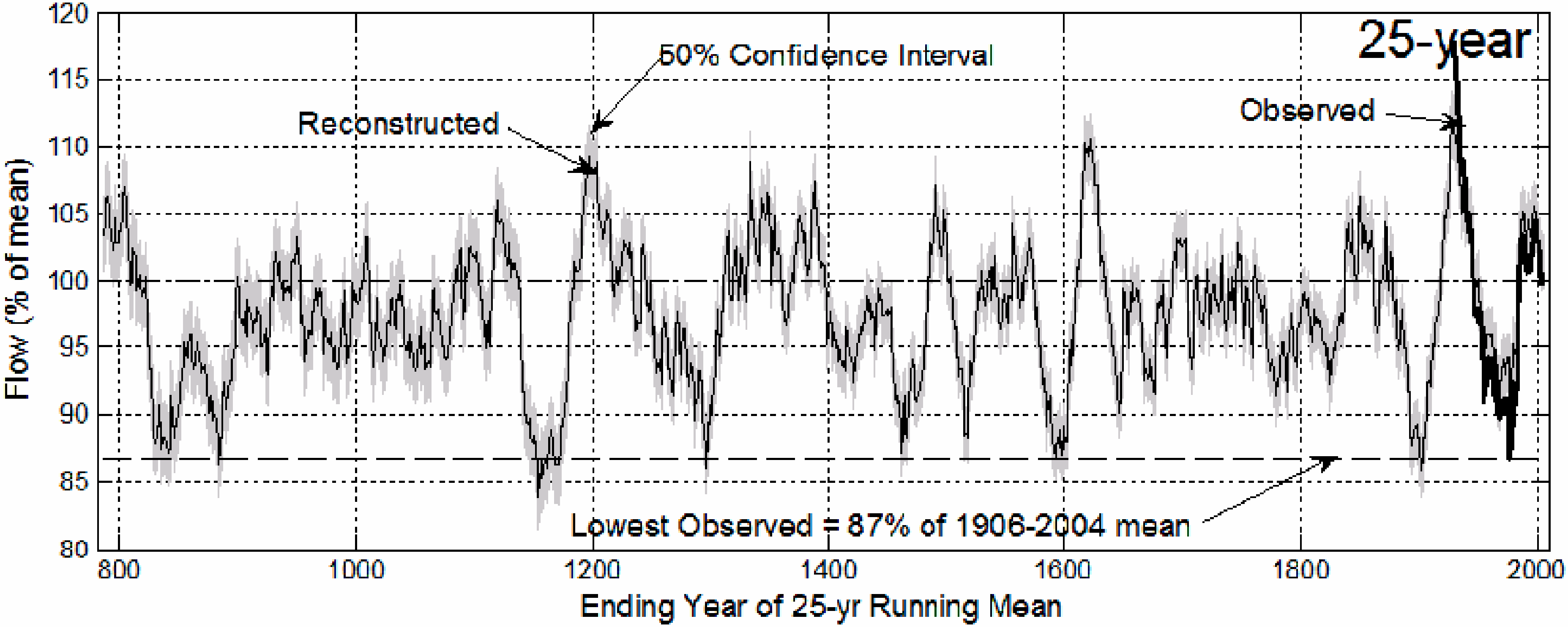
Links to data: **Ni et al. 2002 – Southwest US (AZ/NM) November-April precipitation**



• 1000-year reconstructions of cool-season precipitation for each climate division in Arizona and New Mexico

http://www.ncdc.noaa.gov/paleo/pubs/woodhouse2006/woodhouse2006.html

Links to data: New in 2007: Reconstruction of Colorado River at Lees Ferry, AD 762 - 2005

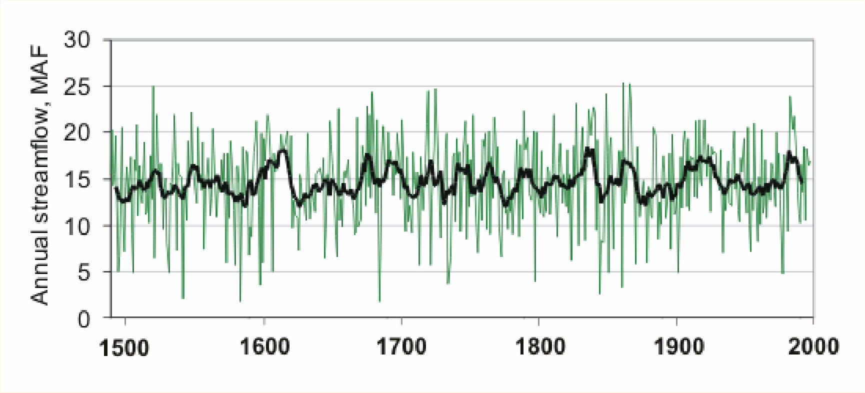


25-yr running means of reconstructed and observed annual flow of the Colorado River at Lees Ferry, expressed as percentage of the 1906-2004 observed mean.

From: Meko et al. 2007. Medieval Drought in the Upper Colorado River Basin, *Geophysical Research Letters*

Part 6:

How the reconstructions can be used in water management



Reconstruction data

?

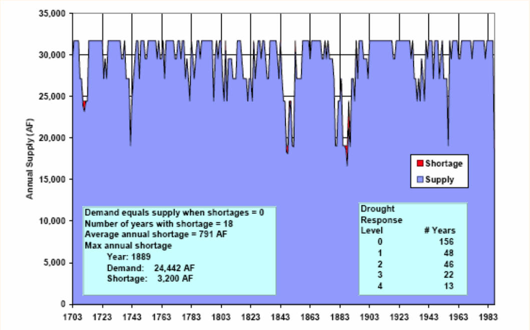


Figure 5. Demands & Supplies: 15% Reduced Flow Hydrology, Current Trends Scenario (demand = 31,700 AF/year).

Policy analysis

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

Applications can be considered in a 4-tiered context:

- Information is ***consulted***; looked up or received in a briefing (awareness)

- After it is consulted, it is ***considered*** in management (how to use?)

- Some form of the information is ***incorporated*** into operations (modeling challenges)

- Information is used in the ***communication of risk***, and ultimately may play a part in decision making (who makes the decisions and upon what are they based?)

From Ray (2004)

• After it is consulted, it is ***considered*** in management.

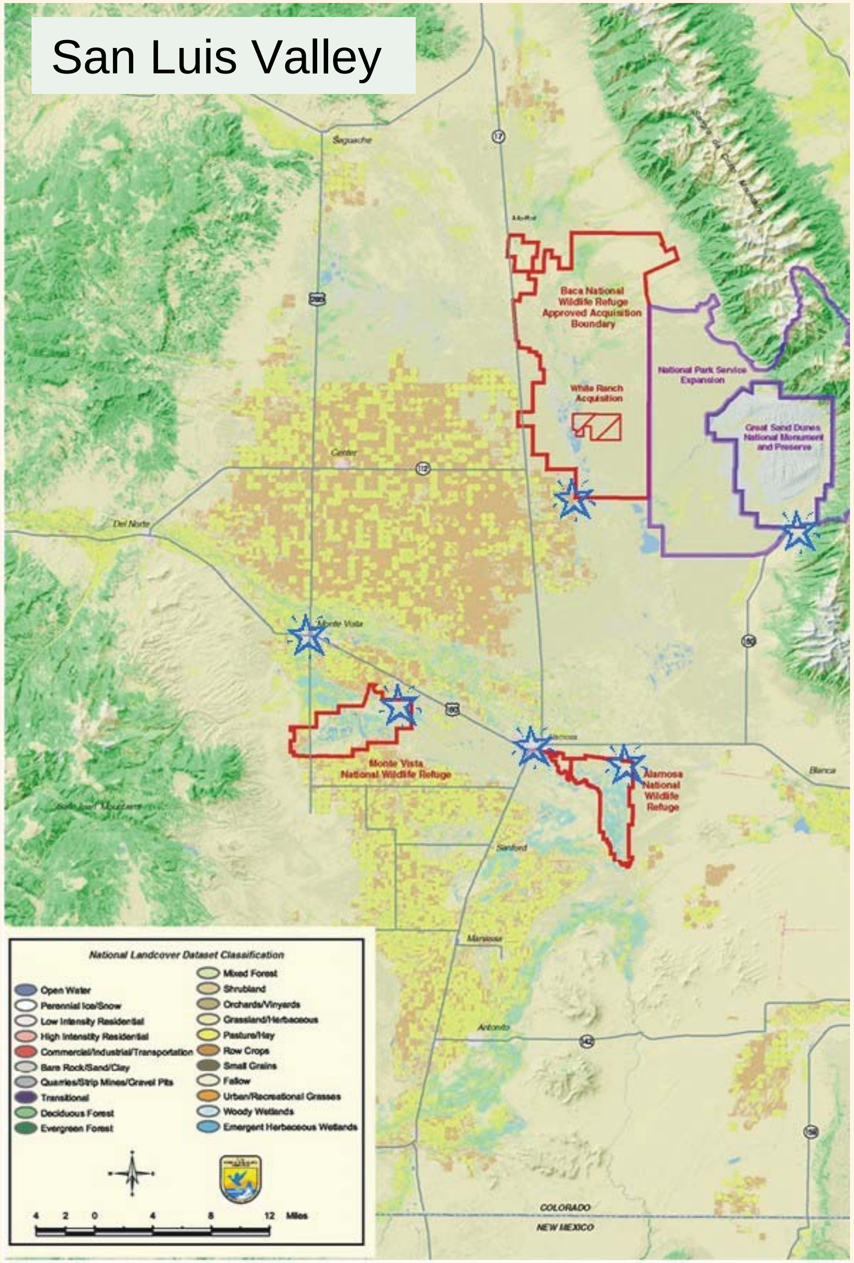
Rio Grande Water Conservation District (Upper Rio Grande River)

Water management concerns:

• rural area dependent on agriculture

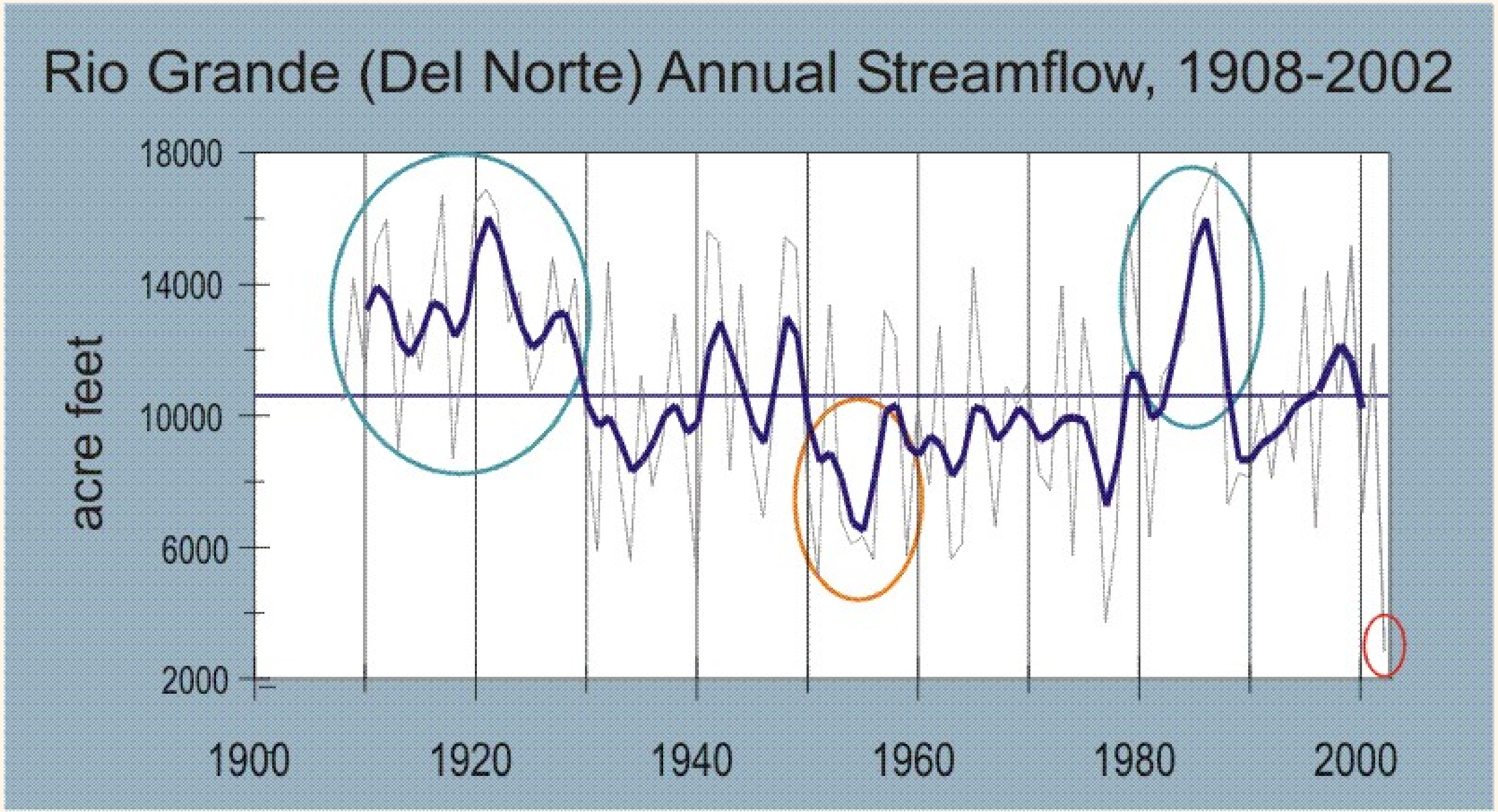
• current unsustained groundwater withdraws

• 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).

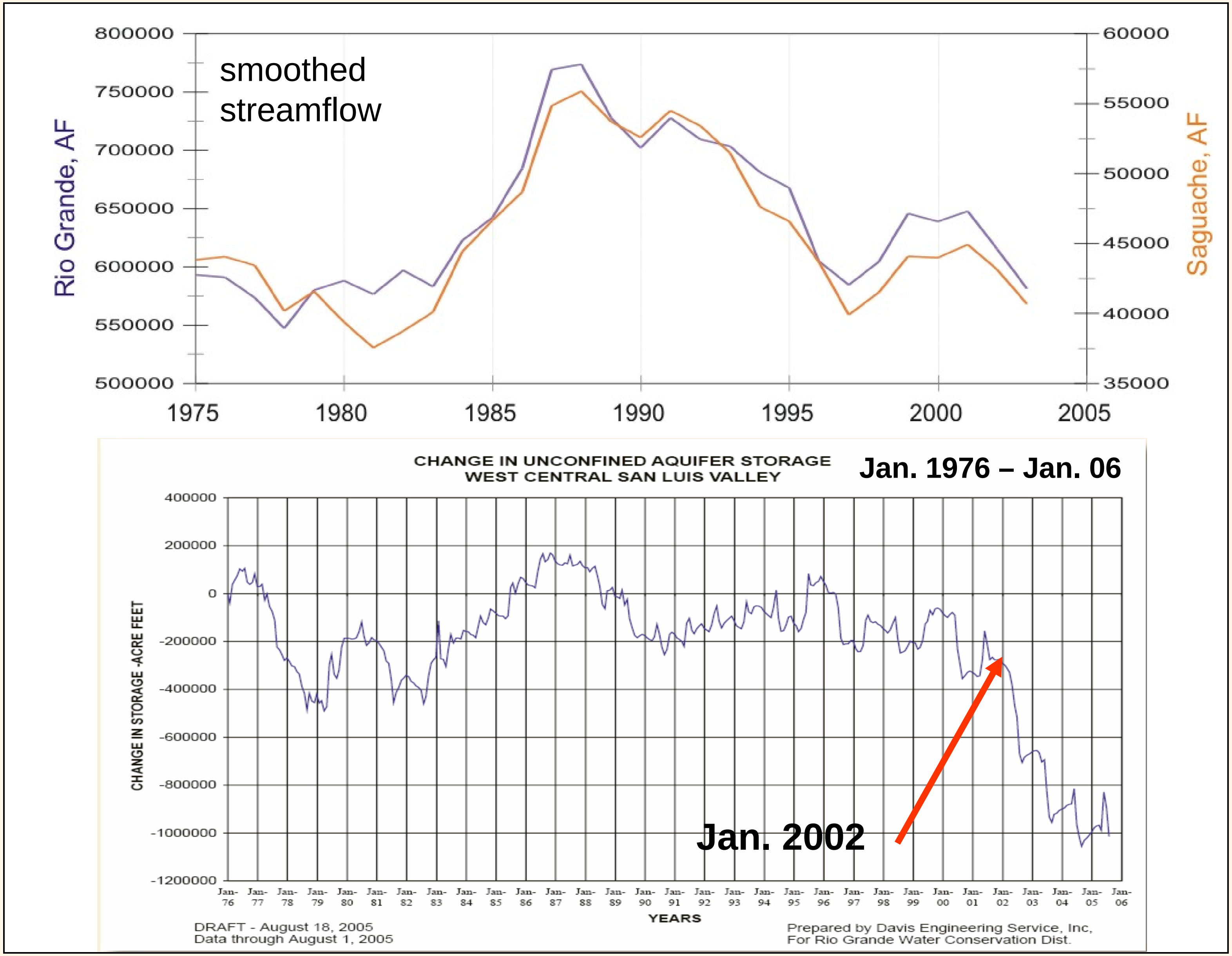


Are the wet periods experienced in the 20th century record the "normal" state?

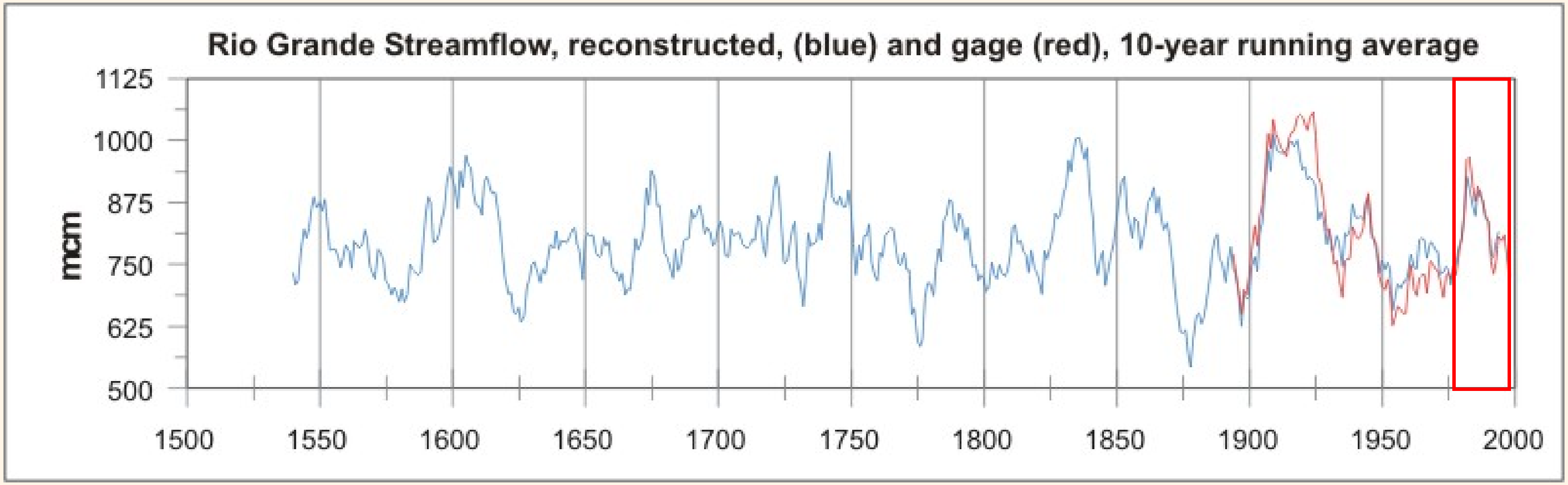
What is the character of long-term, low-frequency variations in water supply that affect aquifer levels?



Comparison of Annual Flow and Changes in Unconfined Aquifer Storage, 1976-2003



Reconstructed Rio Grande Streamflow, 1536-1999



Comparing the short period of instrumental record with the long-term record from the tree-ring data:

Implications for long-term groundwater management?

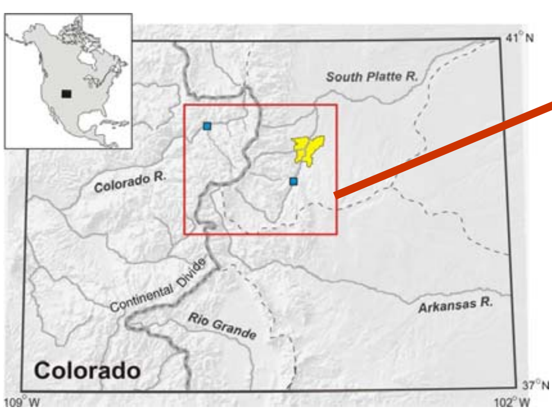
• Some form of the information is ***incorporated*** into operations.

Denver Water

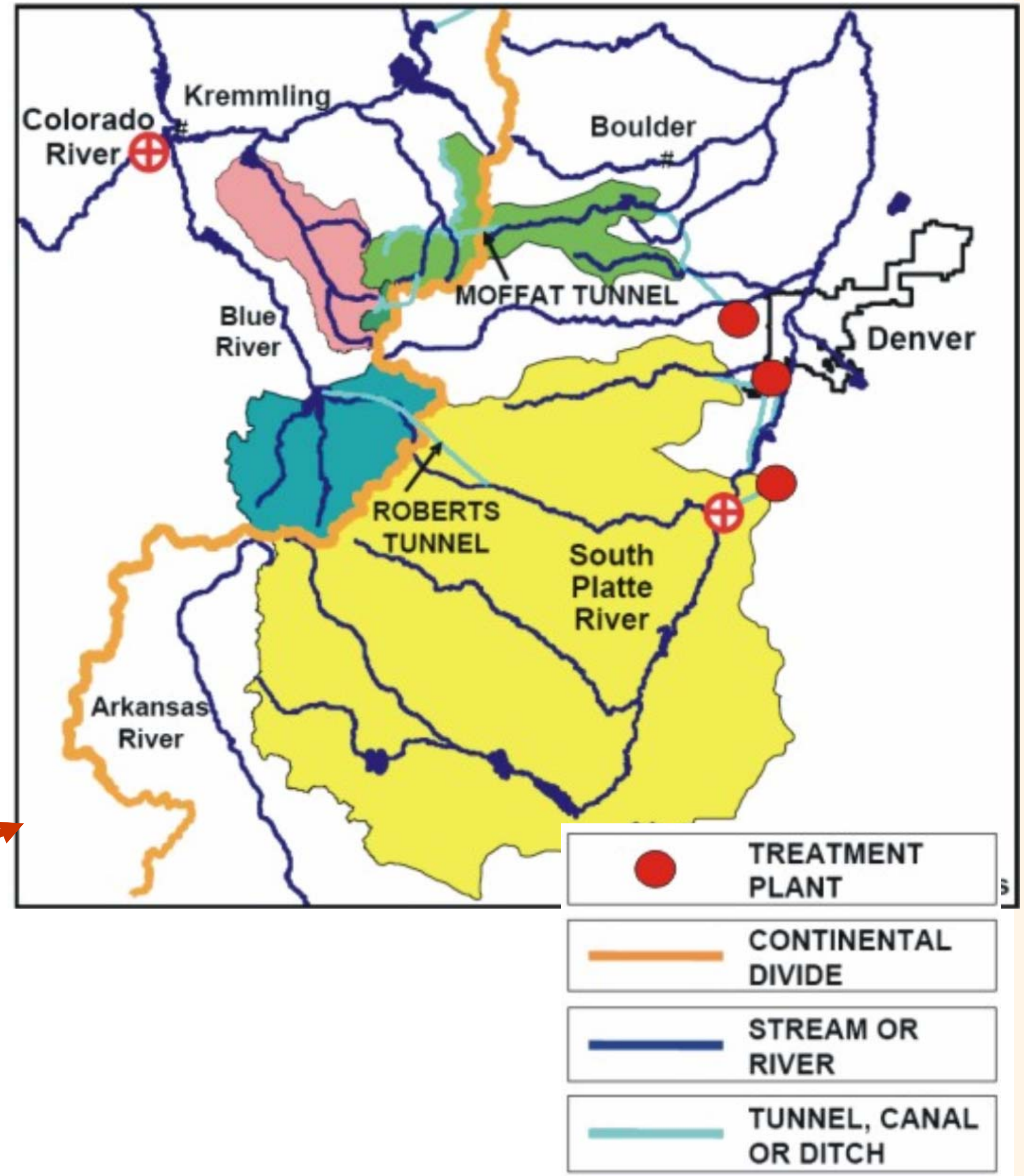
Denver Water uses a water system model called the Platte and Colorado Simulation Model (PACSM)

PACSM is an integrated system of computer programs that simulate streamflows, reservoir operations and water supply in the South Platte and Colorado River basins.

Hydrologic Period: 1947 – 1991
Daily data, 450 locations



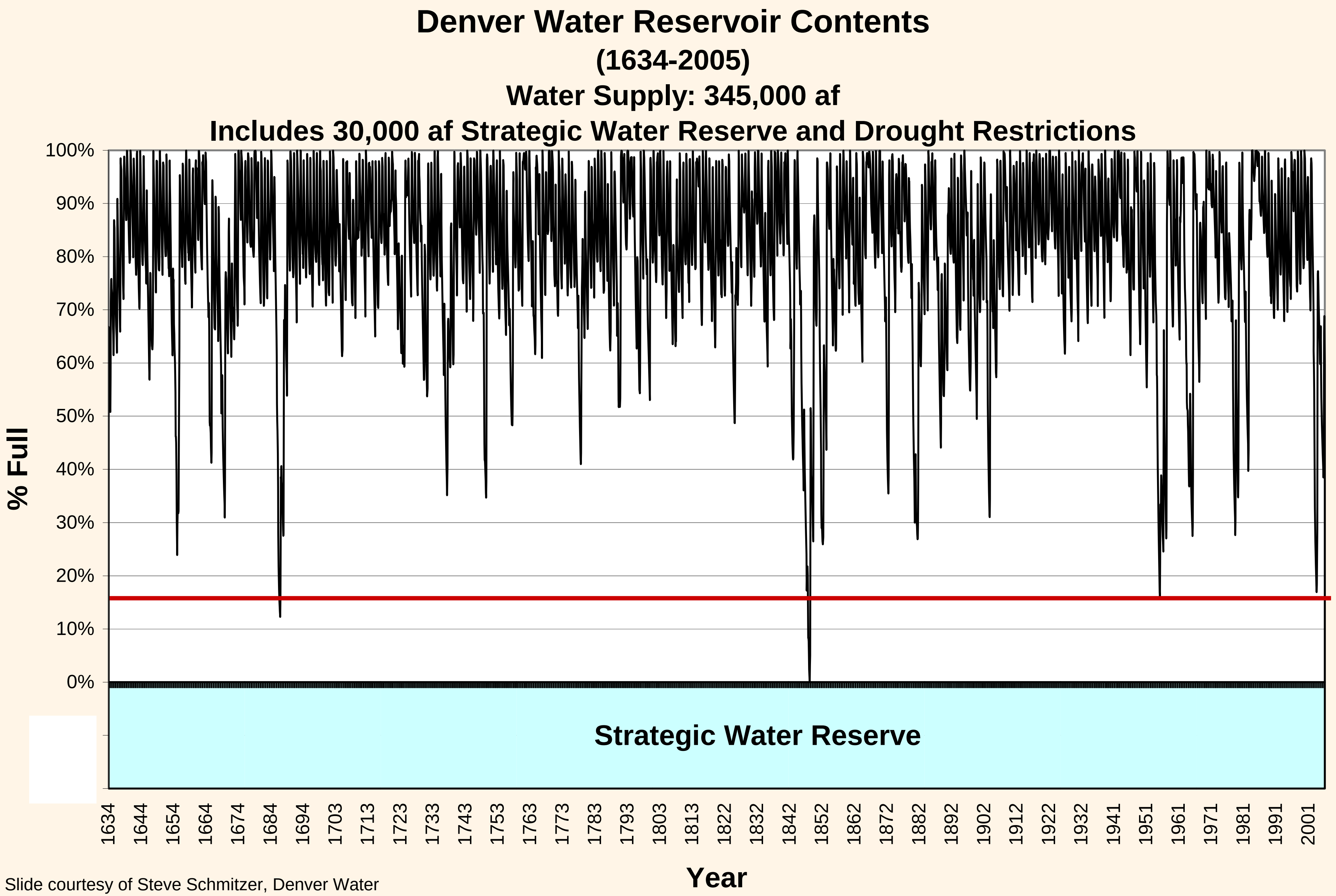
Denver Water Collection System



Denver Water – integrating tree-ring data into a water supply model

- Denver Water's Platte and Colorado Simulation Model (PACSM) requires daily model input from 450 locations
- An "analogue year" approach matched each year in the reconstructed flows (1634-2002) with one of the 45 model years (1947-1991) with known hydrology (e.g., 1654 is matched with 1963), and use that year's daily hydrology
- Reconstructed years with more extreme wet/dry values are scaled
- PACSM was then run to simulate the entire reconstruction period (1634-2002)

Denver Water - water supply yield analyses



Slide courtesy of Steve Schmitzer, Denver Water

• Information is used in the ***communication of risk***, and ultimately may play a part in decision making

Worst case scenarios for drought planning:

An example from the City of Chandler (AZ)

• What should be the basis for a worst case scenario for drought?

• One suggestion was to use the driest year on record, 2003, for 10 or 20 consecutive years.

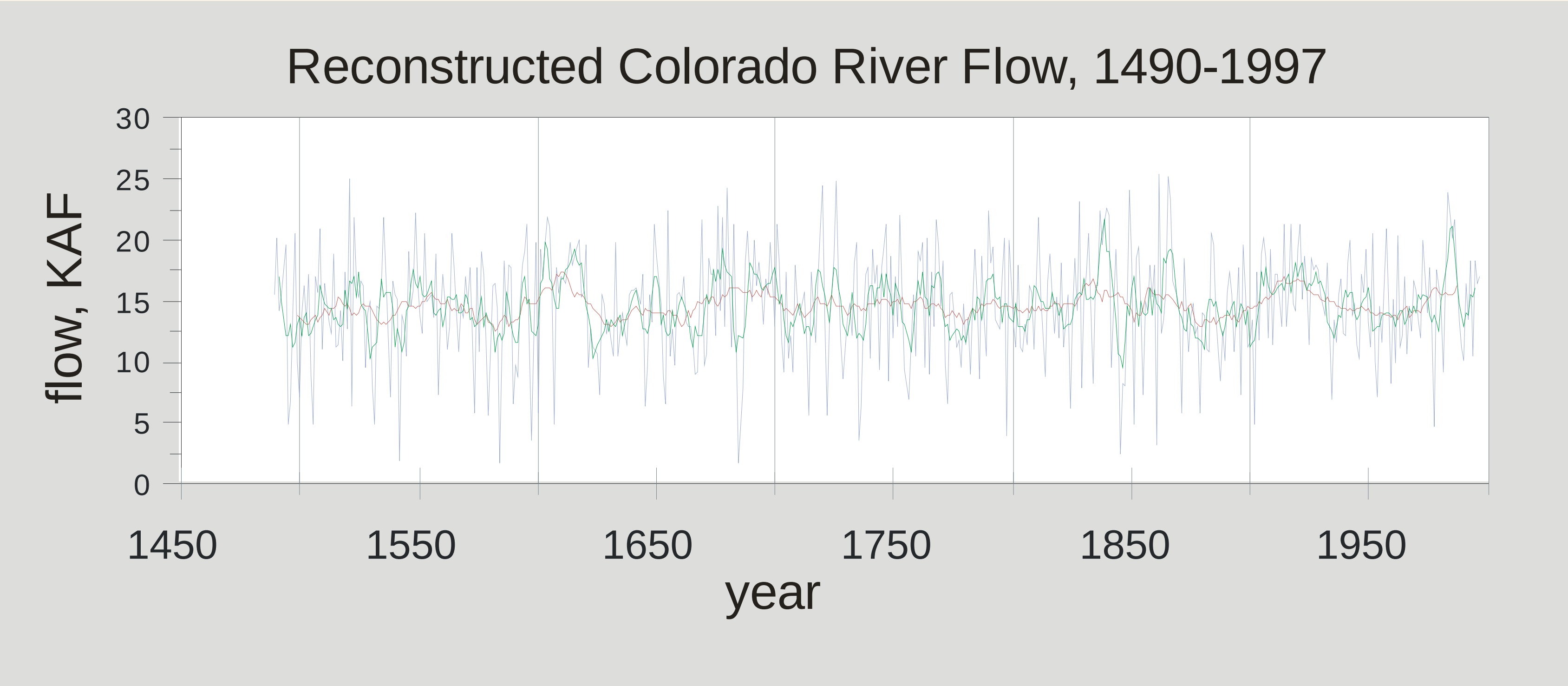
• After considering reconstructions of Colorado River basin streamflow, this seemed improbable

• Instead, a scenario of 10 dry years out of 25 years is being considered as being more realistic

• Although the City is not actually incorporating the streamflow reconstructions into a water supply model, they have found the tree-ring data valuable for decision making regarding drought.

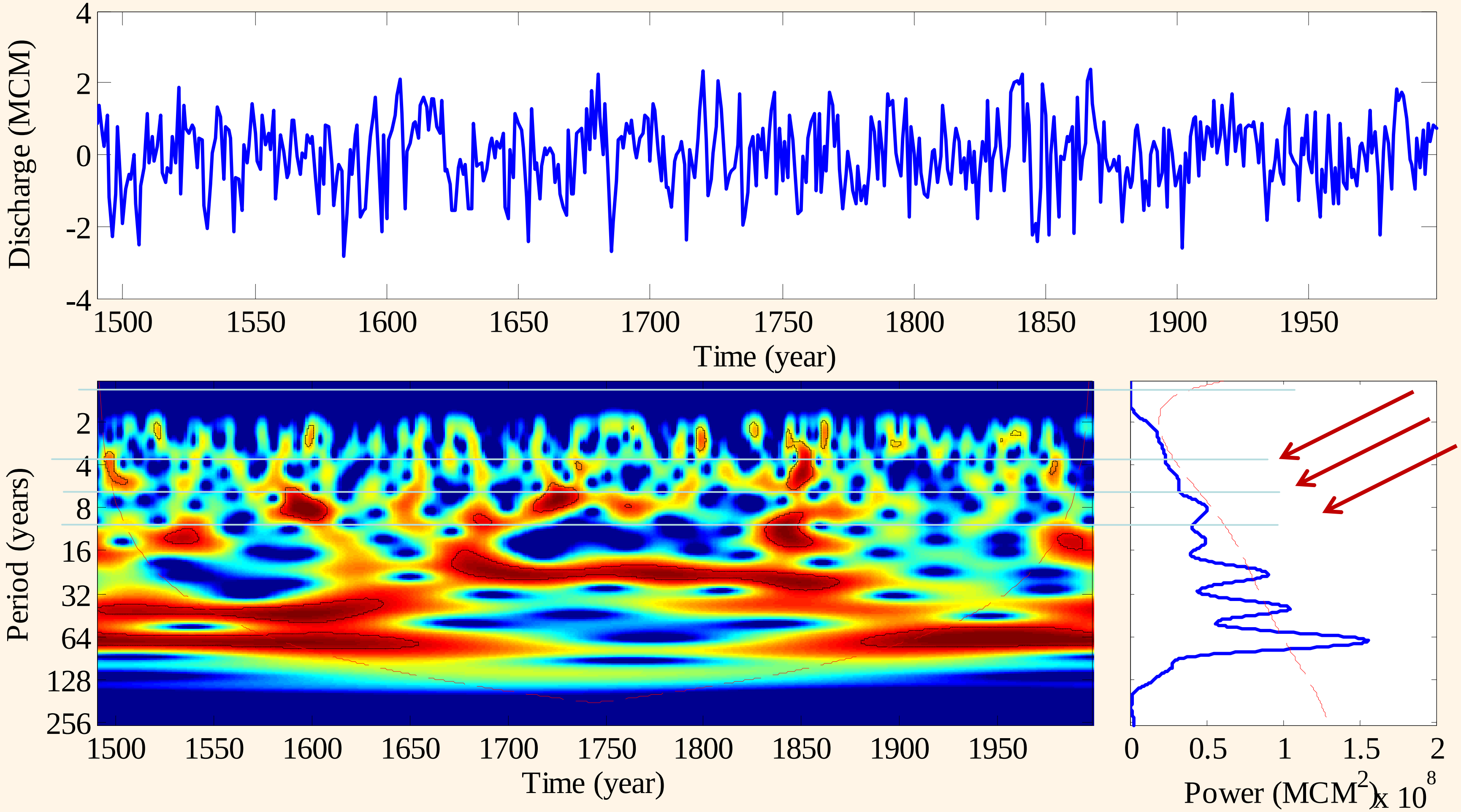
Another application: Using reconstructed climate variability to model possible future variability

1) Long-term climate can contain variability at several different frequencies

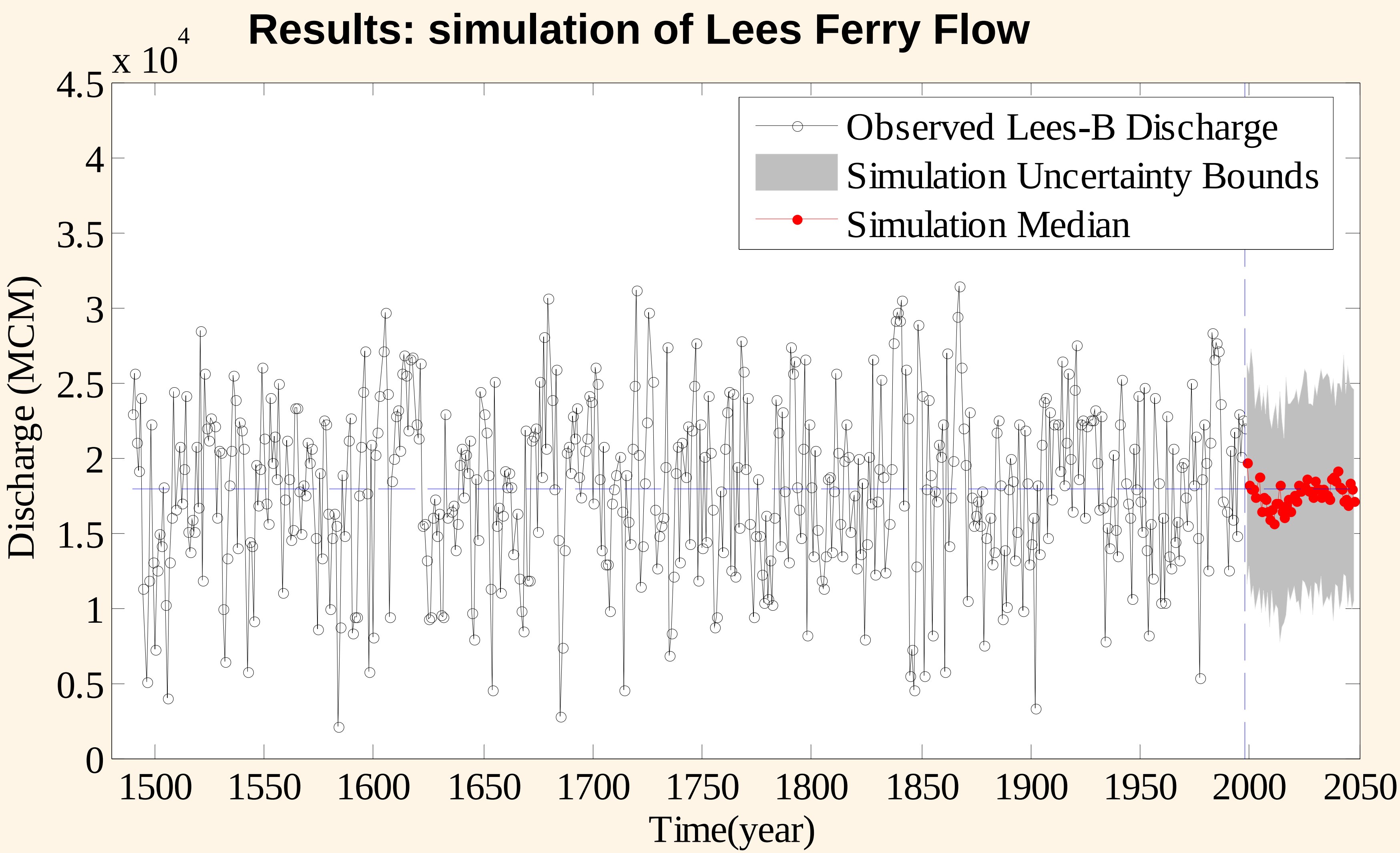


2) This information may be identified and extracted using a statistical approach called wavelet analysis

Lees-B streamflow, reconstruction, wavelet, and global wavelet

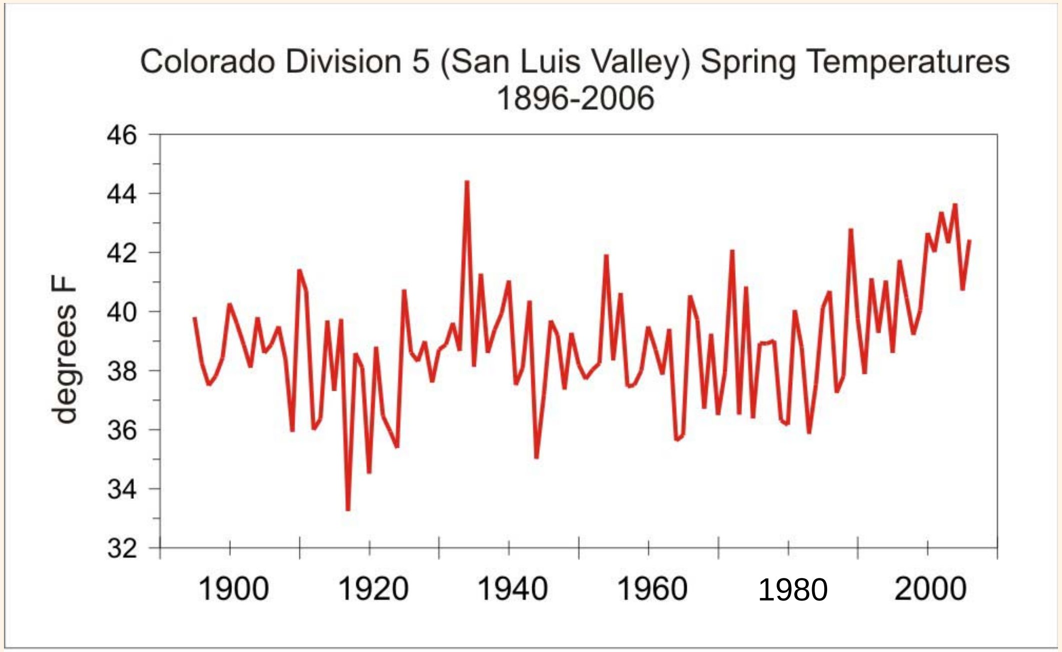


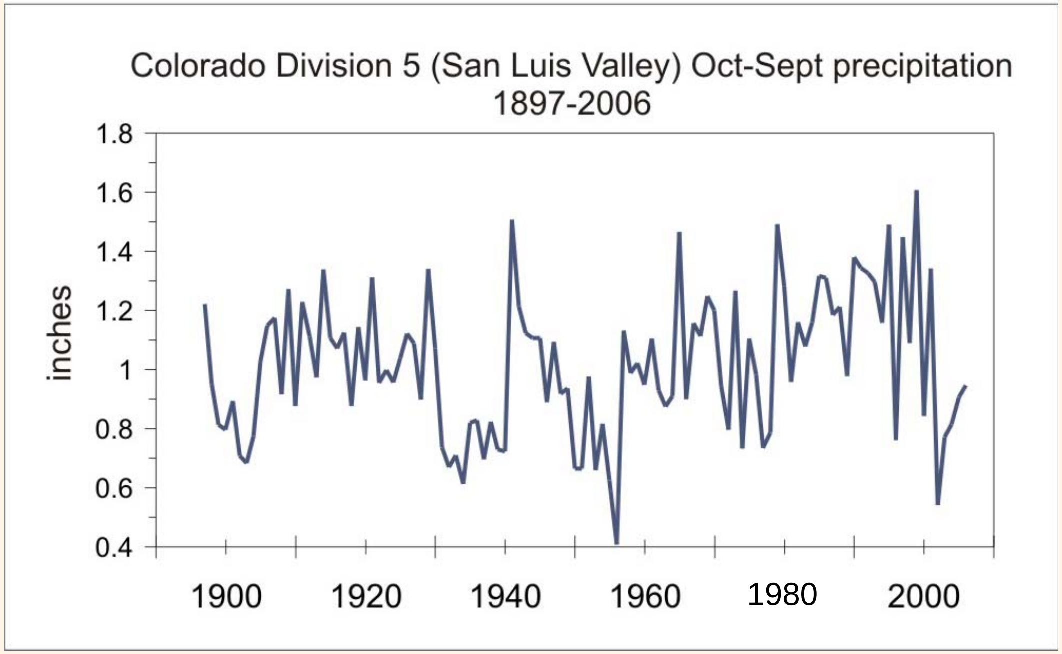
3) The low frequency information can be modeled to simulate low-frequency natural variability into the future.



How relevant is the past to current and future conditions?

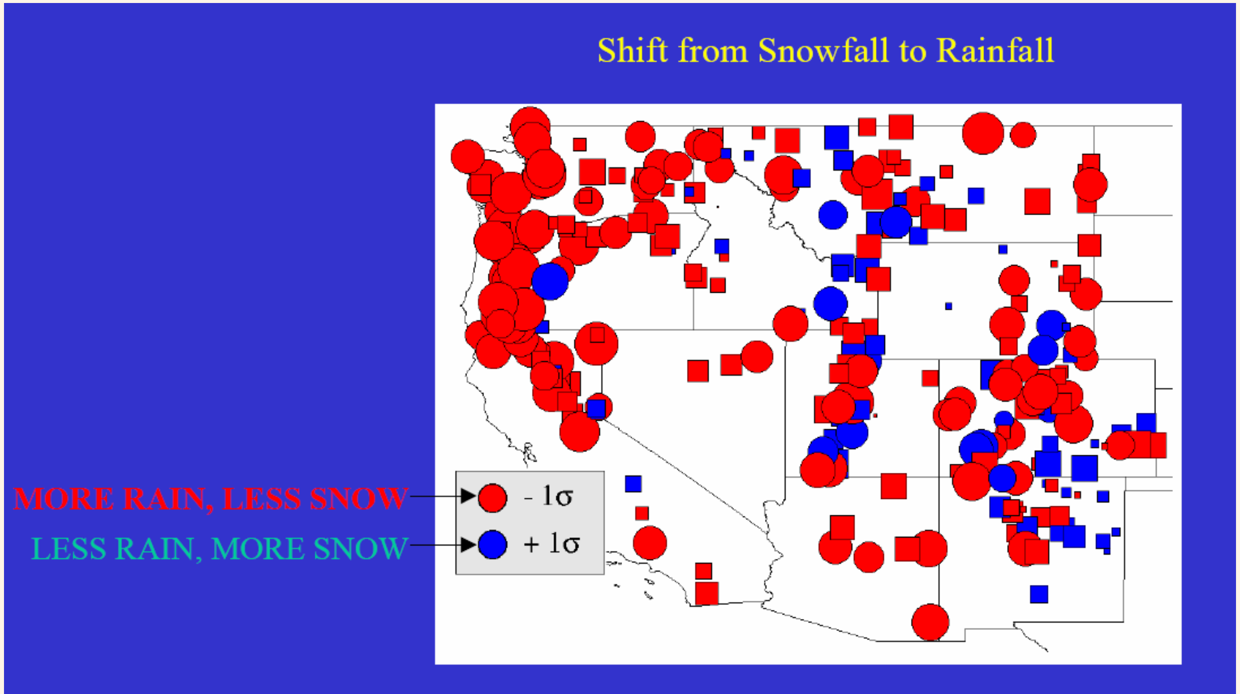
Spring temperatures in the Upper Rio Grande (Colorado) basin have risen, particularly since the 1970s, but clear trends in precipitation are not evident





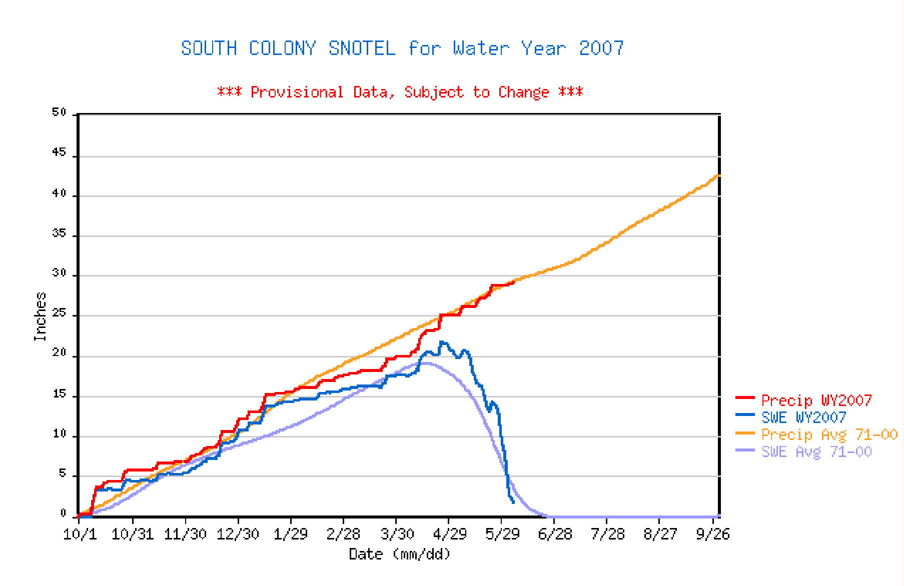
Increased temperatures are already evident in many areas, and are manifested in changes in winter precipitation

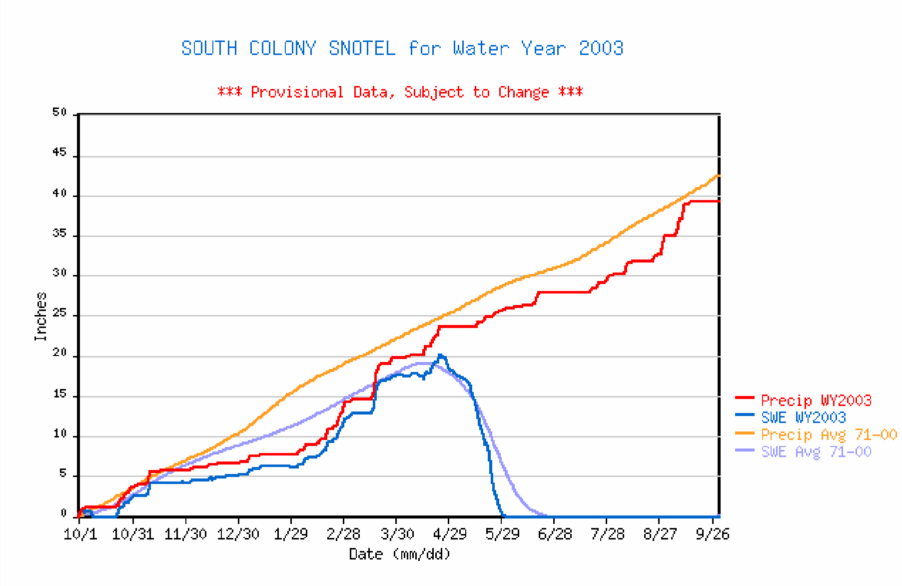
Warming even without changes in precipitation amount will amplify the impacts of drought

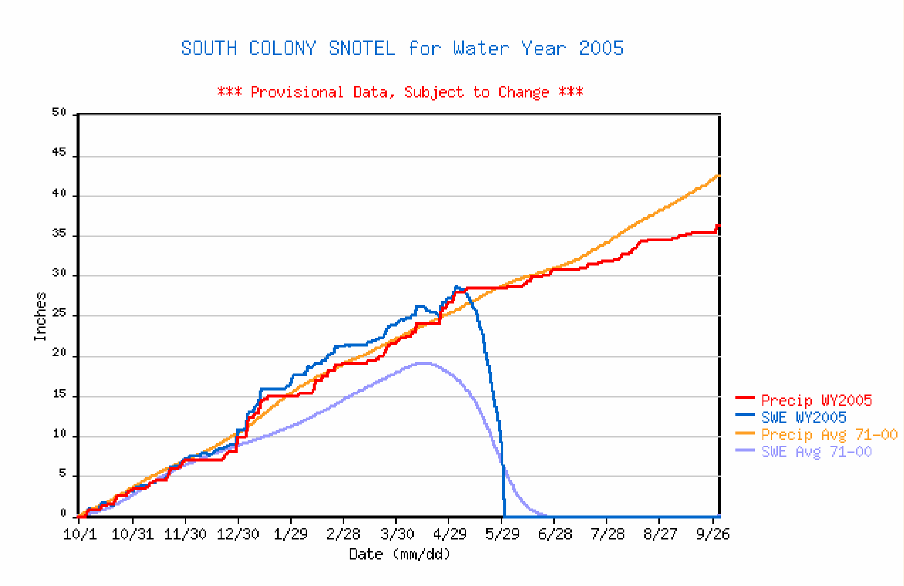


Trends in ratio of winter (Nov-Mar) snowfall water equivalent (SFE) to total winter precipitation (rain *plus* snow) for the period WY1949-2004. Circles represent significant ($p<0.05$) trends, squares represent less significant trends.

In the upper Rio Grande watershed, shifts to more winter rain are not yet evident, but the effects of warmer spring temperatures are causing early melting of snowpacks

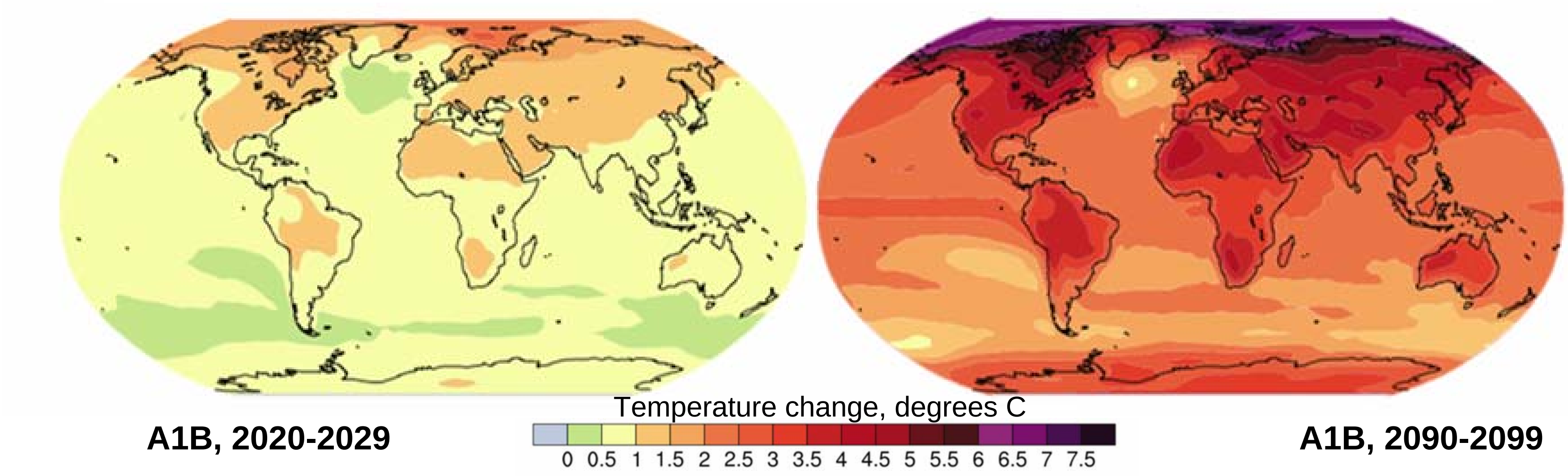




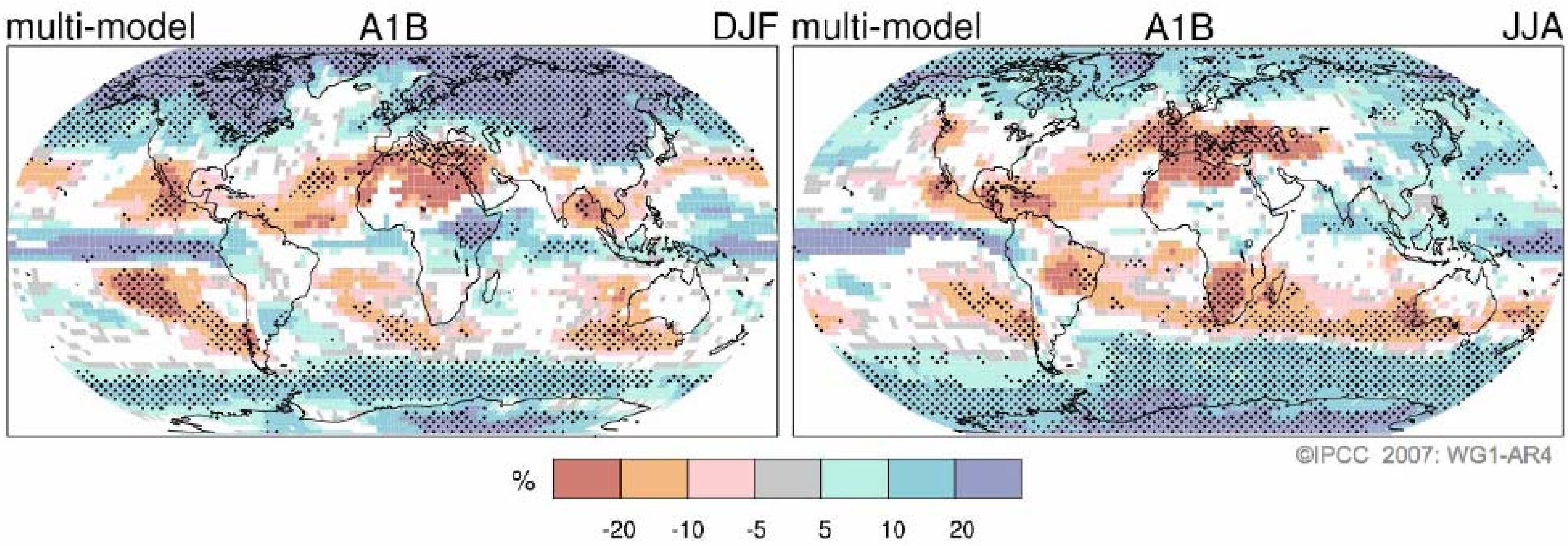


http://www.wcc.nrcs.usda.gov/snow/snotel-wereports.html

Projected Patterns of Temperature Changes

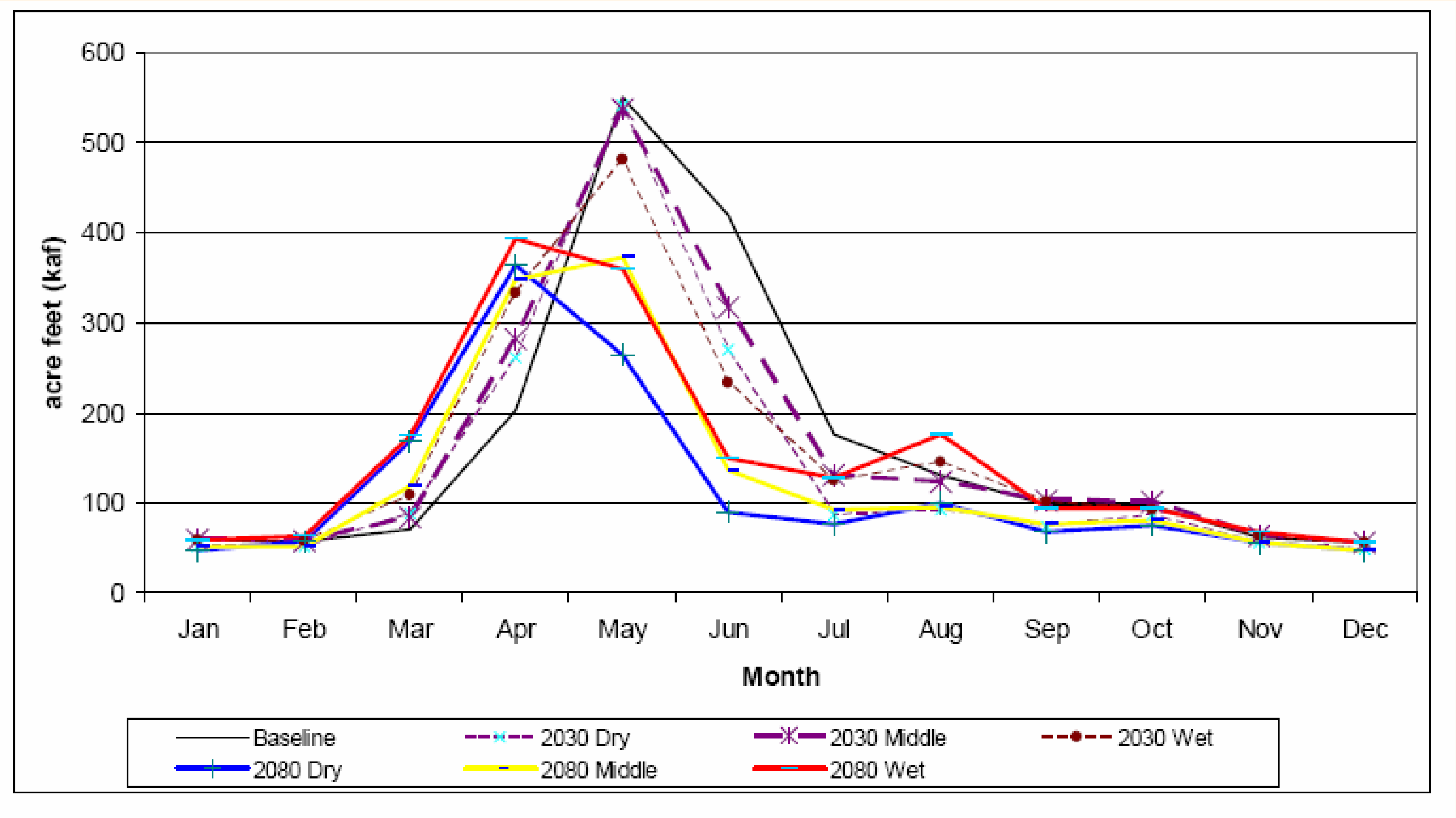


Projected Patterns of Precipitation Changes



Down-scaled projections for the Rio Grande basin

Average monthly streamflow for Rio Grande and tributaries for 3 climate change models and the A1B scenario



From: Hurd and Coonrod (July 2007) *Climate Change Impacts on New Mexico's Water Resources, http://agecon.nmsu.edu/bhurd/hurdhome/index.htm*

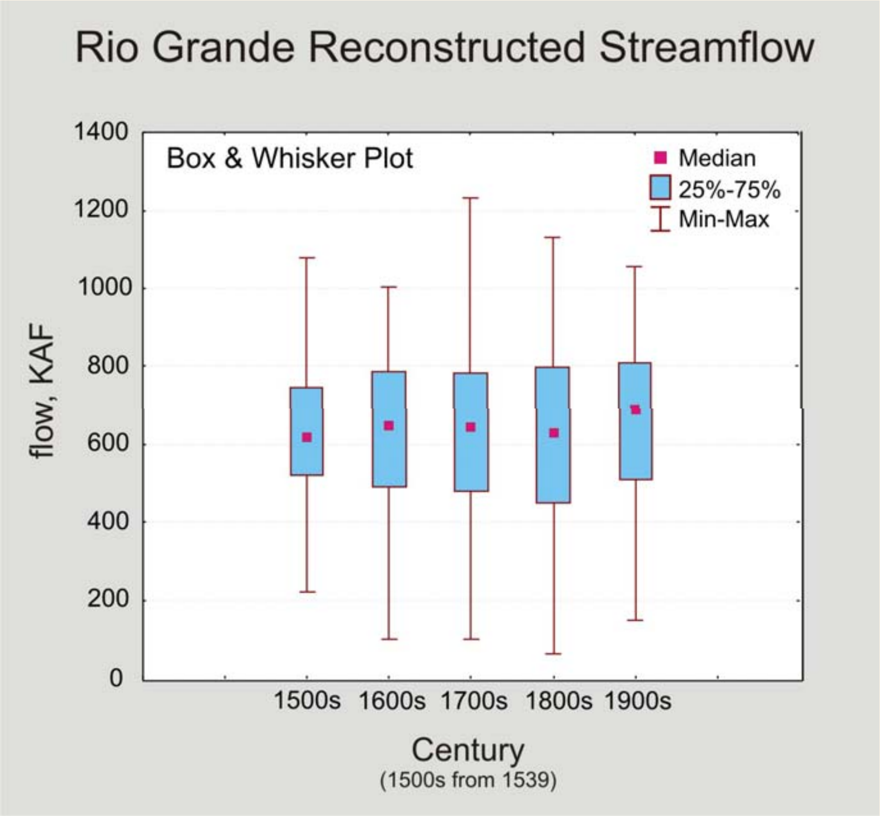
With regard to future climate, two things are more certain:

- increasing temperatures
- decreasing water supply as a result of warmer temperatures and earlier snowmelt

Paleoclimatic records provide a broader range of variability, including droughts, than the instrumental records.

There is no reason to think we will experience a smaller range of natural variability in the future.

Consequently paleohydrologic records, in combination with temperature projections, may be useful for assessing future climate scenarios.



Combining information from the past and scenarios for the future:

An example from the City of Boulder

- Tree-ring streamflow reconstruction data were used as input to a water system model.
- The model was run using several scenarios: here, using a 15% reduction of flow, and current trends in demand.
- Results indicate 13 years would require the City to go to a level 4 drought response.

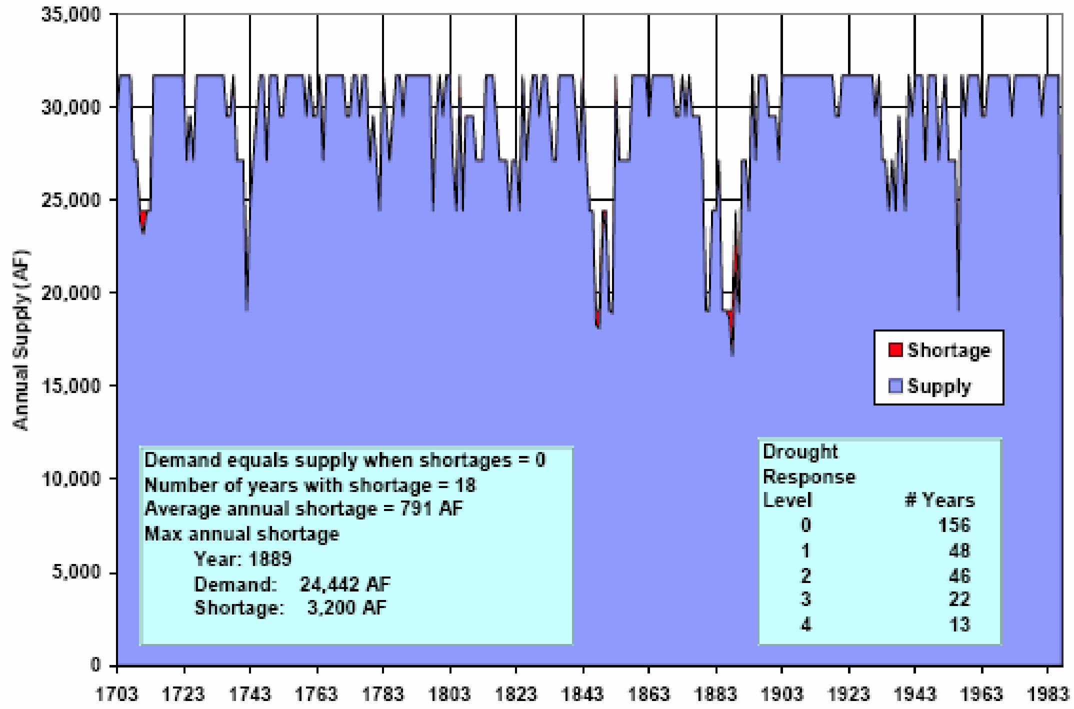


Figure 5. Demands & Supplies: 15% Reduced Flow Hydrology, Current Trends Scenario (demand = 31,700 AF/year).

Table 2: Boulder's Drought Response Triggers and Demand Reductions

Projected Storage Index (1)	Drought Alert Stage	Total Annual Water Use Reduction Goal	Irrigation Season Water Use Reduction Goal
Greater than 0.85	None	0%	0%
Between 0.85 and 0.7	I	8%	10%
Between 0.7 and 0.55	II	14%	20%
Between 0.55 and 0.4	III	22%	30%
Less than 0.4	IV	40%	55%

From Hydrosphere Resource Consultants: Report to the City of Boulder, Sept. 2003

The take-home messages

1) Tree-ring reconstructions are useful in that they provide more “hydrologic experience” without the pain

2) Tree growth in this region is particularly sensitive to variations in moisture availability, and thus streamflow

3) The methods to develop tree-ring chronologies and streamflow reconstructions are designed to capture and enhance this moisture signal

4) A reconstruction is a best-estimate based on the relationship between tree-growth and gaged flows; there is always uncertainty in the reconstructed flows

The take-home messages

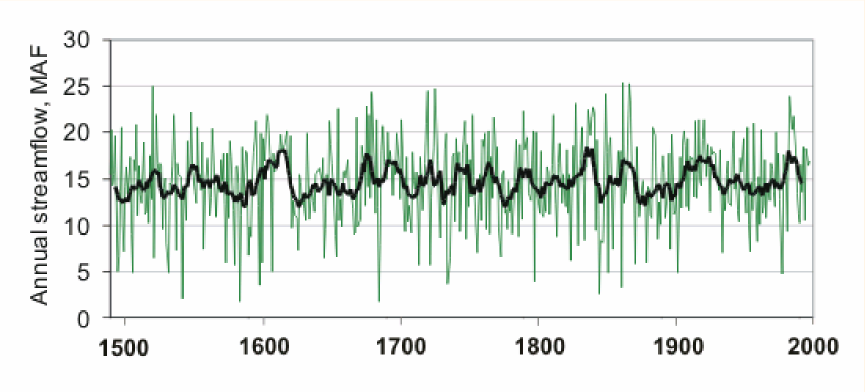
5) The reconstructions (almost) always show drought events more severe/sustained than those in the gaged record

6) There are different levels of application of reconstruction data, depending on the needs and management context of the data user

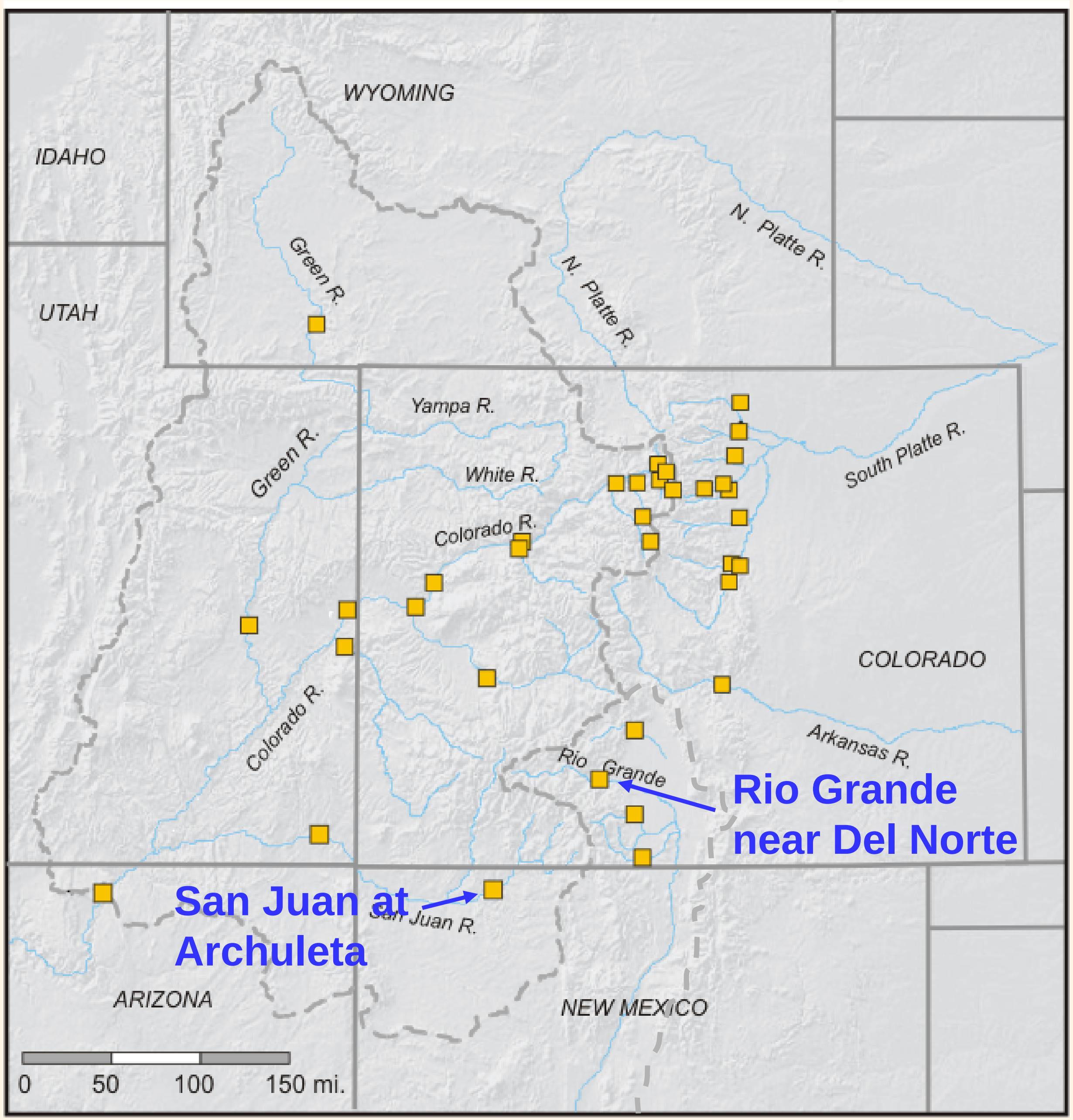
7) Climate change will impact future hydrology, but information about past climate and hydrology is relevant and useful for planning for the future

Part 7:

Existing reconstructions for the Rio Grande and San Juan basins



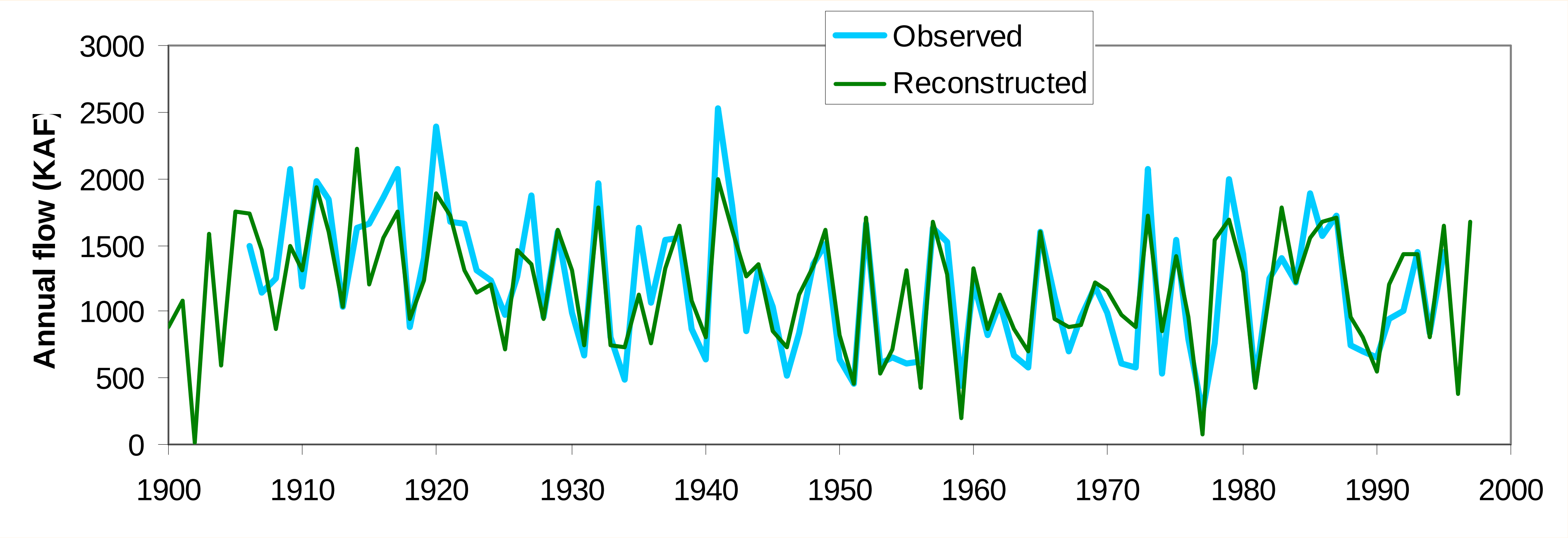
Streamflow reconstructions for the Rio Grande and San Juan River basins



Gage reconstructions

San Juan River at Archuleta, NM

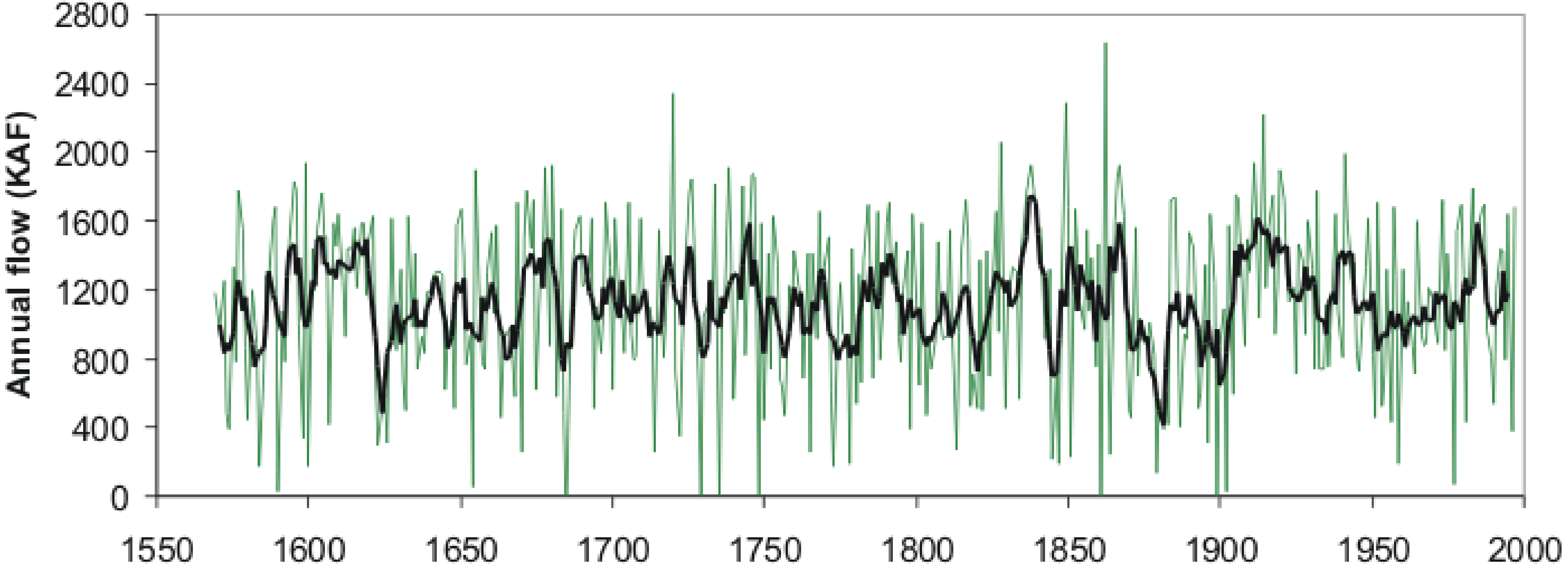
Gaged vs. Reconstructed Flows, 1906-1995



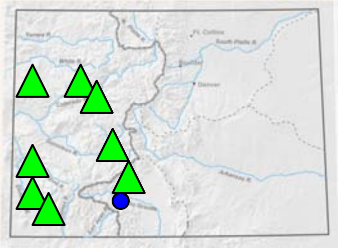
- Natural flow estimates used for the calibration from USBR
- Explained variance = 72%

Not shown, but the 2002 natural flow value was estimated to be -23 KAF (!)

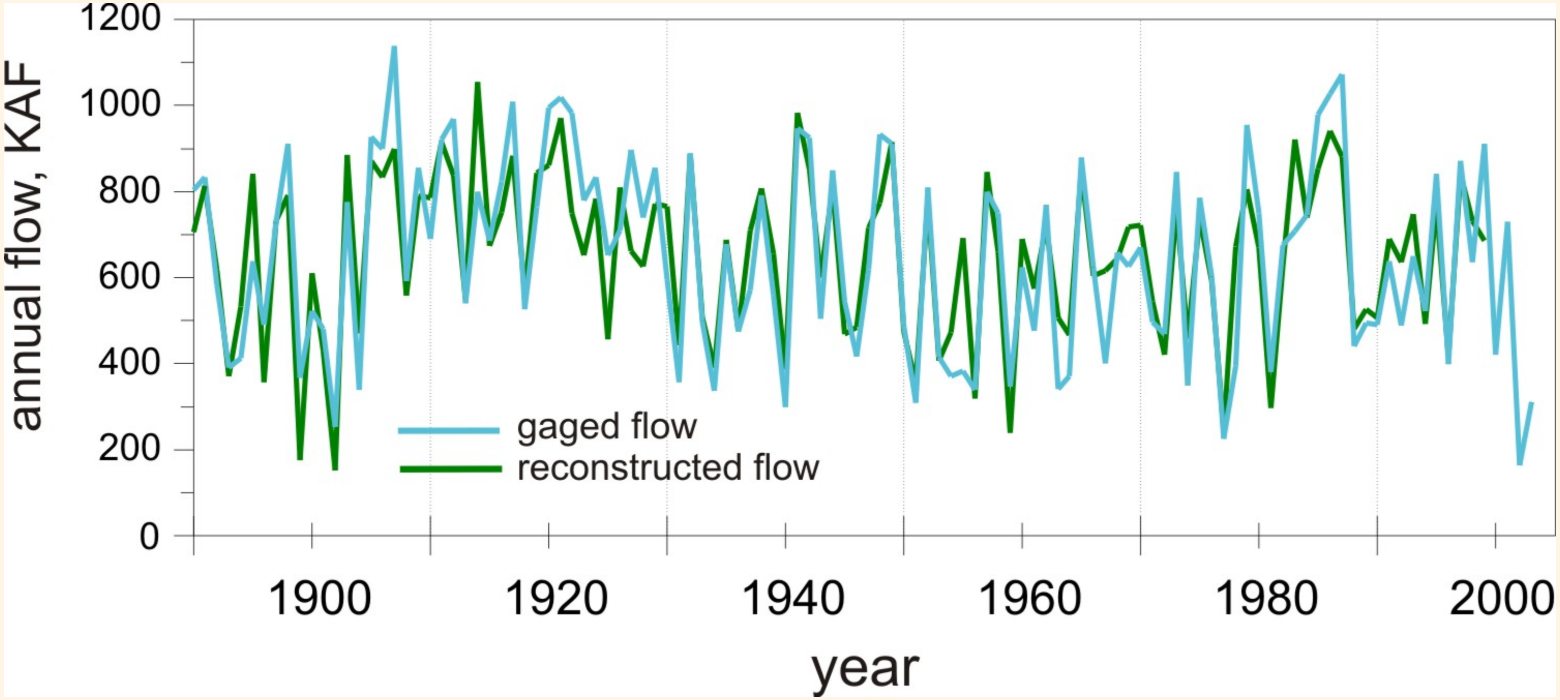
Reconstruction of San Juan River at Archuleta, 1569-1999



- Annual flows in green, 5-yr running mean in black
- 10 years w/ reconstructed flows below 1977 (70 KAF)
- Lowest 5-yr reconstructed running mean (1879-1883) = 423 KAF
- Lowest 20thC 5-yr running mean (1959-1963)= 840 KAF gage, 876 KAF reconstructed
- 2000-2004 running mean = 459 KAF

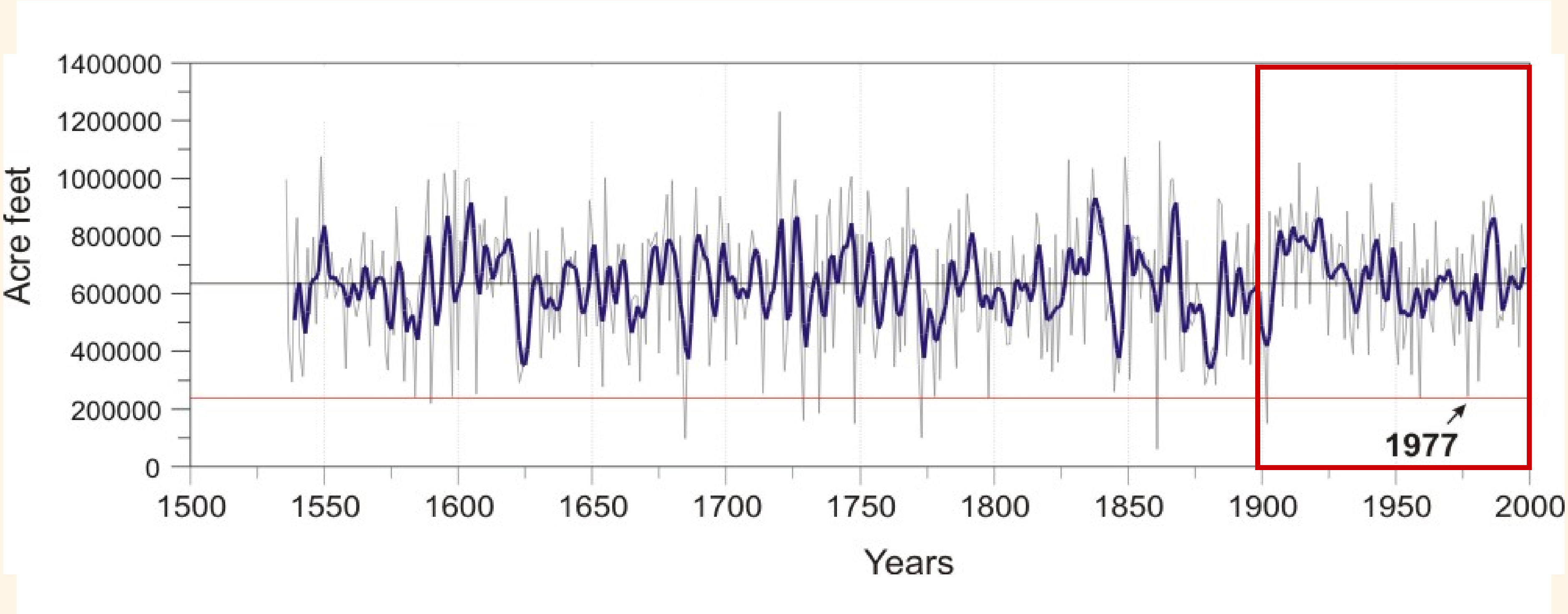


Rio Grande near Del Norte, CO
Gaged vs. Reconstructed Flows, 1890-1997



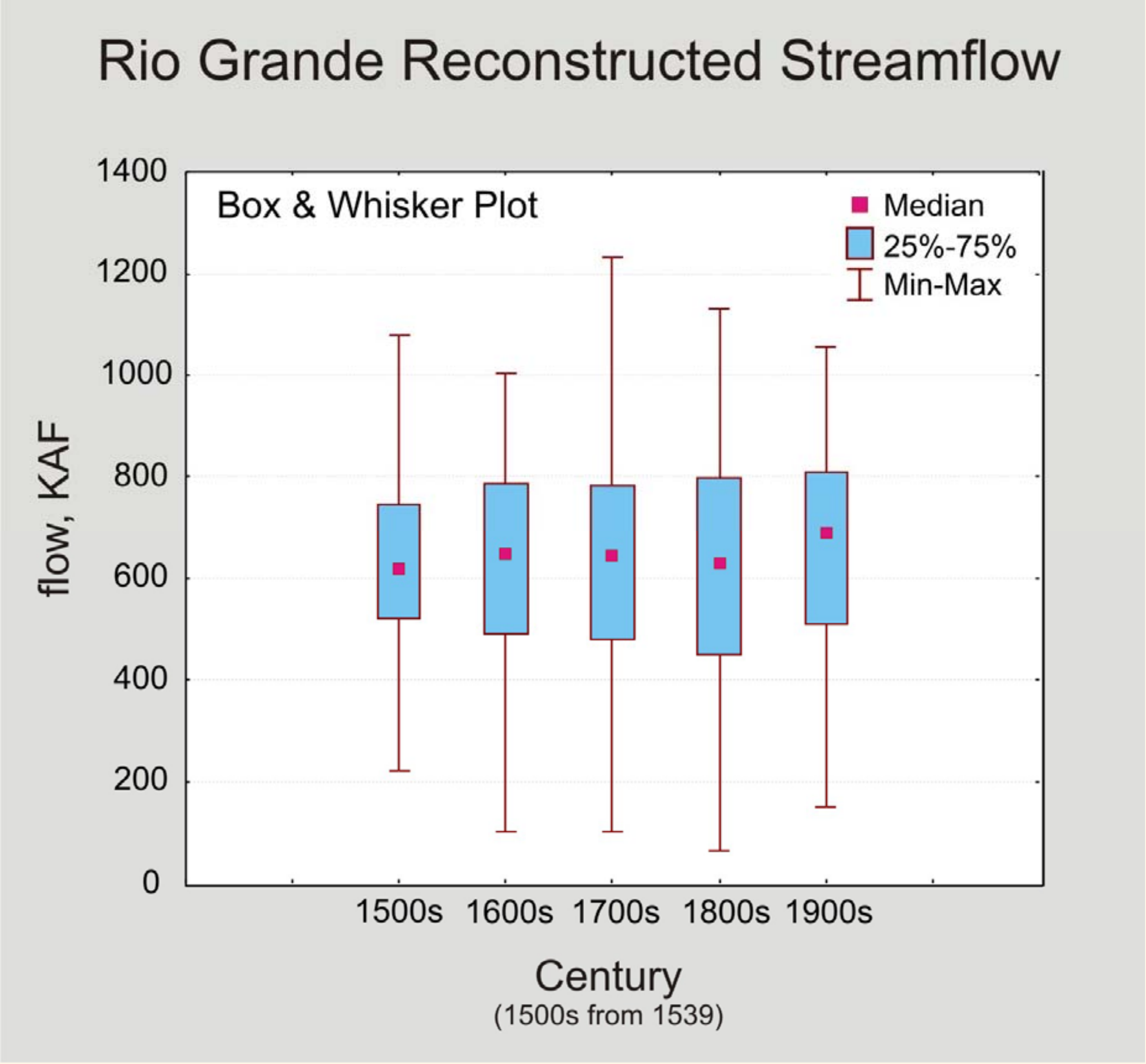
75.5% of the variance in the Rio Grande gage record is explained by the reconstruction. About 25% of the variance is unexplained, representing the uncertainty in the reconstruction model.

Reconstruction of Rio Grande annual streamflow, 1536-1999

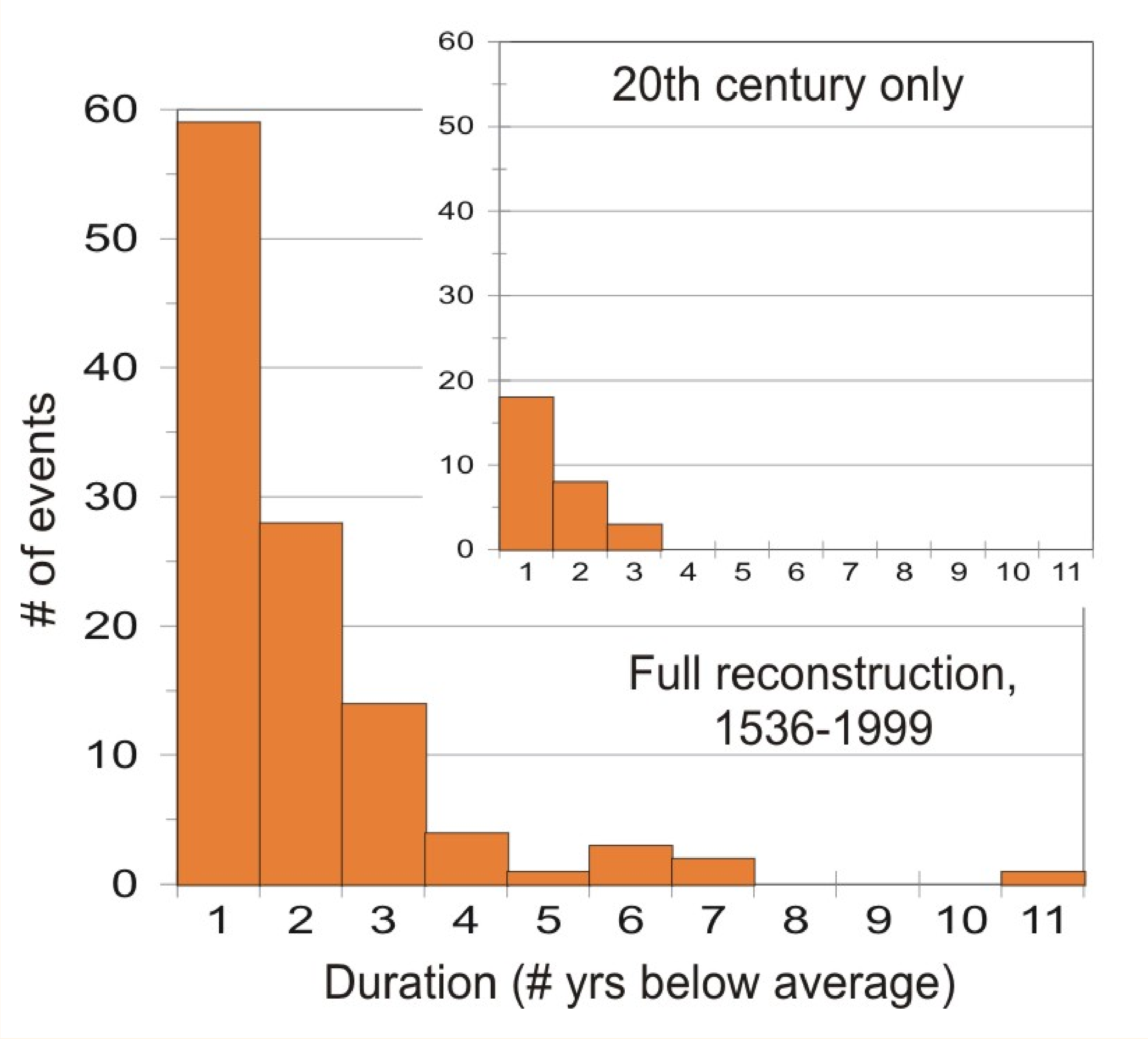


- How representative is the 20th century in the context of the past centuries?
- Have there been more severe droughts prior to the gage record?

Comparison of 20th century and full reconstruction



Drought duration
Reconstructed Rio Grande streamflow

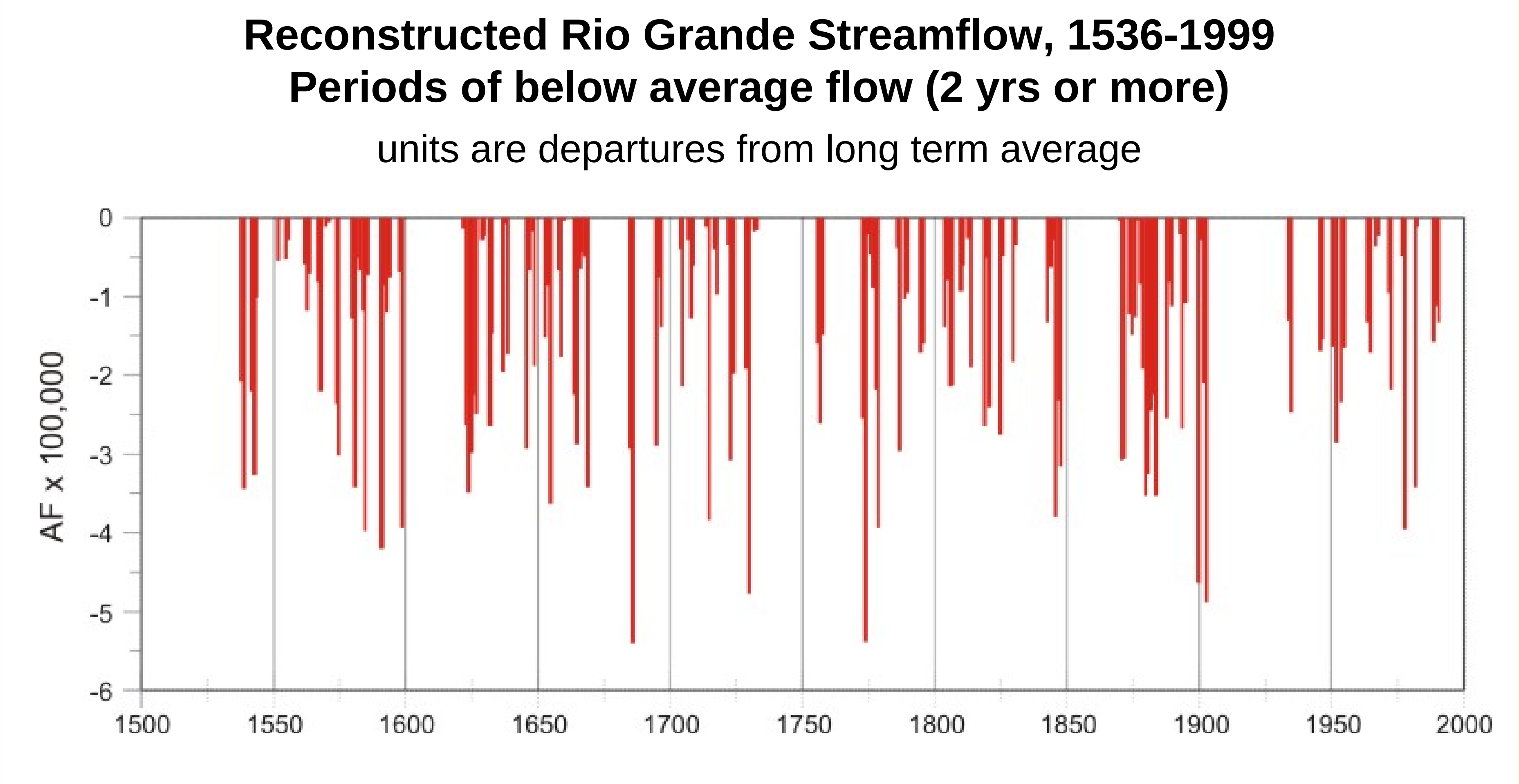


Here, drought is defined as one or more consecutive years below long-term average.

Full reconstruction average = 638 KAF

20th c reconstruction average = 661 KAF

Droughts are not evenly distributed over time



Rio Grande low flow extremes, 1536-1999

Lowest Flows					
SINGLE YEAR		**3-YEAR AVERAGE**		**5-YEAR AVERAGE**	
1861	62335	1845-47	330914	1879-83	338999
1685	99417	1879-81	331303	1622-26	363389
1773	102332	1622-24	337186	1878-82	371327

Historical accounts can help validate the streamflow reconstruction

- 1840s (mid to late) – Severe drought due to below average precipitation occurred (Denevan 1967, Ellis 1974); perhaps in response to these conditions, and an accelerating decrease in bison on the eastern plains, various nomadic Indian groups stepped up their raiding along the Rio Grande (Bloom 1914)

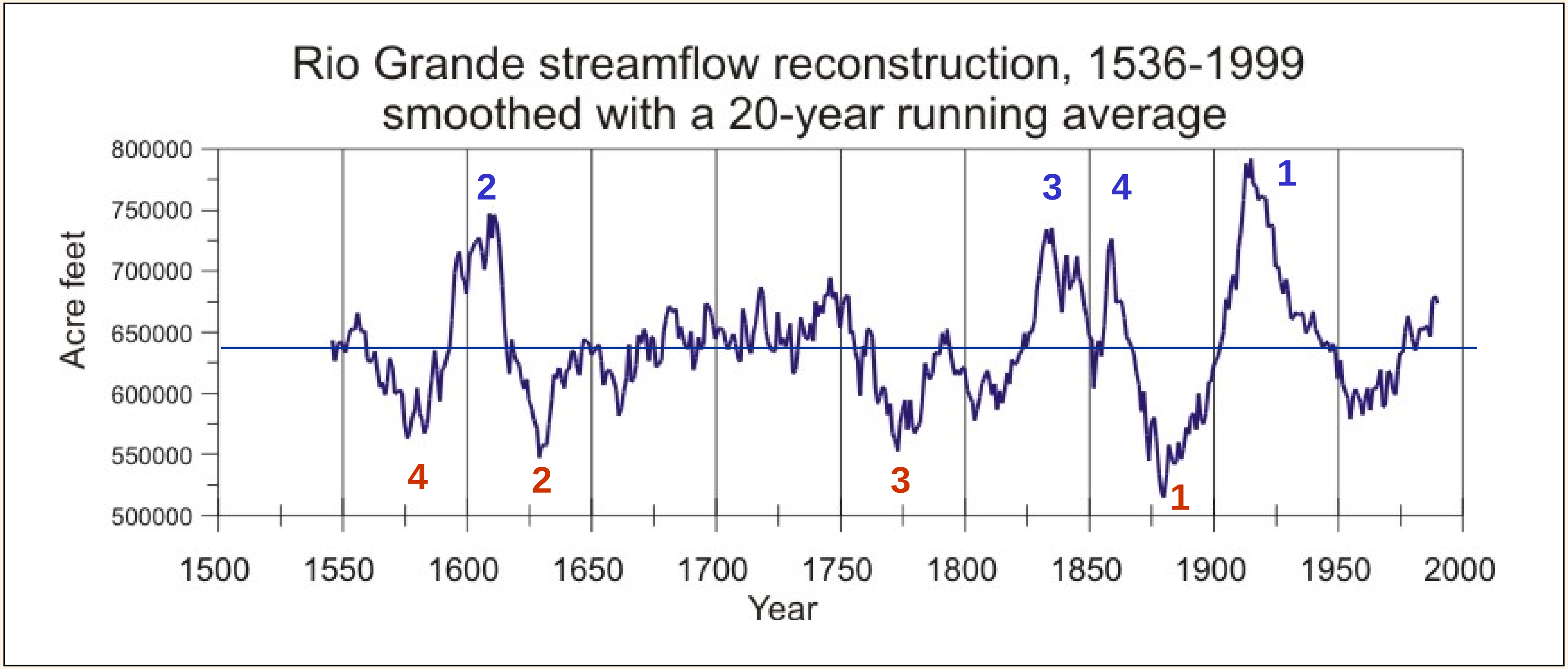
- 1861 - The Rio Grande was dry from Socorro to below El Paso (Follett 1898)

- 1879 - A drought resulted in crop failure and the loss of many sheep for the Navajo, who increased their raids on Zuni and Hispanic livestock (Ellis 1974)

- 1880 - There was a severe drought in the territory (Bancroft 1889)

from Scurlock 1998

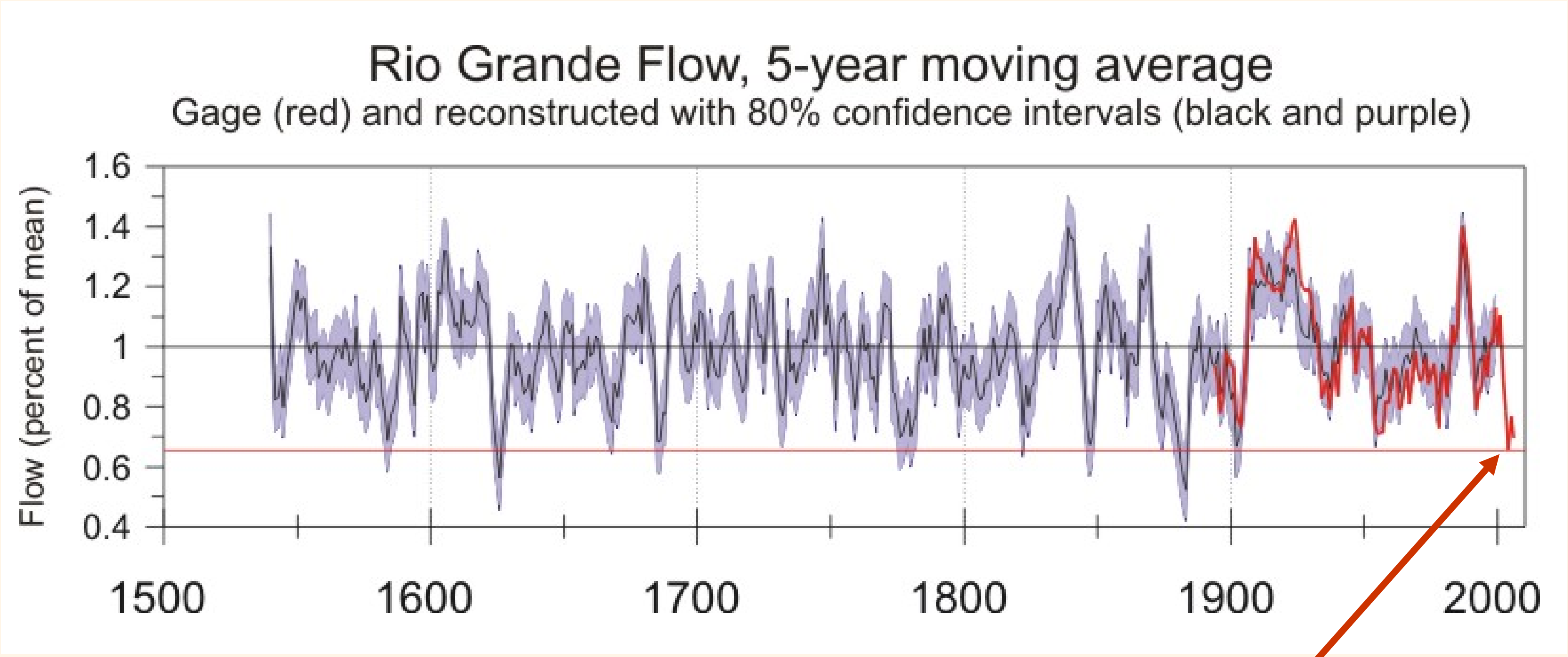
Low-frequency variations - periods of wet and dry conditions



Wettest and driest non-overlapping 20-year averages

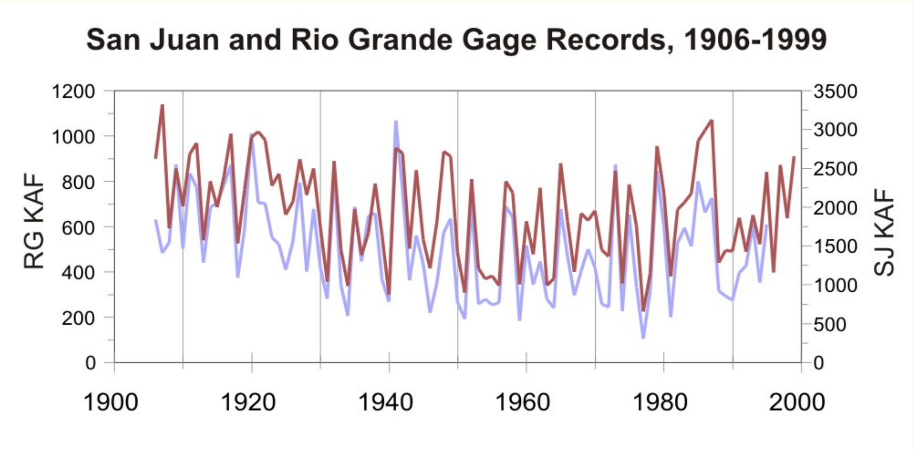
DRIEST	WETTEST
1 **1870-1889**	1 **1905-1924**
2 **1619-1638**	2 **1599-1618**
3 **1763-1782**	3 **1825-1844**
4 **1566-1585**	4 **1849-1868**

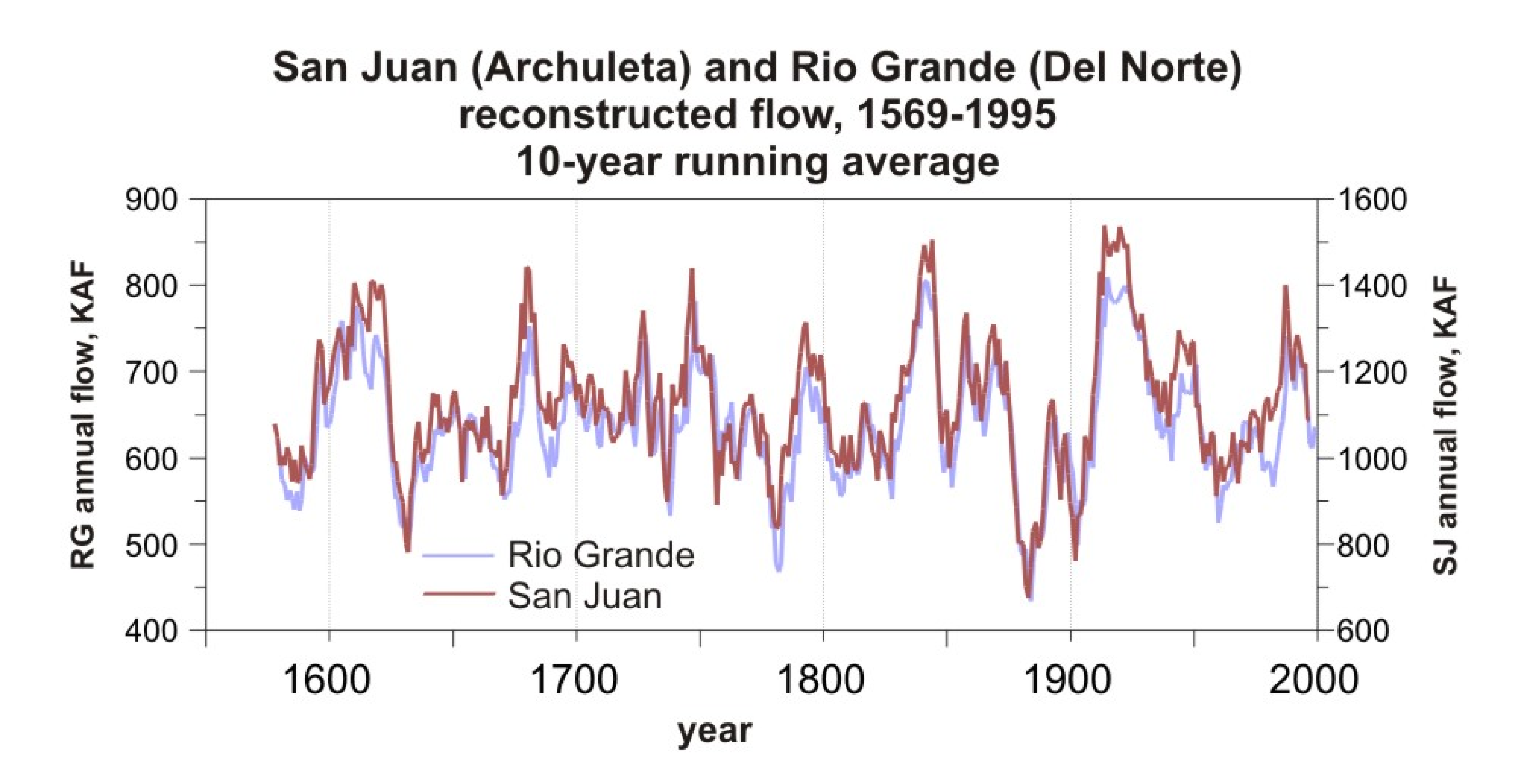
The 2000-2004 drought in a long-term context



2000-2004 average

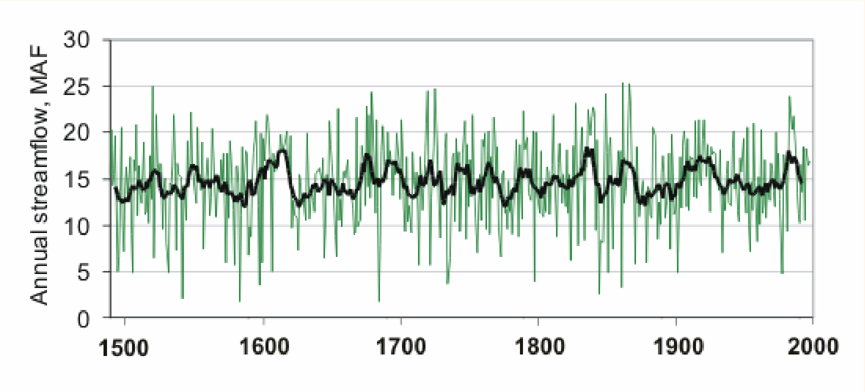
Comparison of San Juan and Rio Grande Annual Streamflow, gaged and reconstructed



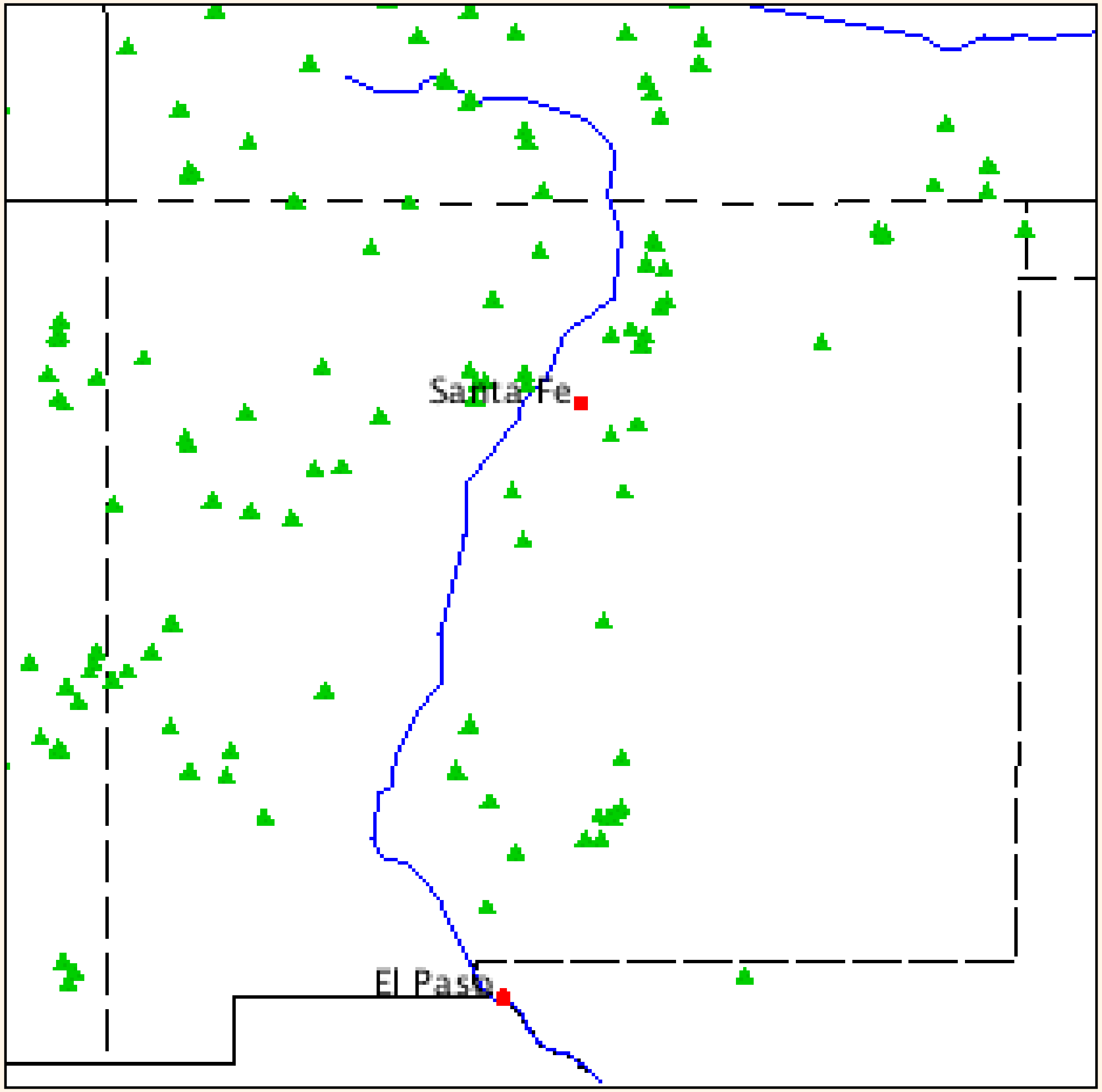


Part 8:

Where to go next



New Mexico chronologies in the ITRDB



Chronologies: building blocks for new flow reconstructions

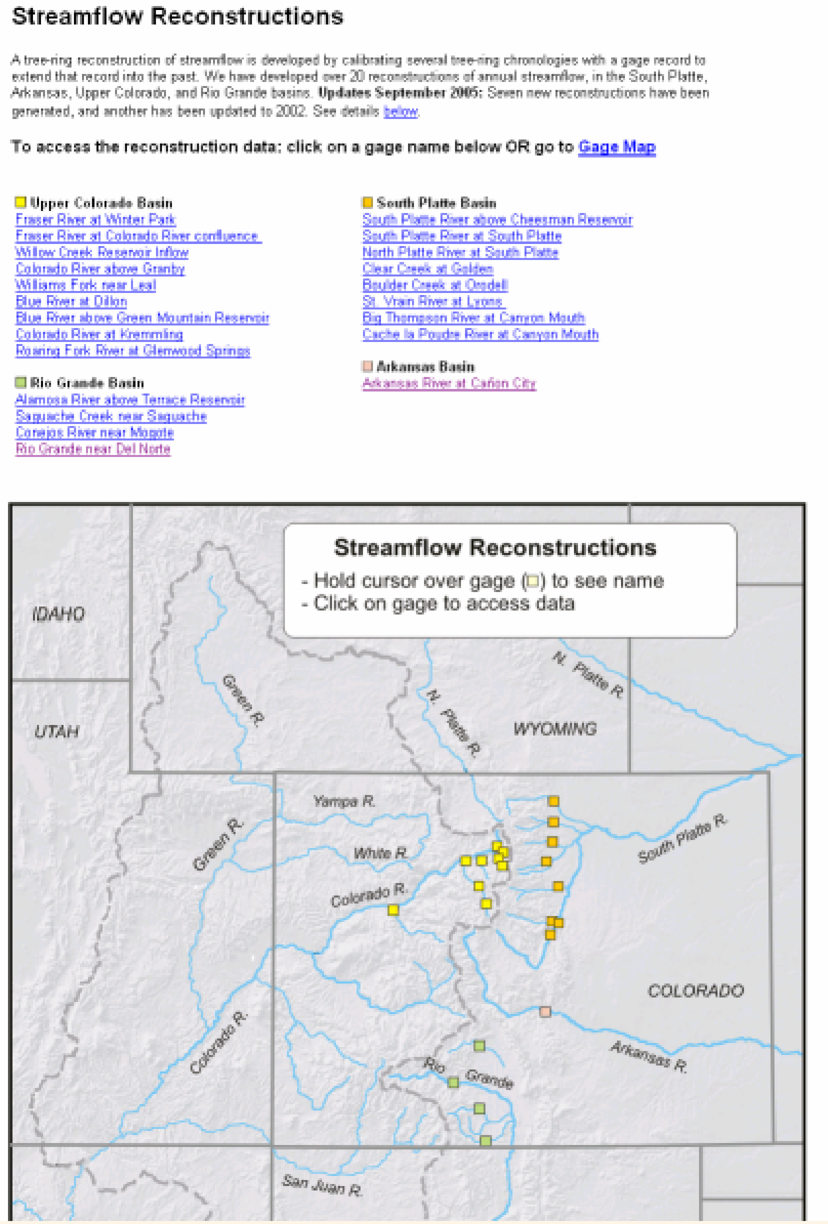
Main limitation of existing data is recentness:

- most collected in 1970s and 1980s; only 12 extend through 1990 or later

At least 4 post-2000 NM chronologies are not in ITRDB, plus the 4 collections in 2007

Future Web resource for NM flow reconstructions

At right: Colorado TreeFlow – data is accessed by clicking on gage name or symbol in map


Streamflow Reconstructions

A tree-ring reconstruction of streamflow is developed by calibrating several tree-ring chronologies with a gage record to extend that record into the past. We have developed over 20 reconstructions of annual streamflow, in the South Platte, Arkansas, Upper Colorado, and Rio Grande basins. **Updates September 2005:** Seven new reconstructions have been generated, and another has been updated to 2002. See details below.

To access the reconstruction data: click on a gage name below OR go to Gage Map

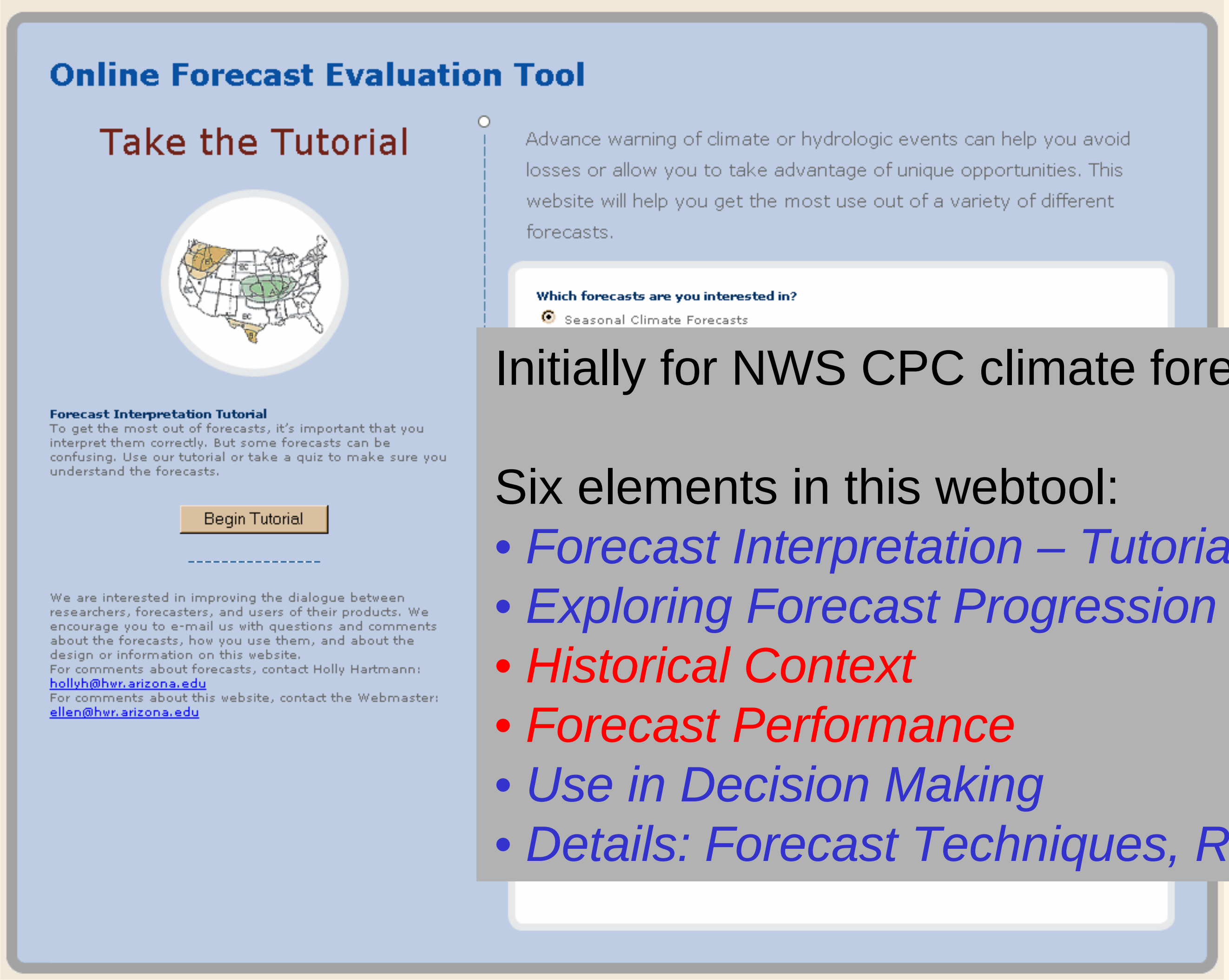
Upper Colorado Basin
Fraser River at Winter Park
Fraser River at Colorado River confluence
Willow Creek Reservoir Inflow
Colorado River above Granby
Williams Fork near Leal
Blue River at Dillon
Blue River above Green Mountain Reservoir
Colorado River at Kremmling
Roaring Fork River at Glenwood Springs

Rio Grande Basin
Alamosa River above Terrace Reservoir
Saguache Creek near Saguache
Conejos River near Mogote
Rio Grande near Del Norte

South Platte Basin
South Platte River above Cheesman Reservoir
South Platte River at South Platte
North Platte River at South Platte
Clear Creek at Golden
Boulder Creek at Orodell
St. Vrain River at Lyons
Big Thompson River at Canyon Mouth
Cache la Poudre River at Canyon Mouth

Arkansas Basin
Arkansas River at Cañon City

Example of Web-based visualization tool for climate data



Initially for NWS CPC climate forecasts

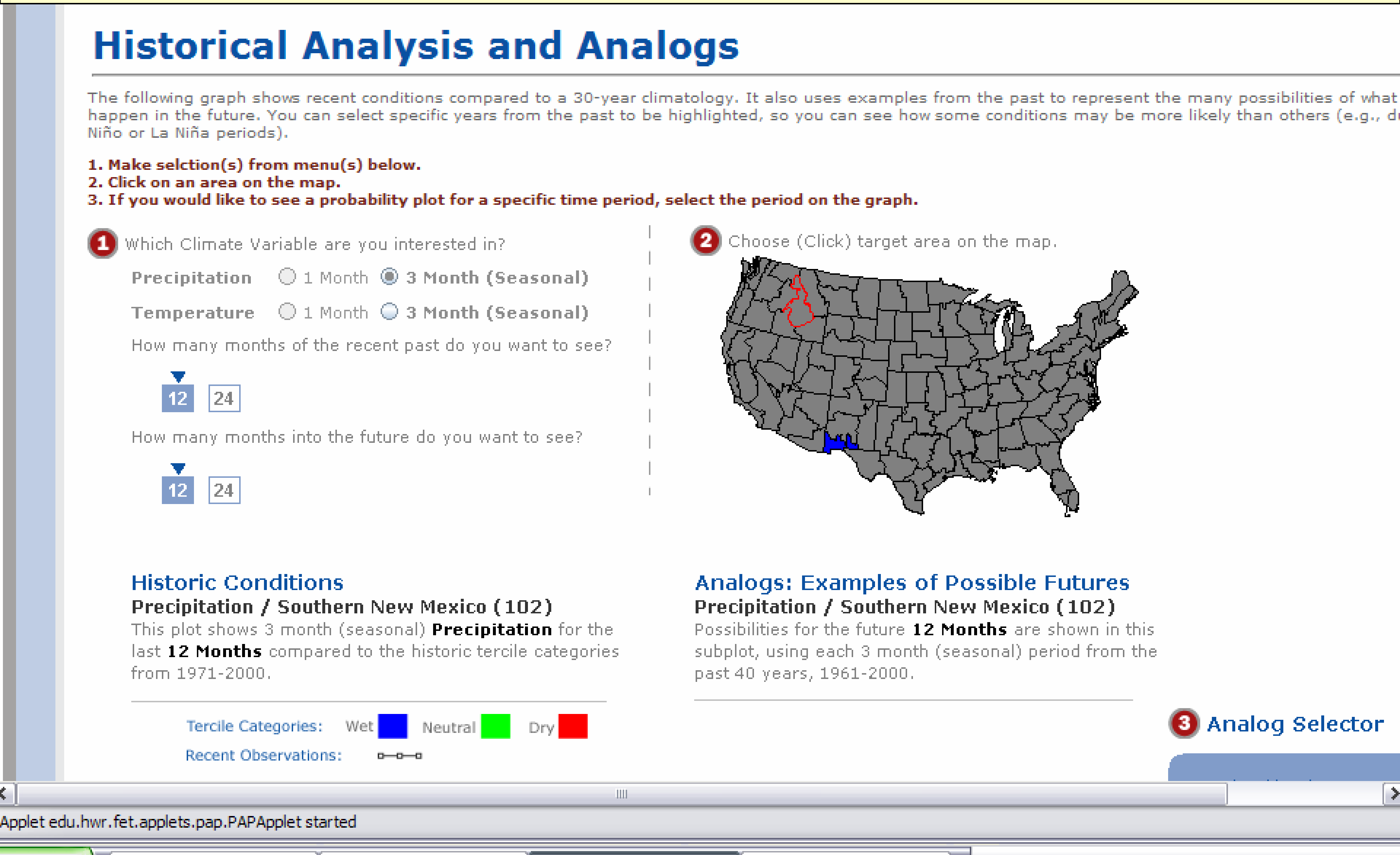
Six elements in this webtool:

- *Forecast Interpretation – Tutorials, Quiz*
- *Exploring Forecast Progression*
- *Historical Context*
- *Forecast Performance*
- *Use in Decision Making*
- *Details: Forecast Techniques, Research*

http://fet.hwr.arizona.edu/ForecastEvaluationTool/

User interface – user follows numbered steps (red circles)

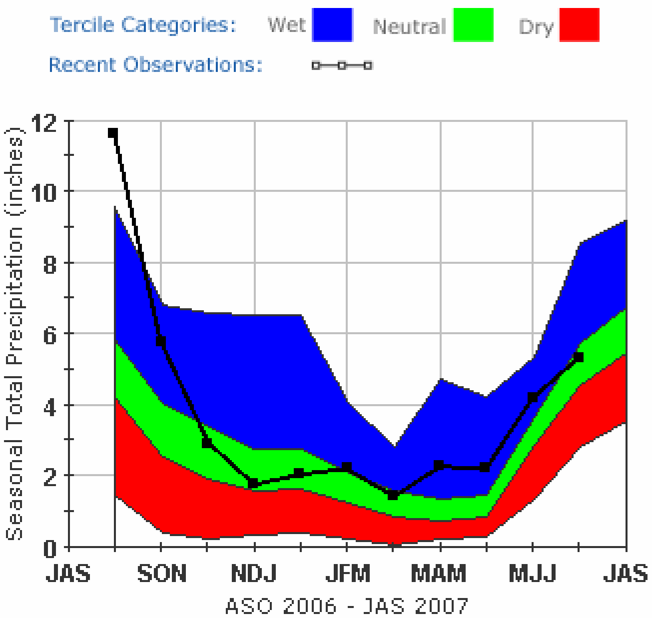
- Southern NM selected as region of interest

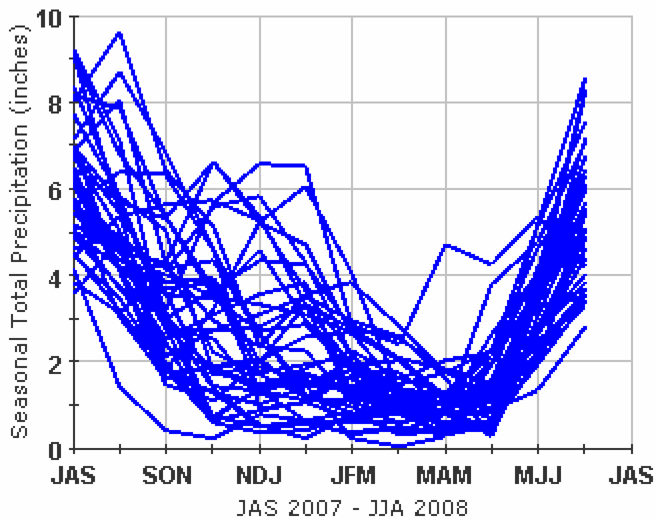


- At left, 1971-2000 climatology for seasonal precip is divided into terciles (wet-neutral-dry)
- Analog Selector (3) is used to highlight analog “possible futures” (blue “spaghetti plot”)

last **12 Months** compared to the historic tercile categories from 1971-2000.

subplot, using each 3 month (seasonal) period from the past 40 years, 1961-2000.





3 Analog Selector

Select/deselect a year by clicking on it.

Select All Clear All

1961	1971	1981	1991
1962	1972	1982	1992
1963	1973	1983	1993
1964	1974	1984	1994
1965	1975	1985	1995
1966	1976	1986	1996
1967	1977	1987	1997
1968	1978	1988	1998
1969	1979	1989	1999
1970	1980	1990	2000

Patterns

El Nino Only
La Nina Only
Neither El Nino nor La Nina
High Pacific Decadal Oscillations
Mid Pacific Decadal Oscillations
Low Pacific Decadal Oscillations

Current Season: **JAS 2007**

4 Probability of Exceedance Graph

To view graph:
Use the slider below to select the season from the chart above. Select a season by moving shaded area and clicking on it.

J A S O N D J F M A M J J A

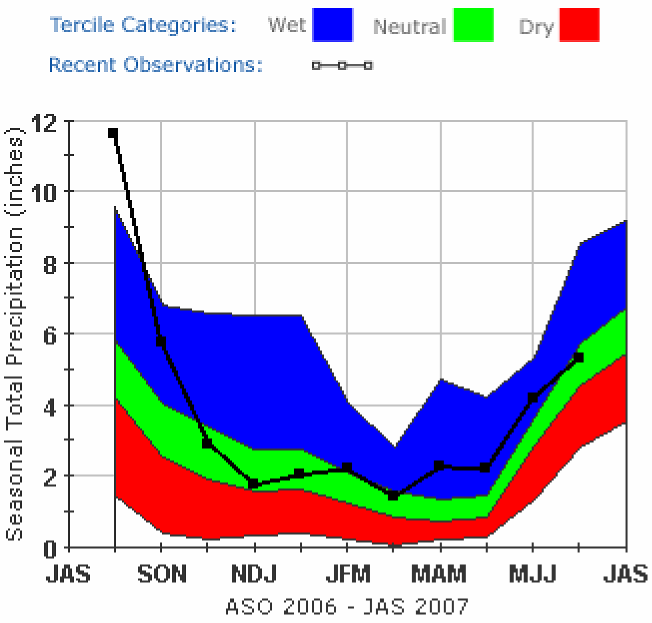
Applet edu.hwr.fet.applets.pap.PAPApplet started

- User has selected all years in 1960s as analogs (blue lines; other years are gray)

Historic Conditions

Precipitation / Southern New Mexico (102)

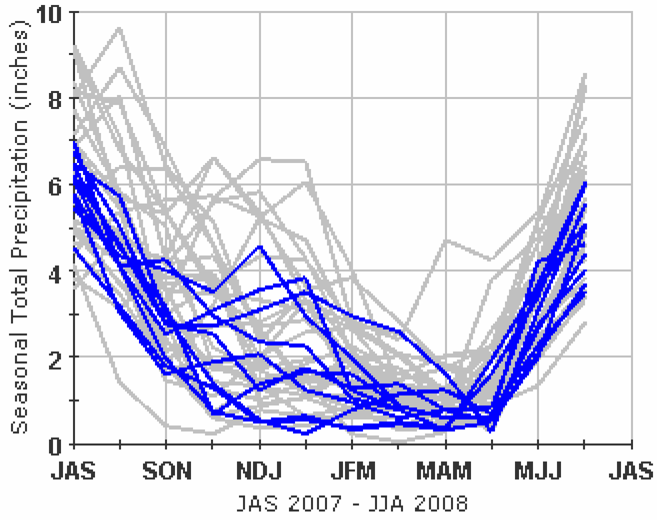
This plot shows 3 month (seasonal) **Precipitation** for the last **12 Months** compared to the historic tercile categories from 1971-2000.



Analogs: Examples of Possible Futures

Precipitation / Southern New Mexico (102)

Possibilities for the future **12 Months** are shown in this subplot, using each 3 month (seasonal) period from the past 40 years, 1961-2000.



Current Season: **JAS 2007**

3 Analog Selector

Select/deselect a year by clicking on it.

Select All   Clear All

1961	1971	1981	1991
1962	1972	1982	1992
1963	1973	1983	1993
1964	1974	1984	1994
1965	1975	1985	1995
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1967	1977	1987	1997
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El Nino Only
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Neither El Nino nor La Nina
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J A S O N D J F M A M J J A

Applet edu.hwr.fet.applets.pap.PAPApplet started

- Here, user has selected all years in 1990s as analogs – note three years with very high winter precip (red oval)

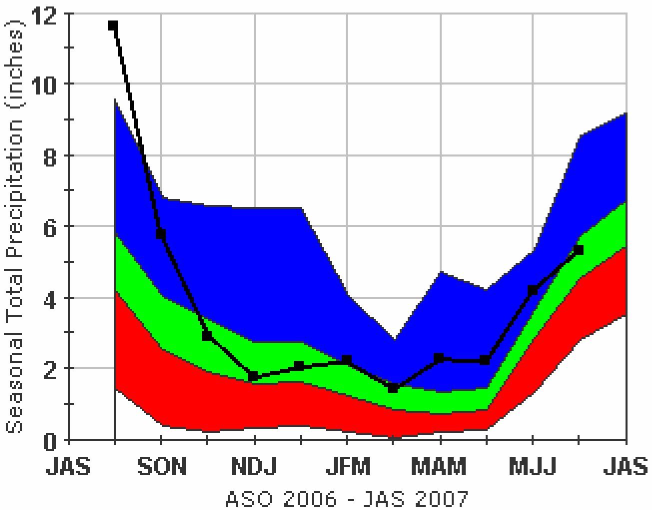
Historic Conditions

Precipitation / Southern New Mexico (102)

This plot shows 3 month (seasonal) **Precipitation** for the last **12 Months** compared to the historic tercile categories from 1971-2000.

Tercile Categories: Wet Neutral Dry

Recent Observations:



Analogs: Examples of Possible Futures

Precipitation / Southern New Mexico (102)

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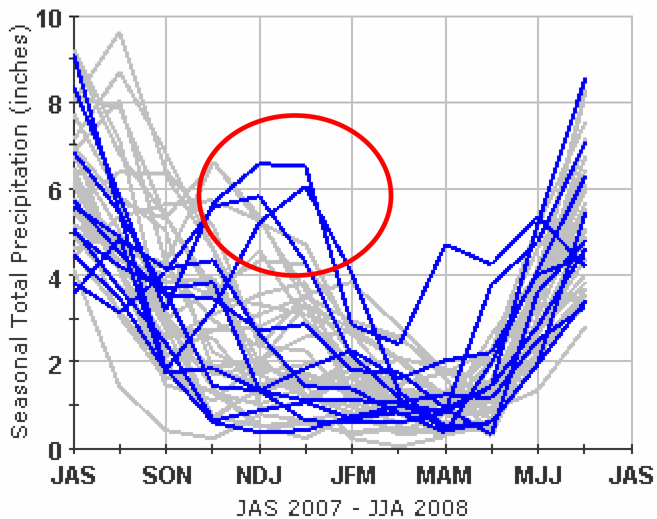

Current Season: **JAS 2007**

4 Probability of Exceedance Graph

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J A S O N D J F M A M J J A

3 Analog Selector

Select/deselect a year by clicking on it.

Select All Clear All

1961	1971	1981	1991
1962	1972	1982	1992
1963	1973	1983	1993
1964	1974	1984	1994
1965	1975	1985	1995
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1967	1977	1987	1997
1968	1978	1988	1998
1969	1979	1989	1999
1970	1980	1990	2000

Patterns

El Nino Only

La Nina Only

Neither El Nino nor La Nina

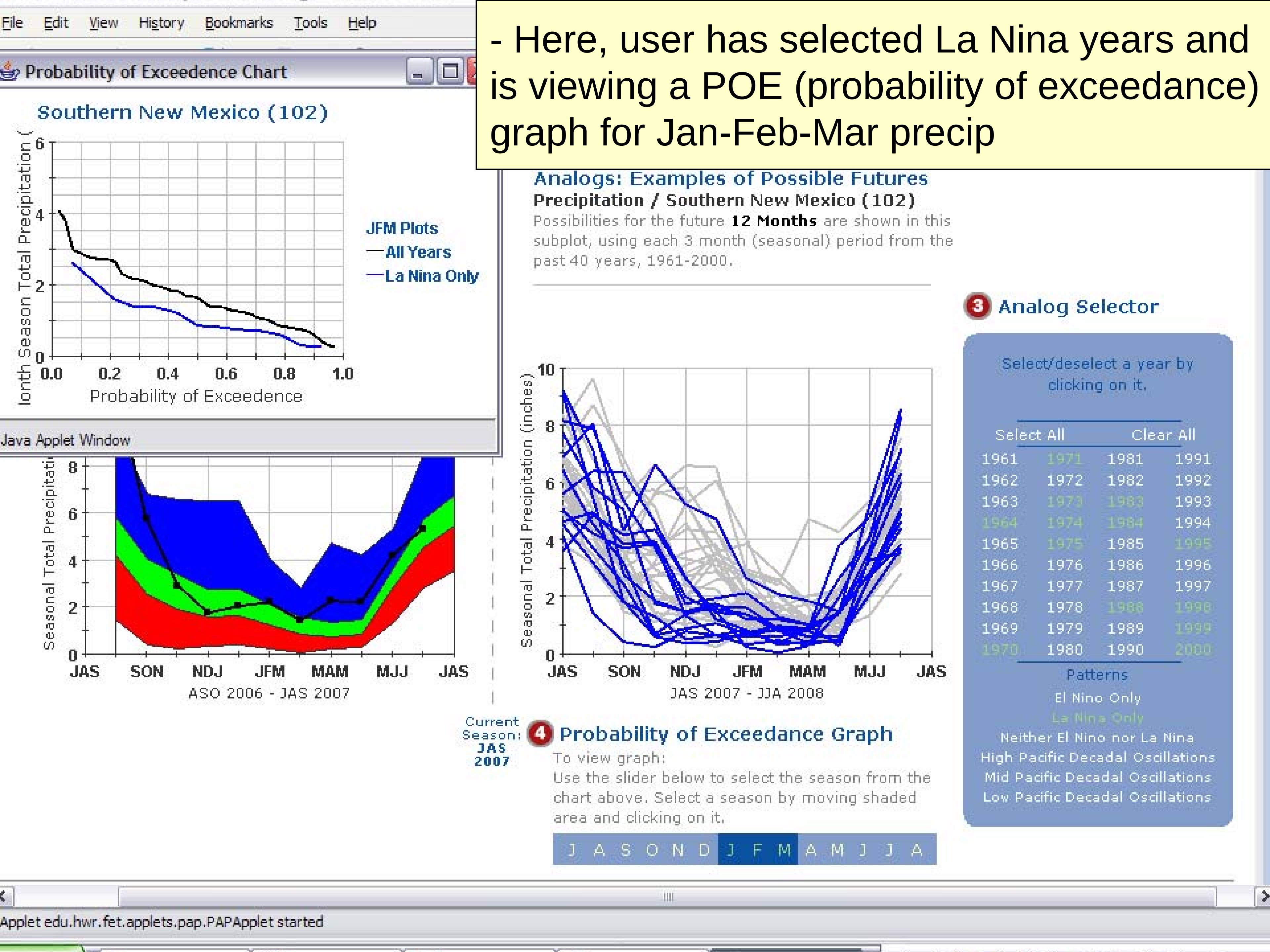
High Pacific Decadal Oscillations

Mid Pacific Decadal Oscillations

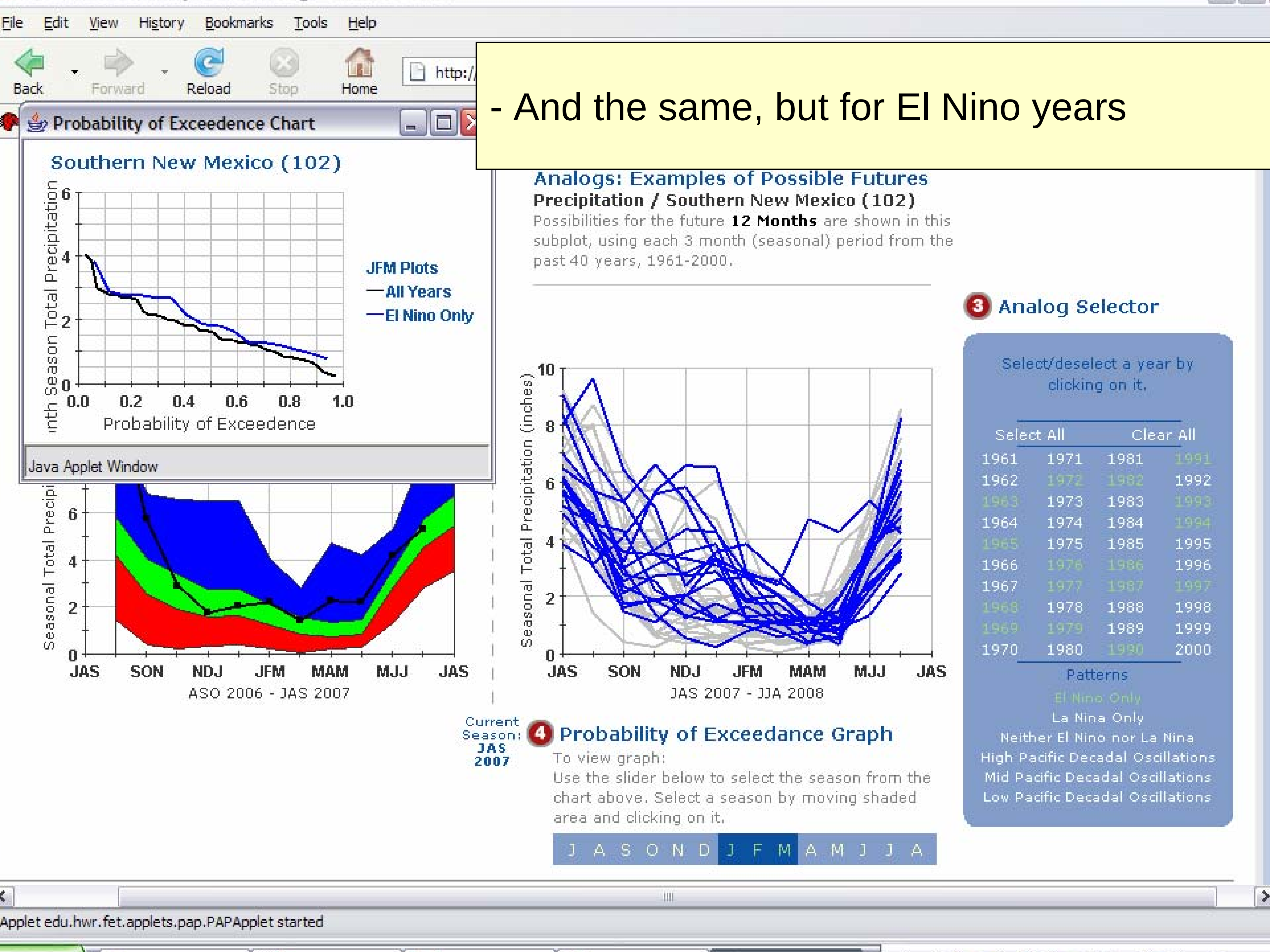
Low Pacific Decadal Oscillations

Applet edu.hwr.fet.applets.pap.PAPApplet started

- Here, user has selected La Nina years and is viewing a POE (probability of exceedance) graph for Jan-Feb-Mar precip



- And the same, but for El Nino years



Potential features of similar visualization tool for paleo-hydrologic data

- Compare segments of reconstructed flow record with distribution of observed flows
- Use segments of reconstructed flow (5-year, 10-year, 20-year) as possible “future analogs”
- Generate probability of exceedance graphs based on reconstructed flows, compare to observed flows

Discussion

- What are your needs and concerns that might be addressed by these data?
- Gages of interest – we will be generating preliminary reconstructions with data currently available (proposal pending for updated and new collections) –what gages should we target?
- Ways to display and analyze data: examples of display from Holly’s work to get you thinking
- Interest in working with whomever is interested to produce results for follow-up workshop next spring