The long view of the Rio

What tree rings tell us about the past variability of the Rio Grande, and what it means for the future

AWRA – NM Chapter – June 2, 2008

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Western Water Assessment

NOAA

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AWRA - NM

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Outline

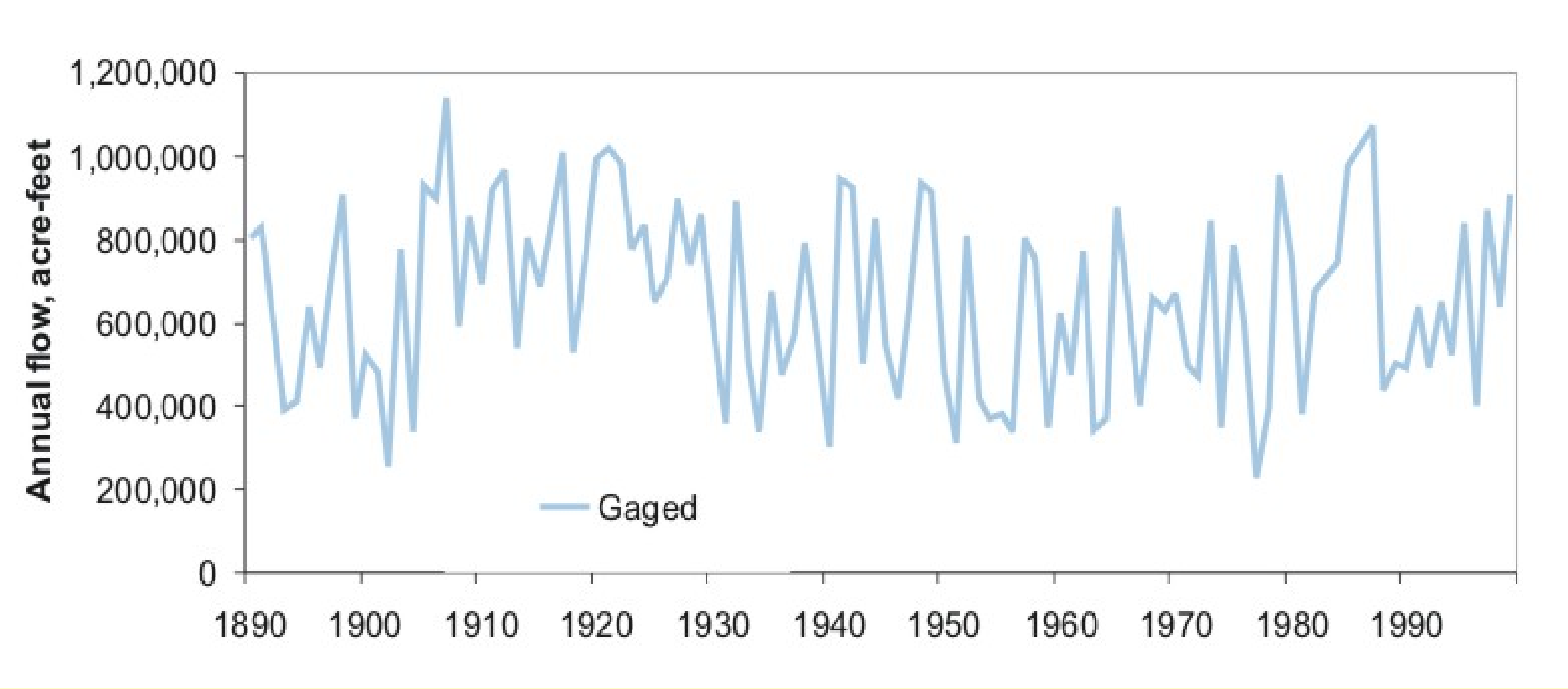
1) Hydrologic experience: gaged record vs. tree rings
2) How we develop tree-ring reconstructions
3) New reconstructions for the Rio Grande basin
4) How tree-ring reconstructions are being used
5) Relevance of paleo to an uncertain future
6) Conclusions

Please ask questions!

Observed hydrology: enough experience?

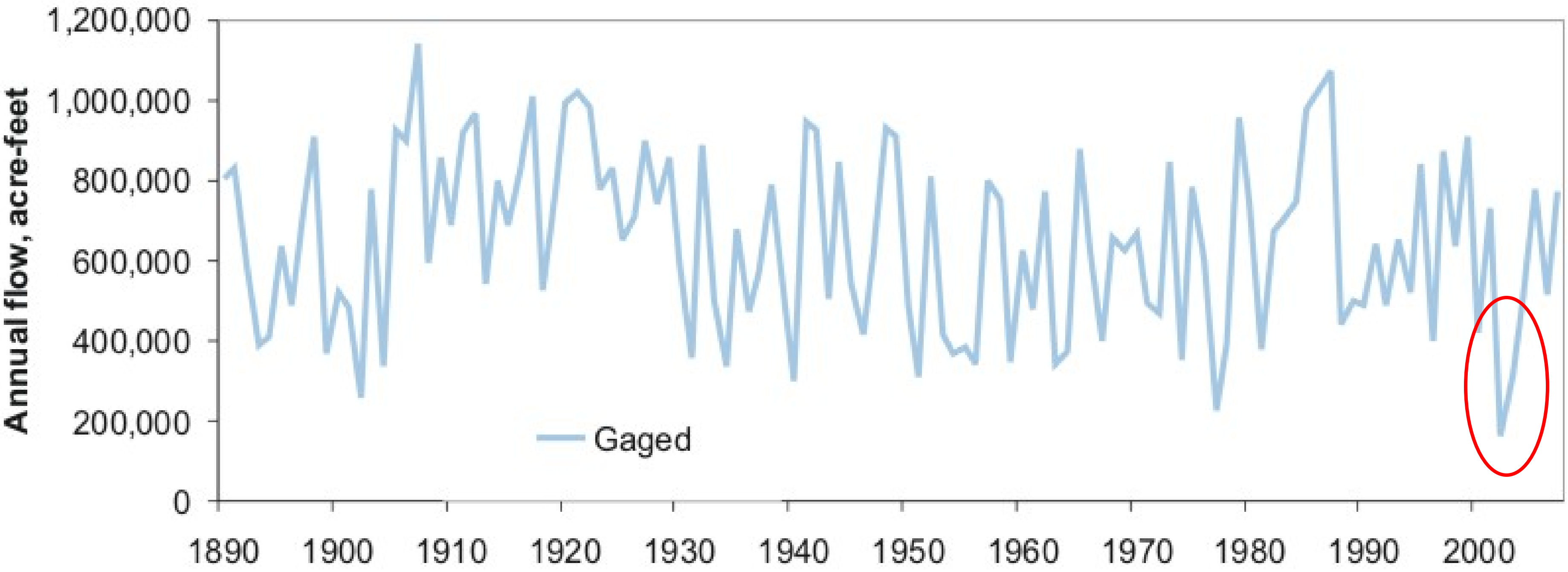
Rio Grande near Del Norte, CO

Gaged Annual Flow, 1890-1999



Observed hydrology: enough experience?

Rio Grande near Del Norte, CO
Gaged Annual Flow, 1890-2007



2002 – Lowest water year flow

2002-03 – Lowest 2-year mean flow

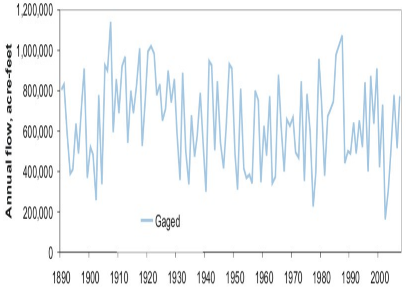
2002-04 – Lowest 3-year mean flow

Even 110 years is not enough!

Tree-ring reconstructions - a surrogate for experience

Rio Grande near Del Norte, CO

Gaged record- 118 years

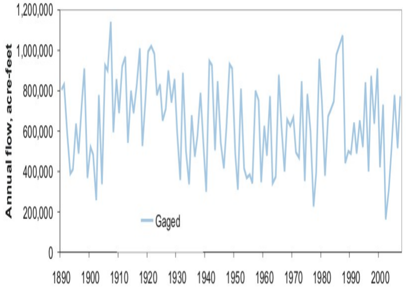


Tree-ring reconstructions - a surrogate for experience

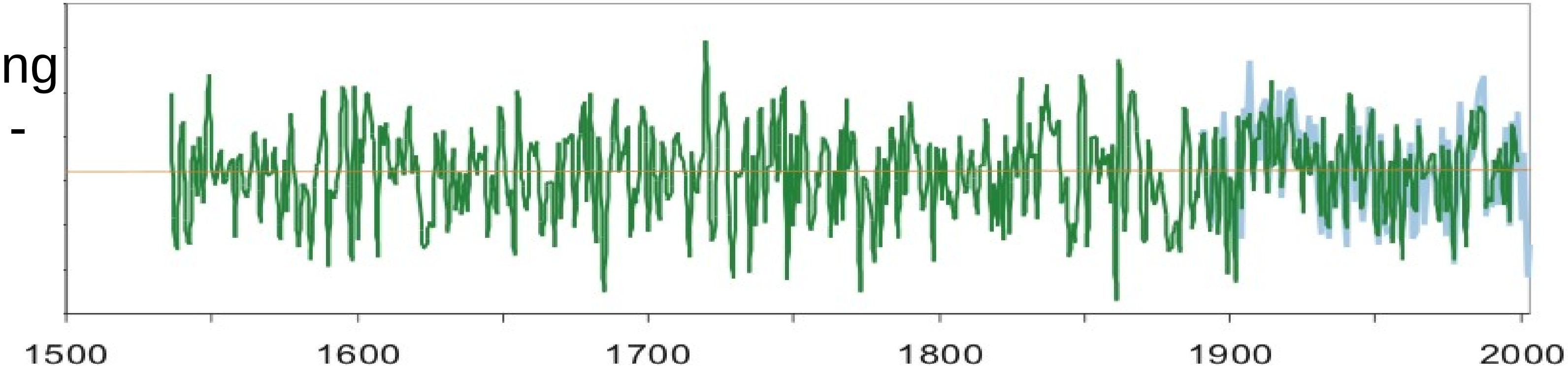
By extending the gaged hydrology by hundreds of years into the past, the reconstructions provide a more complete picture of hydrologic variability

Rio Grande near Del Norte, CO

Gaged record- 118 years



Tree-ring record - 464 years



Tree-ring reconstructions - a surrogate for experience

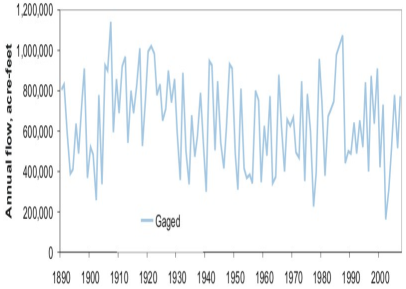
Benefits:

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

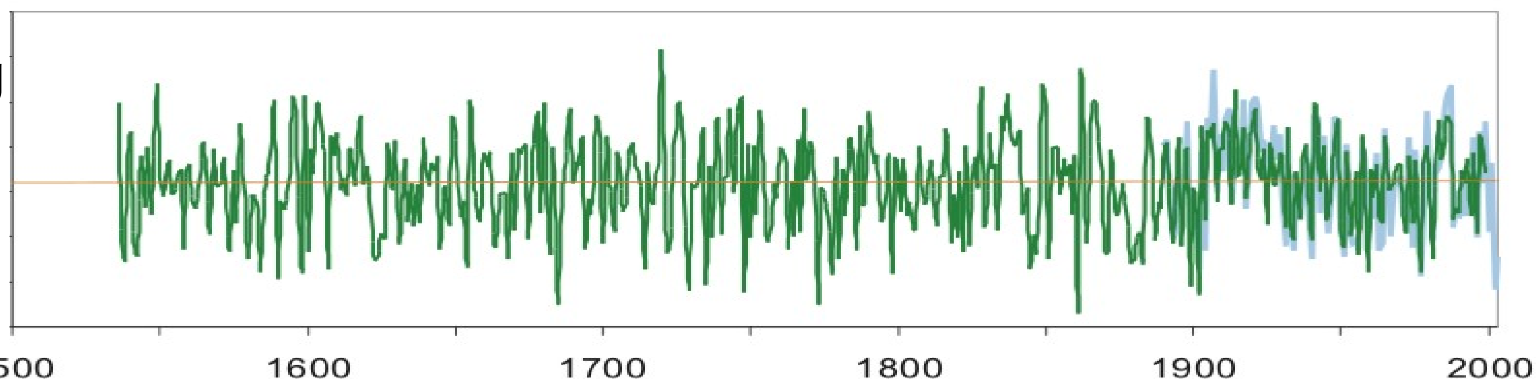
- Better assessment of *risk*

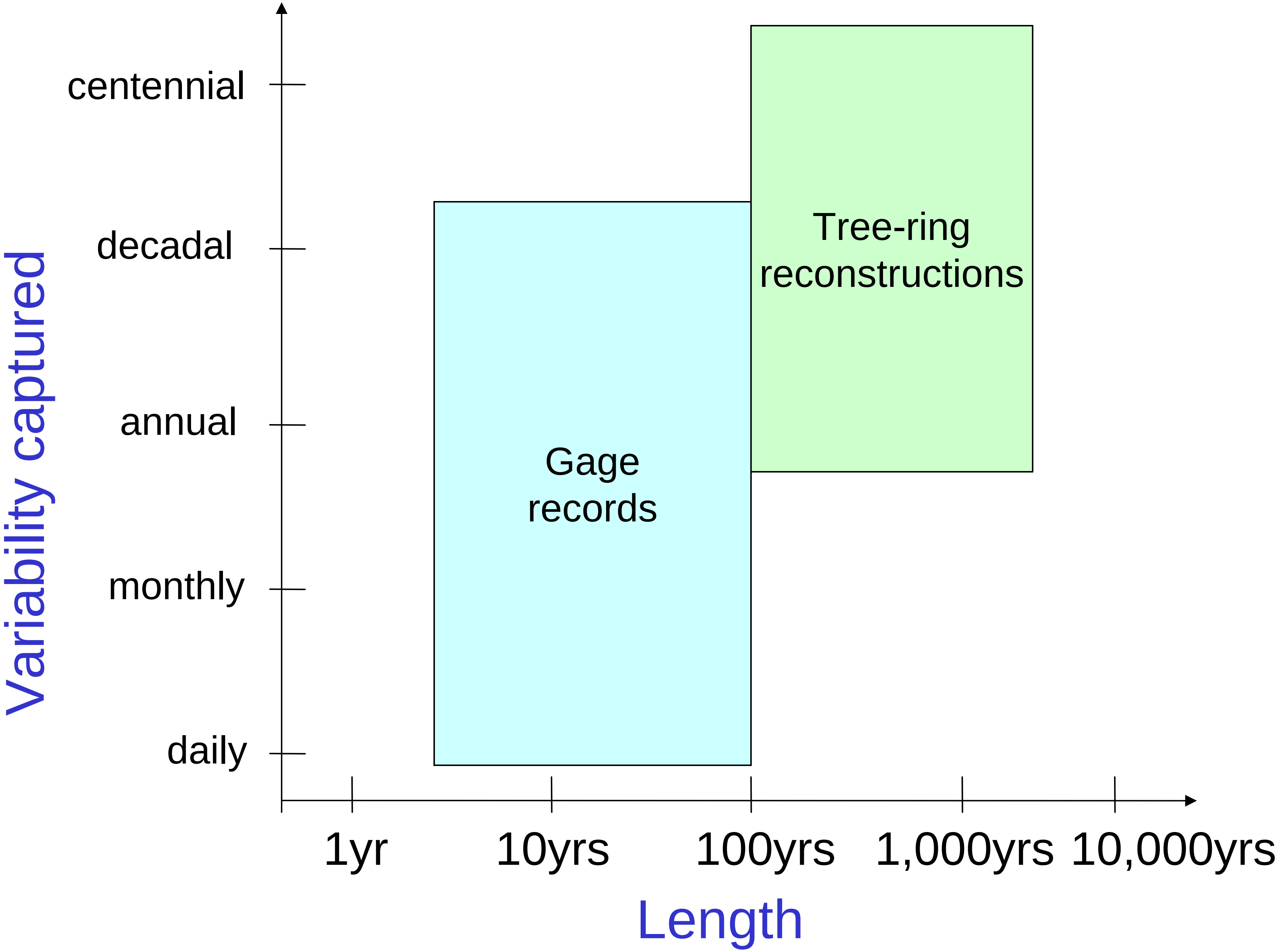
Rio Grande near Del Norte, CO

Gaged record- 118 years

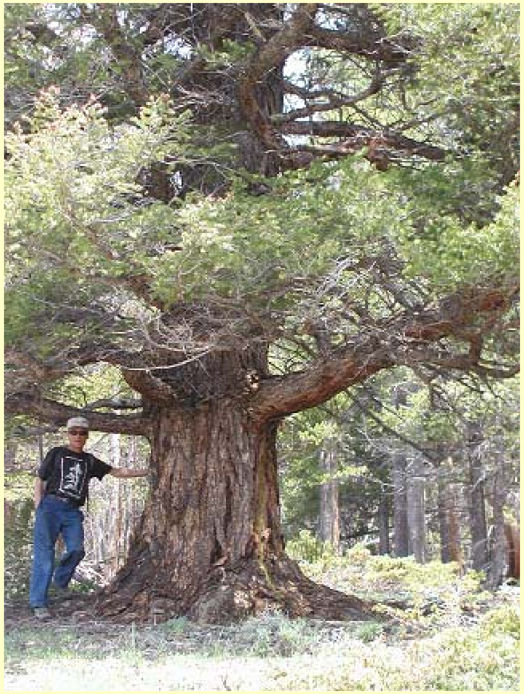


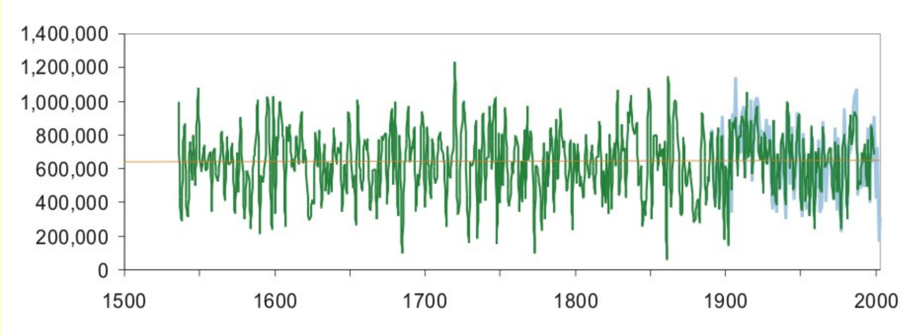
Tree-ring record - 464 years




Variability captured
centennial
decadal
annual
monthly
daily
Gage
records
Tree-ring
reconstructions
1yr
10yrs
100yrs
1,000yrs
10,000yrs
Length

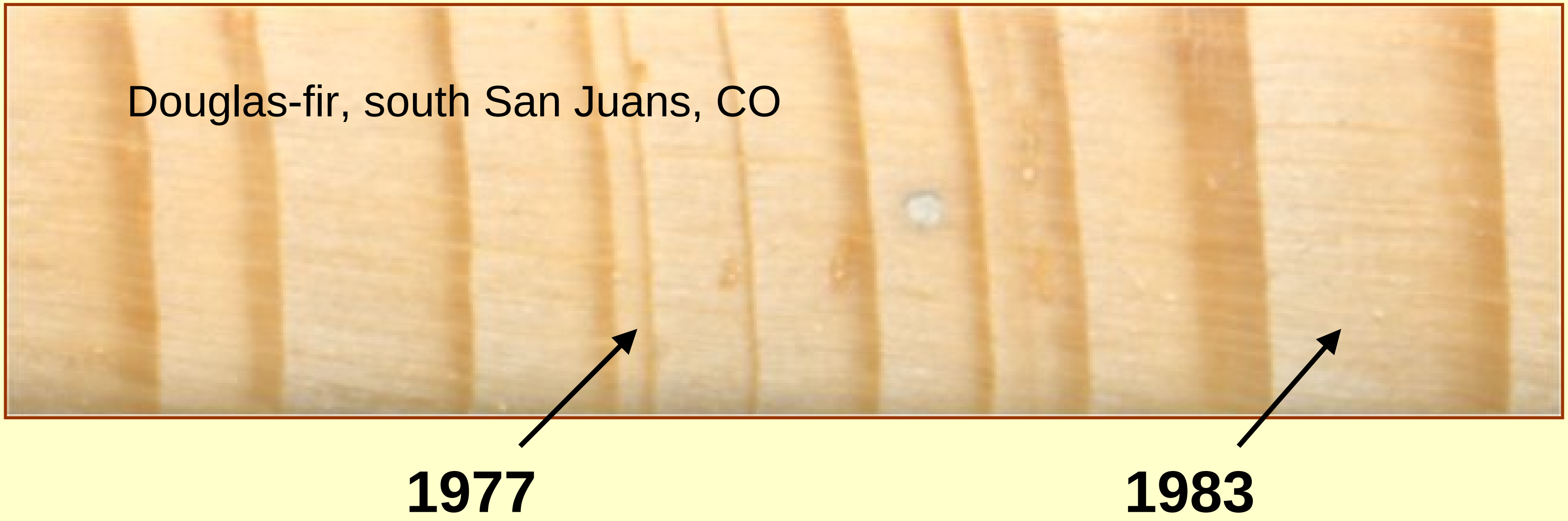
How do we develop tree-ring reconstructions of streamflow (*aka* paleohydrology)?





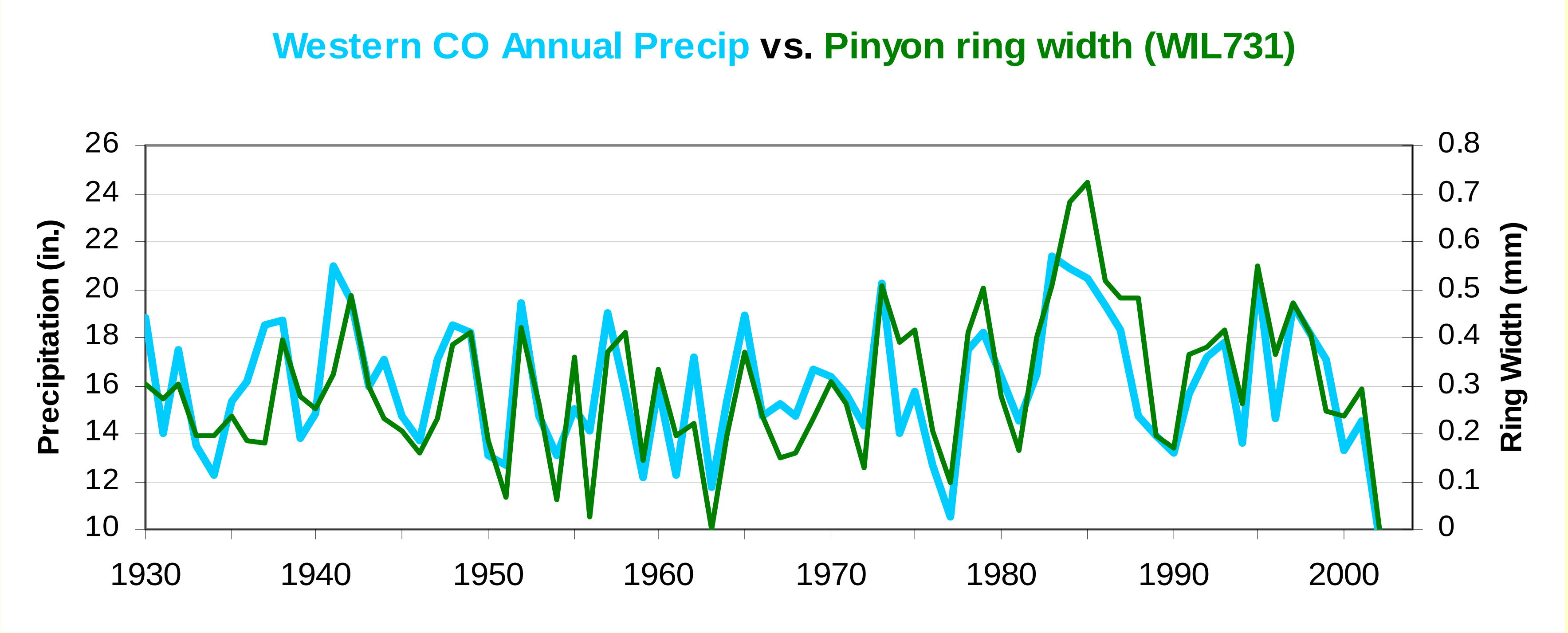
In dry climates, tree growth is limited by moisture availability

So:
– a dry year leads to a *narrow* growth ring
– a wet year leads to a *wide* growth ring



- Ring width mainly reflects precip from previous fall-winter spring = soil moisture at start of growing season

The moisture signal recorded by trees in the interior western US is particularly strong



- The "raw" ring widths from *one* tree are very closely correlated with annual basin precipitation (*r* = 0.78) from 1930-2002
- Our job is to *capture* and *enhance* the moisture signal, and reduce noise, through careful sampling, replication, and data processing

Ring-width and annual streamflow - an indirect but strong relationship

- The growth of moisture-sensitive trees responds to the same set of climatic factors that influence streamflow

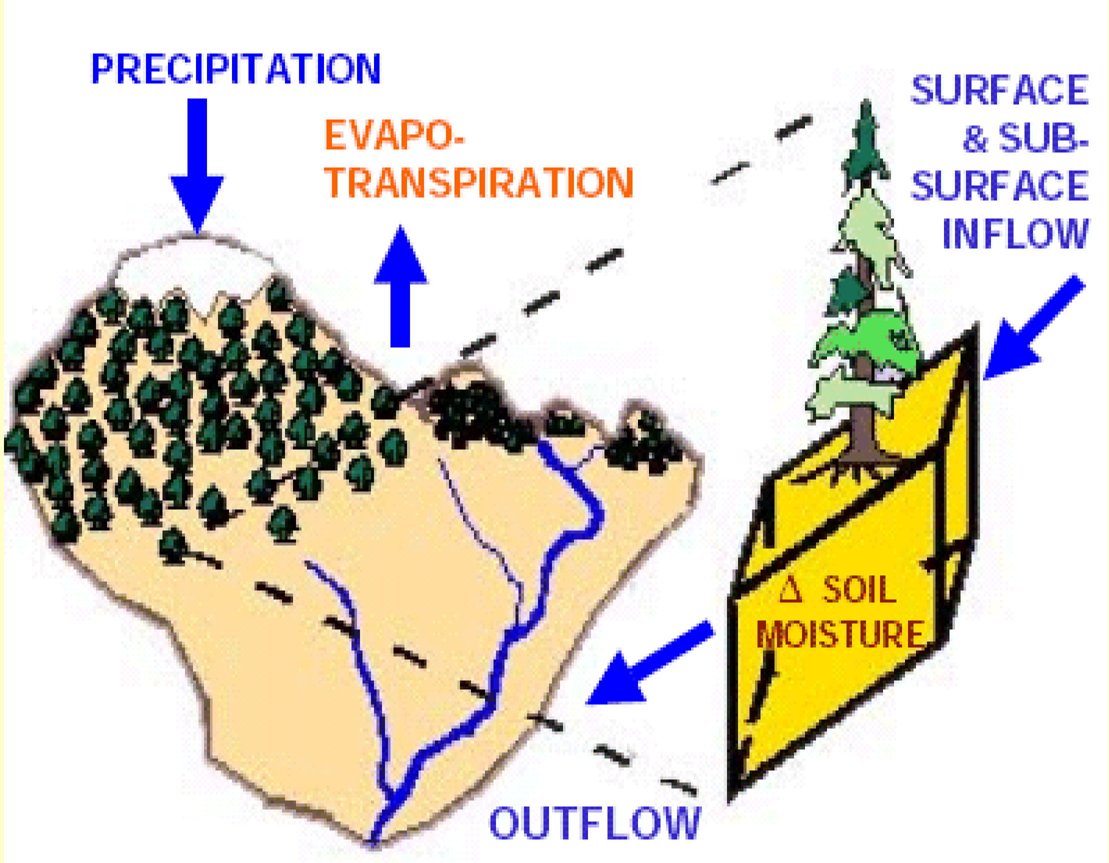
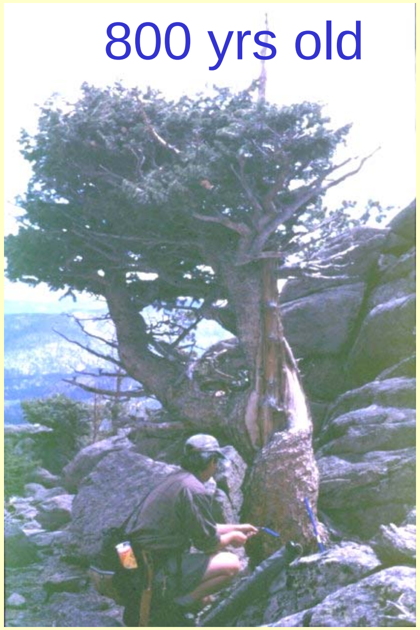


Image courtesy of Dave Meko, LTRR

Collecting moisture-sensitive tree-ring records

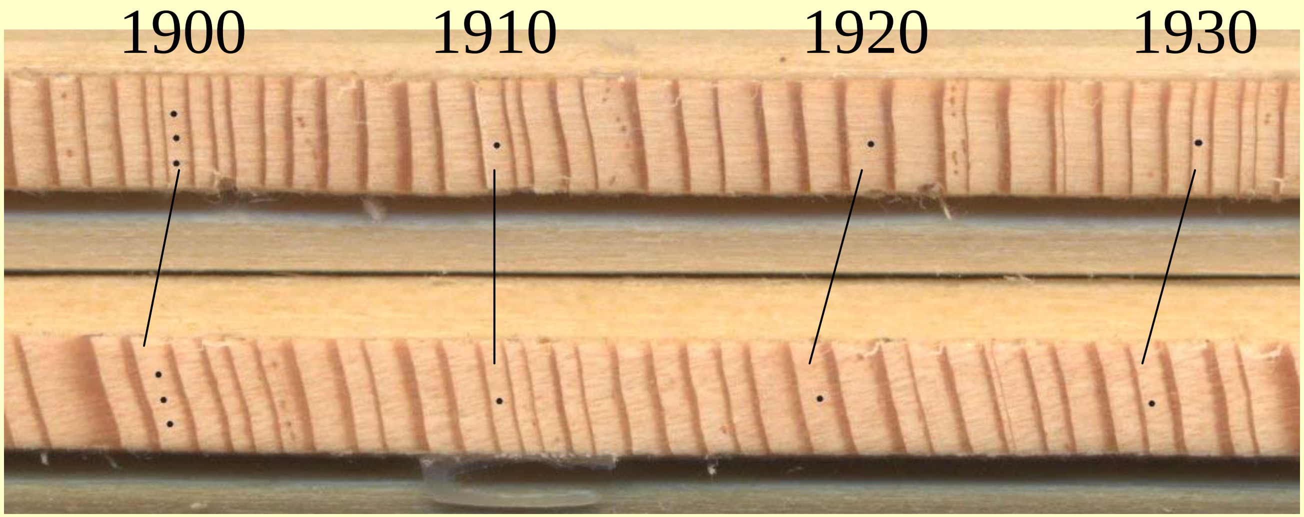
- Dry sites up to 9000’ (2750m)
- Stands of old-appearing ponderosa pine, pinyon pine, or Douglas-fir
- Collect cores from 20-30 trees (same species)



Crossdating the samples

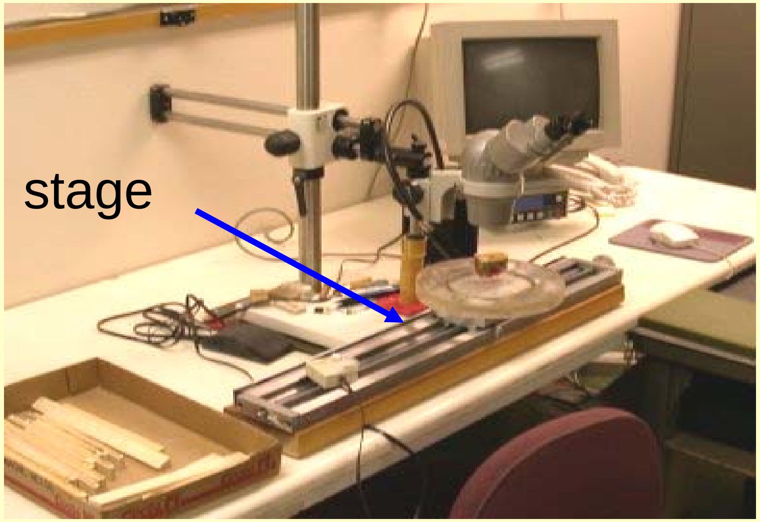
- Because of the common climate signal, the pattern of wide and narrow rings is highly replicated between trees at a site, and between nearby sites

- This allows *crossdating:* the assignment of absolute dates to annual rings

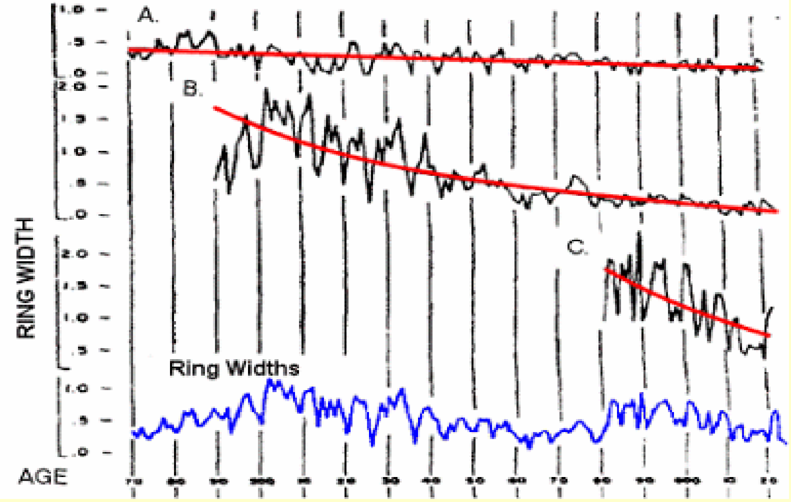


Two Douglas-fir trees south of Boulder, CO

Measuring and detrending the samples

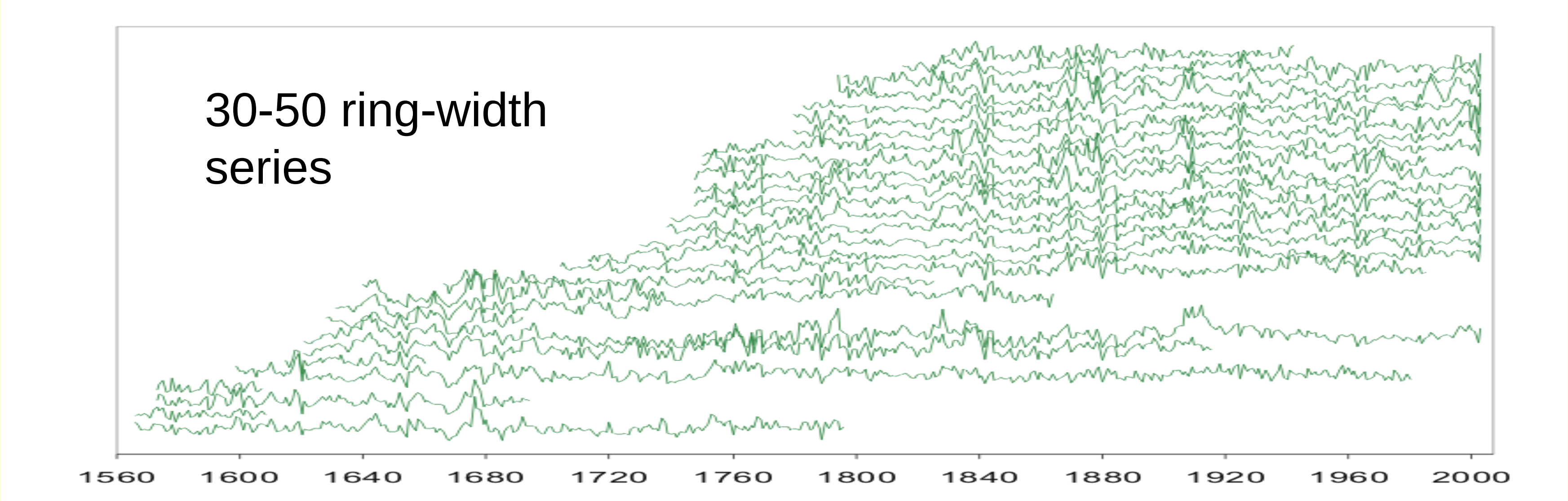


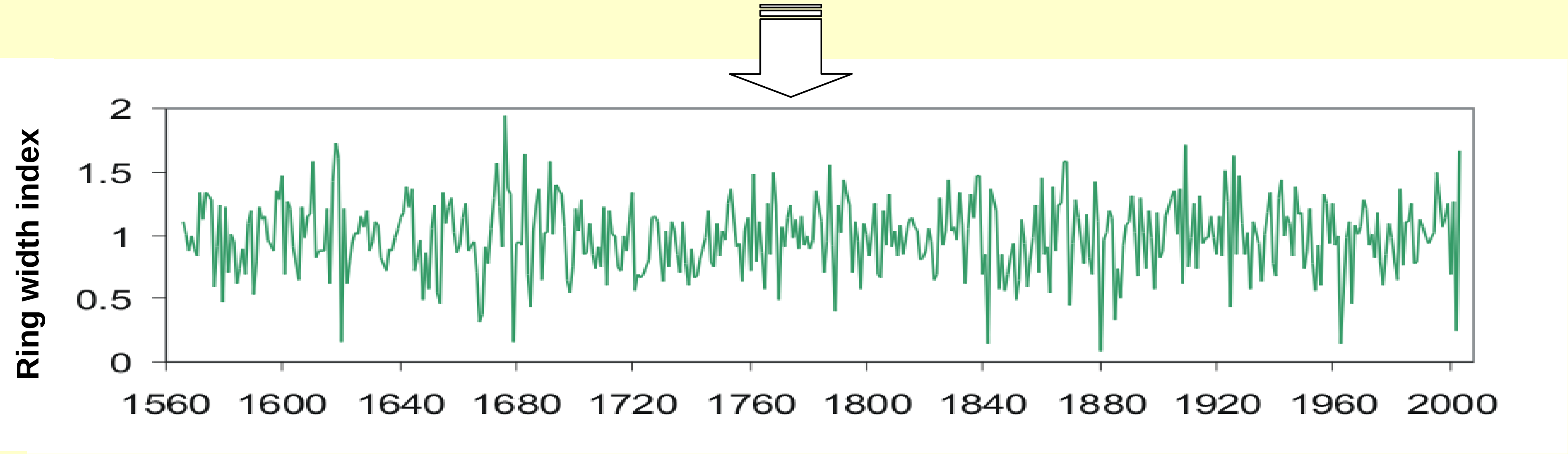
- Measure each ring with computer-assisted measurement system with sliding stage
  - captures position of core to nearest 0.001mm (1 micron)



- Ring-width series typically have a declining trend because of tree geometry
- These are low-frequency *noise* (i.e. non-climatic)
- So we *detrend* ring series are with straight line, exponential curve, or spline

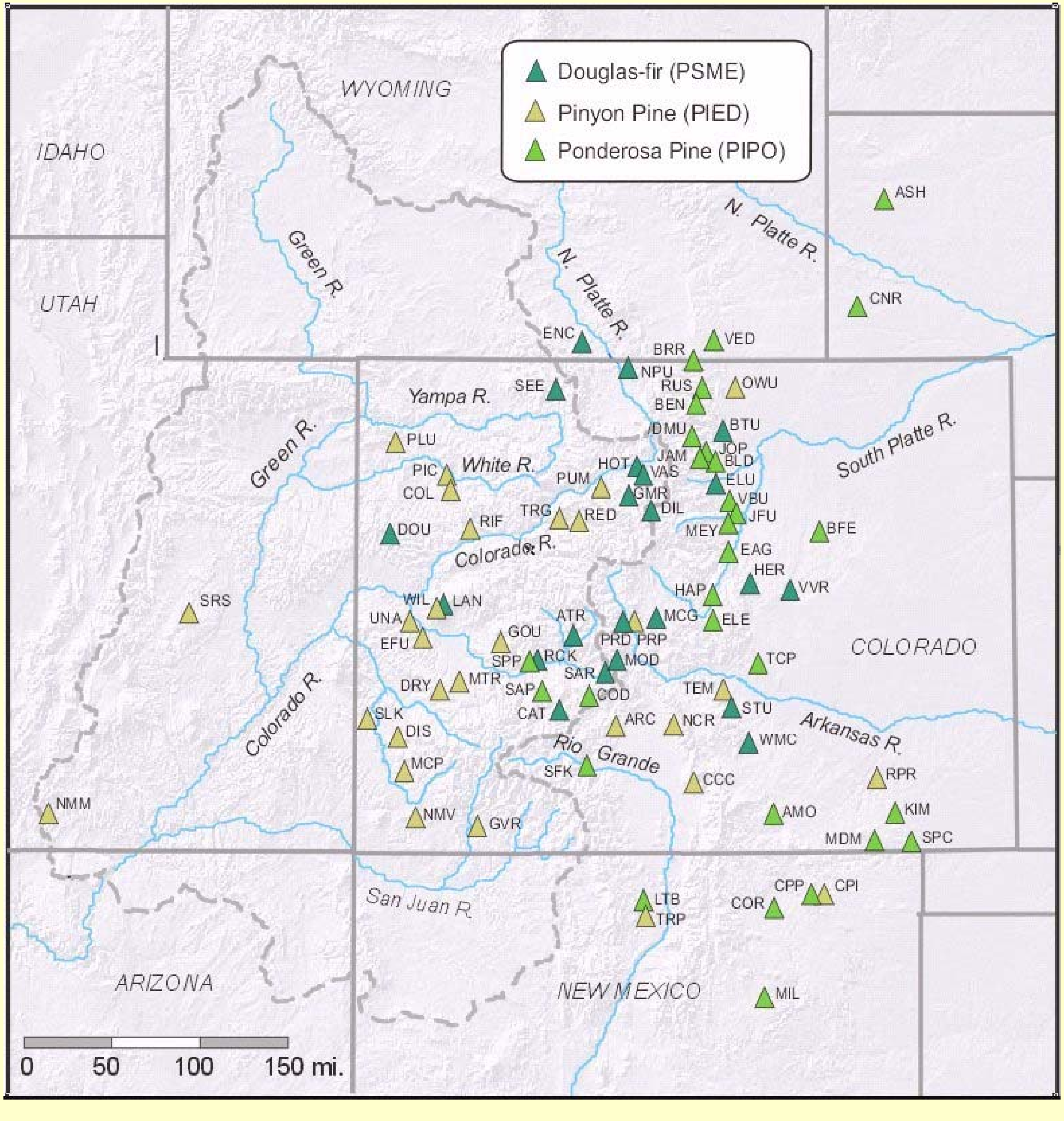
The site *chronology* is the robustly weighted average of all ring-width series for each year





Moisture-sensitive chronologies developed 2000-07 by CU - INSTAAR Dendro Lab

- Average length: 550 years (but >1000 years using dead wood)
- Strong relationships (*r*>0.5) with annual precipitation and annual streamflow



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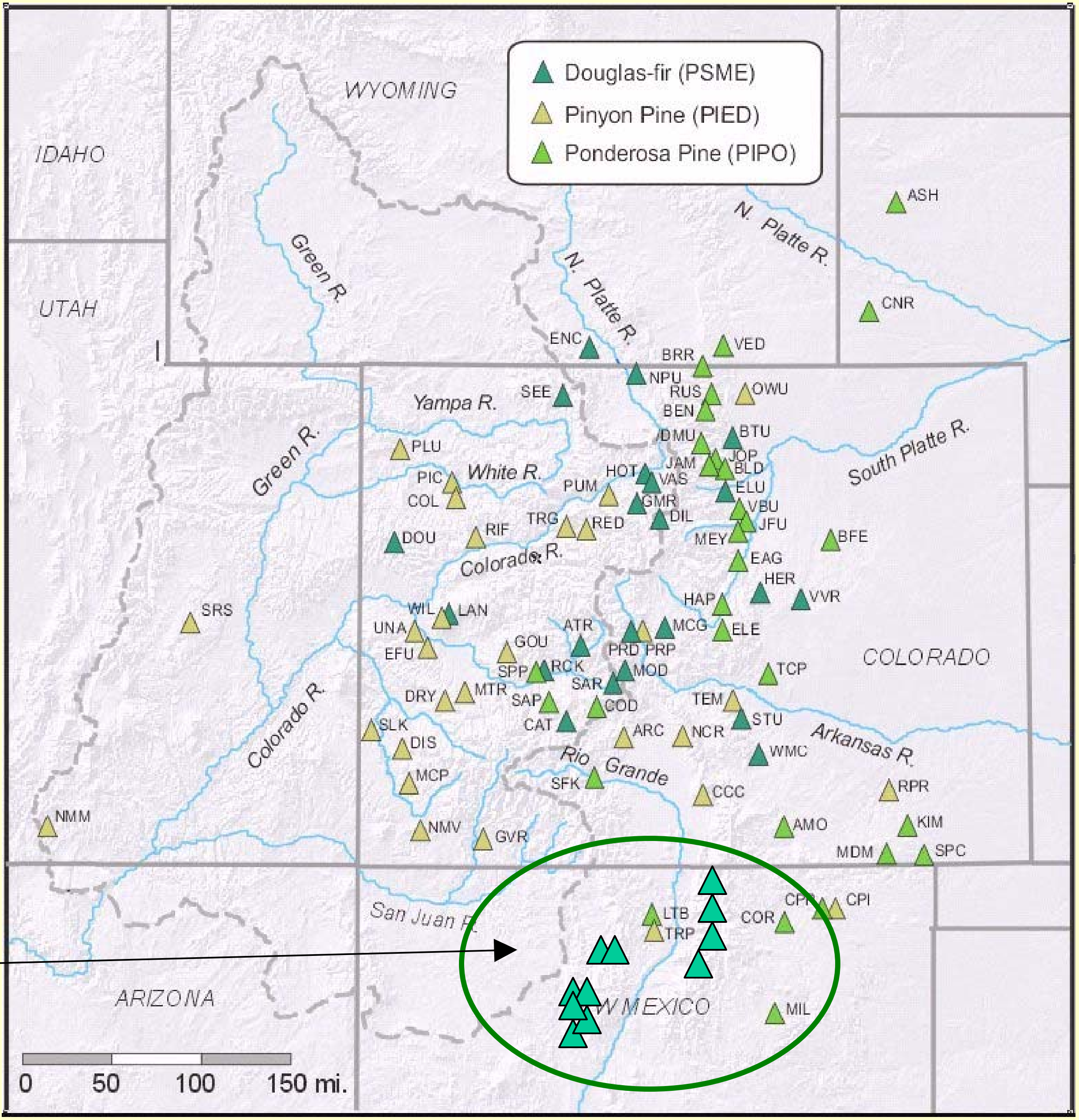
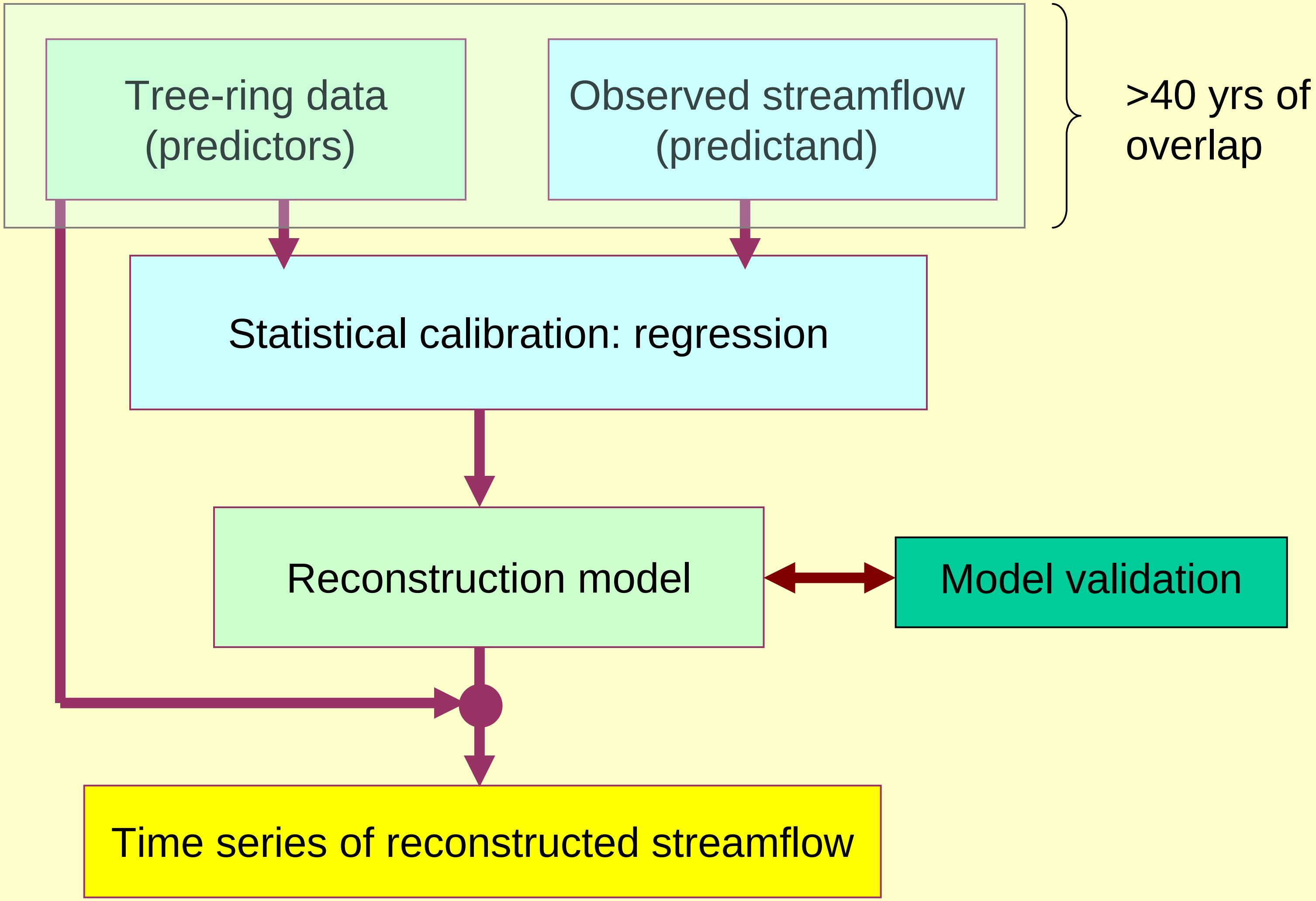
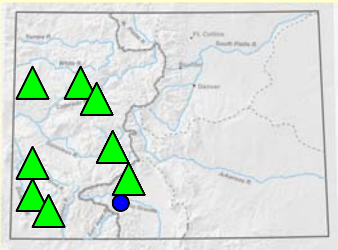
New chronologies developed 2007-08 by U. Ariz. LTRR



Overview of reconstruction methodology



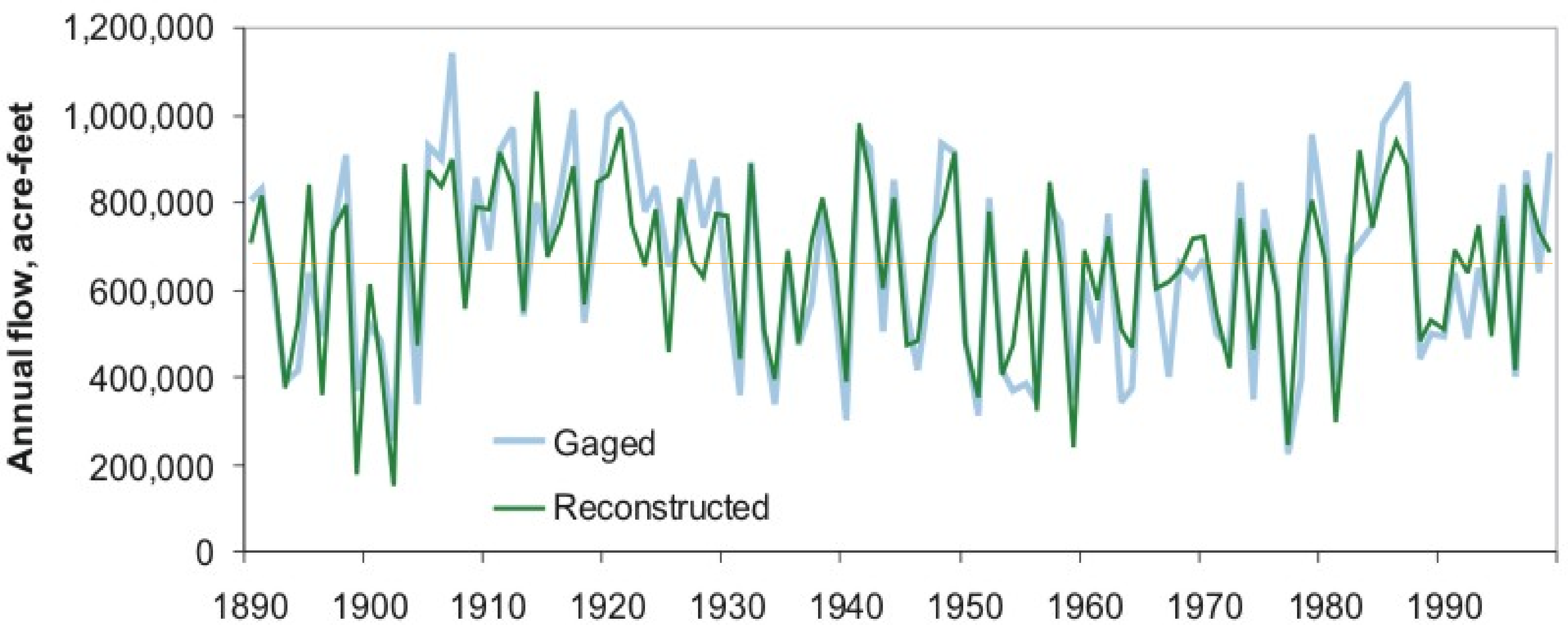
based on Meko 2005



Rio Grande near Del Norte, CO

Forward stepwise regression

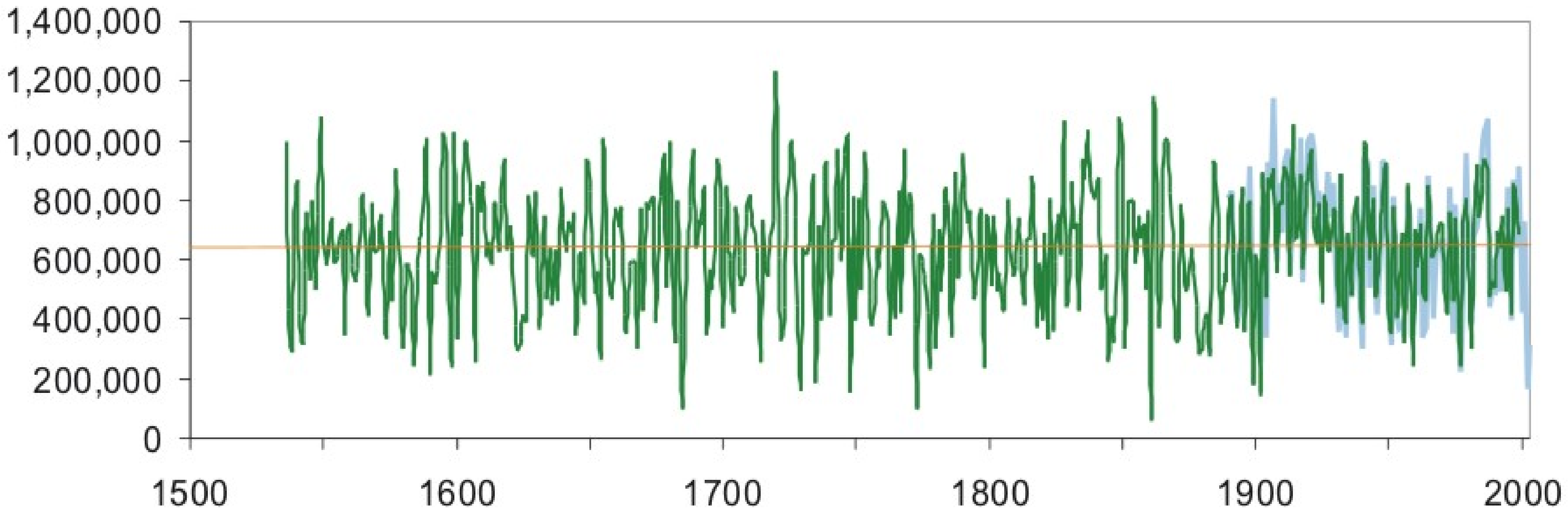
SLK + TRG + ARC + RED + CAT + DRY + MCP + DOU



Calibration: $R2 = 0.76$

Validation: Reduction of error (RE) = 0.74

Full reconstruction of Rio Grande annual streamflow, 1536-1999



- Generally, greater year-to-year variability before 1900
- Also, more extreme high and low flows before 1900

Uncertainty in the reconstructions (the “fine print”)

- 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) and used to generate confidence intervals

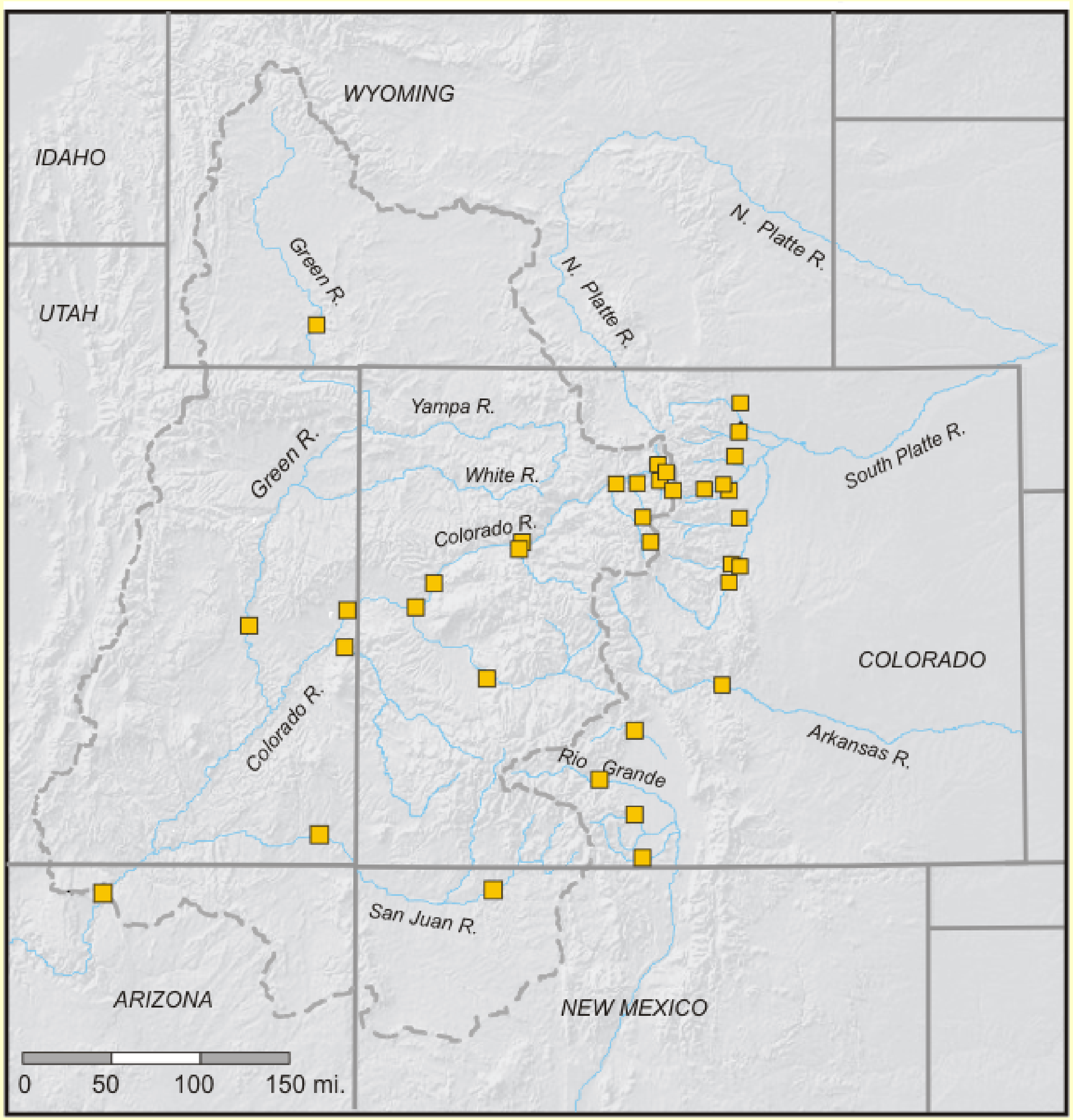
- RMSE does not capture the uncertainty resulting from the sensitivity of model output to the choices made in the treatment of the tree-ring data and development of the model

- A reconstruction is a *best estimate* of past streamflows, and each annual point represents the central tendency of a range of plausible values, given the uncertainty

Gage records (■) reconstructed 2002-2007 using our tree-ring chronologies

- Over 30 reconstructions, developed using observed records from partners

- 350-700 years long, except new Lees Ferry (1250 years)



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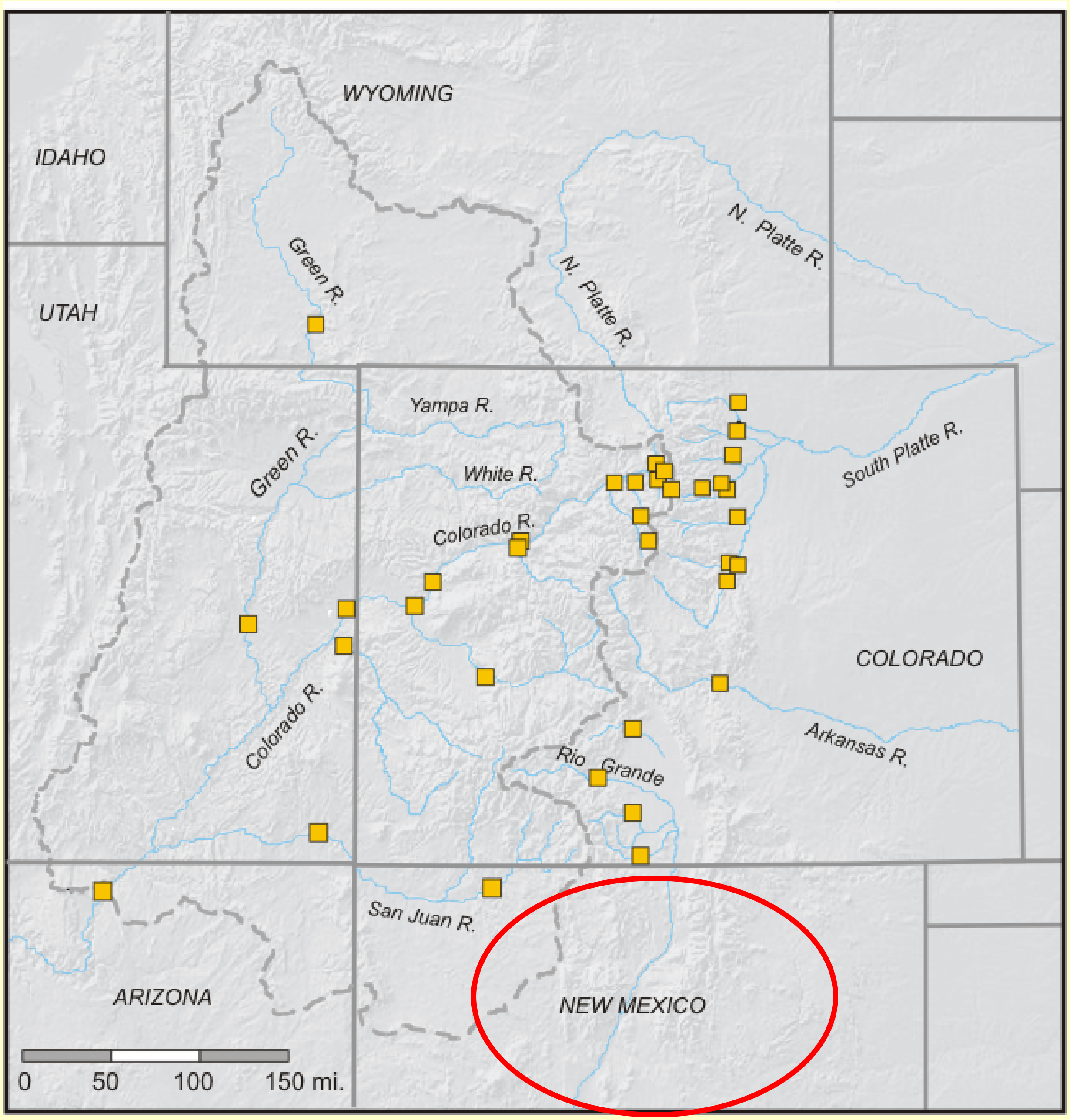


WWA - CLIMAS project:
Tree-Ring Reconstructions of Hydroclimatic Variability in the Rio Grande Basin, New Mexico

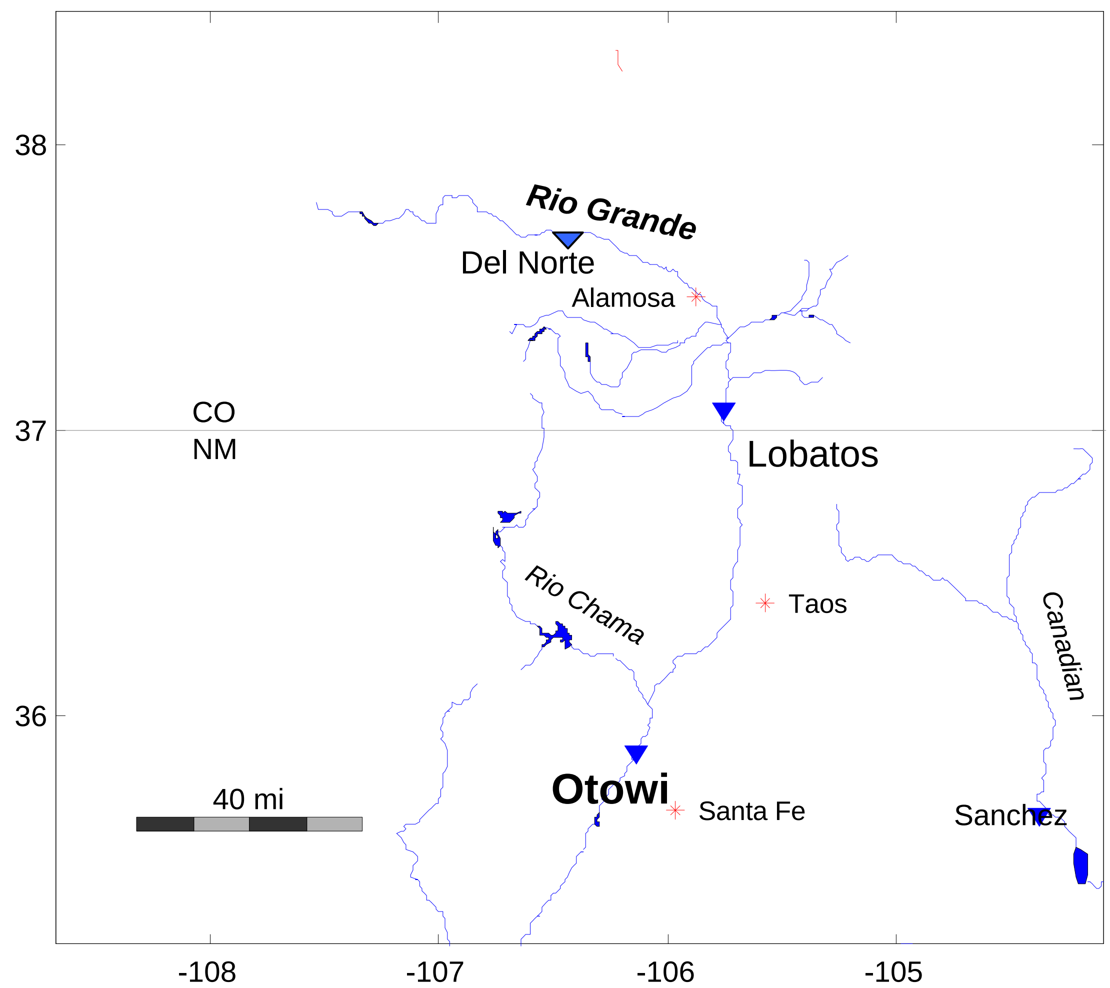
1) Workshop (November 2007) to introduce the use of tree-ring reconstructions of streamflow, and identify gages of interest

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

3) Follow-up workshop (last Friday) to deliver new reconstructions, explore applications, and plan future collaborative work

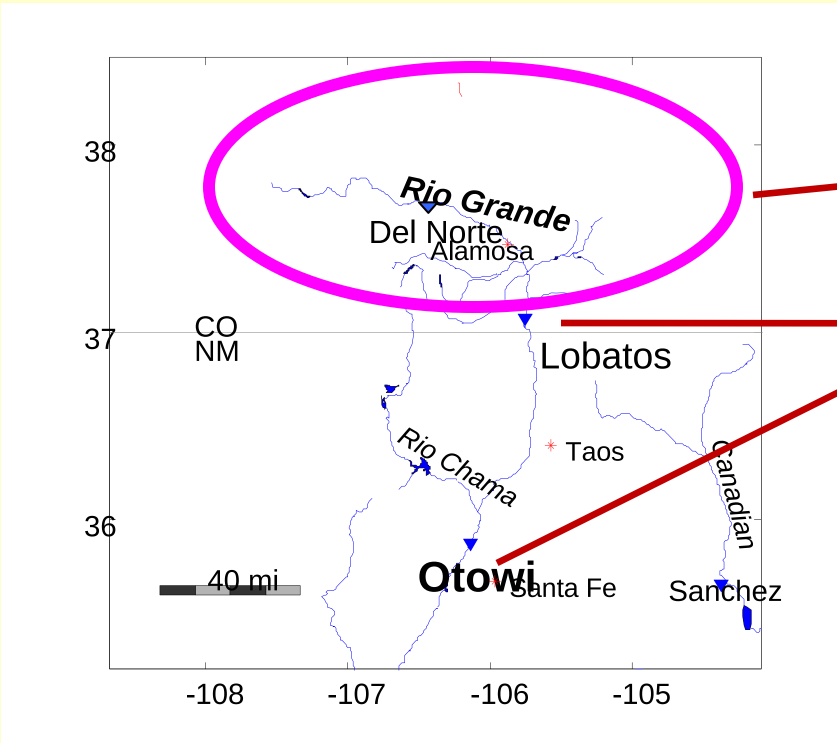
4) Develop web page to feature Rio Grande reconstructions

Upper Rio Grande basin



Map courtesy of Dave Meko, LTRR

Estimation of Otowi natural flows



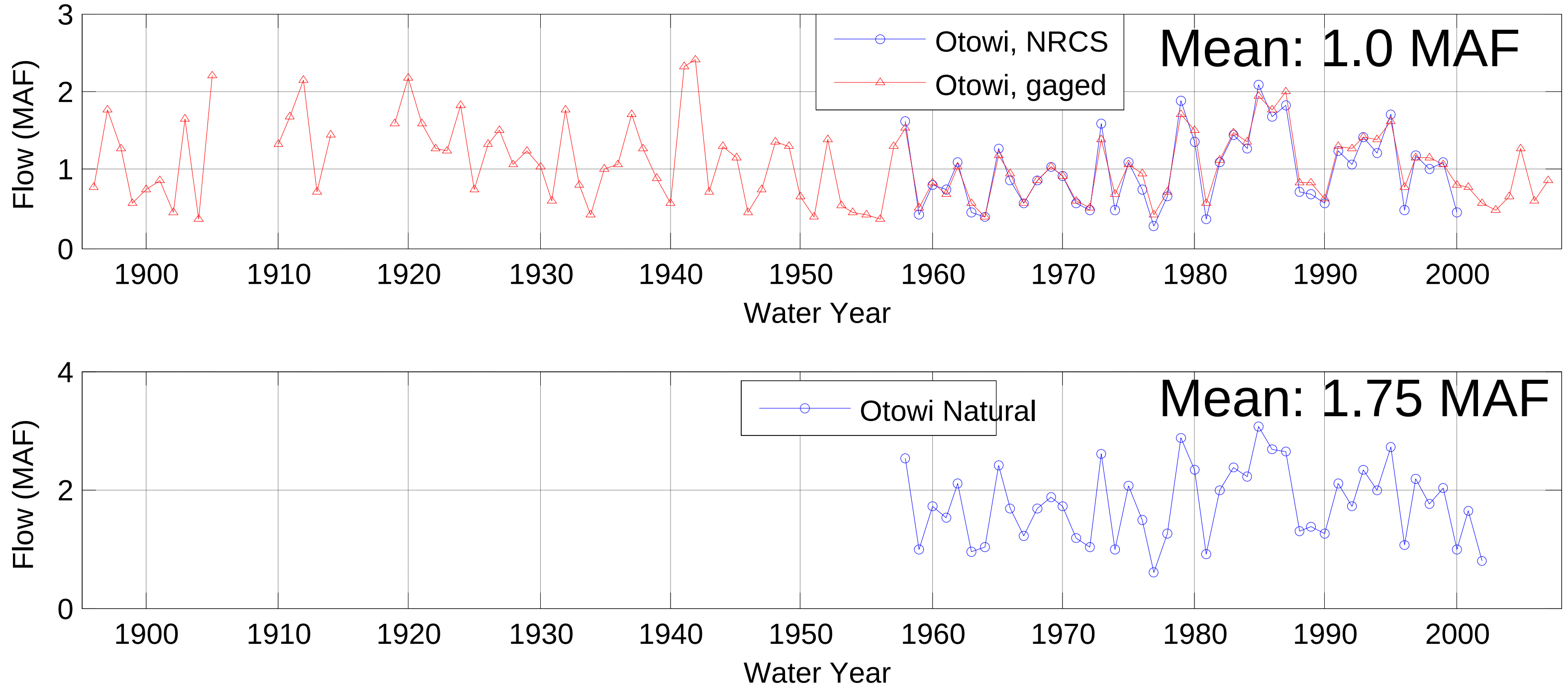
$Q_1 =$ sum of flow at 10 gages in Colorado

$$\Delta Q = Q_{OTO} - Q_{Lobatos}$$

$$I = Q_1 + \Delta Q$$

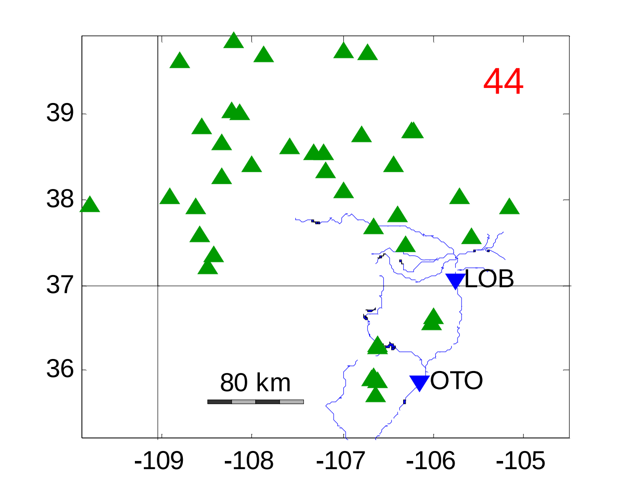
- Q_{OTO} is NRCS
- $Q_{lobatos}$ is gaged

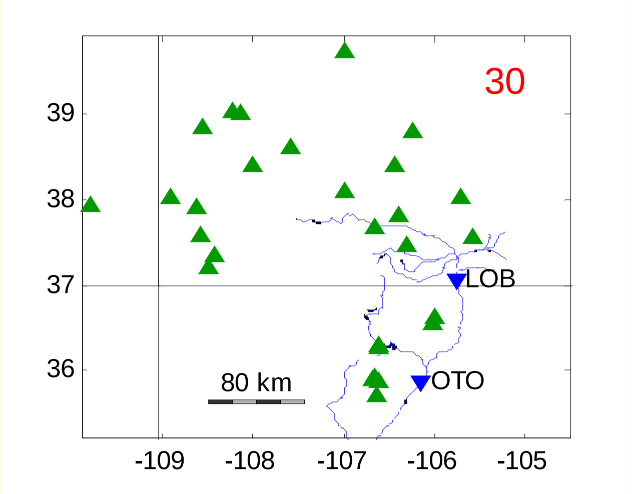
Otowi Natural – comparison w/ Otowi Gaged

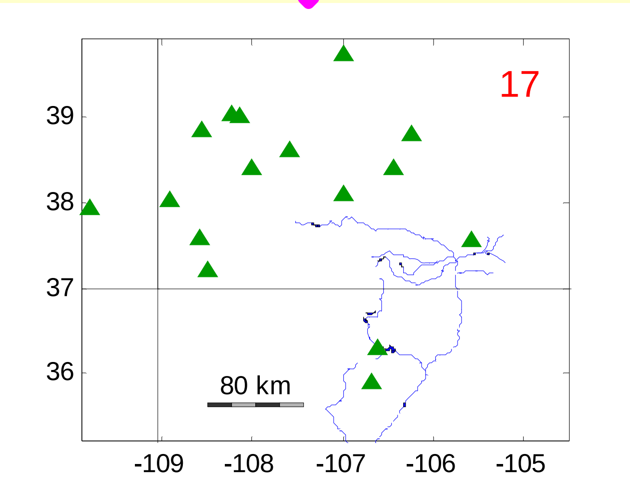


- Correlation Otowi NRCS – Otowi Natural: 0.985 – so essentially identical records, but different scaling

Tree-ring network – Otowi natural flow reconstruction

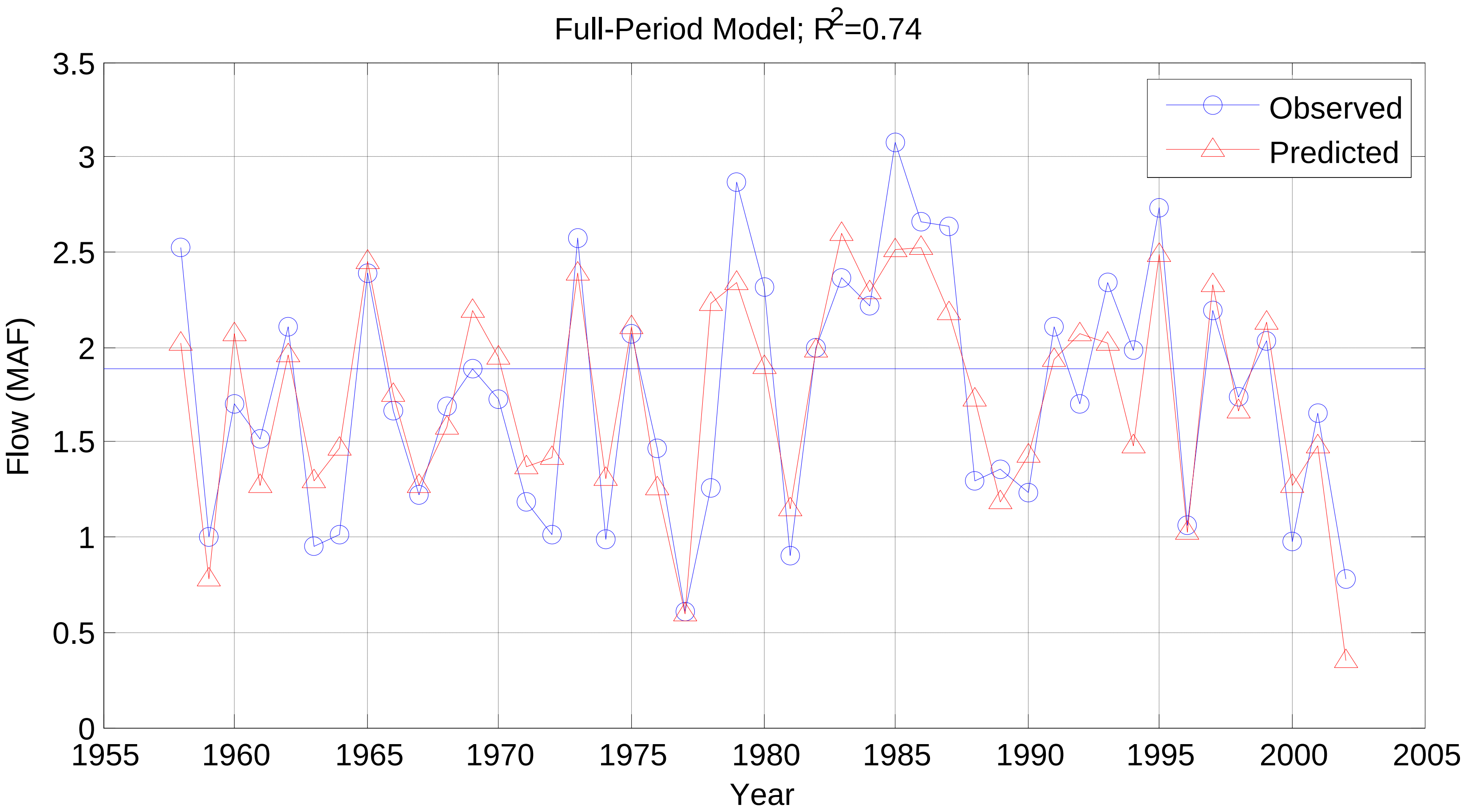






- 44 initial chronologies
- 30 complete through year 2002
- 17 complete 1450-2002
- (Same network also used in reconstruction of Otowi NRCS)
- Mean of 17 chronologies used as single predictor in linear regression

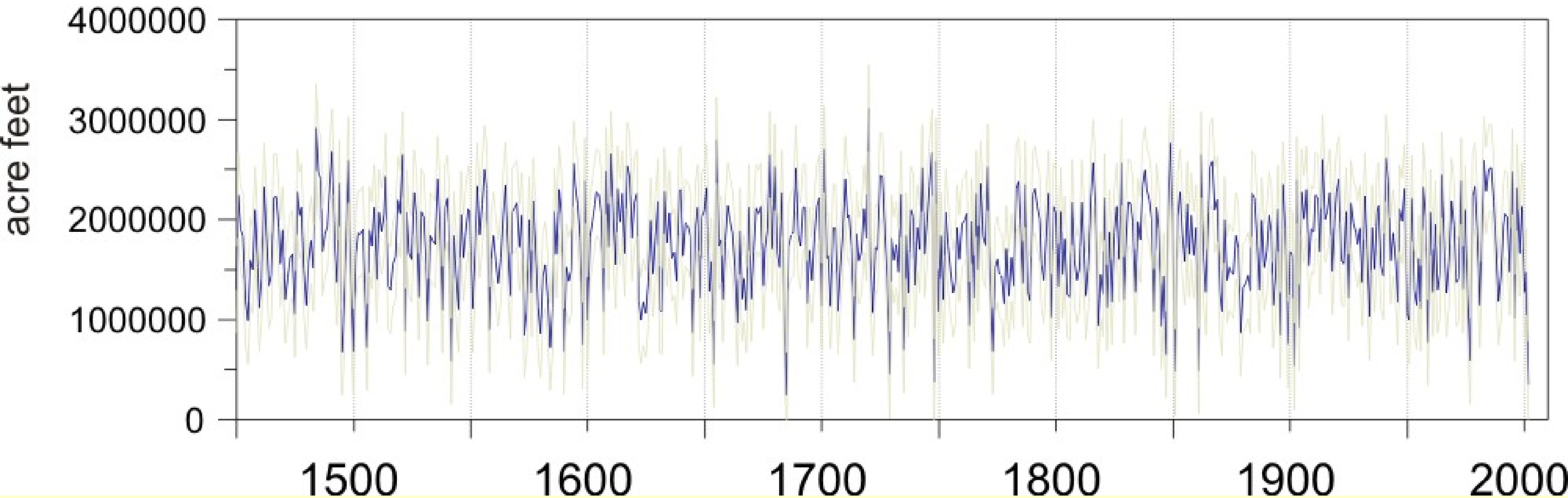
Reconstruction Accuracy



Calibration: R2 = 0.74

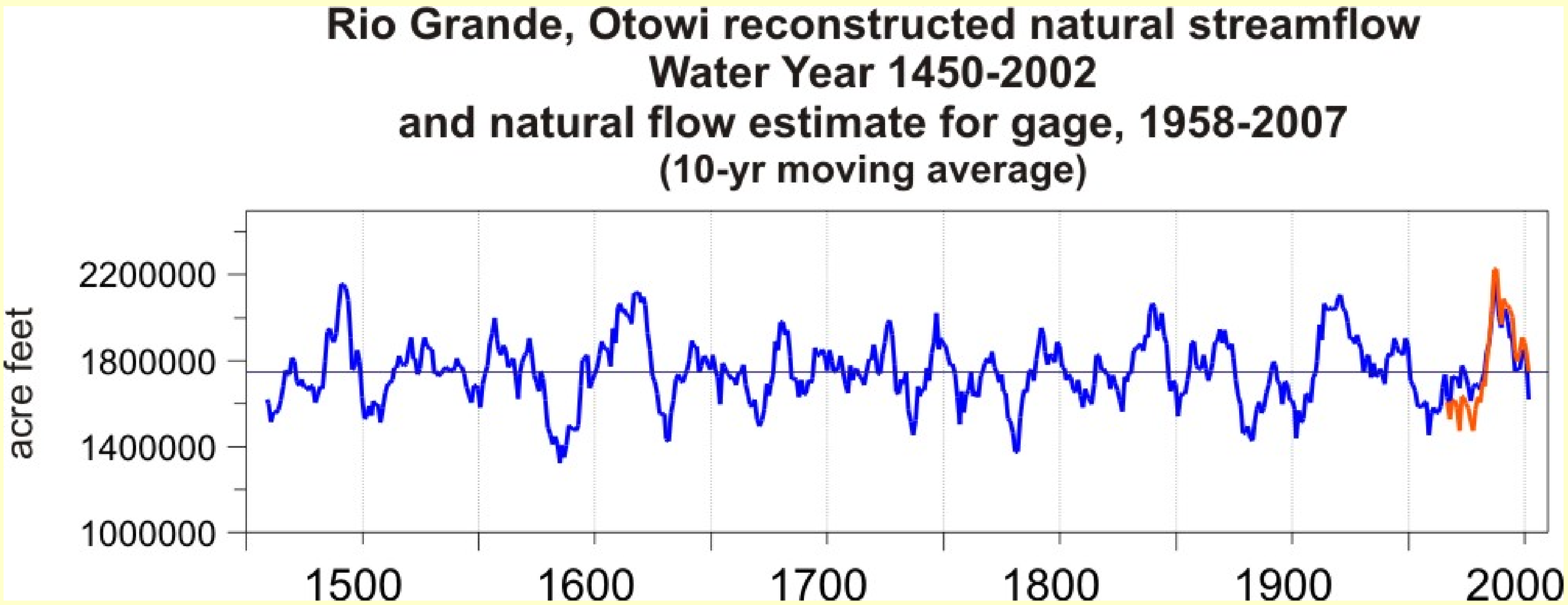
Validation: Reduction of error (RE) = 0.72

Otowi Reconstructed Natural Streamflow, Water Year 1450-2002
with 80% confidence interval (gray lines)



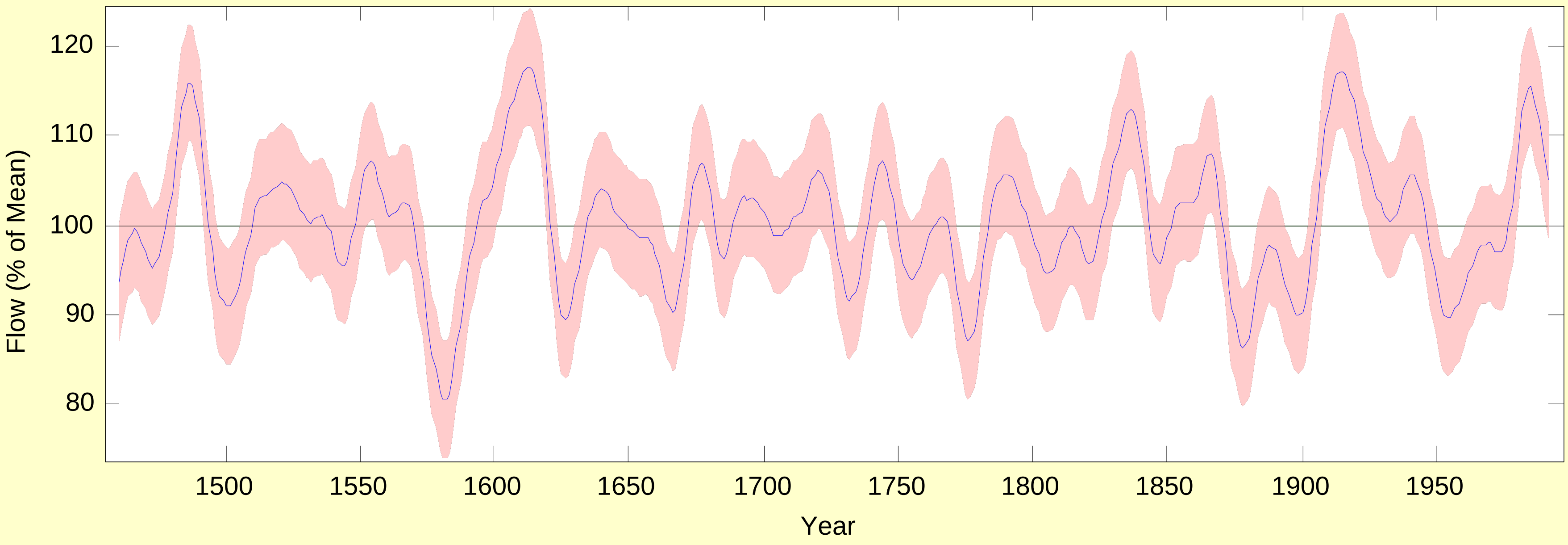
Driest year	% of long-term mean		Wettest year	% of long-term mean
1685	14		1720	178
2002	20		1484	167
1748	22		1655	160
1729	26		1849	158
1851	27		1701	155

*** 1977, driest in the gage record, is 10th, 34%**



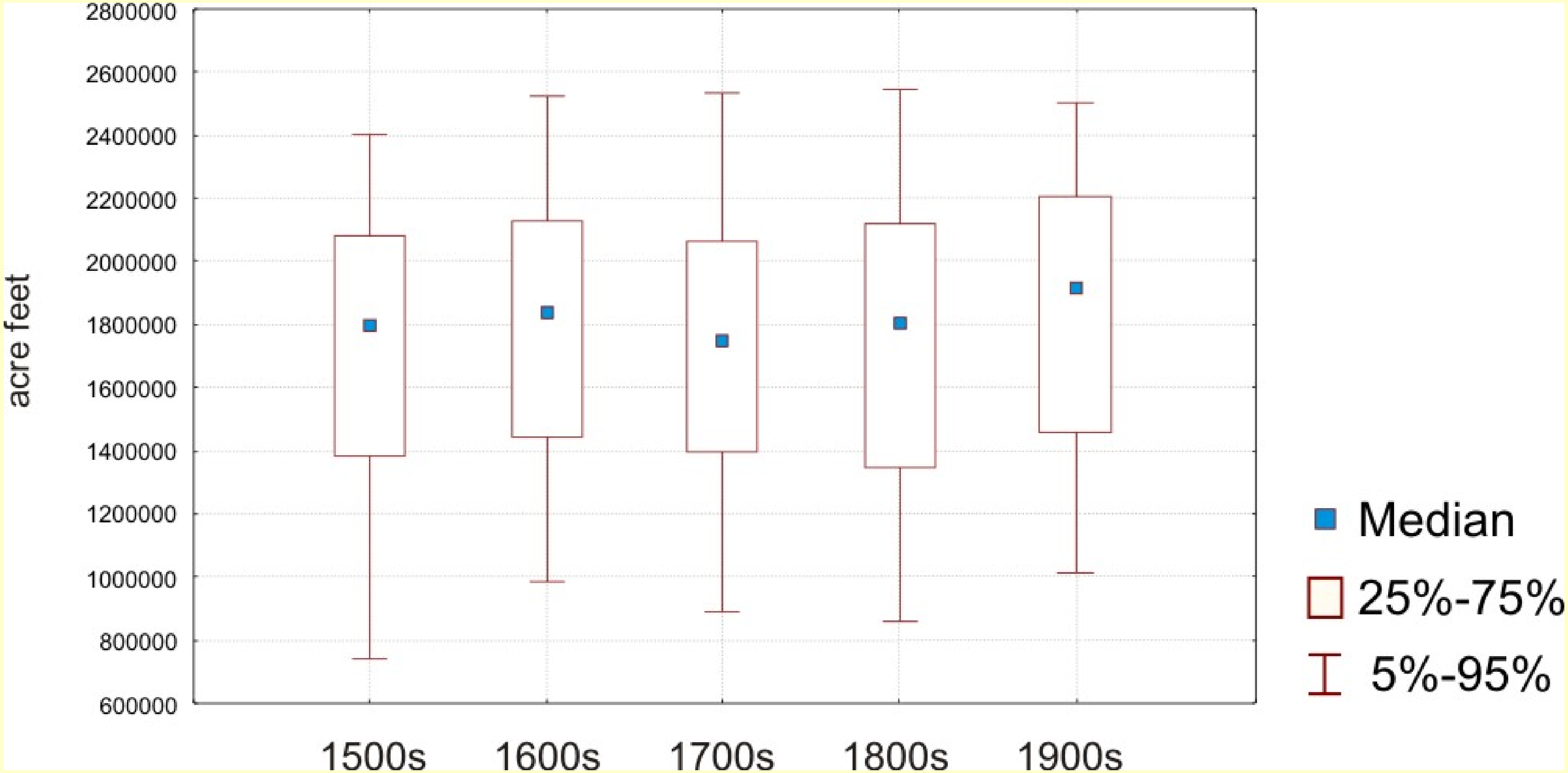
5 Driest Decades	5 Wettest Decades
1576-1585	1978-1987
1772-1781	1482-1491
1623-1632	1610-1619
1874-1883	1912-1921
1893-1902	1831-1840
1950-1959	

Otowi reconstructed natural flow, decadal-scale variability (gaussian smoothing) with 80% confidence band



- Uncertainty at 80% CI, for this smoothing, is about ±5 percent of the long-term mean
- More confidence in the *timing* of anomalies than in specific magnitudes

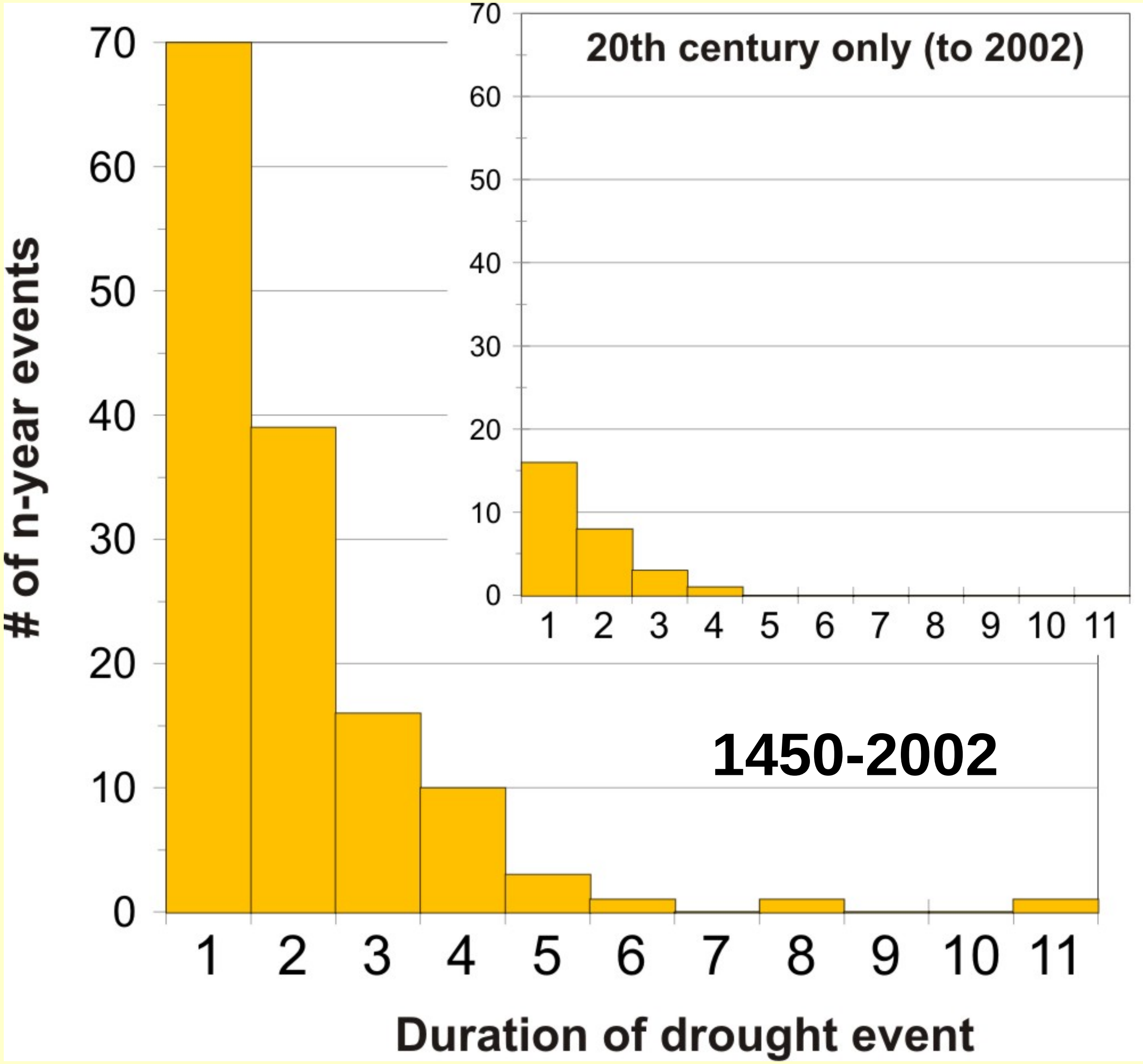
Otowi natural flow reconstruction, distribution of annual flows by century



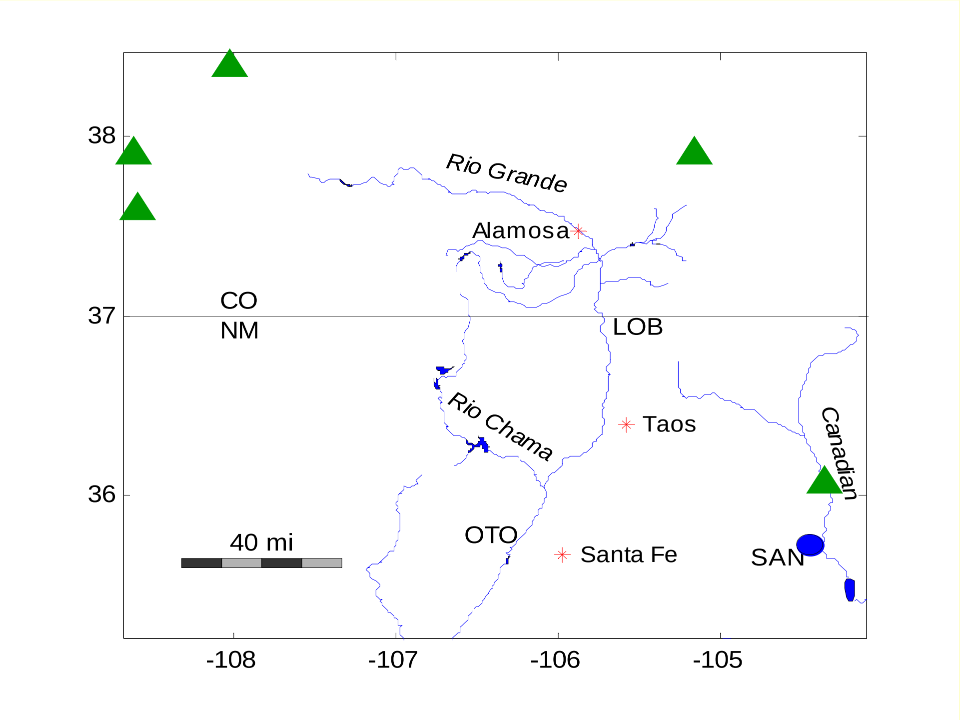
Non-stationarity at century time scales

Drought Duration and Frequency, Otowi

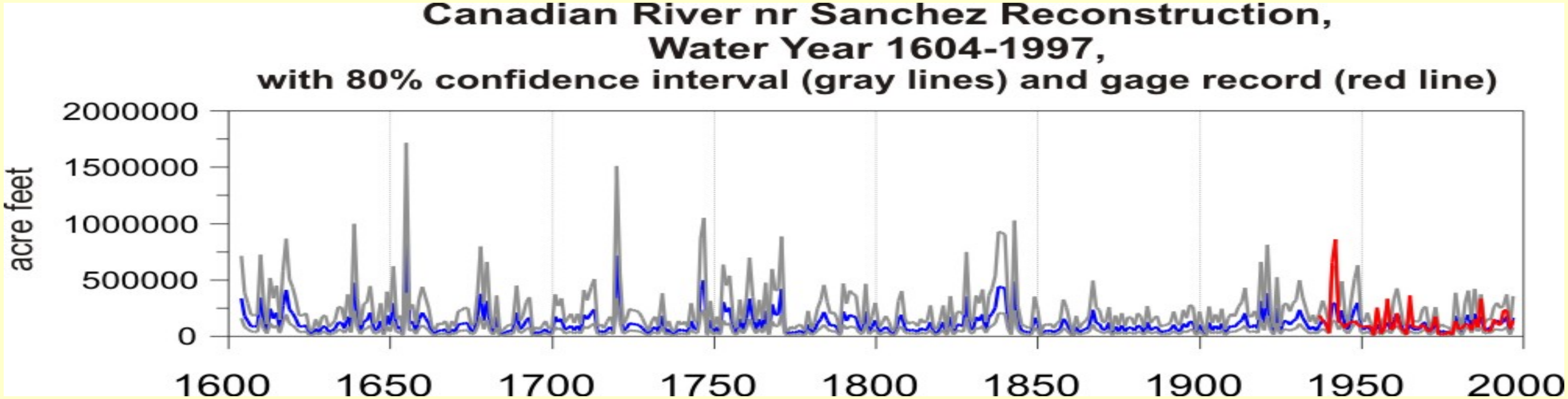
Drought is defined as a single year or set of n consecutive years below the long-term median



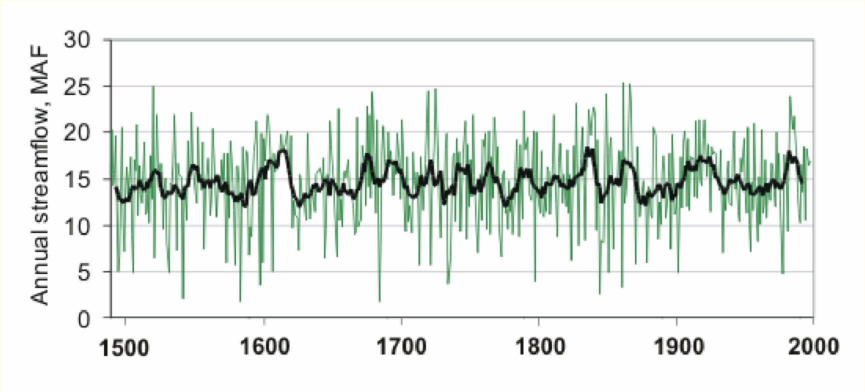
Canadian River flow reconstruction



- Log transformation of flows
- 5-predictor model, selected forward stepwise
- Variance explained = 61%



How can reconstructions of streamflow can be used in water management?



Reconstruction data

?

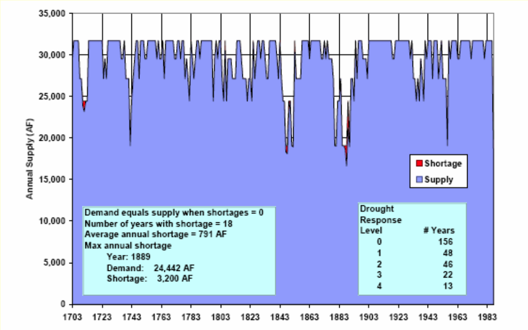


Figure 5. Demands & Supplies: 15% Reduced Flow Hydrology, Current Trends Scenario (demand = 31,700 AF/year).

Decision support

Using the reconstructions - two degrees of difficulty

1) Provide long-term context for the gage record

- *can be qualitative (graphics + text) or quantitative*

2) Input into a system model to assess management scenarios

- *requires further processing of the reconstruction data*
- *can lead to more effective communication of risk*

Denver Water - water supply yield analyses

Challenge:

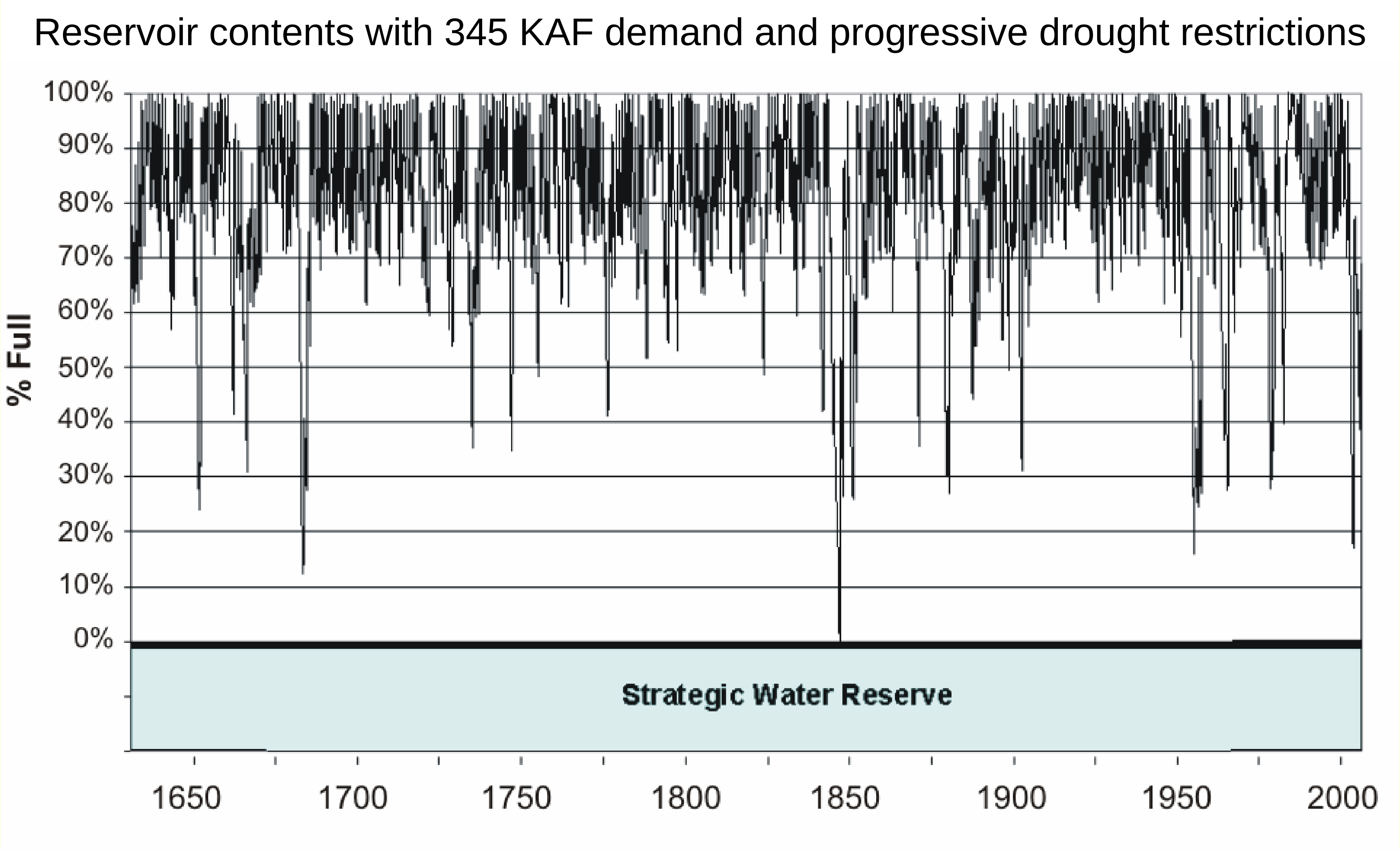
Denver Water's Platte and Colorado Simulation Model (PACSM) requires daily model input from 450 locations

Solution:

An "analogue year" approach

- Match each year in the reconstructed flows with one of the 45 model years (1947-1991) with known hydrology and use that year's daily hydrology
- Years with more extreme wet/dry values are scaled accordingly
- Data are assembled as new sequences of model years
- PACSM is used to simulate the entire tree-ring period, 1634-2002

Denver Water - water supply yield analyses



- Two paleo-droughts (1680s, 1840s) deplete contents lower than 1950s design drought

Applications of paleo-data in the Rio Grande Basin

NMISC - S. S. Papadopulos (MacClune, Llewellyn, Hathaway):

Used middle Rio Grande PDSI reconstruction to assess recurrence, duration, and extreme 20th century wet and dry events in a long-term context), and then to generate synthetic hydrologies representative of long-term conditions to run in URGWOM

NMISC - AMEC Engineering

Will use non-parametric KNN approach to use tree-ring data to generate sets of daily model input to run in the URGWOM model

City of Santa Fe – U. Arizona LTRR

Will develop new tree-ring chronologies and tree-ring reconstructions of streamflow for the Santa Fe River to run in the City's water supply model

OK, so paleo provides a bigger window on past hydrology, but what about the future?

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L22708, doi:10.1029/2007GL031764, 2007

Warming may create substantial water supply shortages in the Colorado River basin

Gregory J. McCabe[1] and David M. Wolock[2]

Received 21 August 2007; revised 19 October 2007; accepted 25 October 2007; published 27 November 2007.

[1] The high demand for water, the recent multiyear drought (1999–2007), and projections of global warming have raised questions about the long-term sustainability of water supply in the southwestern United States. In this study, the potential effects of specific levels of atmospheric warming on water-year streamflow in the Colorado River basin are evaluated using a water-balance model, and the results are analyzed within the context of a multi-century tree-ring reconstruction (1490–1998) of streamflow for the basin. The results indicate that if future warming occurs in the basin and is not accompanied by increased precipitation, then the basin is likely to experience periods of water supply shortages more severe than those inferred from the long-term historical tree-ring reconstruction. Furthermore, the modeling results suggest that future warming would increase the likelihood of failure to meet the water

substantially since the Compact was written [*Diaz and Anderson*, 1995].

[4] The long-term sustainability of the water-supply system in the Colorado River basin will be affected by the future levels of natural flows that replenish the reservoirs. One approach to defining future expectations of flow is to "reconstruct" historical long-term flow estimates from tree rings [*Woodhouse et al.*, 2006]. This long-term historical context provides an indication of flow conditions that have occurred in the past and may occur in the future. A contrasting approach to predicting future flow conditions in the Colorado River basin is based on climate model simulations. *Christensen and Lettenmaier* [2006], for example, report 8% to 11% reductions in UCRB runoff by the end of the 21st century.

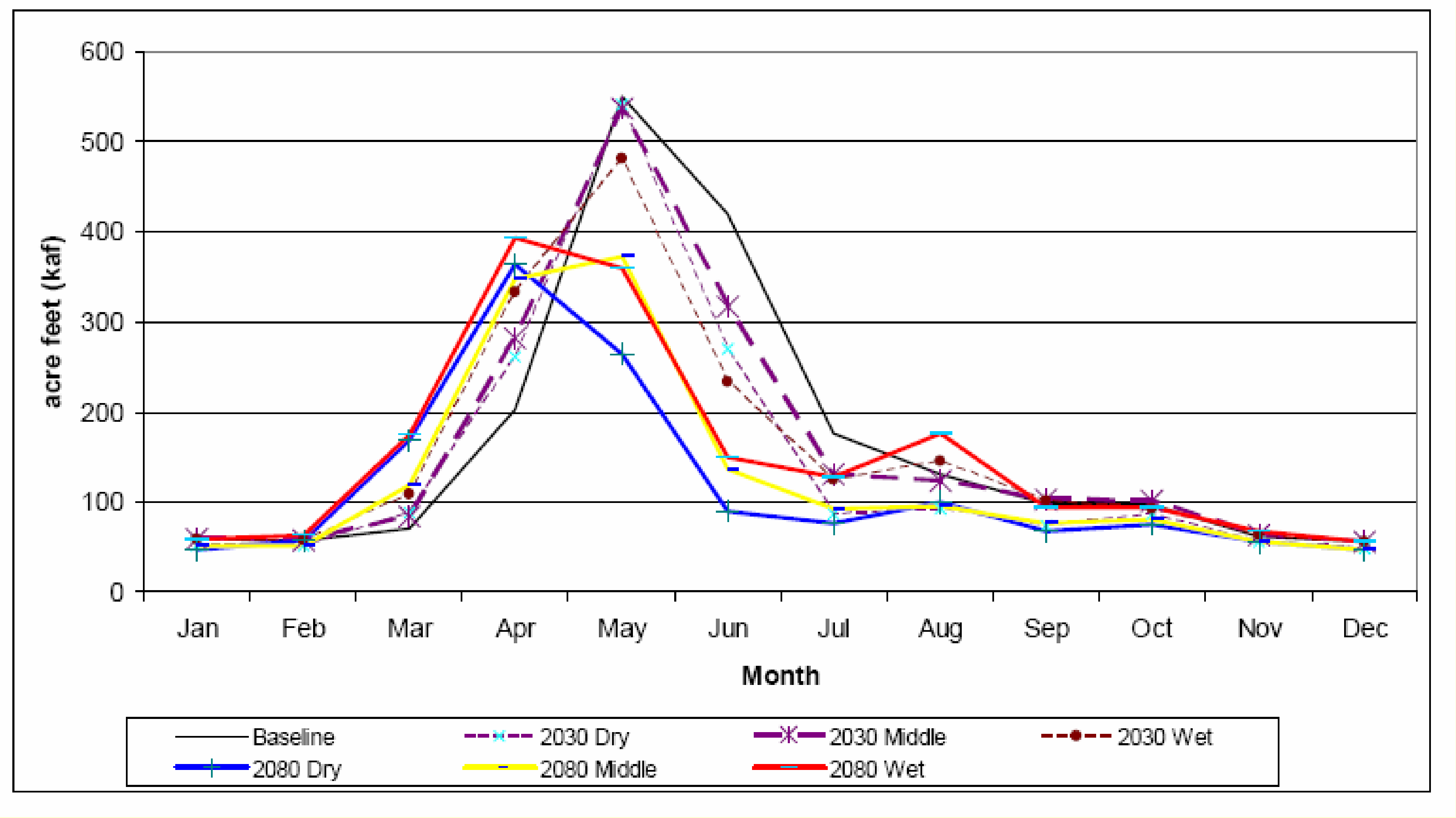
[5] The objective of this study is to evaluate the sensi-

Anthropogenic climate change will likely impact future hydrology in the Rio Grande basin

- Precipitation change uncertain *(increase? decrease?)*
- Temperature increase very likely (already being observed regionally and in most locations)
  - increase in evapotranspiration
  - decrease in soil moisture
  - decreased snowpack accumulation (more precip. falls as rain)
  - increased sublimation from snowpack
  - earlier meltout of snowpack
- *Likely effects on hydrology: lower flows, earlier peak flows*
- Precipitation change could either (partly) mitigate these effects or make things worse
- Was 2000+ drought the first salvo?

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



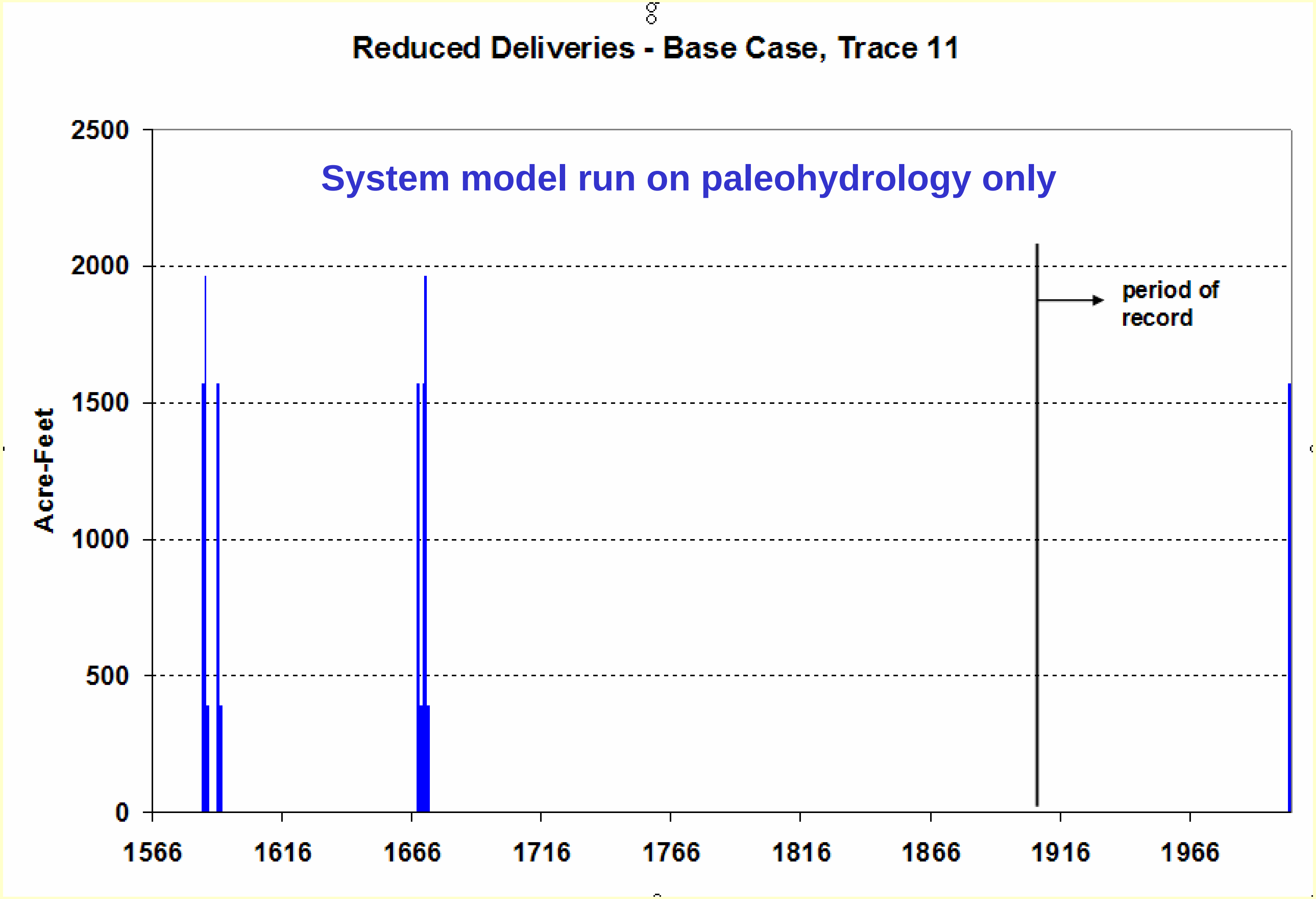
From: Hurd and Coonrod (July 2007) *Climate Change Impacts on New Mexico's Water Resources, http://agecon.nmsu.edu/bhurd/hurdhome/index.htm*

Paleohydrology + GCM output: best of both worlds?

- **Paleohydrology** – captures full range of natural variability better than gage records, but can't predict the future
- **GCM output** (with hydrologic downscaling) - represents future trends (at least temp.), but poorly simulates interannual and interdecadal variability
- Combine via hydrologic modeling = full natural variability + future trends, to assess the joint risk of variability and change
- But how to characterize the uncertainty in the combined product? Is it just too uncertain? Will public, stakeholders, decisionmakers buy into it?

Integration of tree-ring flow reconstruction with climate change scenarios - City of Boulder, with U. of Colorado, AMEC, and Stratus Consulting, NOAA-funded

- Monthly temps & precip, and observed streamflow (1953-2002) are resampled to pair the paleo streamflows for 1566-2002 with corresponding monthly temperature and precipitation
- Effectively disaggregates the annual paleo streamflows into estimated climatic variables (monthly precipitation and temperature) so that those variables can be manipulated independently
- Then the simulated monthly temperature and precipitation are input into a snowmelt-runoff (SRM) and water-balance (WATBAL) model to produce modeled Boulder Creek flows
- Then changes in temperature and precipitation forecasted from climate models are combined with the paleodata to produce simulations of past hydrology under plausible future climate conditions
- Allows water managers to assess the joint risks of climate variability and climate change
- *Southwest Hydrology*, Jan/Feb 2007



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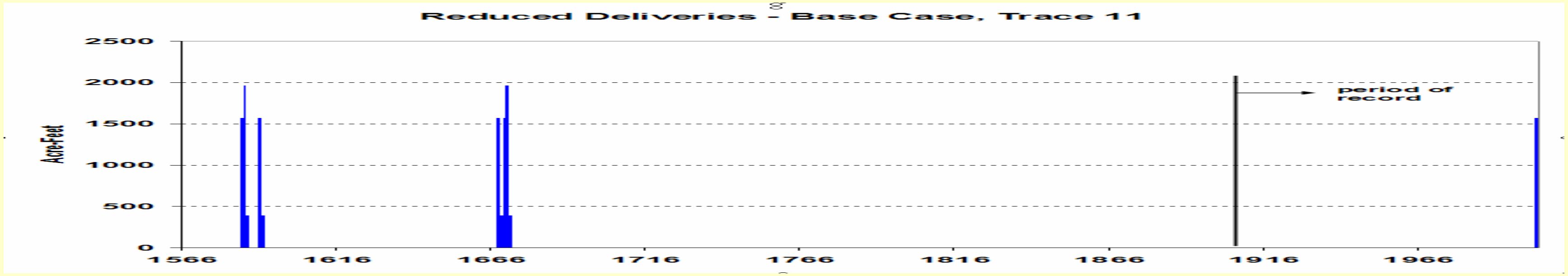

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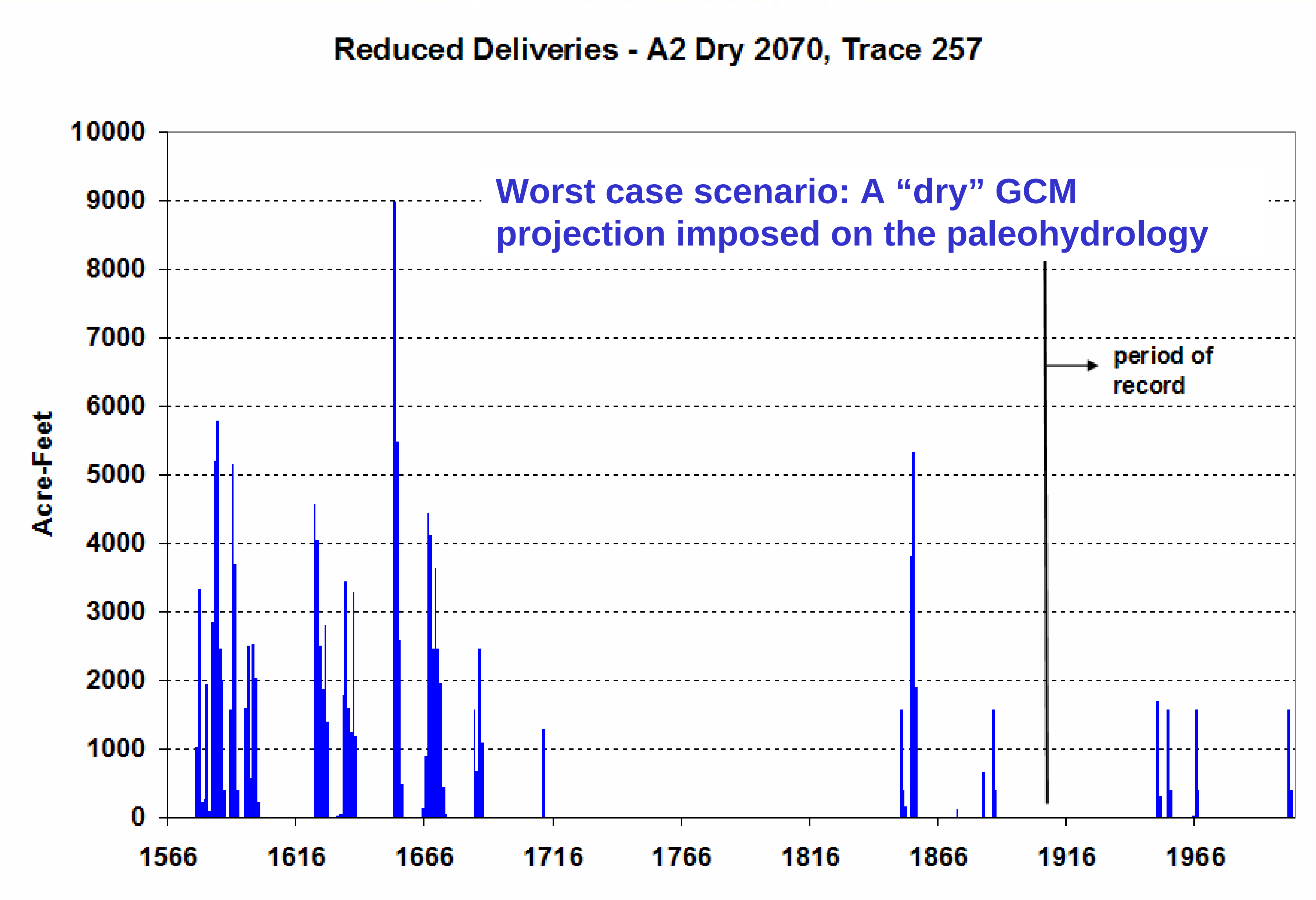
A "Worst Case" Scenario



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Conclusions

- Tree-ring reconstructions exploit a robust relationship between tree growth and moisture to provide useful information about past hydrologic variability

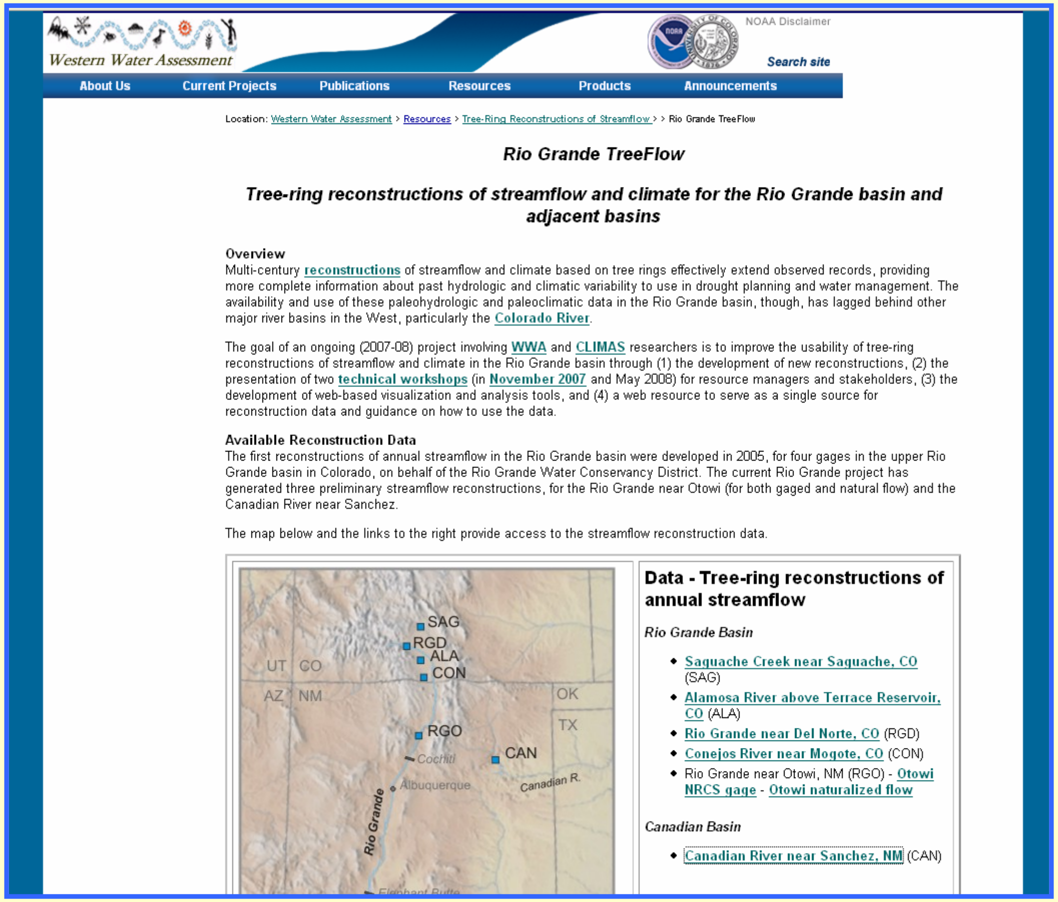
- New reconstructions for the Rio Grande capture events and regime shifts not seen in the observed hydrology

- Reconstructions can be effectively used “as-is”, or processed to input into models for rigorous policy and risk analyses

- Expectations of future streamflows should be based on both past natural variability - more fully seen in tree rings - and projections of future climate

New web resource: ***Rio Grande TreeFlow***

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



- Overview
- Access to Rio Grande/NM reconstruction data
- Links to analysis/visualization tools
- Information about applications of data
- Links to other resources

Future expansion - each item above will have separate page

Thank you