A tree-ring reconstruction of Animas River streamflow and its use in water management

Jeff Lukas

University of Colorado and

Western Water Assessment

INSTAAR University of Colorado Boulder

Mountain Studies Institute
SAN JUAN MOUNTAINS, COLORADO

Western Water Assessment

Agenda

- Review of "Tree-ring 101"
  - How tree rings record climate information
  - Building the tree-ring chronology
  - Generating reconstructions of streamflow
- The new Animas flow reconstruction(s)
  - How it was generated
  - What it tells us about past flow variability
- How the reconstruction can be used in water management

Discussion:

- How to best use the streamflow reconstructions?
- What other climate-based information do you need in preparing for an uncertain hydrologic future?

Please ask questions!

Acknowledgements

Workshop assistance:

MSI - Koren Nydick

WWA - Connie Woodhouse, Brad Udall

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, Wright Water Engineering

Funding:

NOAA Climate Programs Office: Western Water Assessment and Climate Change Data and Detection (GC02-046); Denver Water; US Geological Survey

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

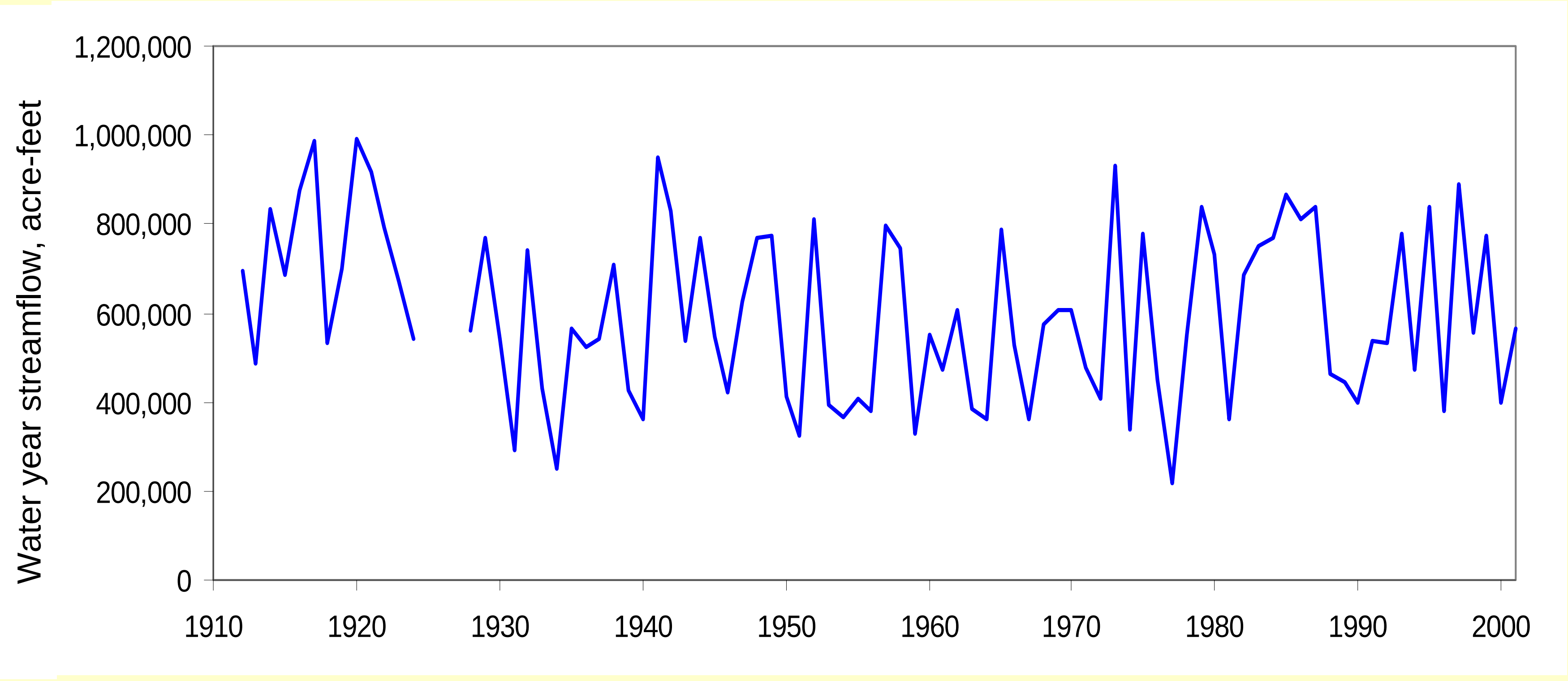
Western Water Assessment

http://wwa.colorado.edu

Quick links to main projects and resources

How much hydrologic experience is enough?

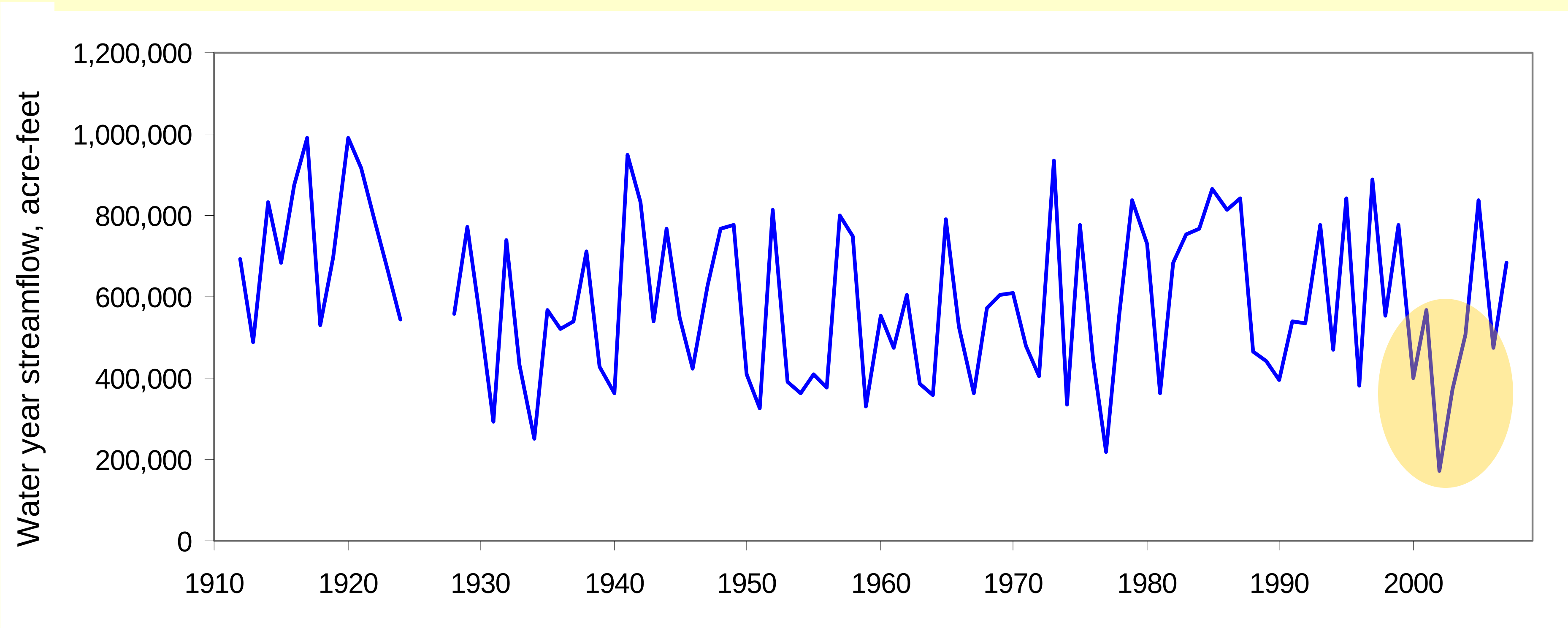
Animas at Durango water year flow, 1912-2001



- Is 80+ years of gaged flow enough to fully describe potential future variability?

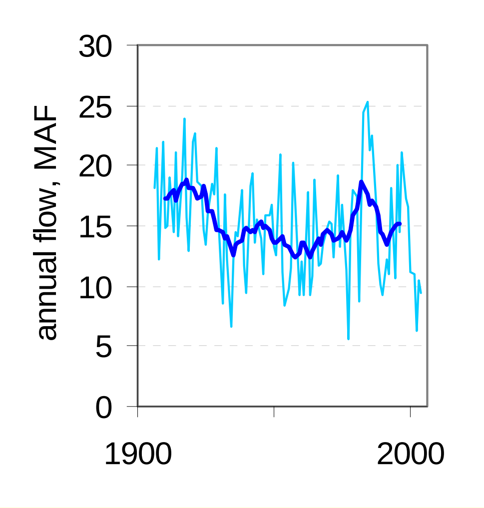
How much hydrologic experience is enough?

Animas at Durango water year flow, 1912-2007



- *Even a long gaged record is inadequate to describe the variability of the system*

Tree-ring reconstructions - a surrogate for experience



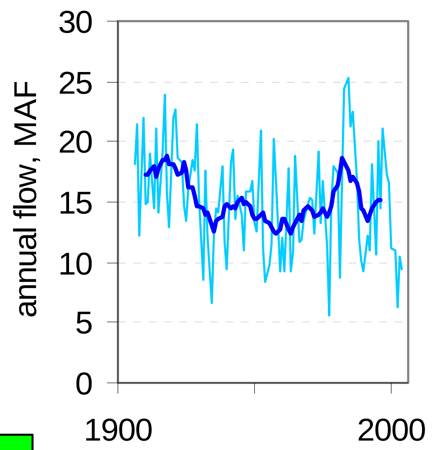
Colorado at Lees Ferry

Gaged (natural flow) record

1906-2004

Tree-ring reconstructions - a surrogate for experience

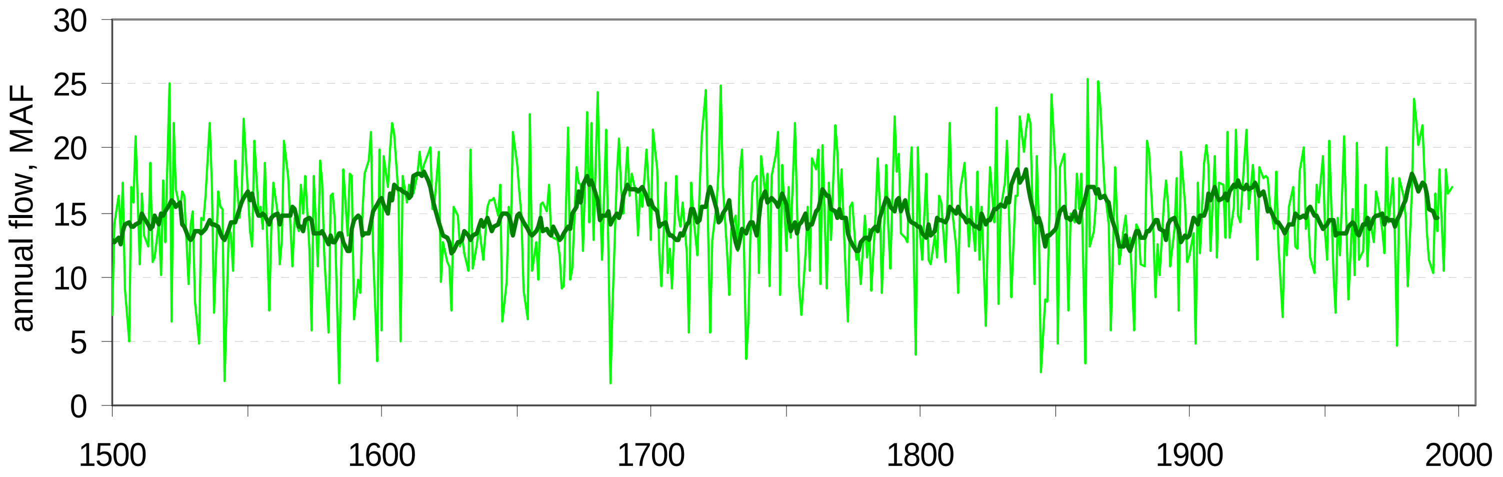
By extending the gaged hydrology by hundreds of years into the past, the reconstructions provide a more complete picture of hydrologic variability



Colorado at Lees Ferry

Gaged (natural flow) record

1906-2004



Tree-ring reconstruction

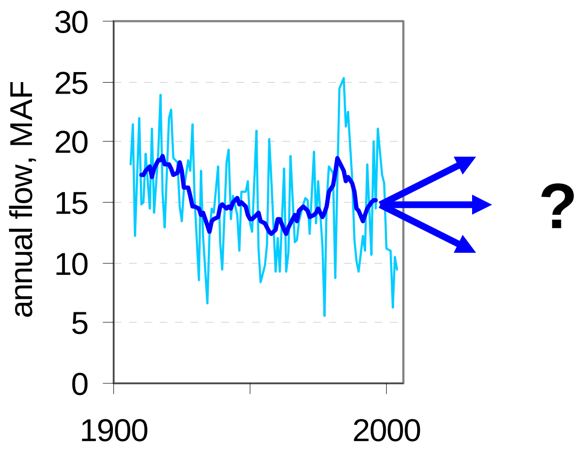
1490-1997

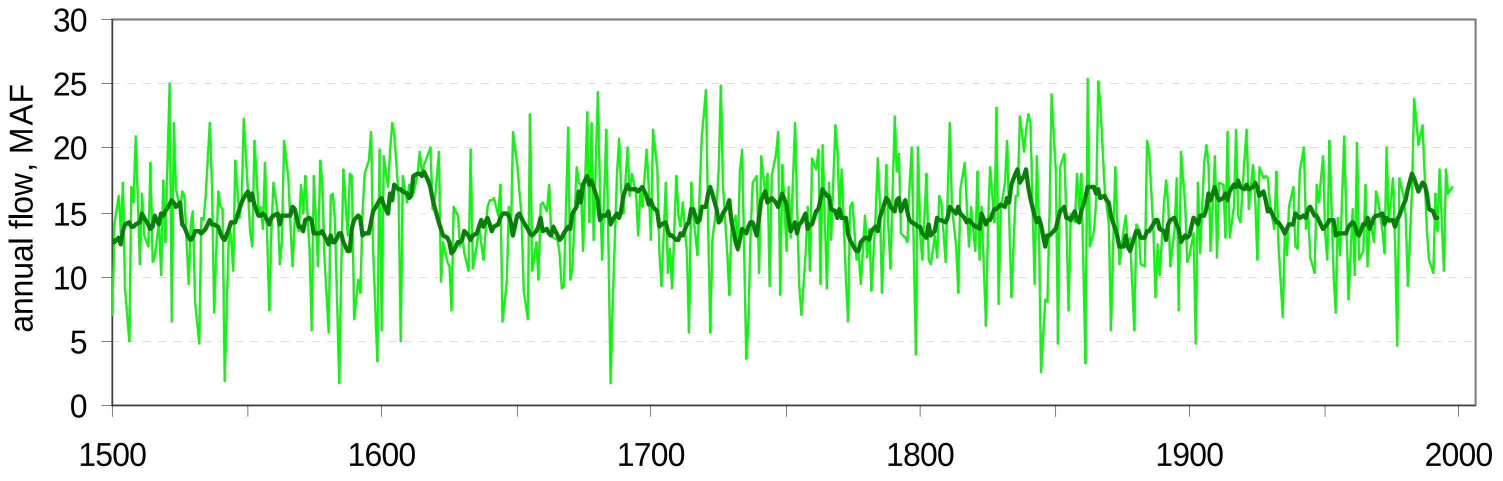
Tree-ring reconstructions - a surrogate for experience

Payoff:

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

- Better assessment of *risk*

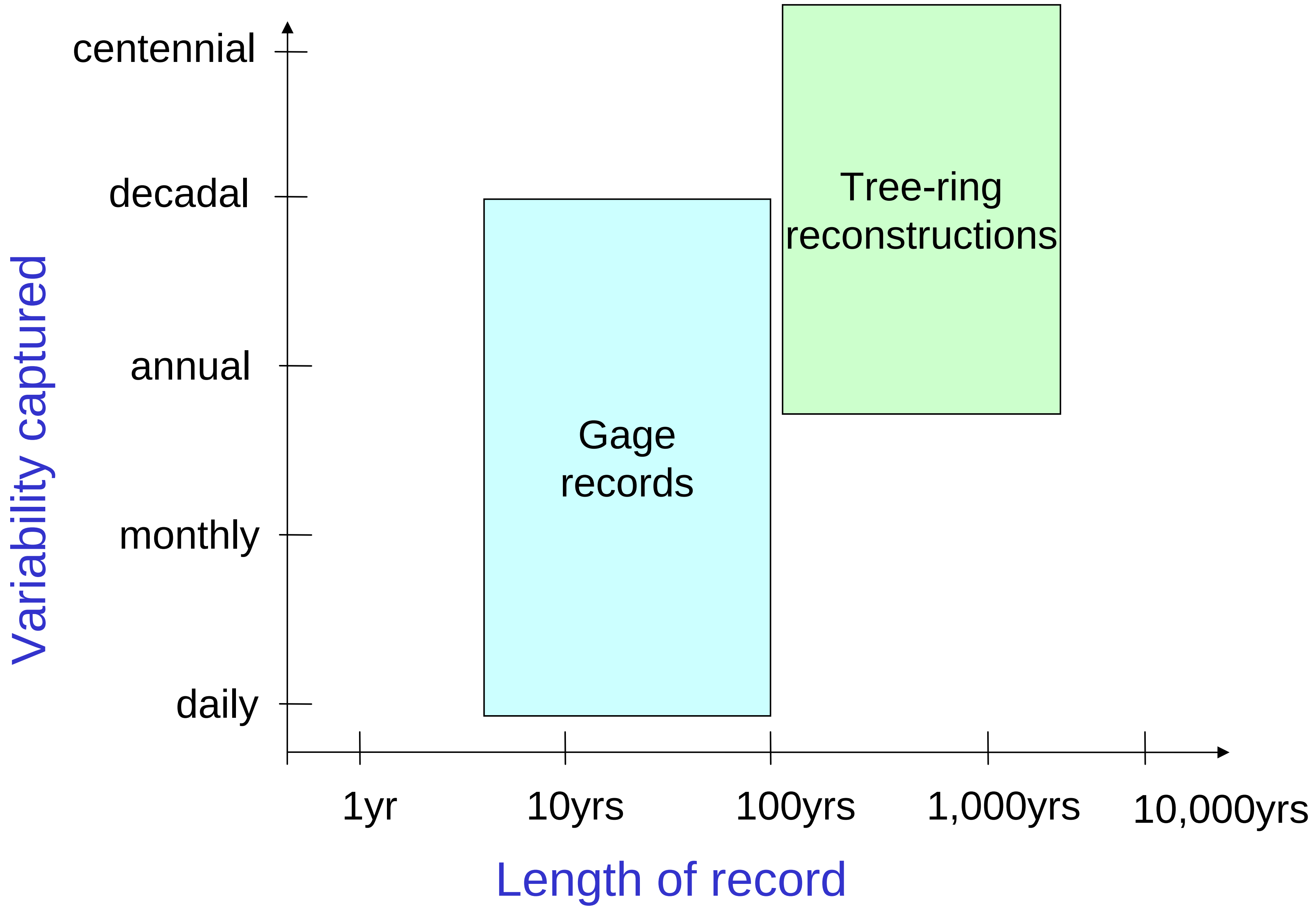




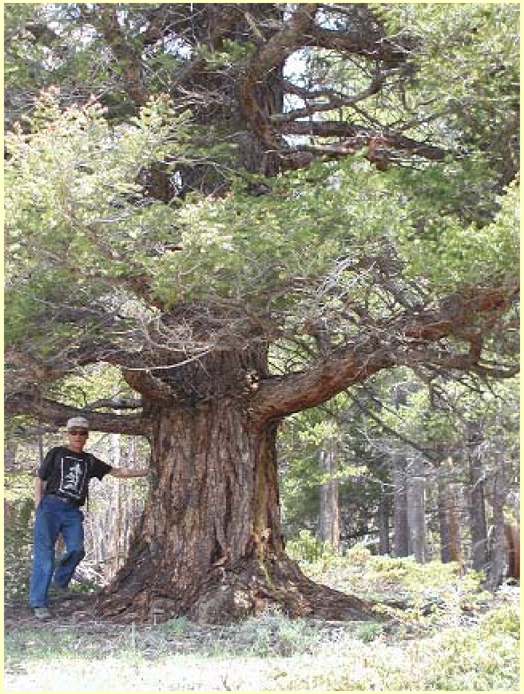
Tree-ring reconstruction

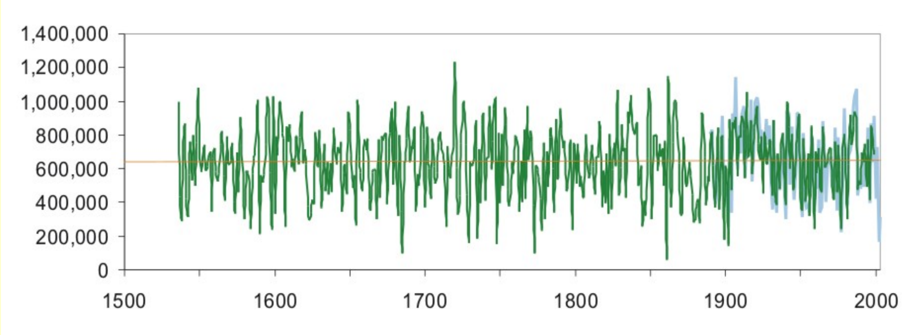
1490-1997

Time scales of gaged vs. tree-ring records



How do we develop tree-ring reconstructions of streamflow?





In dry climates, tree growth is limited by moisture availability

So:

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

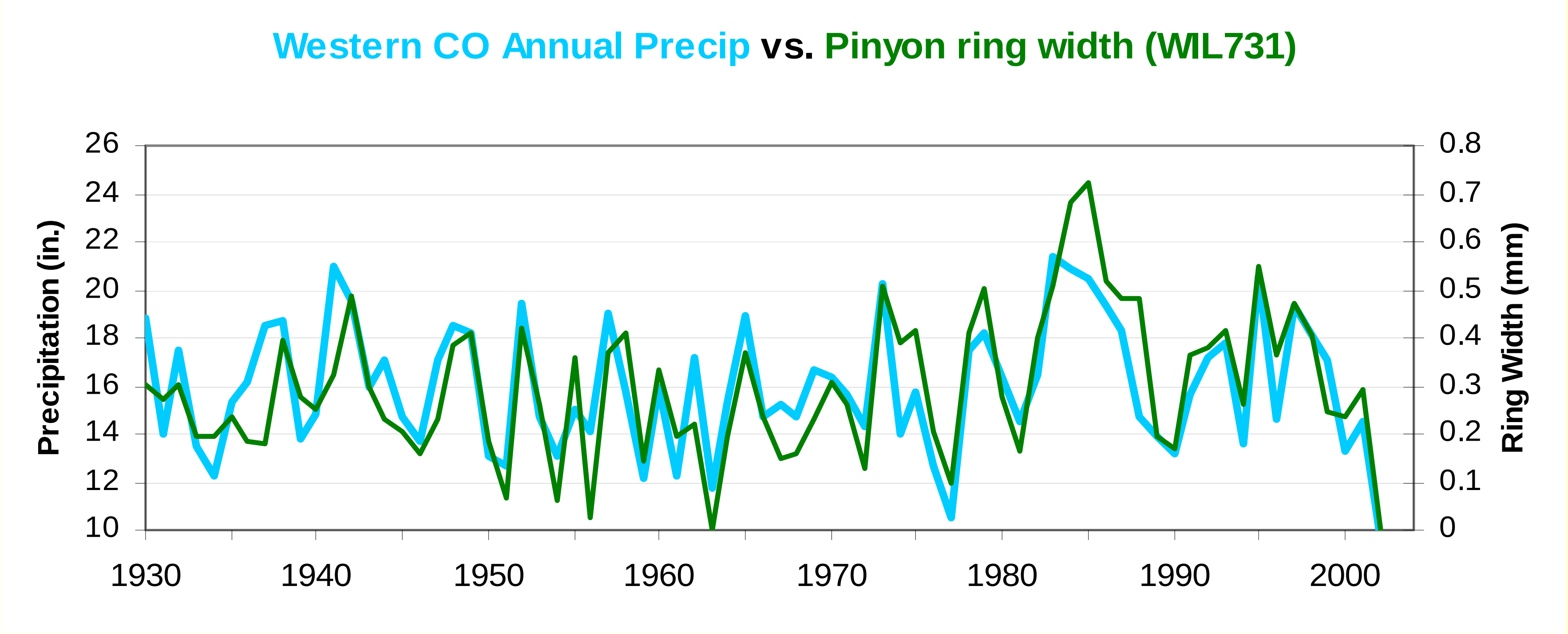
– a wet year leads to a *wide* growth ring

1977 – very dry!

1983 – very wet!

Growth is mainly influenced by what's in the ground at the start of the growing season (winter/spring precip)

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

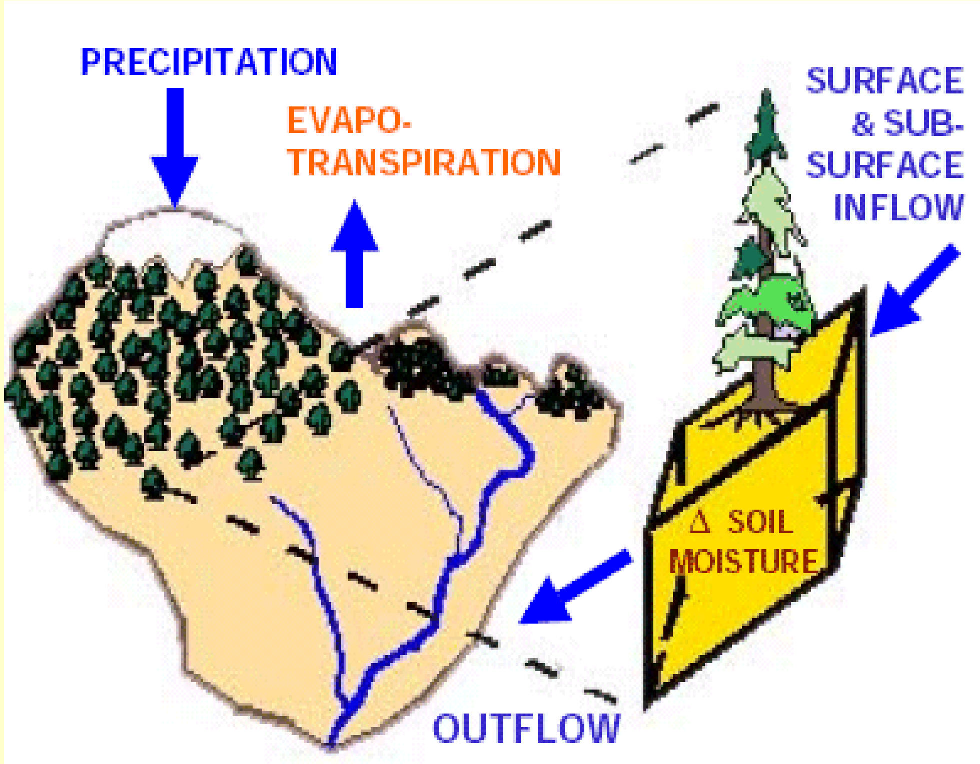


- The “raw” ring widths from *one* tree are very closely correlated with annual basin precipitation (r = 0.78) from 1930-2002

- Our job is to *capture* and *enhance* the moisture signal, and reduce noise, through careful sampling, replication, and data processing

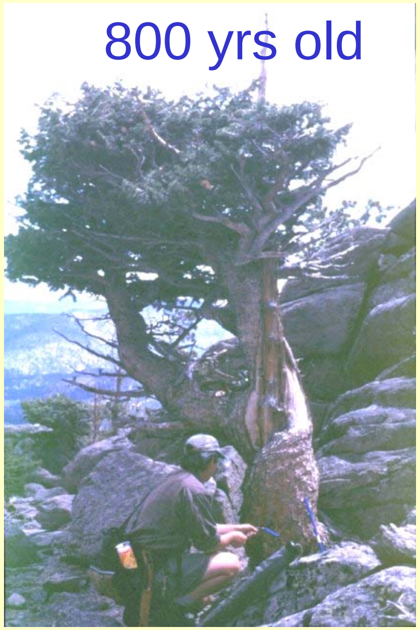
Ring-width and annual streamflow - an indirect but strong relationship

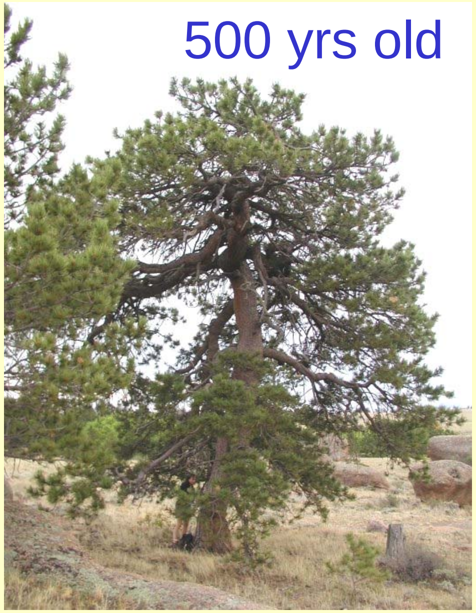
- Growth of moisture-sensitive trees responds to the same set of climatic factors that influence streamflow

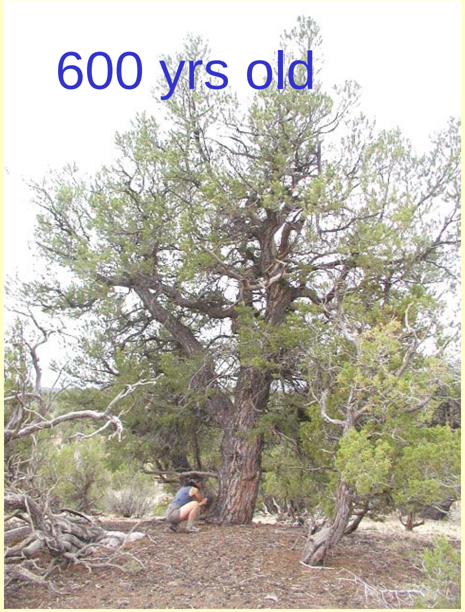


Collecting moisture-sensitive tree-ring records

- 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)



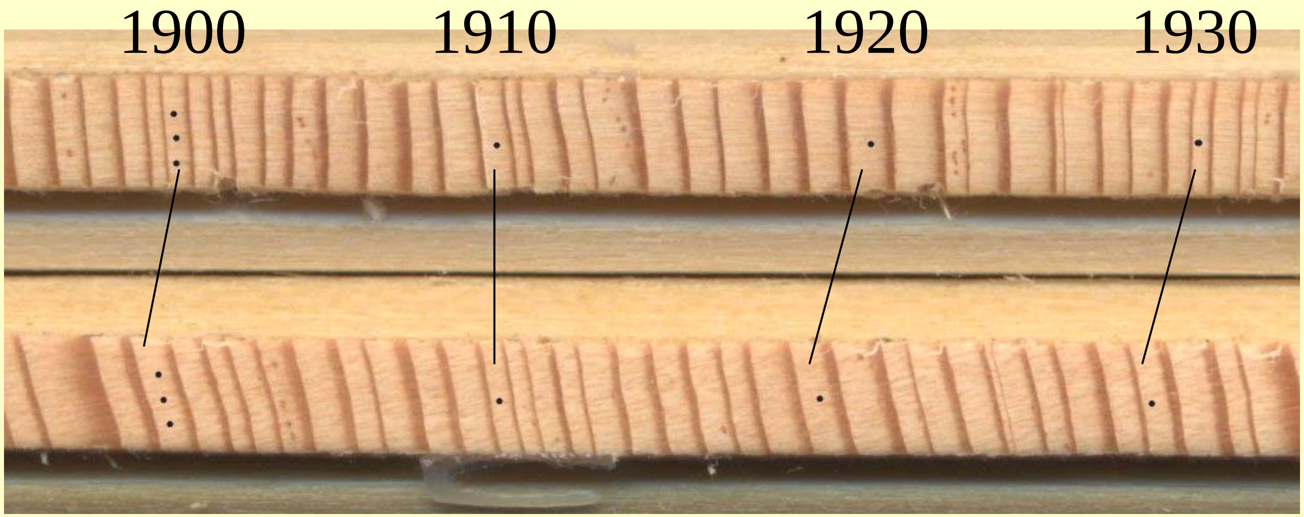




Crossdating the samples

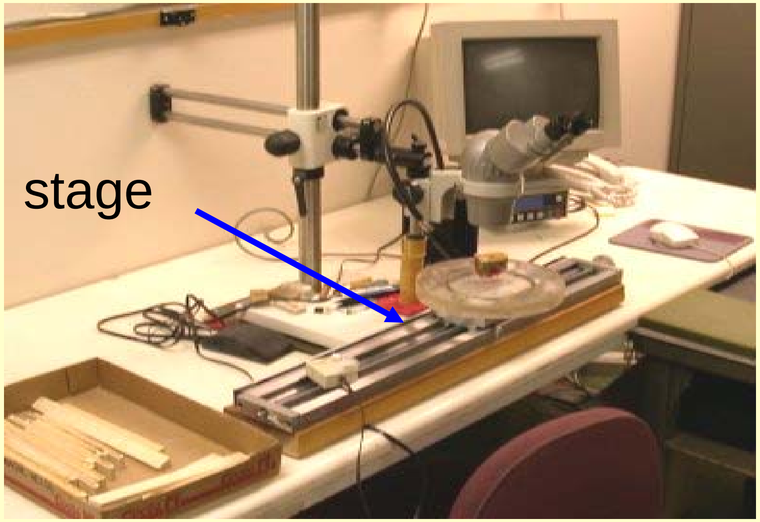
- Because of the common climate signal, the pattern of wide and narrow rings is highly replicated between trees at a site, and between nearby sites

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

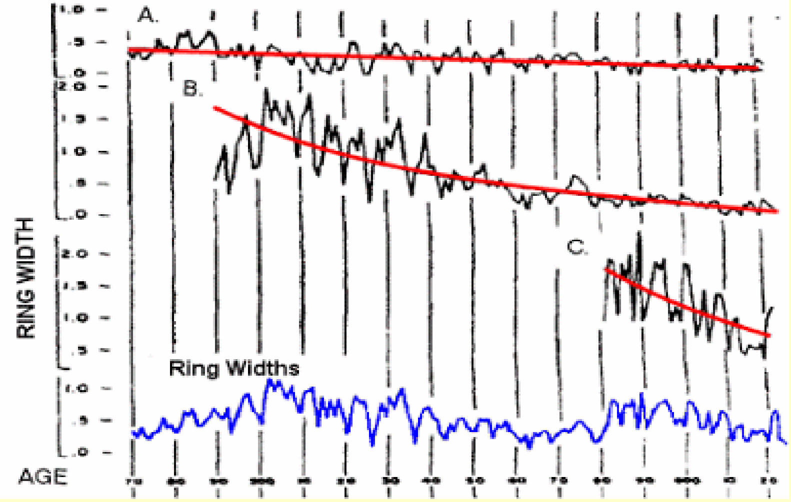


Two Douglas-fir trees south of Boulder, CO

Measuring and detrending the samples

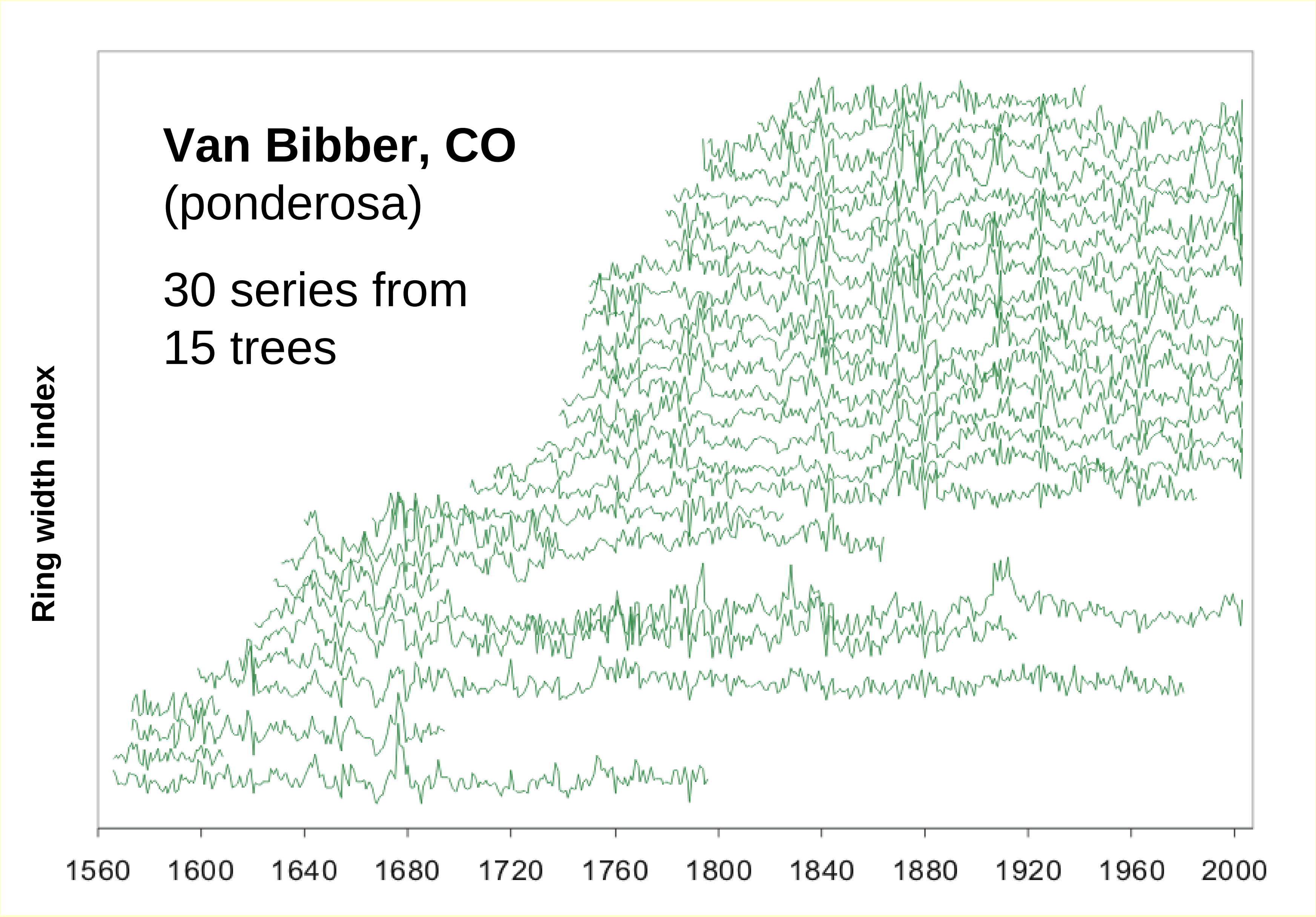


- Measure each ring with computer-assisted measurement system with sliding stage
  - captures position of core to nearest 0.001mm (1 micron)

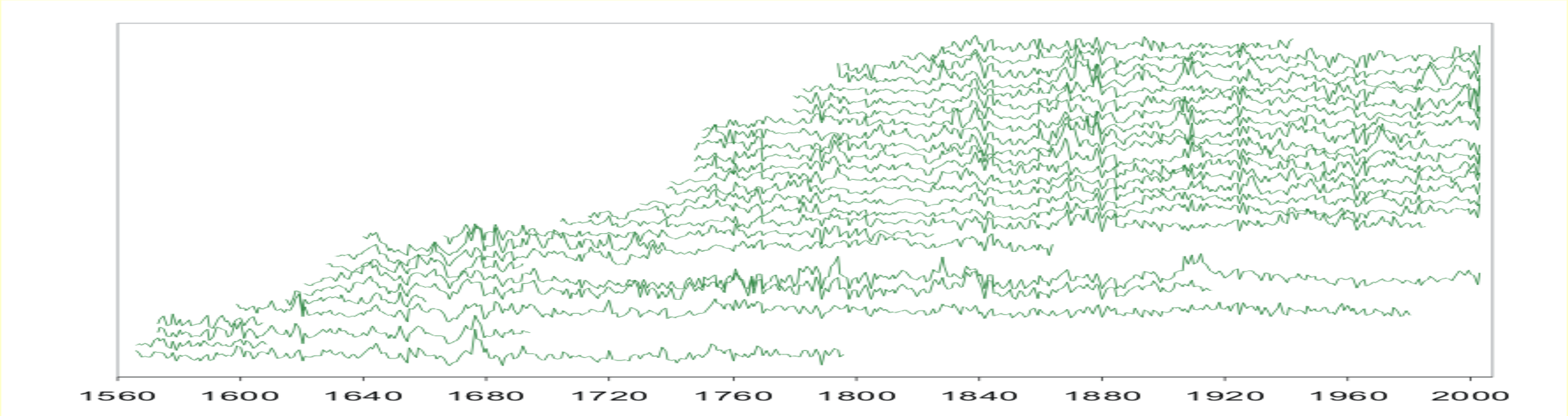


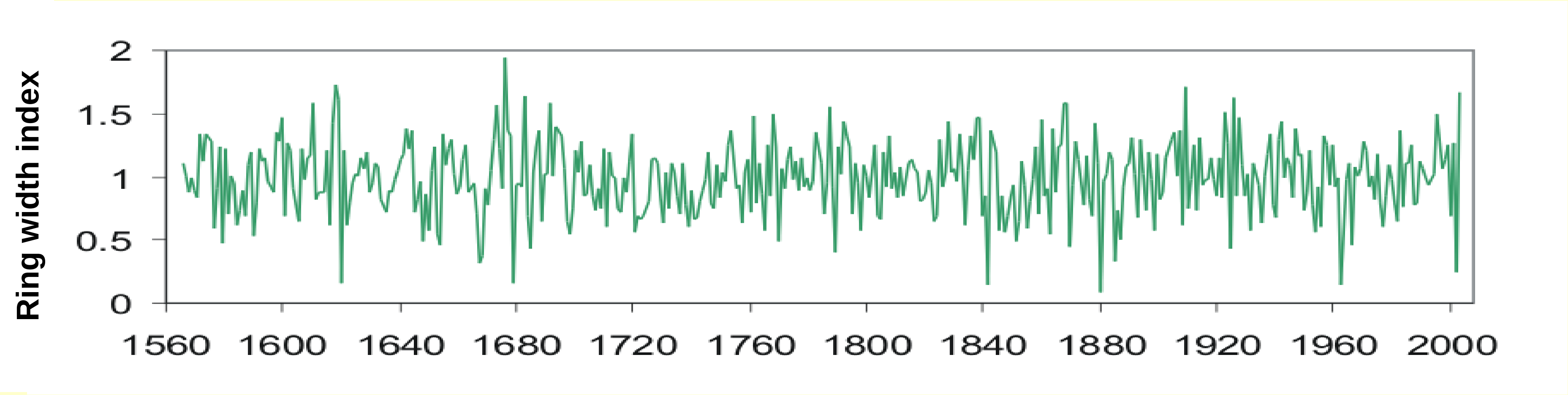
- Ring-width series typically have a declining trend because of tree geometry
- These are low-frequency *noise* (i.e. non-climatic)
- So ring series are detrended with straight line, exponential curve, or spline

We average the measurements from all trees at the site…



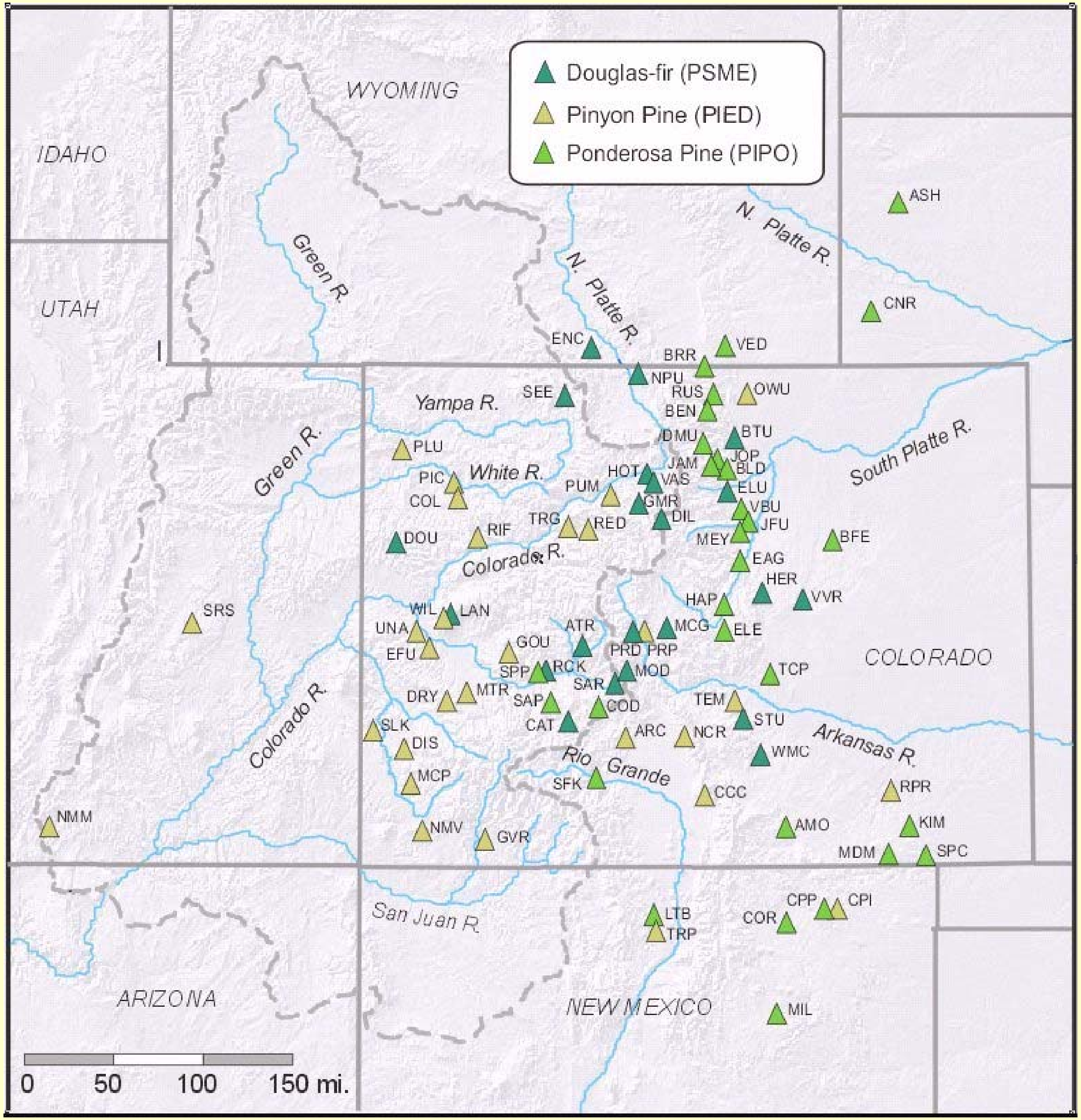
…to enhance the common (climate) signal in the resulting site *chronology*



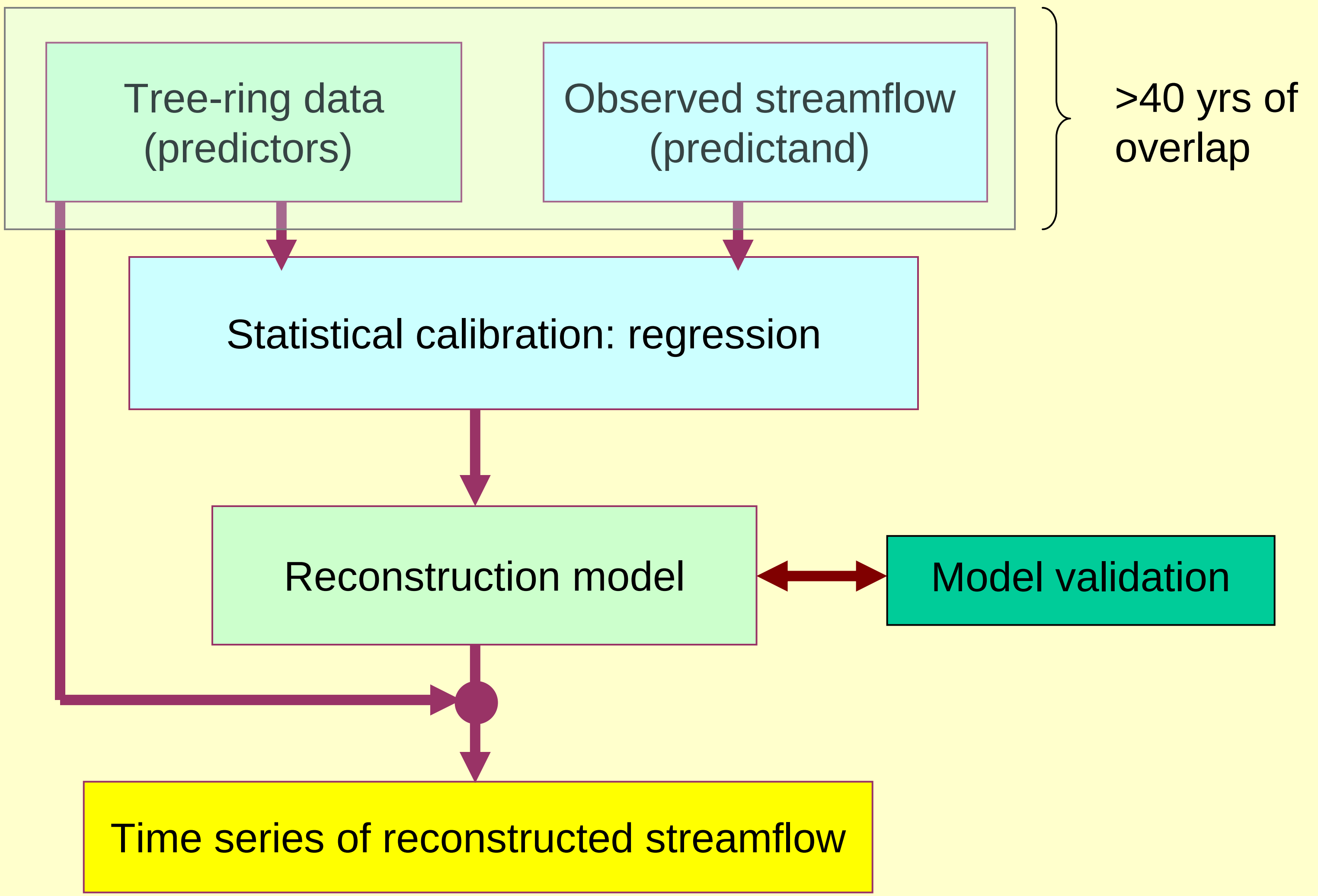


Moisture-sensitive chronologies developed by CU - INSTAAR Dendro Lab

- Average length: 550 years
- Strong relationships with annual precipitation and annual streamflow
- Building blocks for streamflow reconstructions



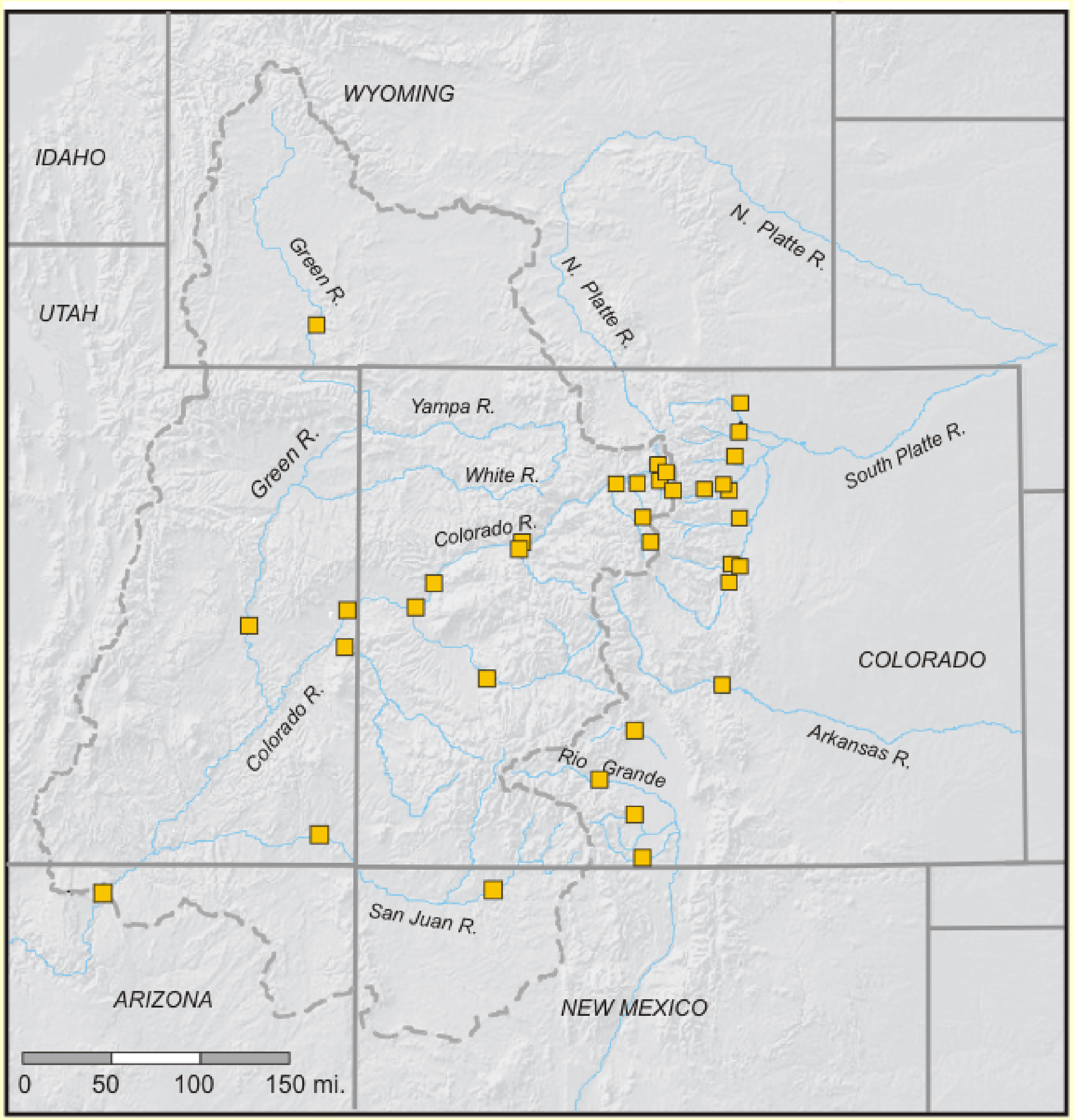
Overview of reconstruction methodology



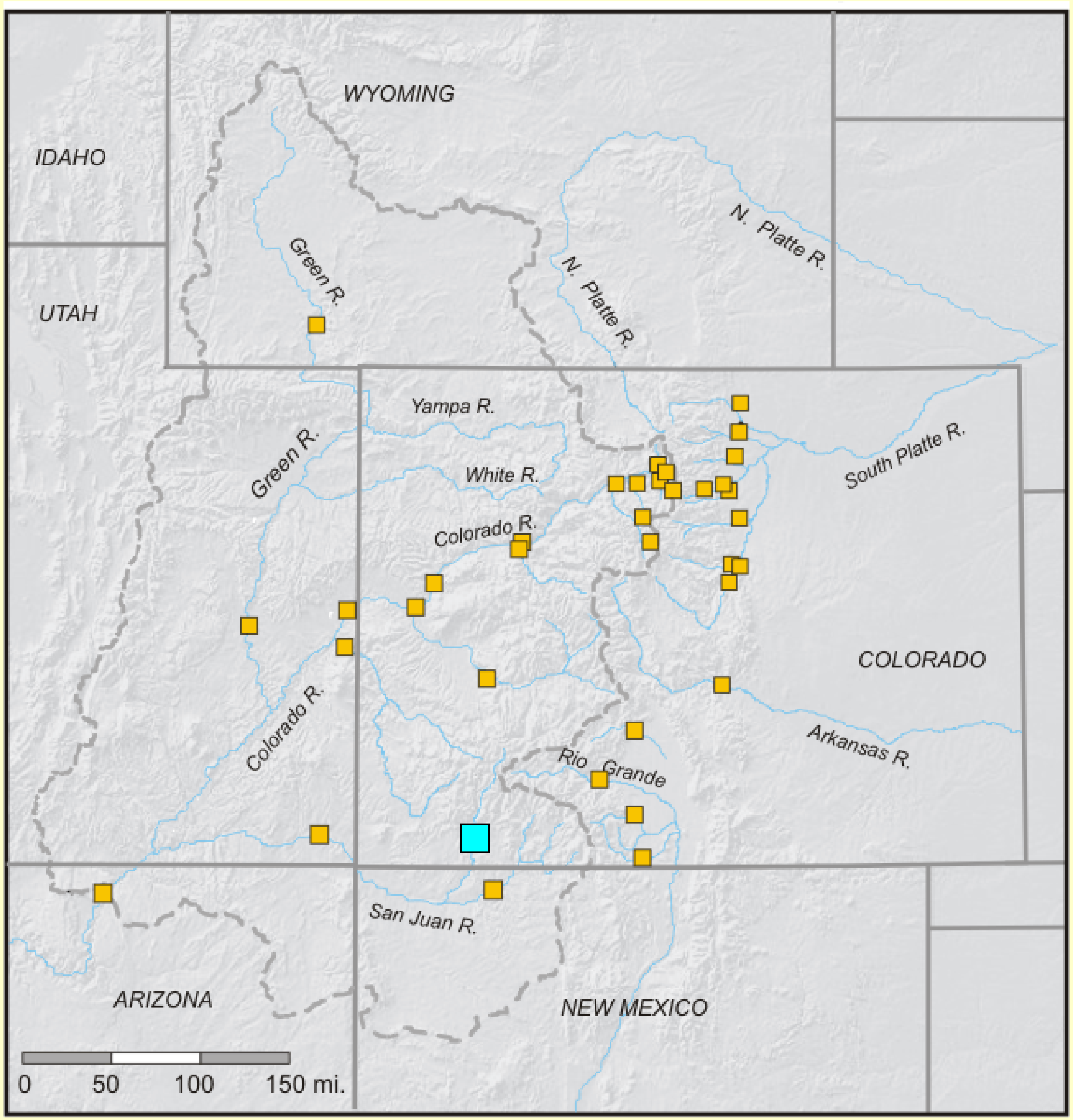
based on Meko 2005

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

- Over 30 reconstructions, representing nearly all of the streamflow leaving Colorado

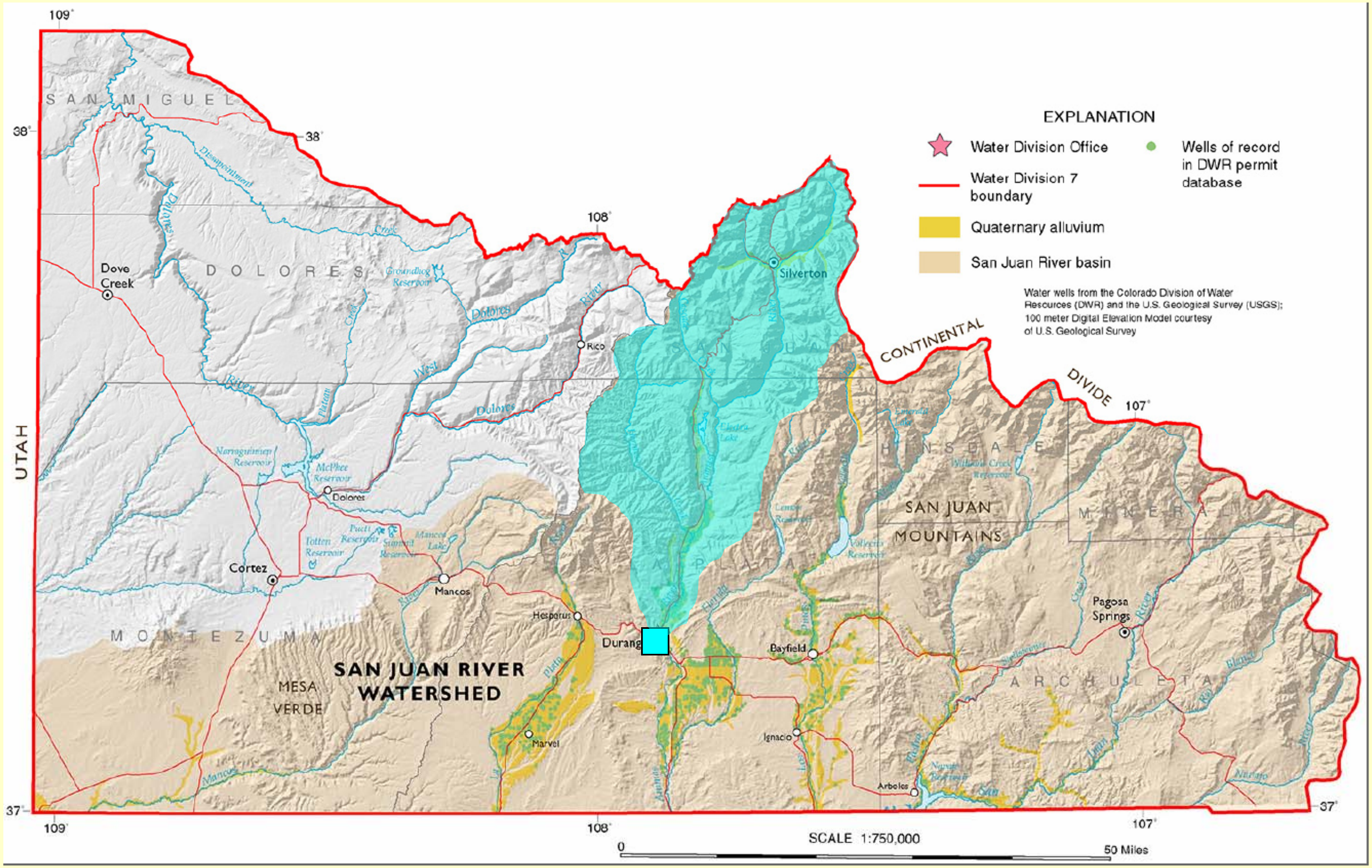


Animas River at Durango

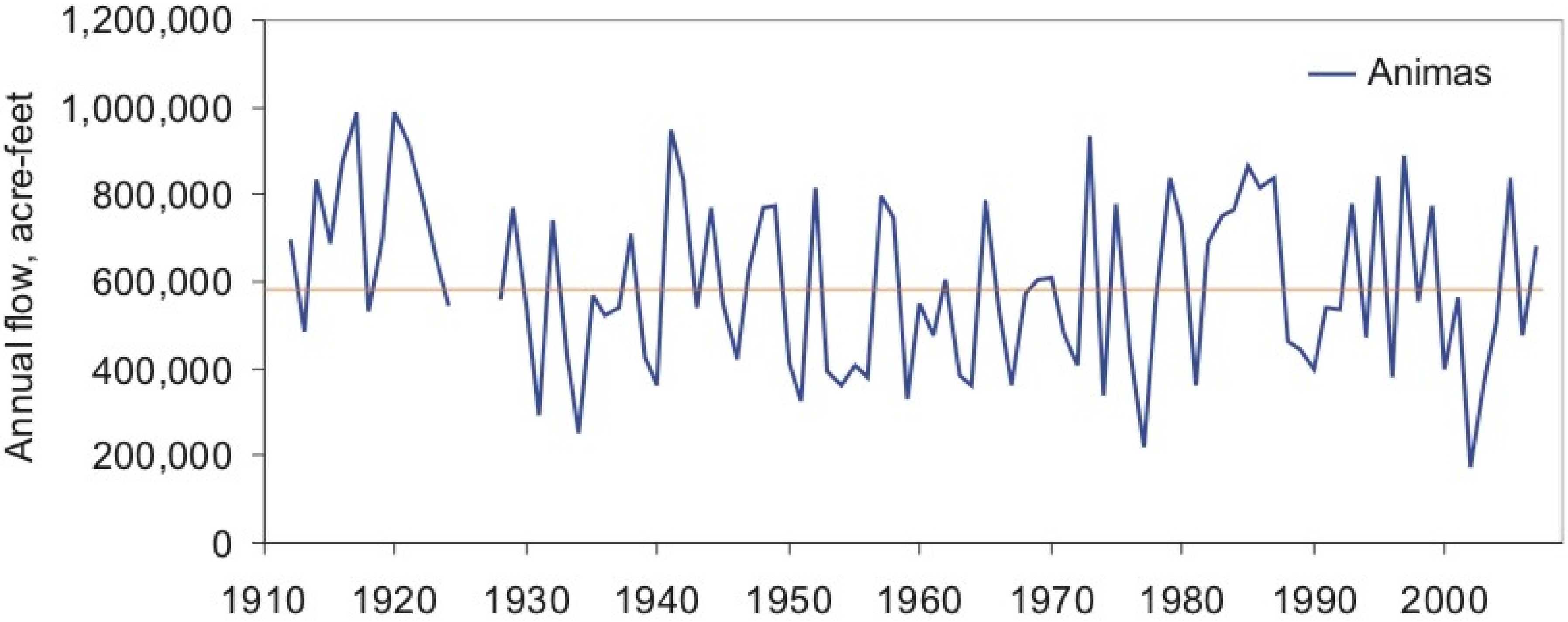


Animas River at Durango

- Basin above gage: 692 sq mi.
- Only 0.7% of Colorado's area, but produces about 3.7% of the runoff

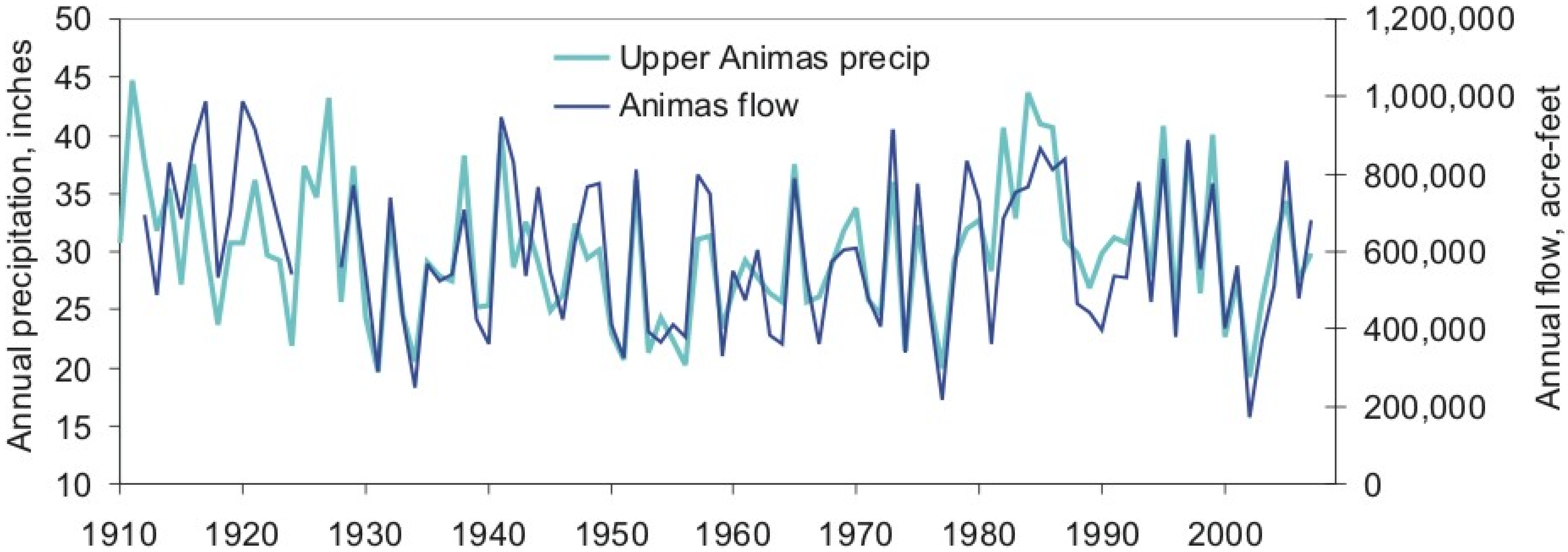


Animas at Durango – gaged water year flow, 1912-2007



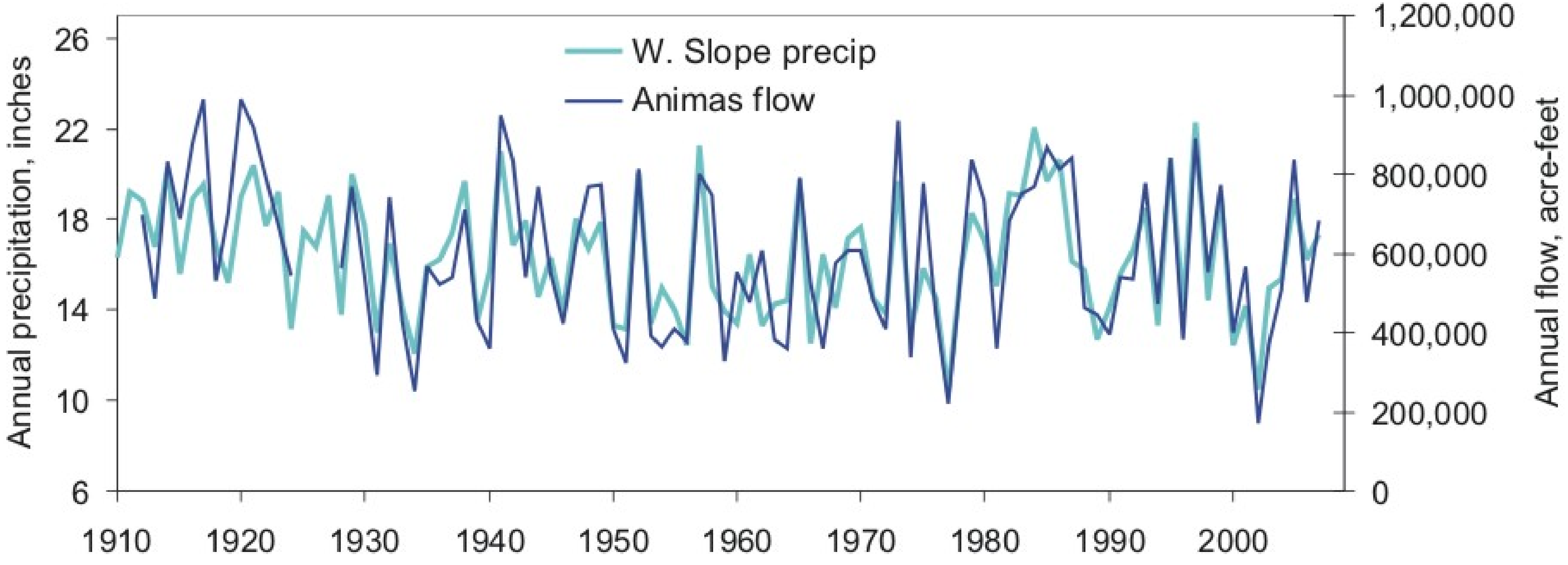
- Continuous record since 1928
- Minor upstream impoundments/depletions
- Annual (water year) flow has ranged from 174 KAF (2002) to ~1000 KAF (1917, 1920)
- Mean of 595 KAF (orange line)

We expect variation in Animas flow to relate strongly to annual precipitation in upper Animas basin



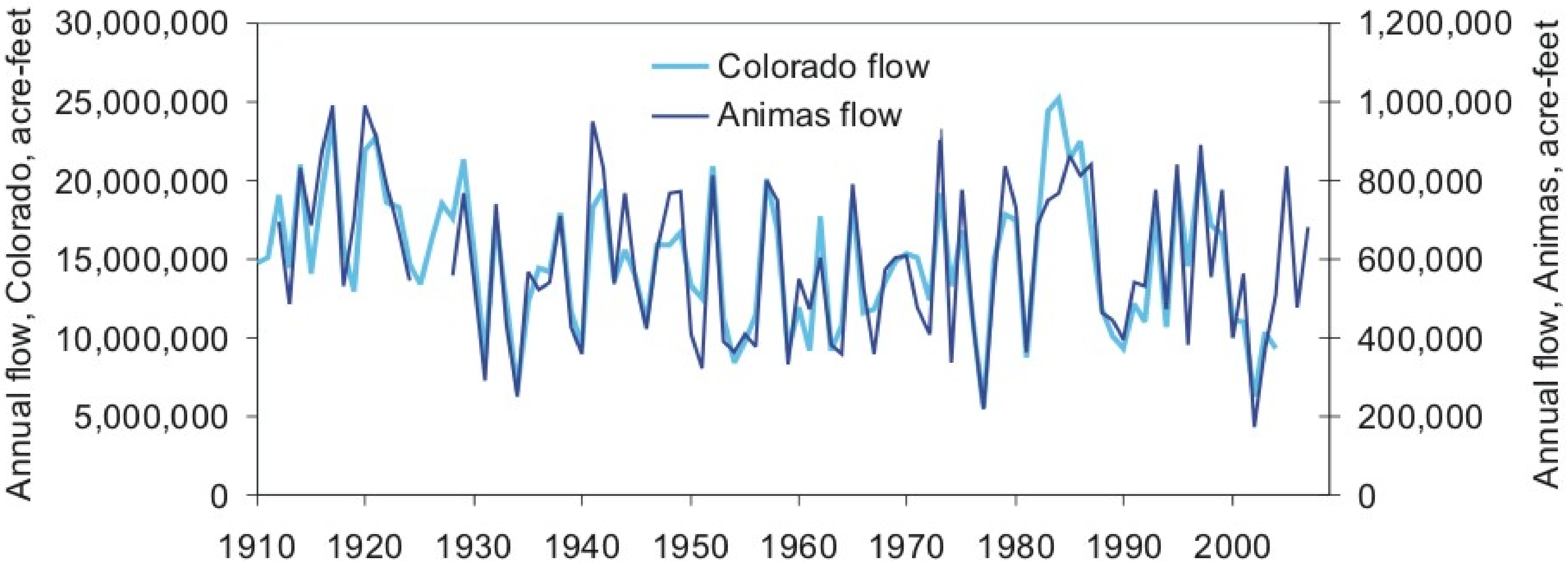
- Correlation coefficient *r* = 0.79
- Precip record is interpolated from nearby stations (Durango, Silverton, Telluride, etc.) – so not perfectly representative
- Temperature, humidity, winds, account for the variance in flow not explained by precipitation

Animas flow has equally strong relationship with precipitation across the West Slope



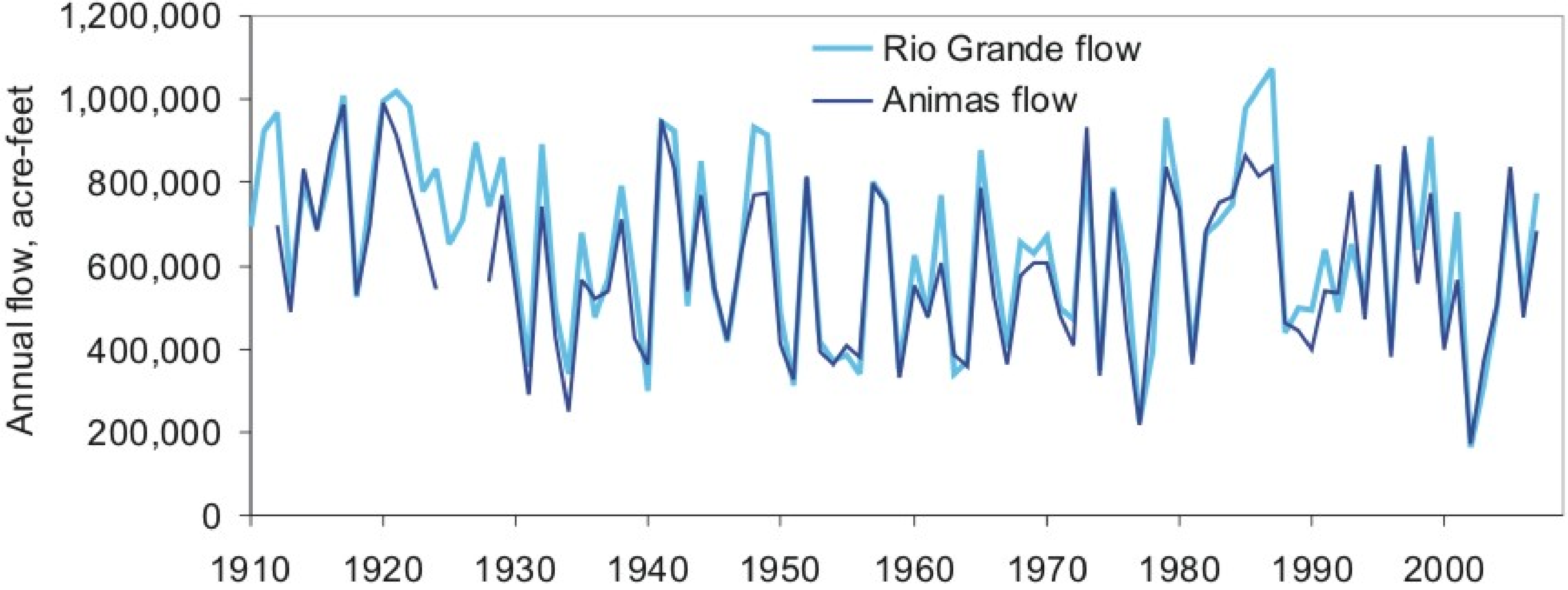
- Correlation coefficient *r* = 0.81
- Precip record is averaged from all West Slope stations
- Most of the hydroclimatic signal in Animas gage record is regional and not specific to the Animas basin (track and size of storm systems)

Animas flow represents only 4% of upper Colorado basin flow, but the variability is very similar



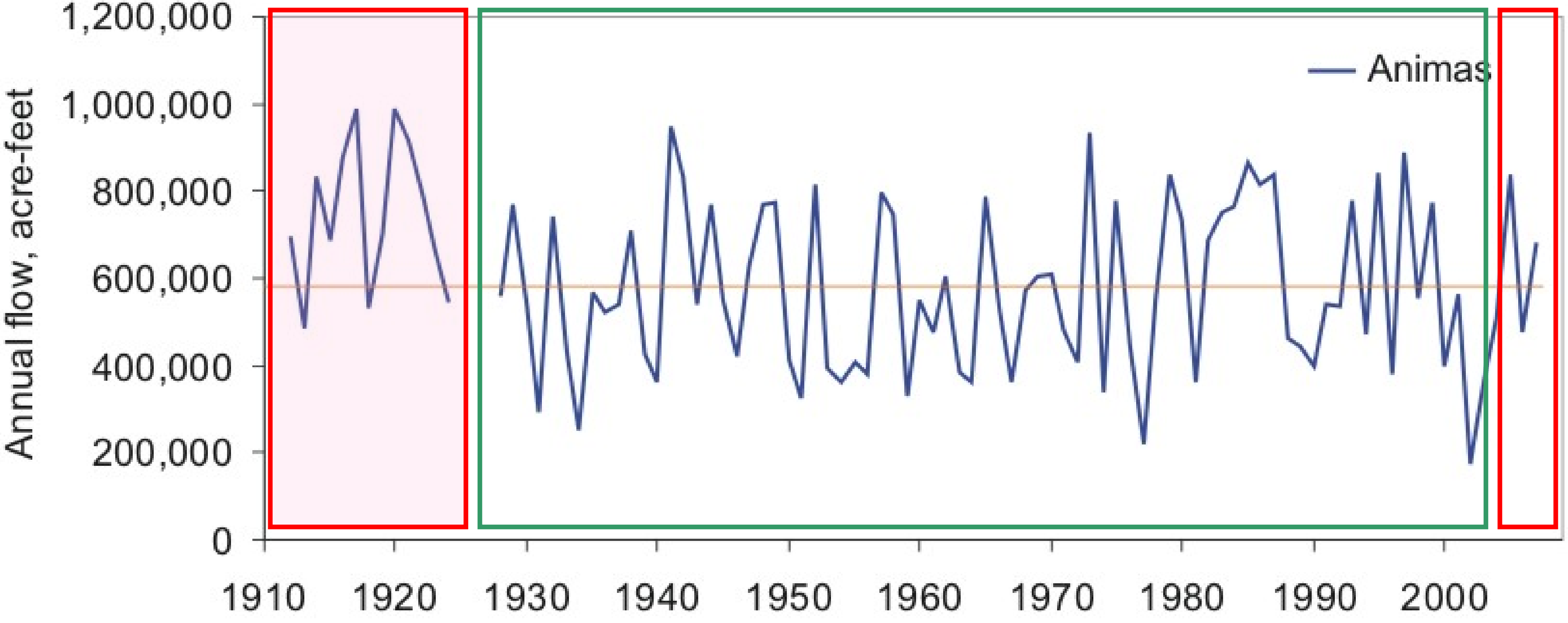
- Correlation coefficient $r = 0.88$
- Again, indicates regional nature of hydroclimatic variability captured in the Animas gage record

Variability of Animas flow is very similar to upper Rio Grande flow (contiguous headwaters)



- Correlation coefficient *r* = 0.93
- Similarity of gage records also gives us confidence that the Animas record does not have trends or systematic errors

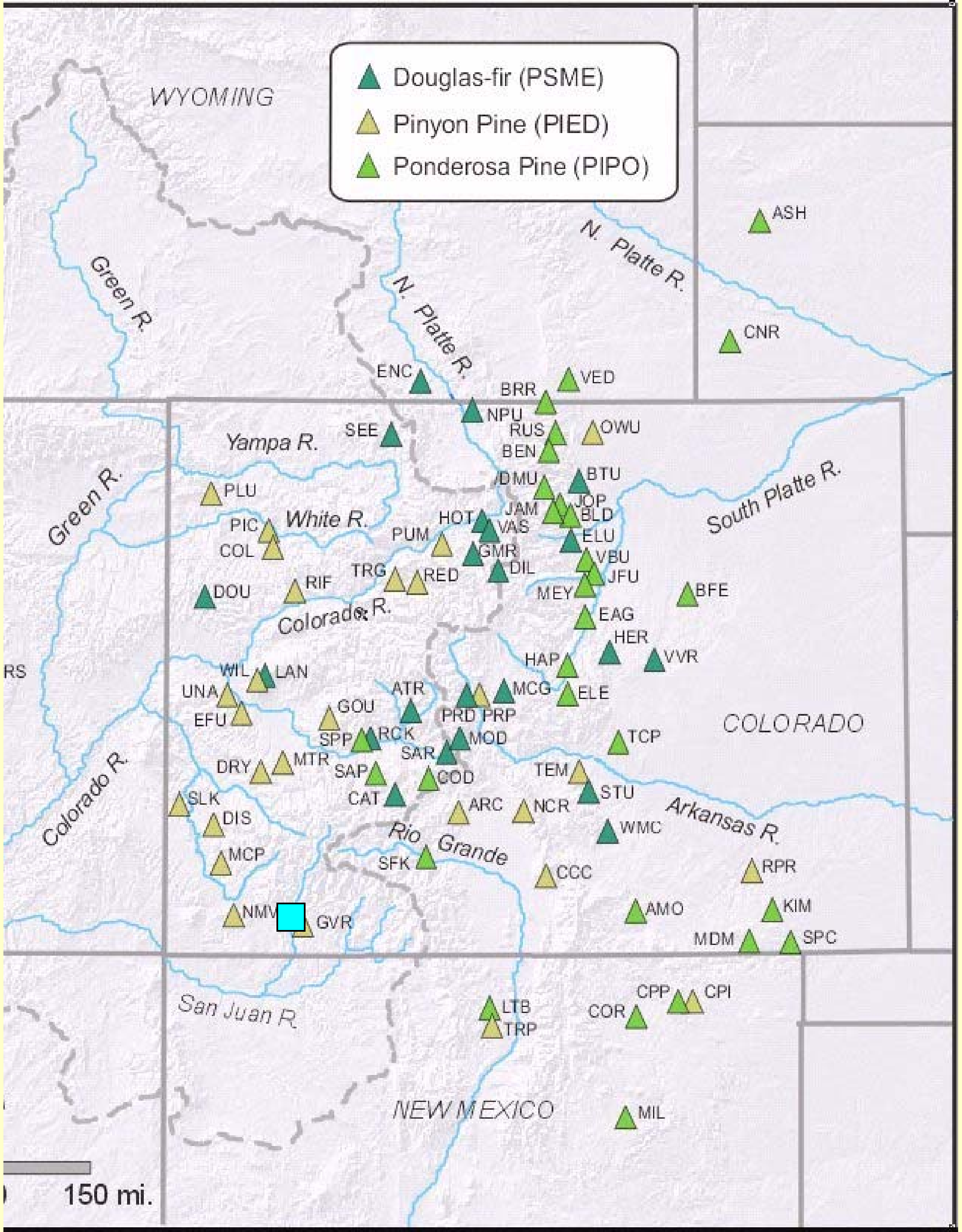
Animas at Durango – gaged flow record for calibration with tree-ring data - 1928-2002



- Gage from 1912-1925 can’t be used, since it’s not continuous – but may be useful for additional model validation (also 1898, 1900)
- Gage from 2003-2007 can’t be used, since it doesn’t overlap with many tree-ring chronologies

Back to the tree-ring data

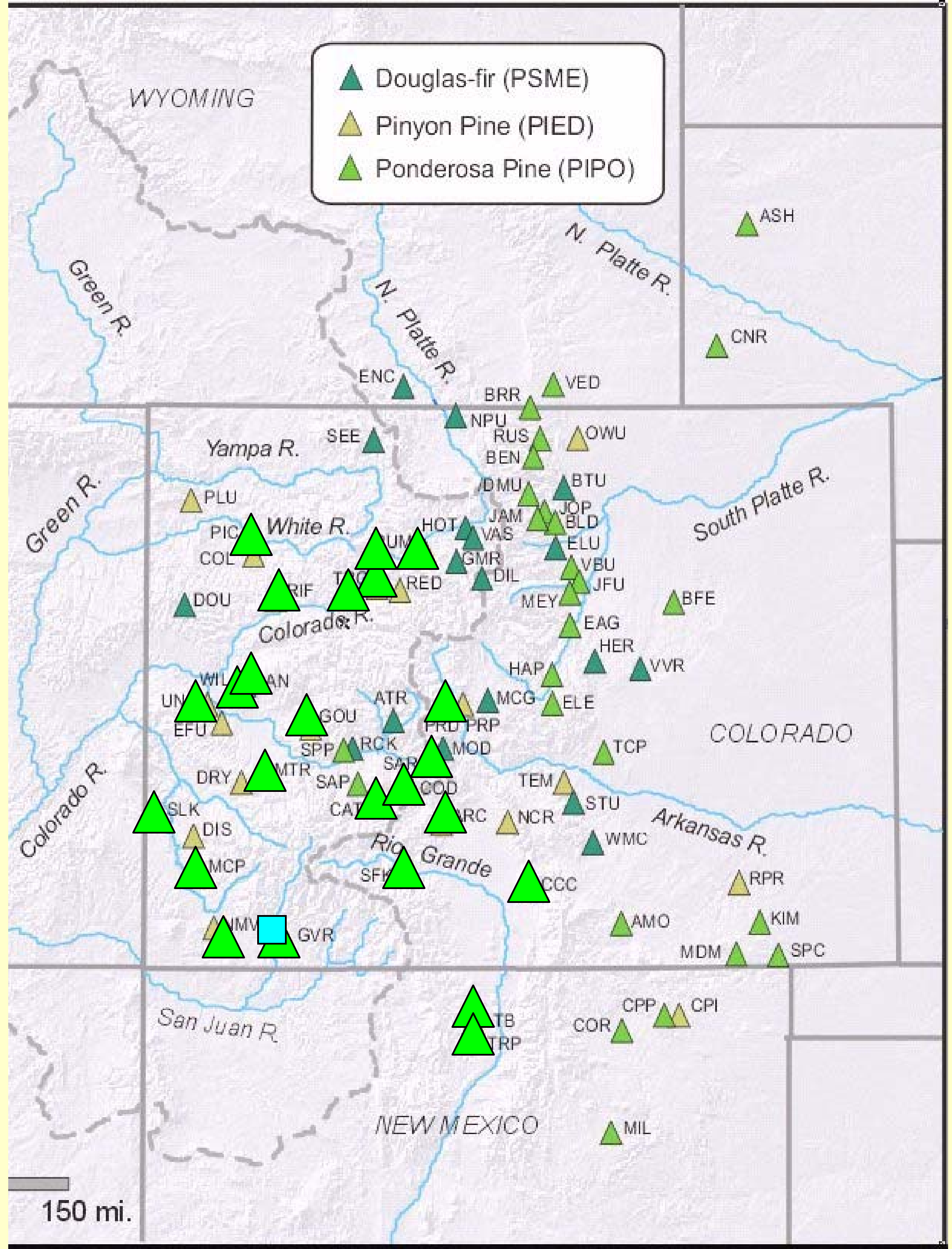
- No chronologies are actually within the upper Animas basin
- But that's OK, because we need trees that will capture the regional flows of moisture that drive variability in Animas flow



Screening the tree-ring data

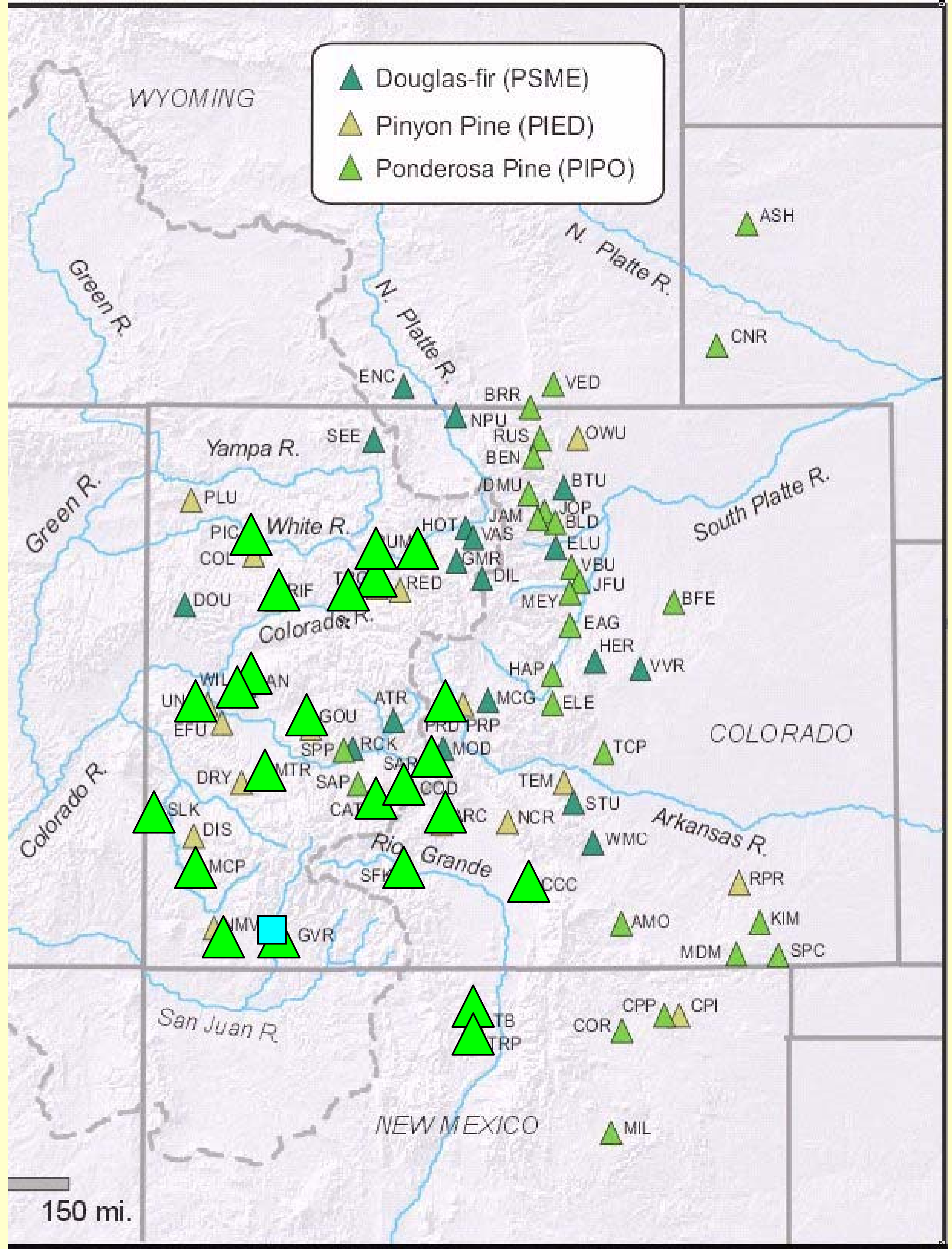
- **Length** – back before 1570 and up through 2002
- **Correlation** – significant (at p<0.05) correlation with Animas flow
- **Location** – not in Front Range/eastern CO

- *Leaves "pool" of 24 chronologies for calibration with Animas flow record*



Correlations between each tree-ring chronology and Animas flow, 1928-2002

SLK11	0.79
MCP	0.78
NAV3	0.77
WIL44	0.76
UNA44	0.76
MTR	0.73
GOU	0.69
TRG61	0.69
RIF17	0.68
CAT	0.65
LTB	0.65
BLU2	0.64
TRP	0.62
GVR	0.62
CCC	0.62
ARC	0.60
SAR	0.59
PUM85	0.59
COD	0.58
SFK	0.58
PRD	0.56
PIC14	0.55
EGL34	0.52
LAN34	0.49

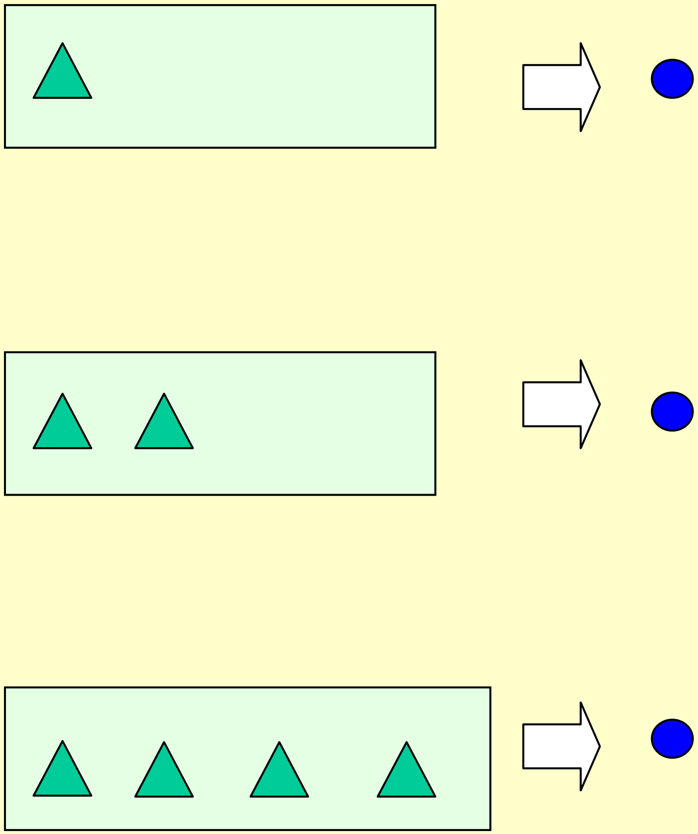


Model calibration: Forward stepwise regression

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)

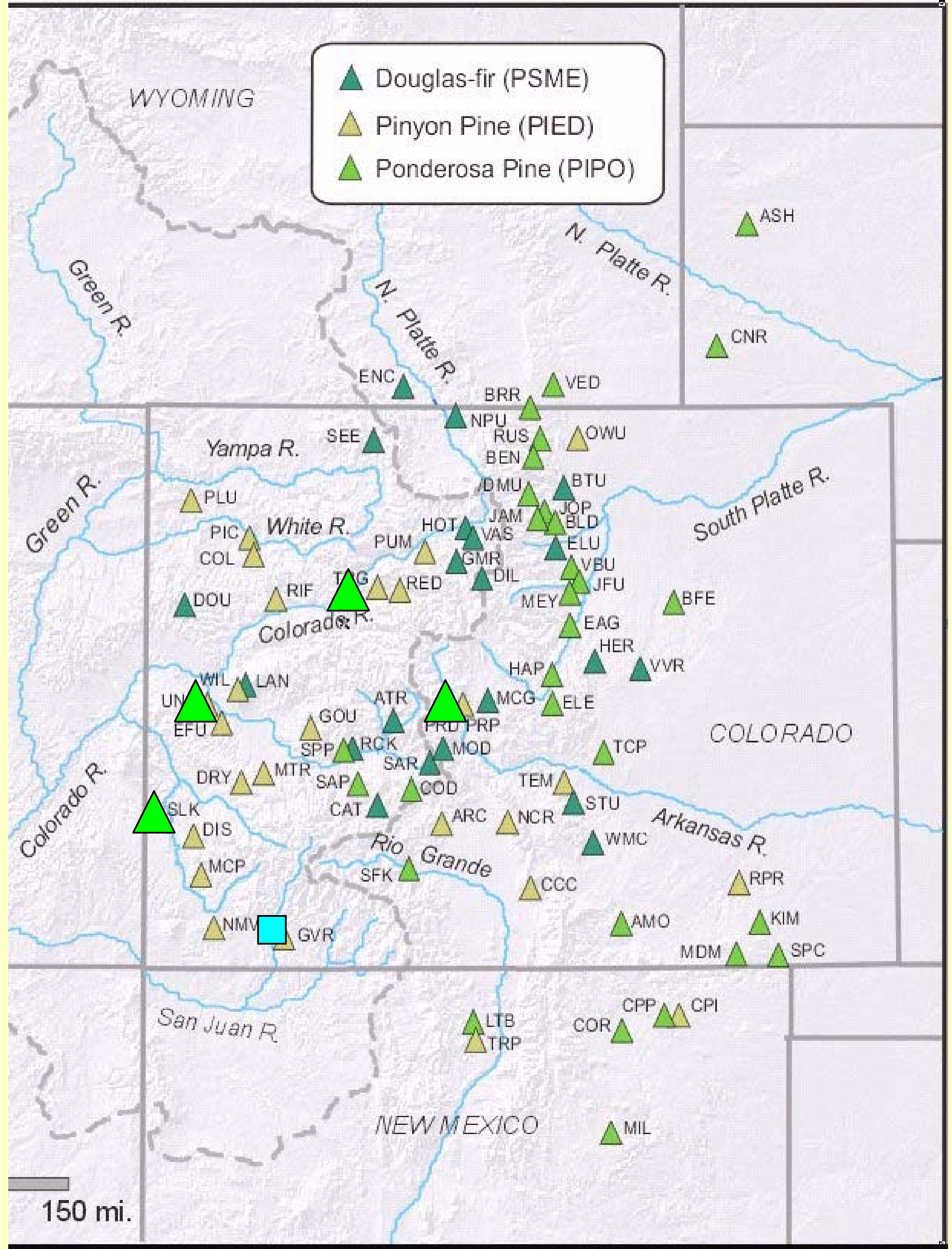
3) The process ends when no additional chronology significantly improves the fit of the regression to the flow record



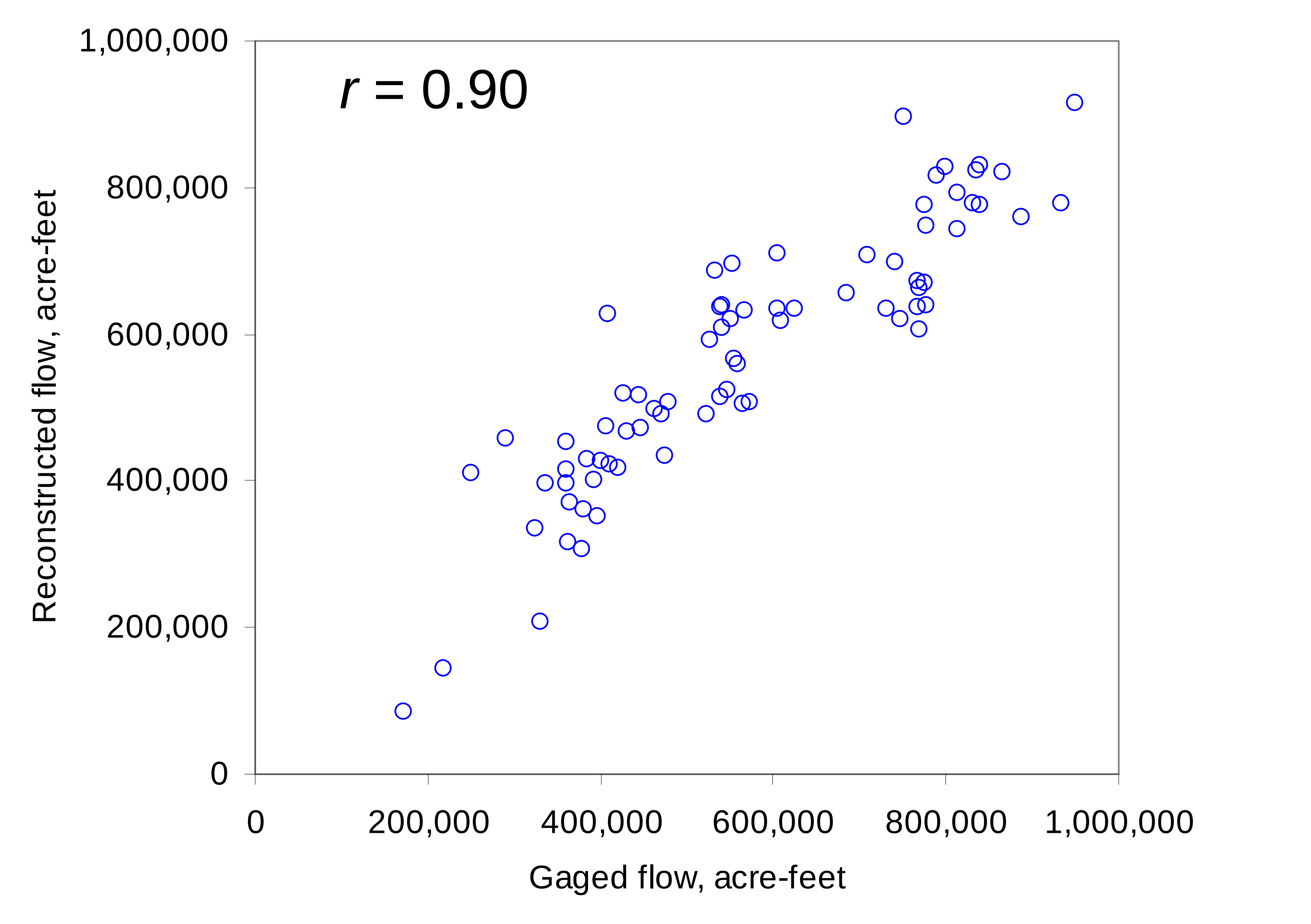
Result of forward stepwise regression

- 4 chronologies (SLK, WIL, TRG, PRD) selected for model
- Correlation of model with Animas flow: ***r* = 0.91**

SLK11	0.79
MCP	0.78
NAV3	0.77
WIL44	0.76
UNA44	0.76
MTR	0.73
GOU	0.69
TRG61	0.69
RIF17	0.68
CAT	0.65
LTB	0.65
BLU2	0.64
TRP	0.62
GVR	0.62
CCC	0.62
ARC	0.60
SAR	0.59
PUM85	0.59
COD	0.58
SFK	0.58
PRD	0.56
PIC14	0.55
EGL34	0.52
LAN34	0.49



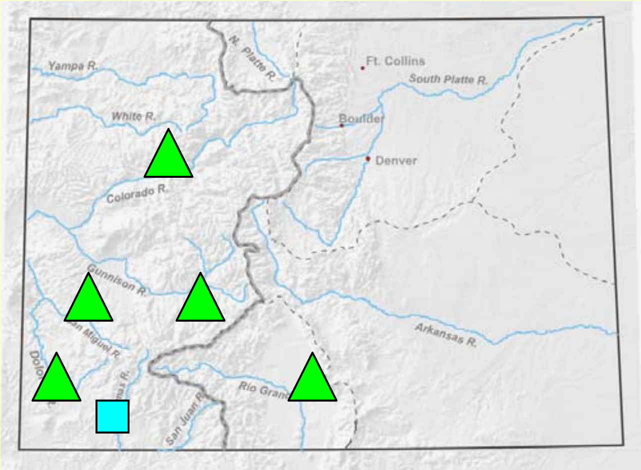
Animas at Durango – fit of reconstructed flows to gaged flows, 1928-2002 (“best-fit” model)



Animas at Durango – fit of two alternate reconstruction models, 1928-2002

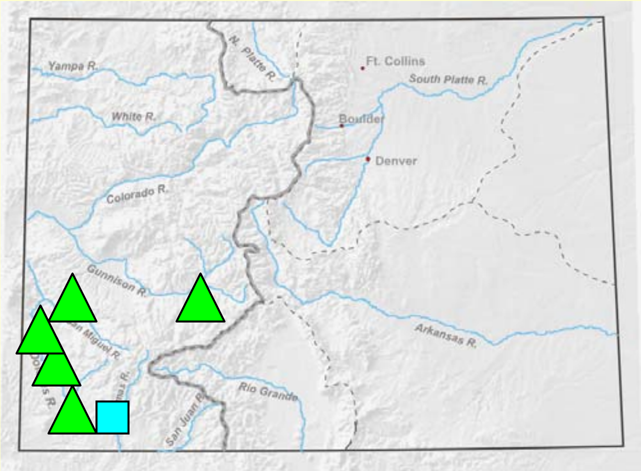
Alternate stepwise model

- Chronologies in best-fit model excluded from pool
- 5 chronologies (MCP, CAT, MTR, BLU2, CCC) selected for model



"Naïve" model

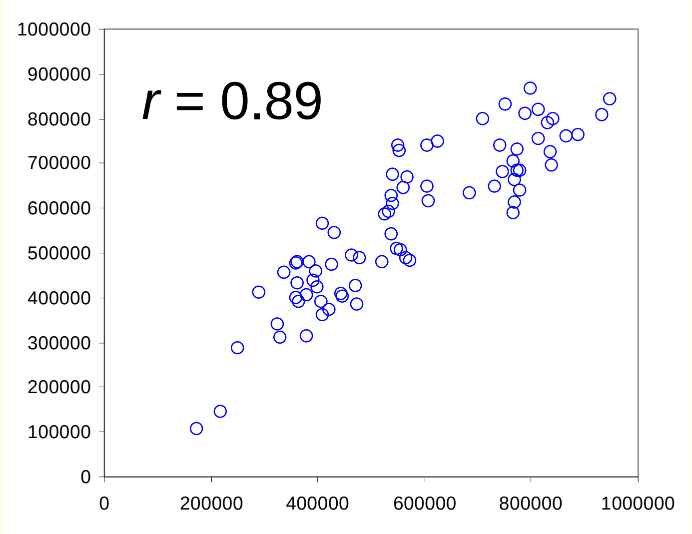
- Mean of the 5 chronologies closest to Animas basin (MCP, CAT, MTR, SLK, NAV) regressed against gaged flow



Animas at Durango – fit of two alternate reconstruction models, 1928-2002

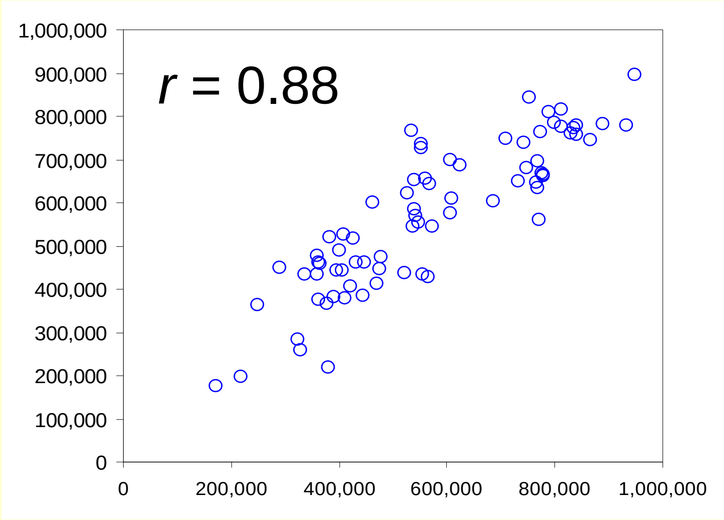
Alternate stepwise model

- Chronologies in best-fit model excluded from pool
- 5 chronologies (MCP, CAT, MTR, BLU2, CCC) selected for model

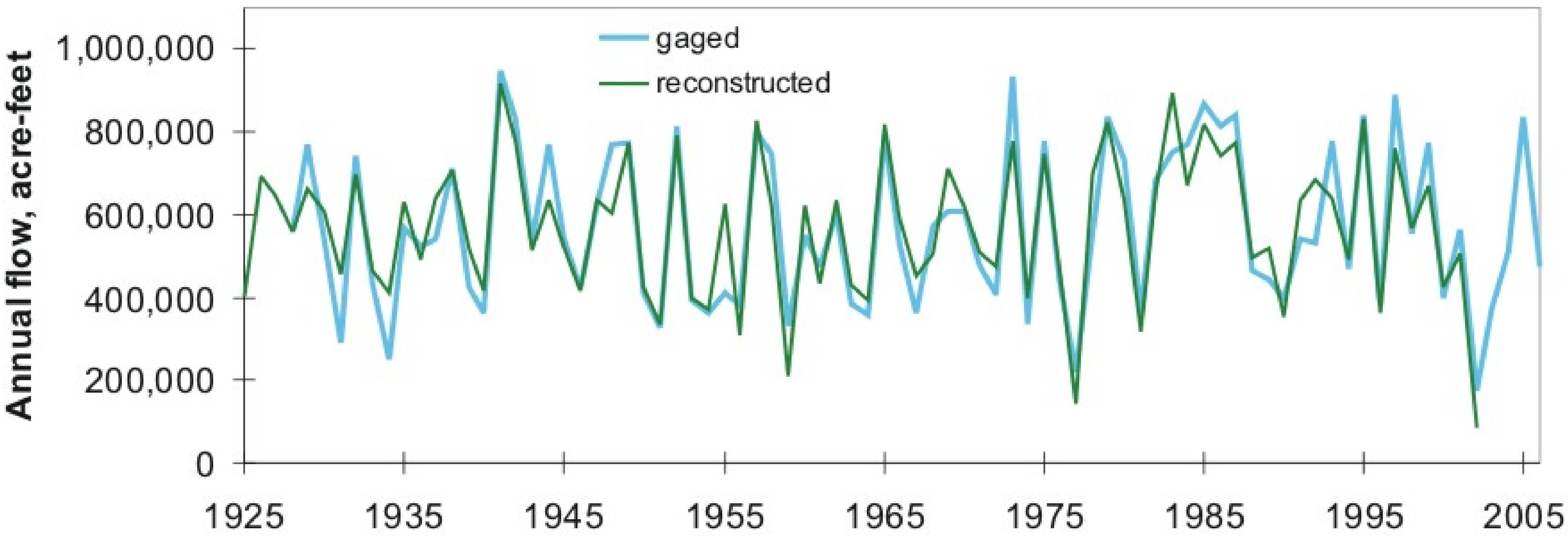


“Naïve” model

- Mean of the 5 chronologies closest to Animas basin (MCP, CAT, MTR, SLK, NAV) regressed against gaged flow

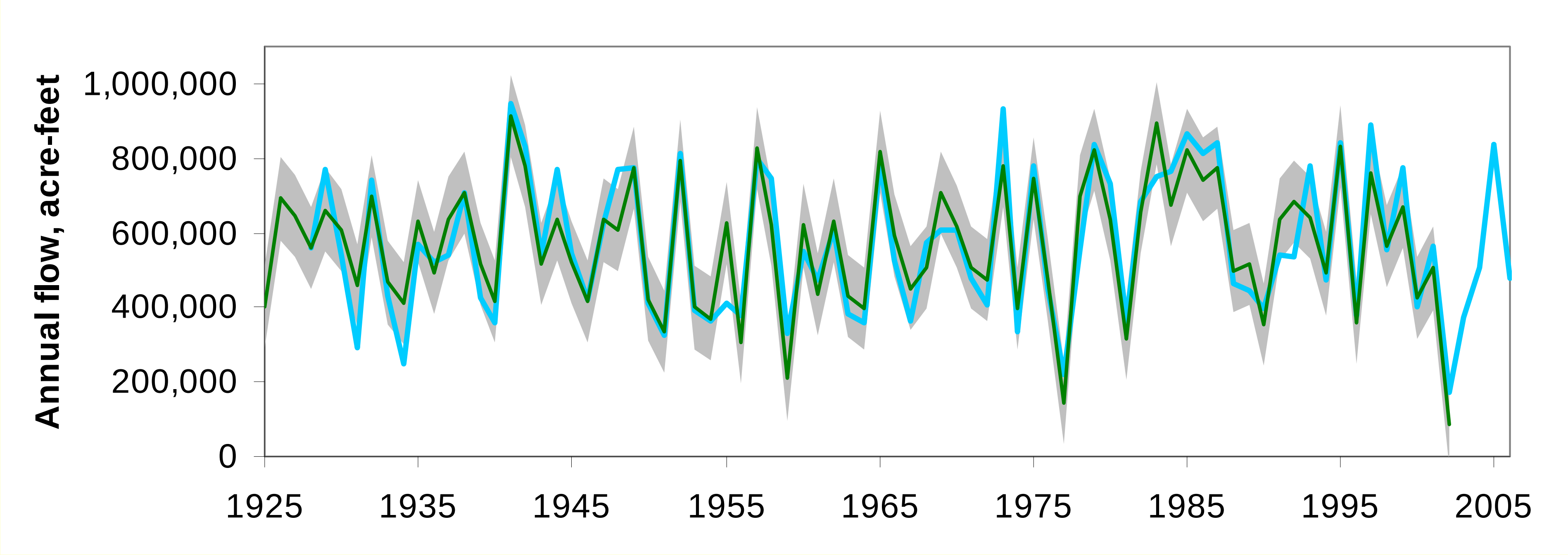


Animas at Durango – fit of reconstructed flows to gaged flows, 1928-2002



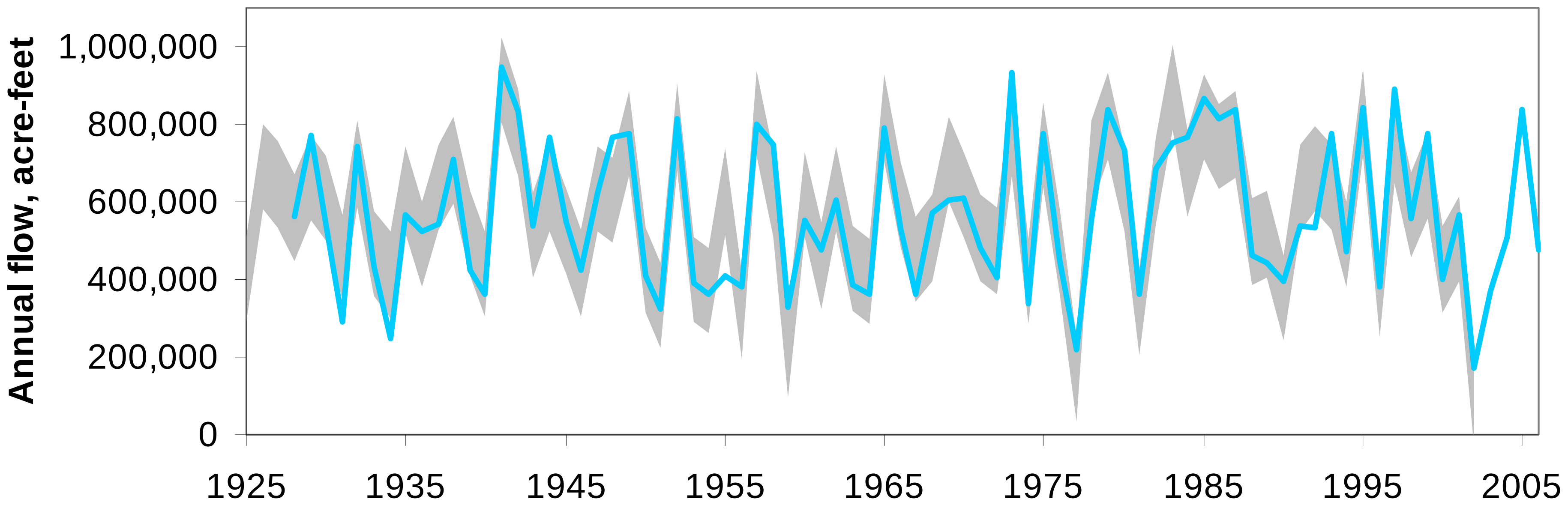
- Calibration: R^2 (explained variance) = 0.81
- Validation: RE (reduction of error) = 0.79
- RMSE (root mean square error) = 86 KAF (~15% of mean flow)

Animas at Durango – fit of reconstructed flows to gaged flows, 1928-2002, with 80% confidence band (gray) based on the errors



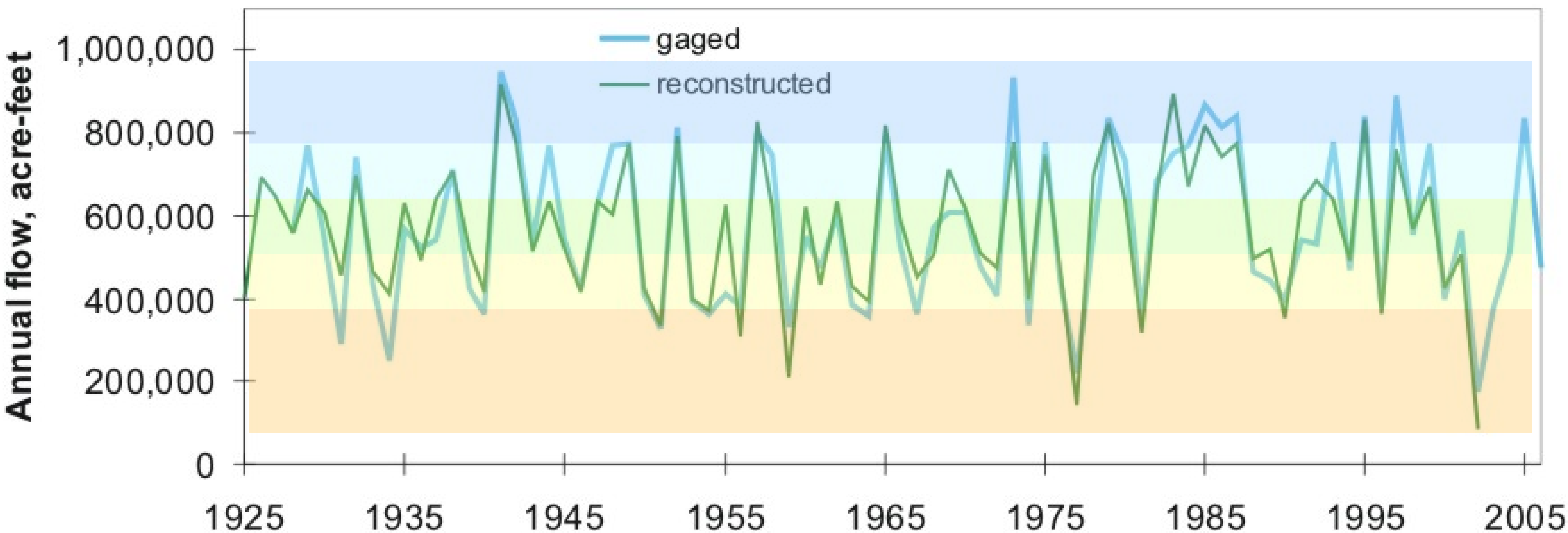
- RMSE = 1 standard deviation
- 80% confidence intervals = +/-1.282 SD (+/- 110 KAF)

Animas at Durango – gaged flows, 1928-2002, and 80% confidence band (gray) around reconstructed flows



- RMSE = 1 standard deviation
- 80% confidence intervals = +/-1.282 SD (+/- 110 KAF)

Animas at Durango – How well does the reconstruction capture the category (quintile) of gaged flow?



- Gaged and reconstructed flows split into 5 quintiles: very wet (80th-100th percentile, wet (60-80), average (40-60), dry (20-40), very dry (0-20)
- Each quintile contains 15 years (75 yrs / 5)

Animas at Durango – How well does the reconstruction capture the category (quintile) of gaged flow?

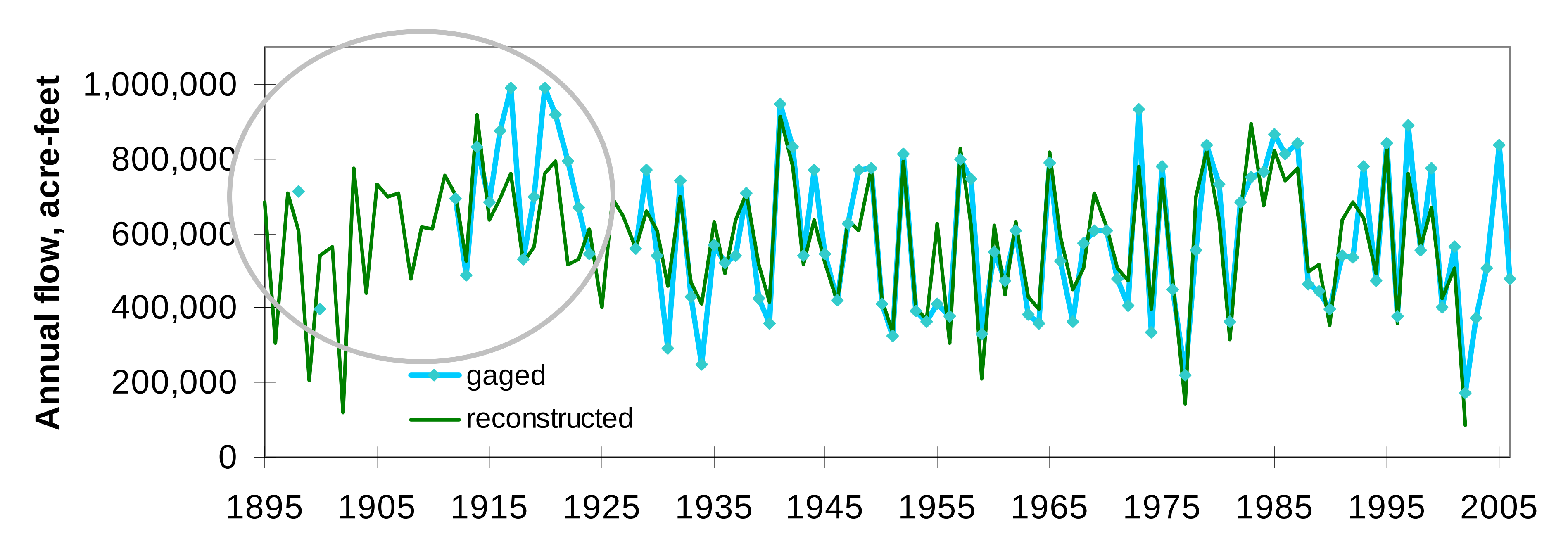
Reconstructed flow

Gaged flow

QUINTILE	very wet	wet	average	dry	very dry
very wet	**13**	2			
wet	2	**9**	4		
average		4	**8**	3	
dry			3	**9**	3
very dry				3	**12**

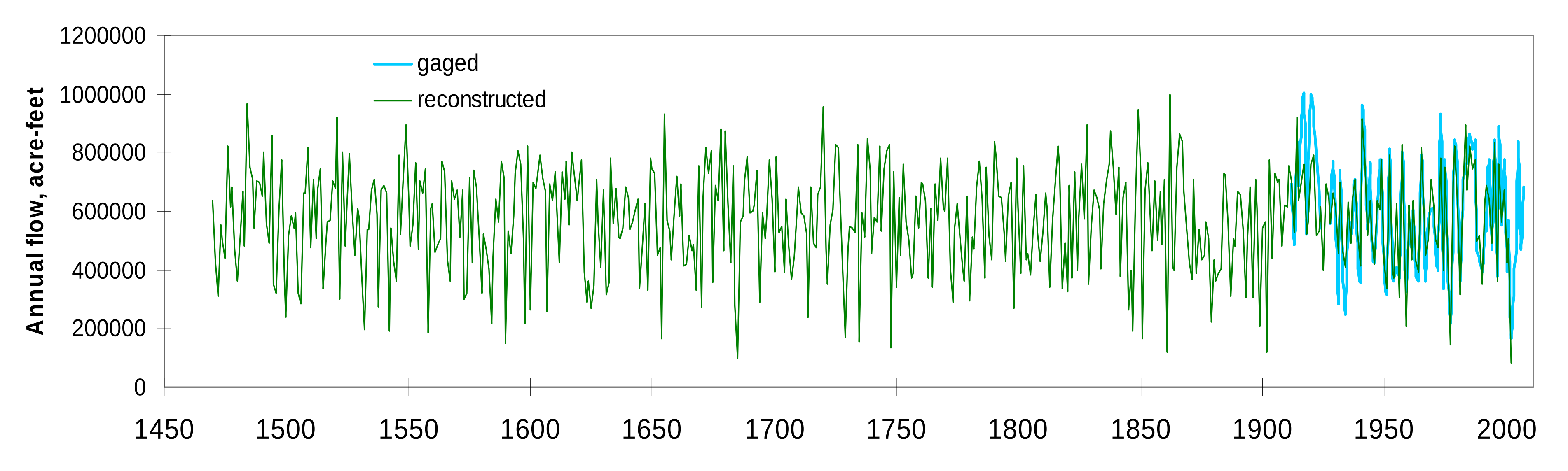
- Overall, reconstruction correctly classifies 51 of 75 years (69%)
- All reconstructed flows are within one category of the correct quintile

How does the Animas at Durango reconstruction fit to independent gage data (1898, 1900, 1912-1925)?

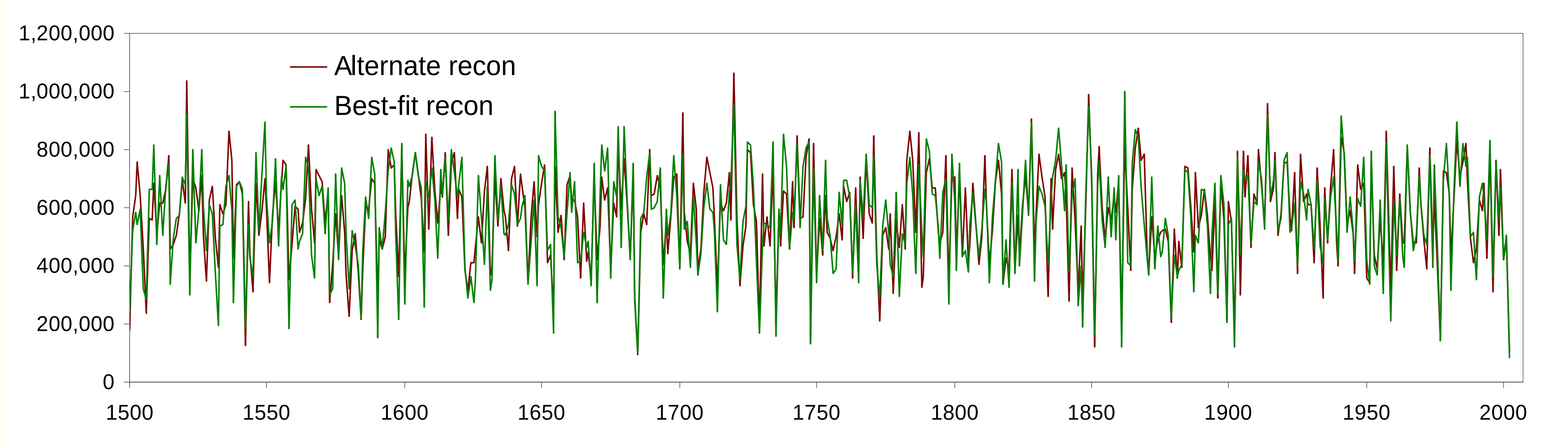


- Reconstruction doesn’t capture full extent of 1917-1922 high flows
- Overall, fit with the independent data (R2 = 0.50) is worse than with calibration data, but still acceptable

Animas at Durango – reconstructed annual flows, 1470-2002 ("best-fit" model)



Animas at Durango – reconstructed annual flows, 1500-2002, "best-fit" model vs. alternate stepwise



- Correlation of *r* = 0.90 between two flow reconstructions developed from independent sets of tree-ring data

- Indicates strength of regional climate/hydro signal captured by all tree-ring chronologies in the area

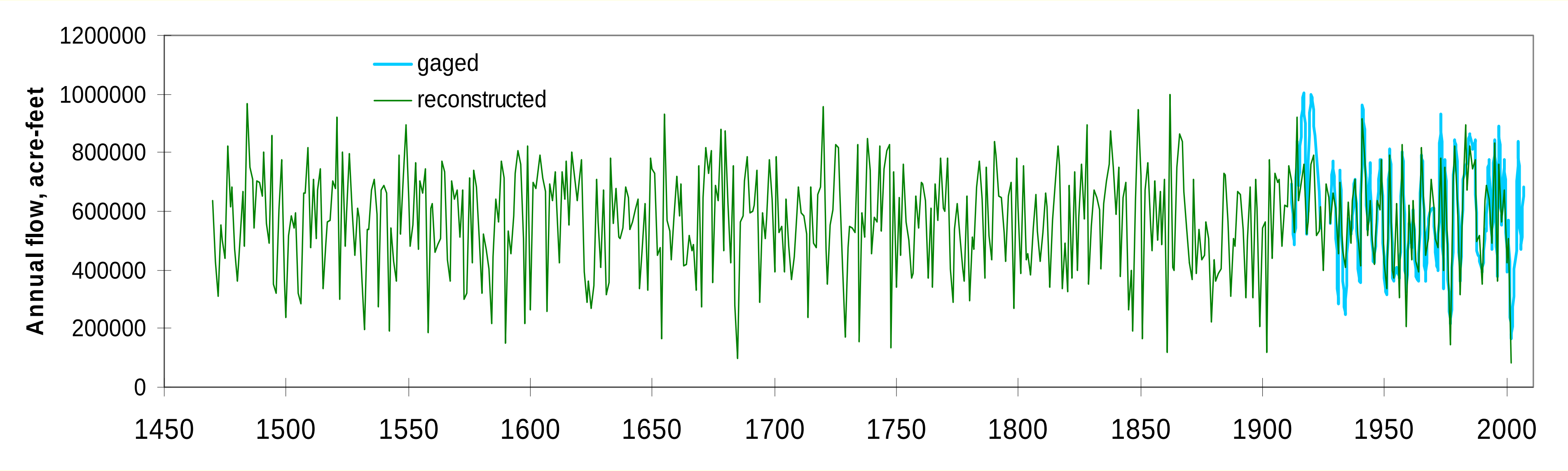
Questions that can be answered with the new Animas reconstruction

- How does the most recent drought on the Animas compare to the ~500-year paleo record?

- What are the most severe and sustained droughts that have occurred prior to 1900?

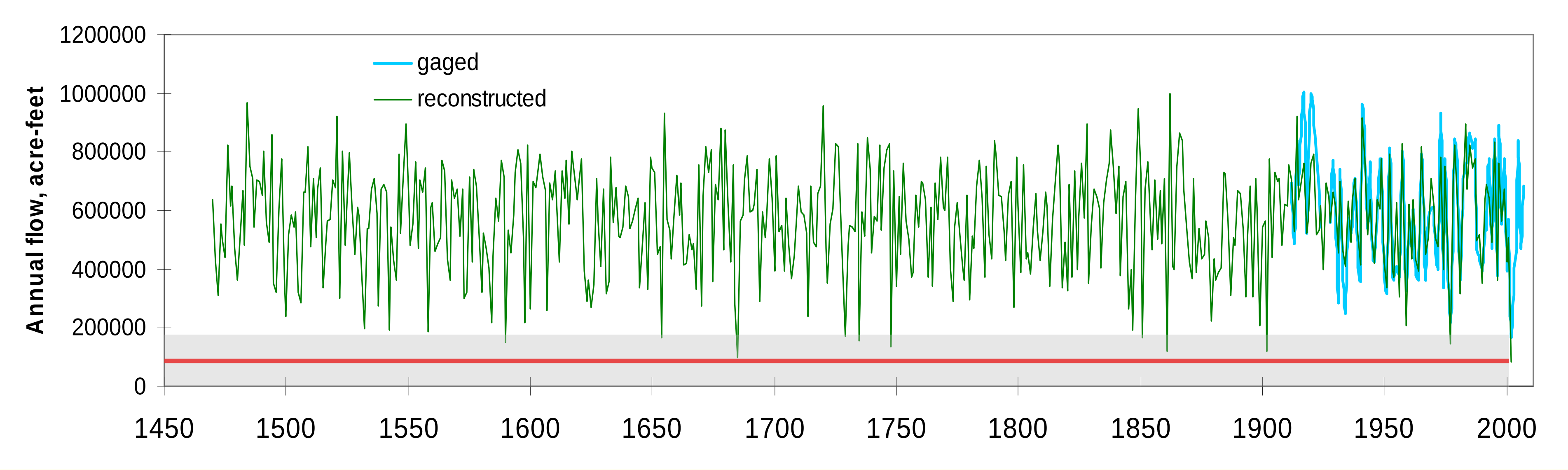
- How does the 20th century—our usual frame of reference—compare to the previous four centuries?

Animas at Durango – reconstructed annual flows, 1470-2002



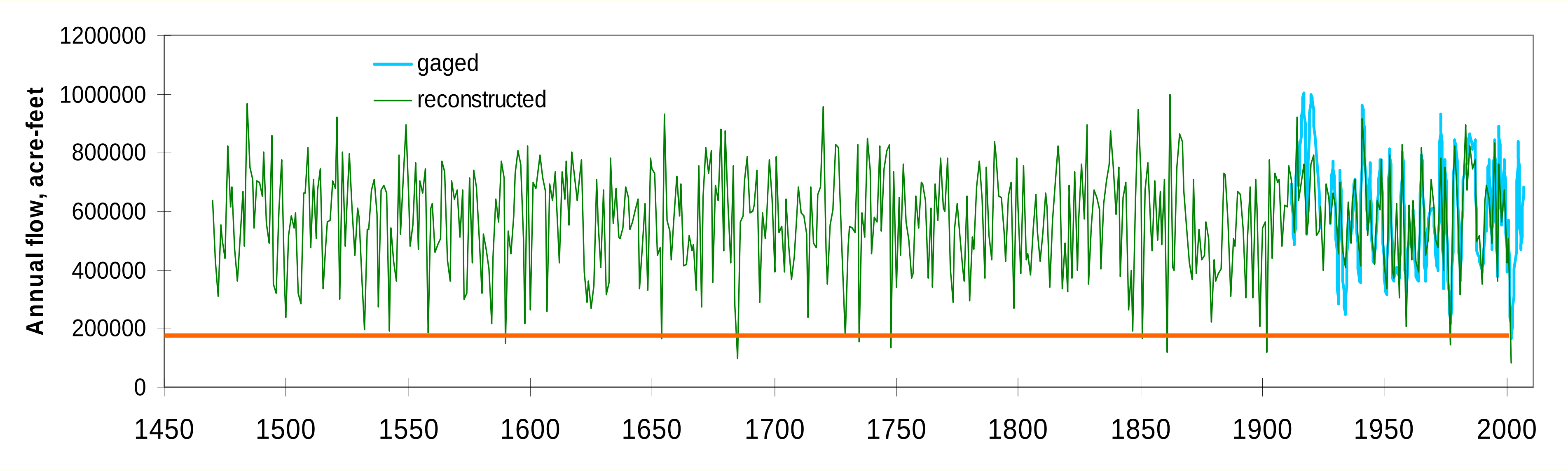
- periods of higher and lower interannual variability

Was 2002 the lowest flow of the past ~530 years?



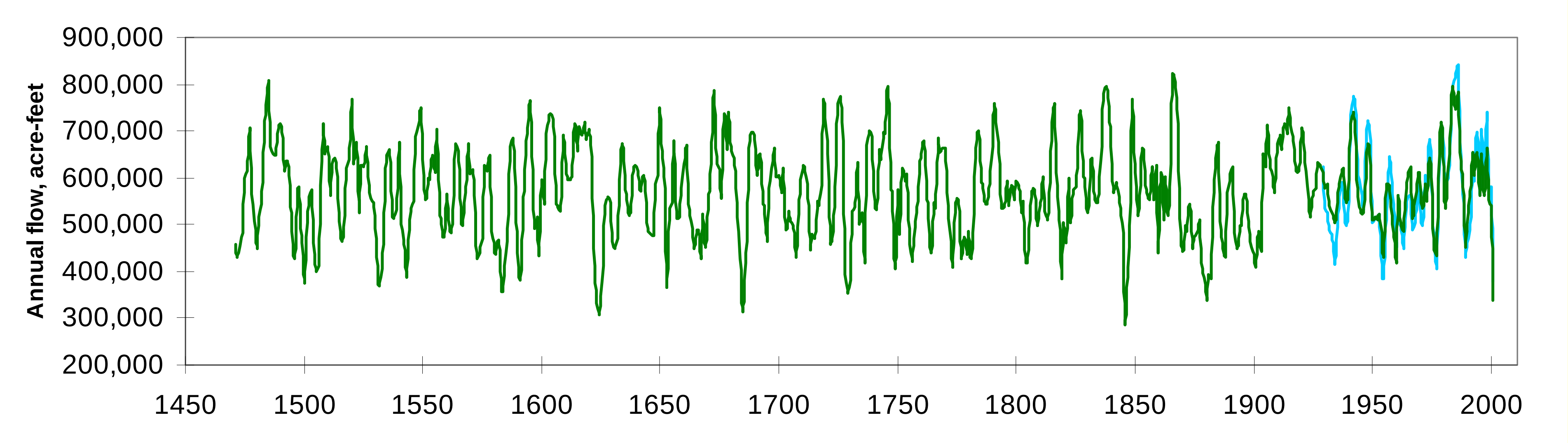
- 2002 reconstructed flow (84 KAF; red line) is the lowest since 1470, but underestimates the 2002 gaged flow (173 KAF)
- Gray band shows 80% confidence around 2002 reconstructed flow

Was 2002 the lowest flow of the past ~530 years?



- 11 reconstructed flow years are lower than the 2002 gaged flow (173 KAF; orange line)
- *Safe statement:* 2002 was one of the 10 lowest flows of the past 530 years, and possibly the lowest.

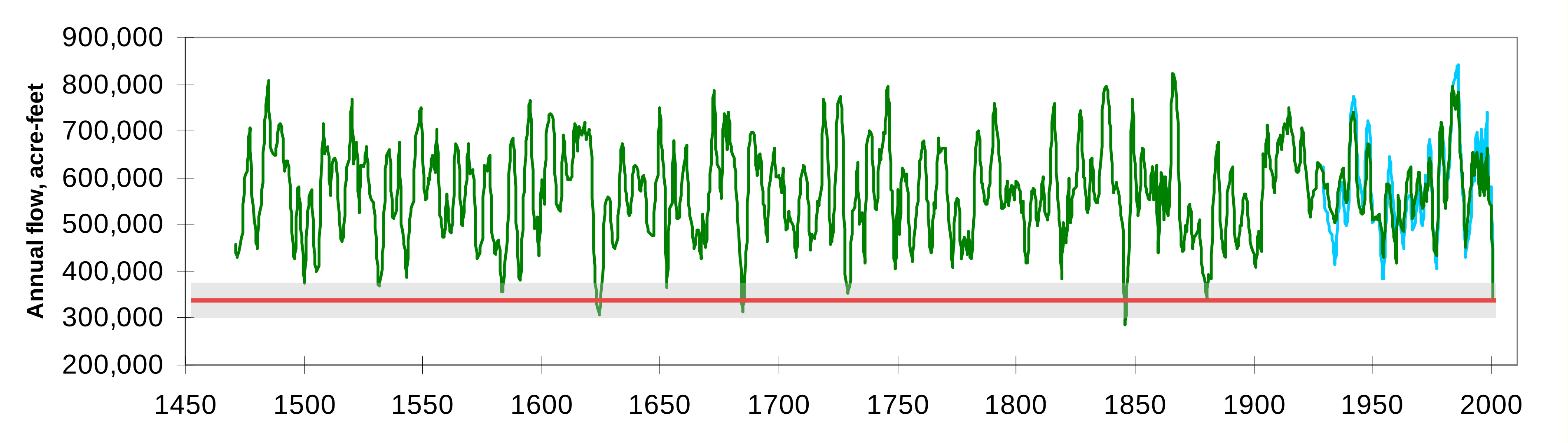
Animas at Durango – reconstructed annual flows, 1470-2002, with 3-year running mean



- Severe 3-year droughts in 1620s, 1680s, 1840s, 1870s, 2000s

Animas at Durango – reconstructed annual flows, 1470-2002, with 3-year running mean

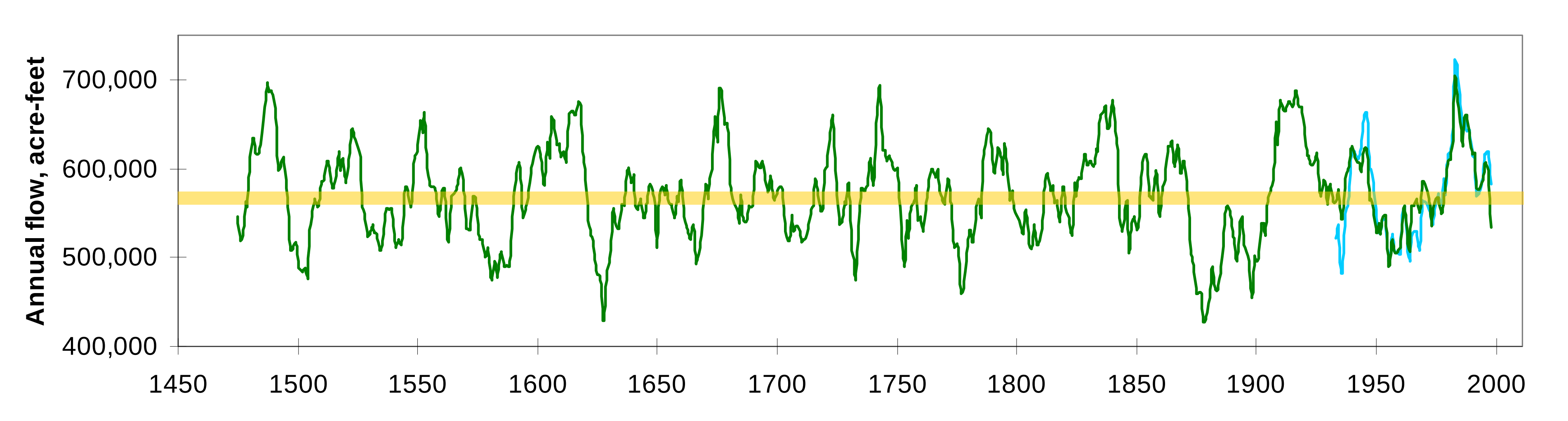
Were any past 3-yr droughts worse than 2002-04 (350 KAF gaged)?



- Three 3-year periods before 1900 have lower reconstructed flow than 2002-04 gaged (red line)

- Considering uncertainty (80% CI), 1845-47 is very likely to have had lower flow than 2002-04 gaged

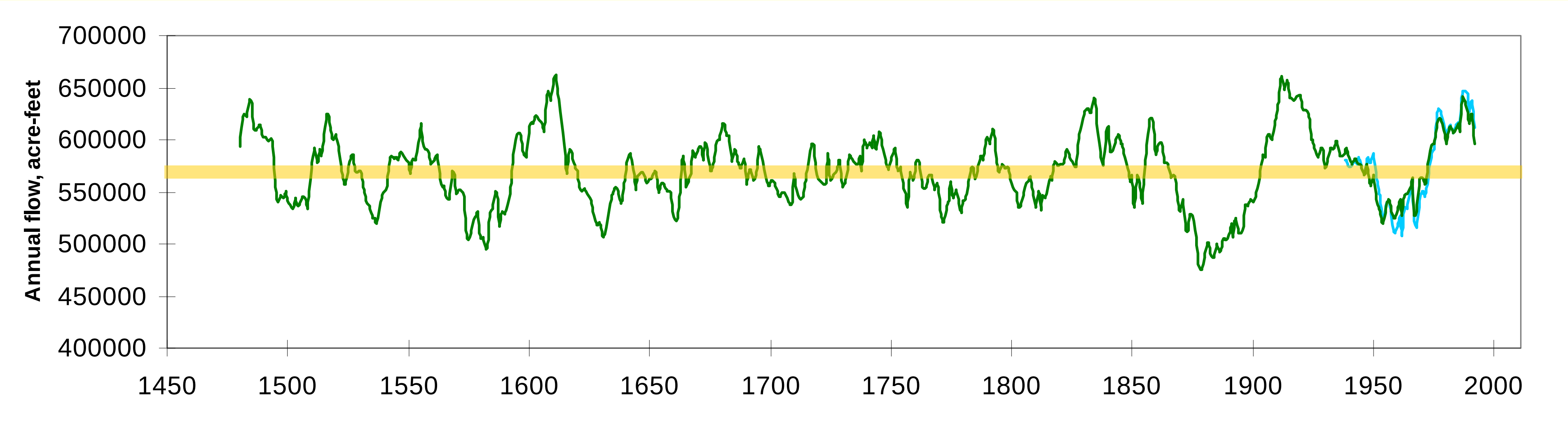
Animas at Durango – reconstructed annual flows, 1470-2002, with 10-year running mean



- 5 driest and wettest non-overlapping 10-yr periods:

Driest	Wettest
1873-1882	*1978-1987*
1623-1632	1482-1491
1893-1902	1738-1747
1772-1781	1671-1680
1576-1585	*1912-1921*

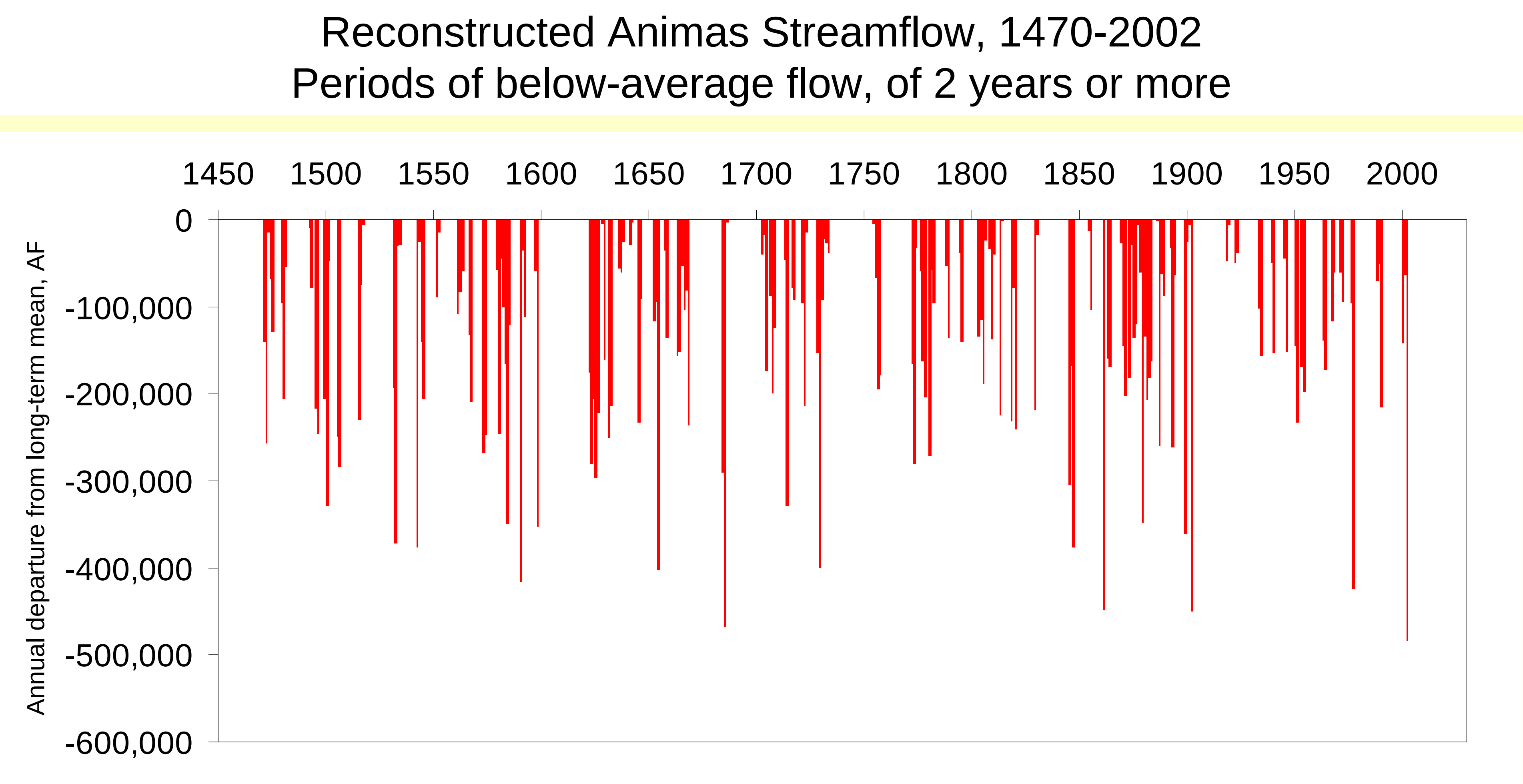
Animas at Durango – reconstructed annual flows, 1470-2002, with 20-year running mean



- 5 driest and wettest non-overlapping 20-yr periods:

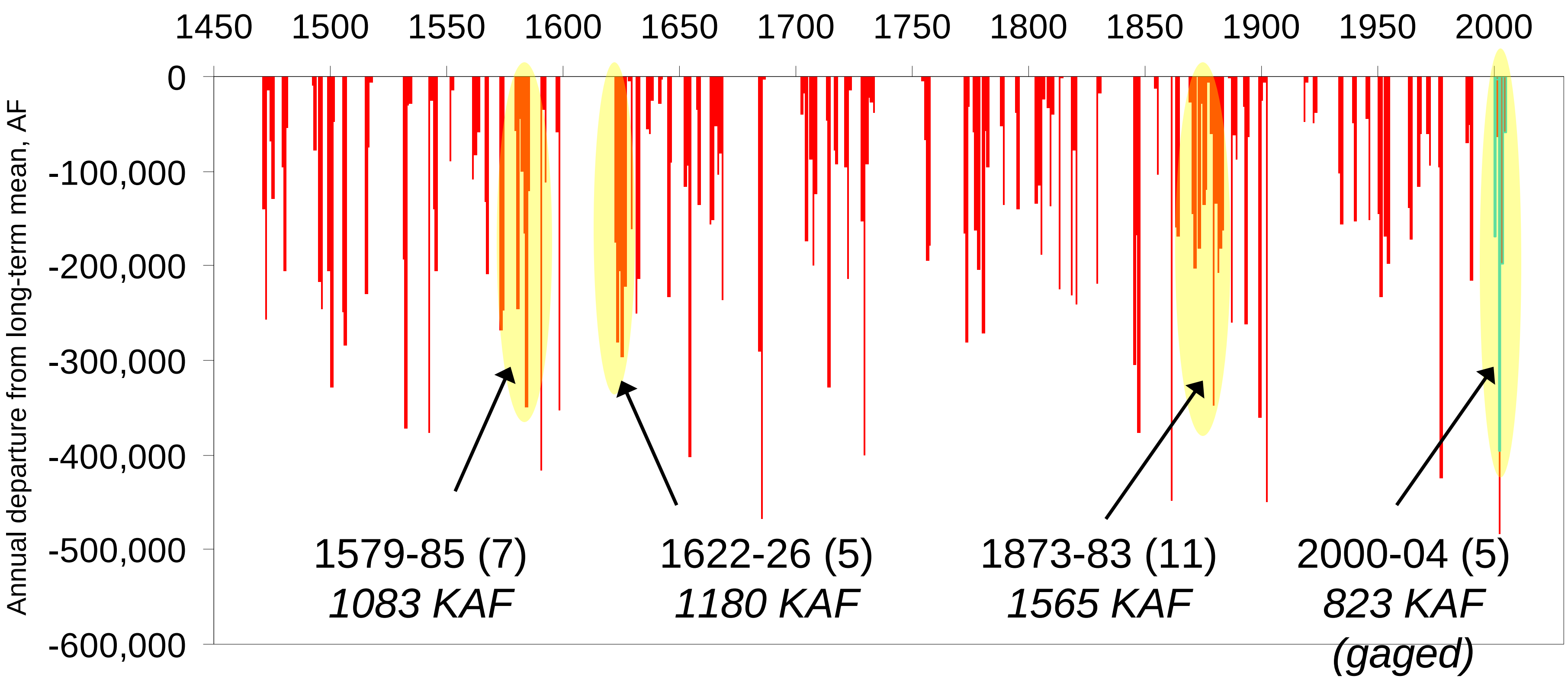
Driest	**Wettest**
1870-1889	1602-1621
1573-1592	*1903-1922*
1622-1641	1825-1844
1945-1964	*1978-1997*
1528-1547	1475-1494

Multi-year droughts: unevenly distributed over time, with some longer droughts before 1900



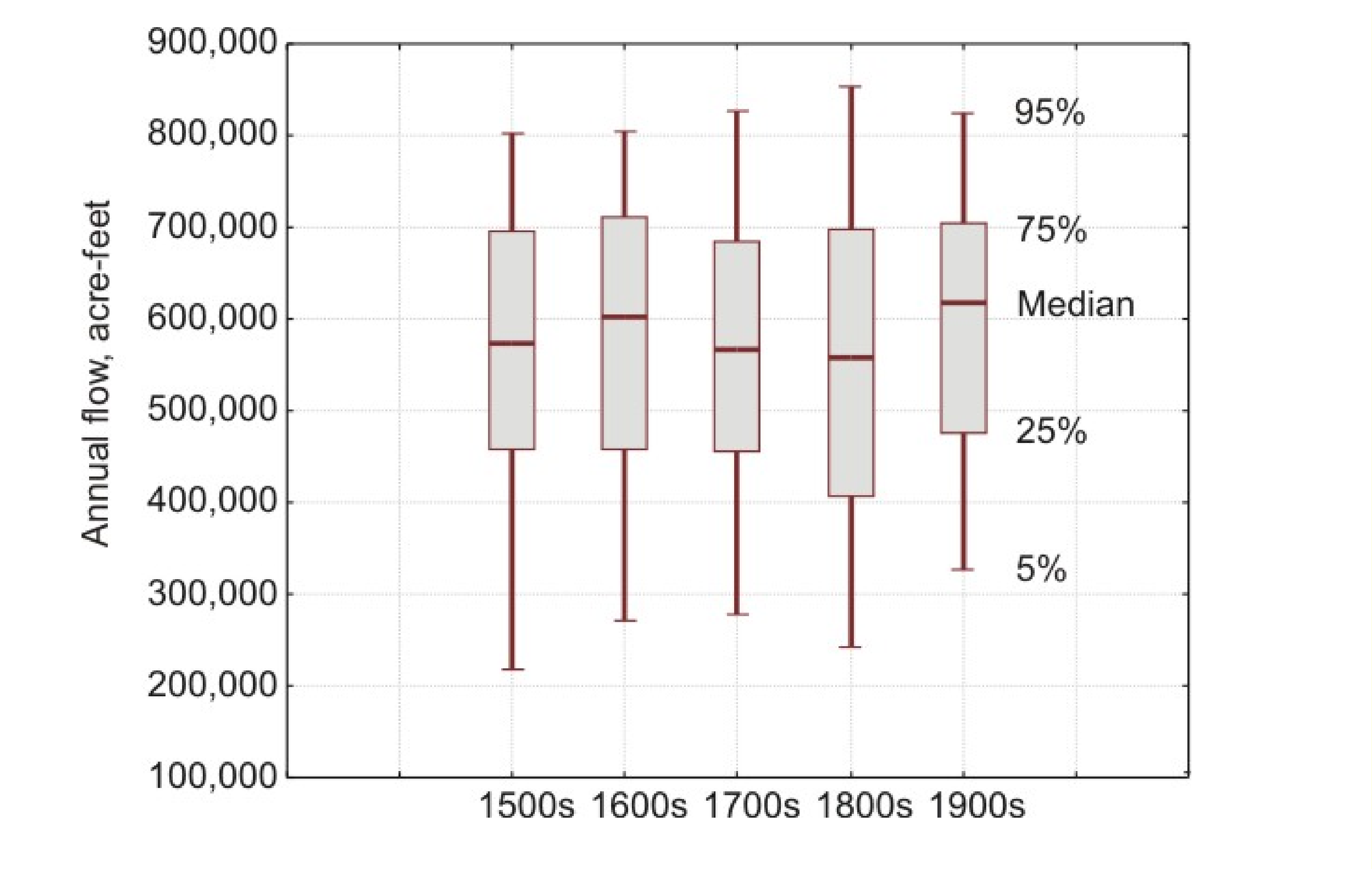
Multi-year droughts: unevenly distributed over time, with some longer droughts before 1900

Reconstructed Animas Streamflow, 1470-2002
Periods of below-average flow, of 2 years or more



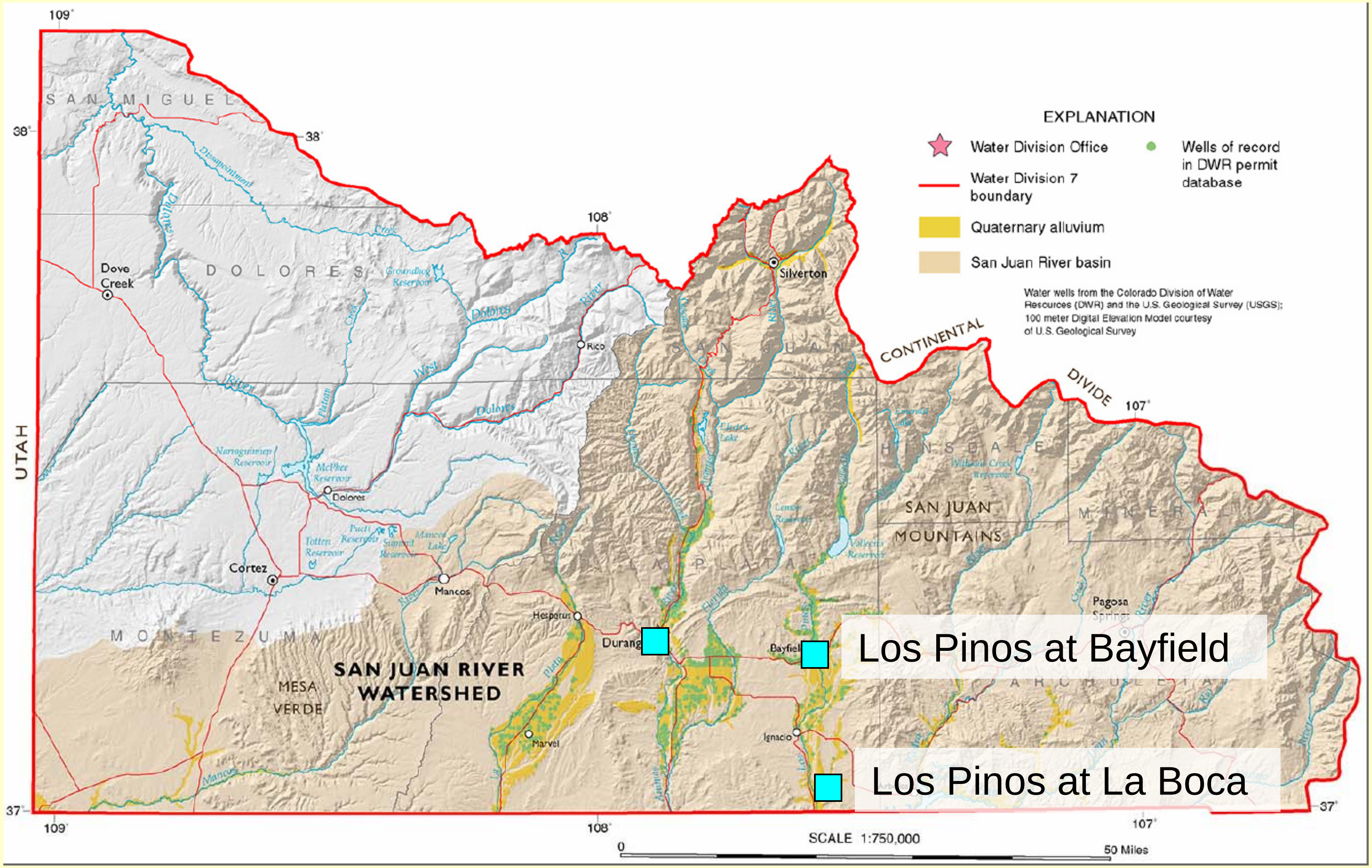
- The reconstruction tends to *underestimate* the persistence of 20th century droughts, so pre-1900 droughts may have been worse than shown

Distribution of annual flows by century: non-stationary behavior

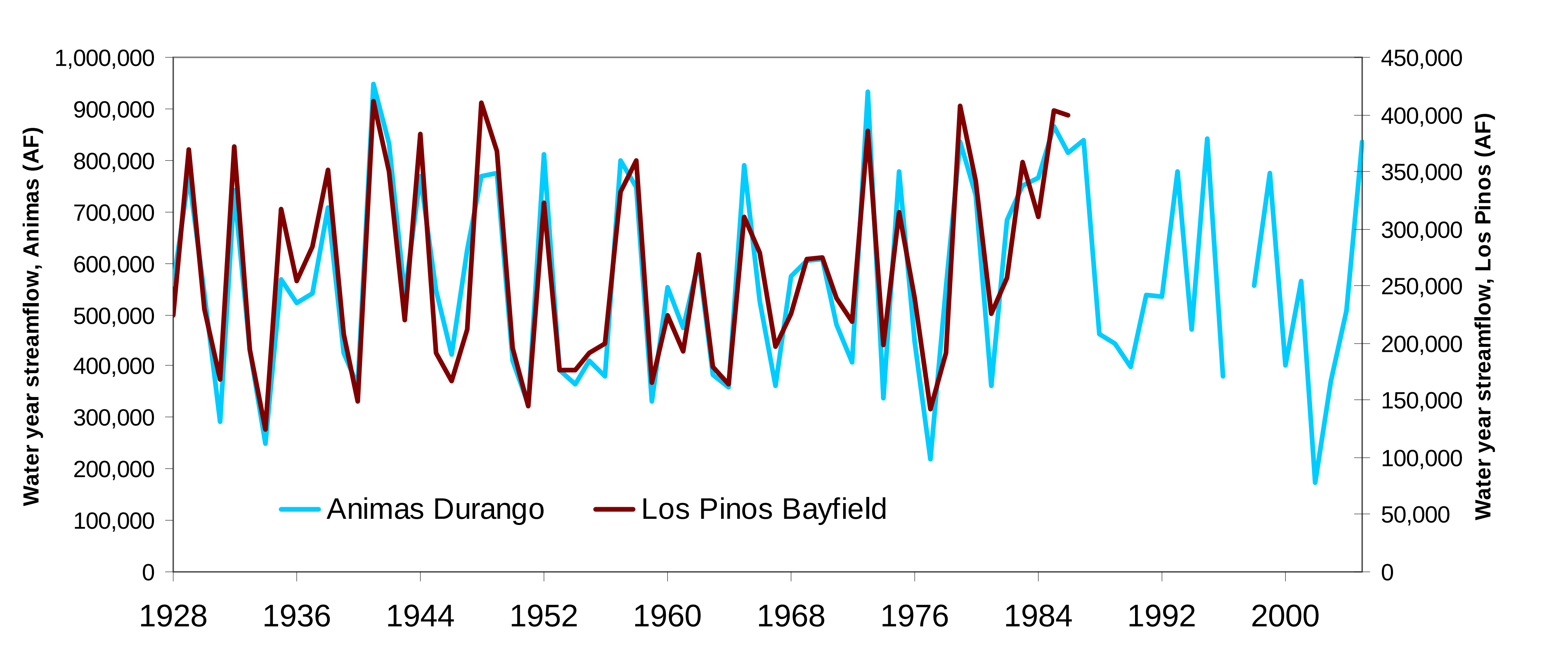


- 1900s had higher median flows, and narrower distribution of flows, than previous centuries

Los Pinos - a case study of gage record quality and impacts on reconstructions

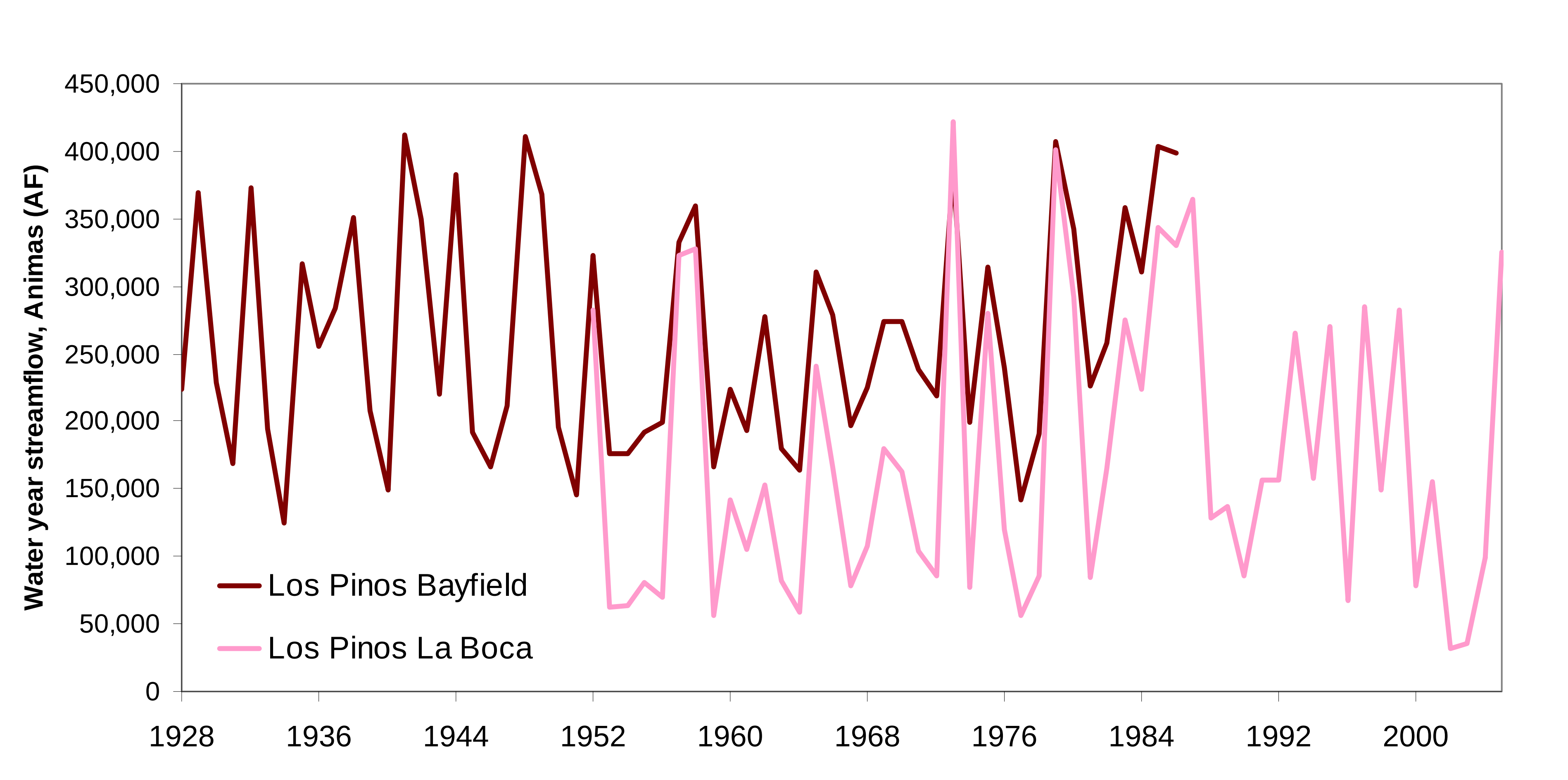


Los Pinos at Bayfield



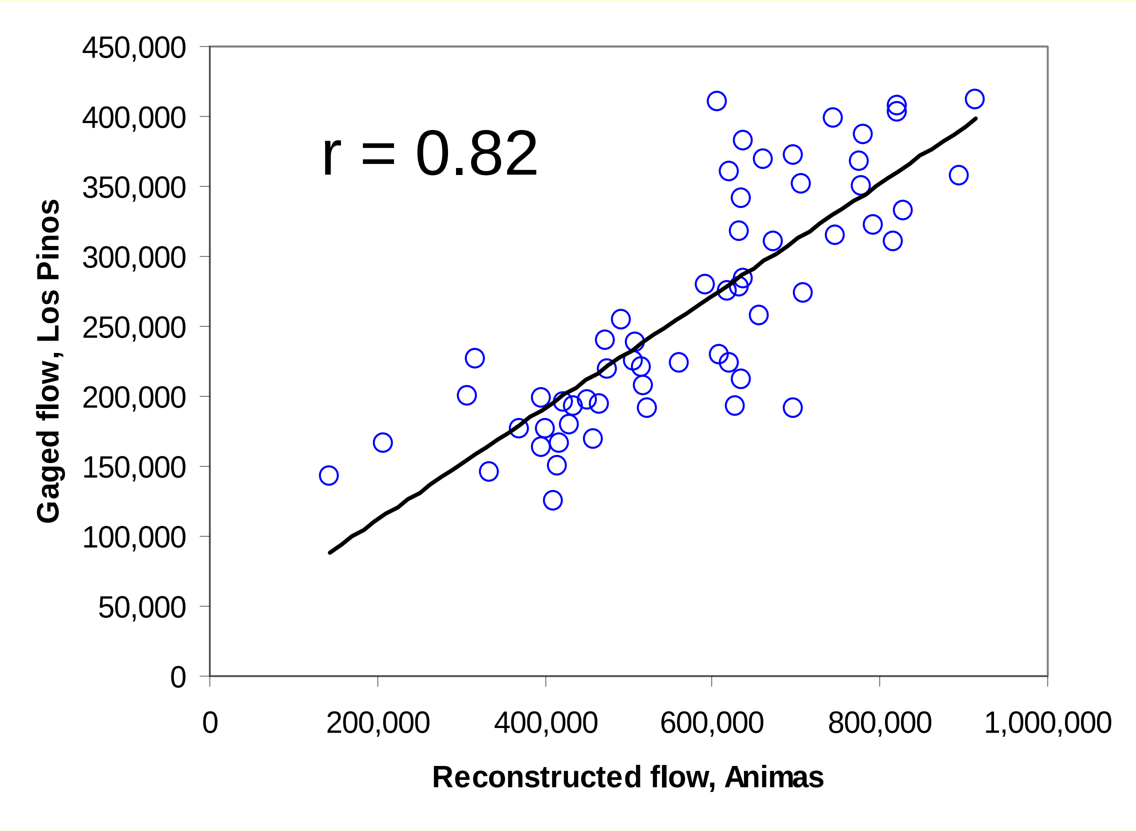
- Los Pinos at Bayfield is above most ag depletions (but below Vallecito Res.) and matches the Animas record well (r = 0.92)
- Unfortunately, record ends in 1986
- Influence of Vallecito seen in diminished extremes after ~1940?

Los Pinos at La Boca

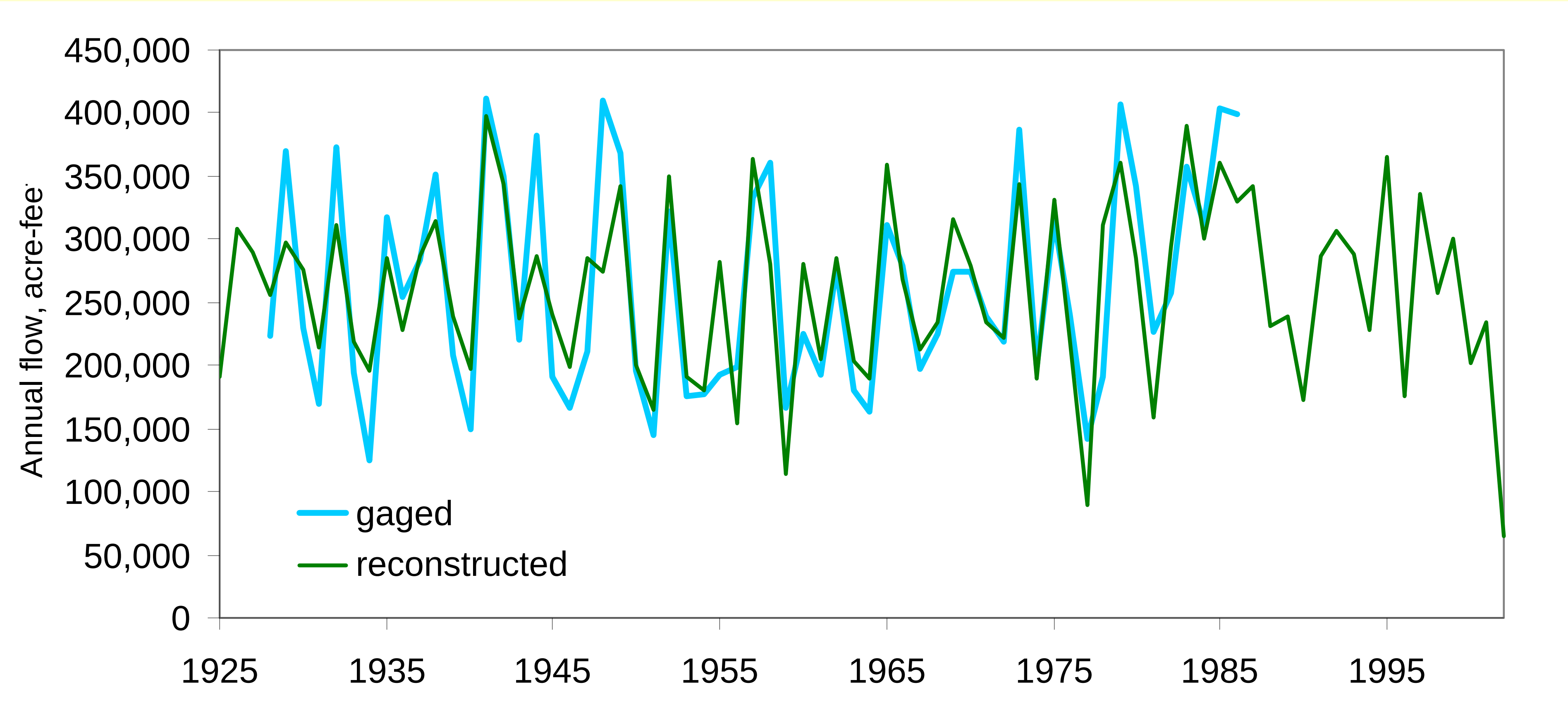


- Los Pinos at La Boca extends to present, but shows ~100 KAF of depletions vs. Bayfield gage, with “flattening” of variation in low flows

Re-scaling of Animas reconstruction to fit Los Pinos at Bayfield gage record

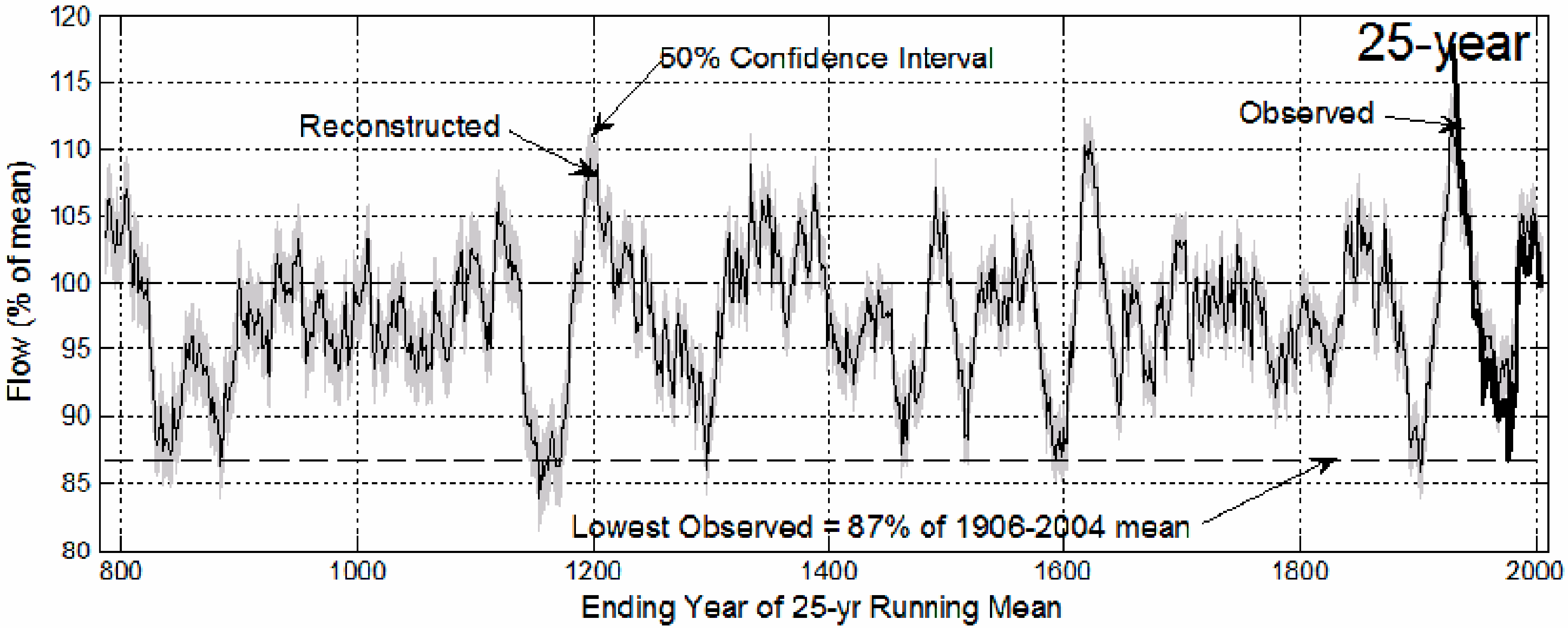


Los Pinos at Bayfield reconstruction model vs. gaged flows



- Calibration: R^2 (explained variance) = 0.67
- Full reconstruction would be identical to Animas at Durango, just scaled differently

Extending the window onto the past: Colorado River at Lees Ferry, reconstructed annual flows AD 762 – 2005, with 25-year running mean



Because of the relationship of Animas and Lees Ferry gaged flow, this reconstruction is very applicable to the Animas (re-scale to Animas)

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

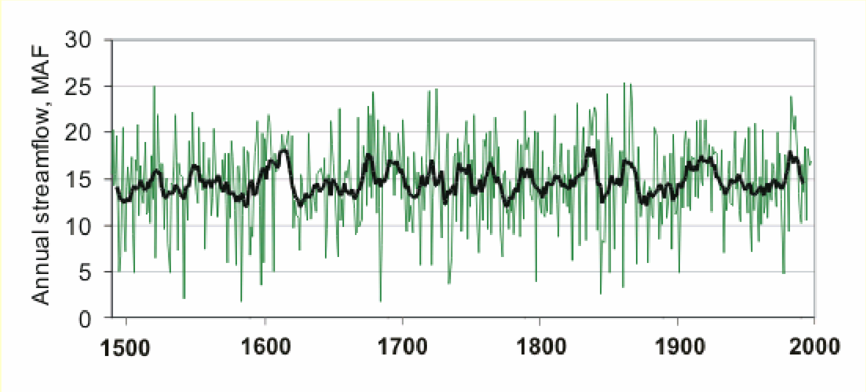
What version(s) of the Animas at Durango reconstruction would you like to have available?

a) best-fit reconstruction (1470-2002)

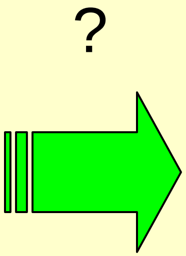
b) “naïve” reconstruction (1491-2002)

c) extended reconstruction (762-2005; re-scaled Lees Ferry)

How can the new Animas reconstruction of streamflow can be used in water management & drought planning?



Reconstruction data



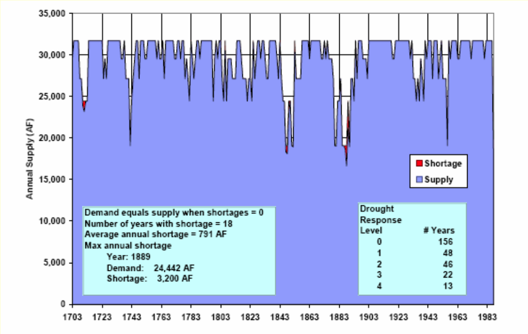
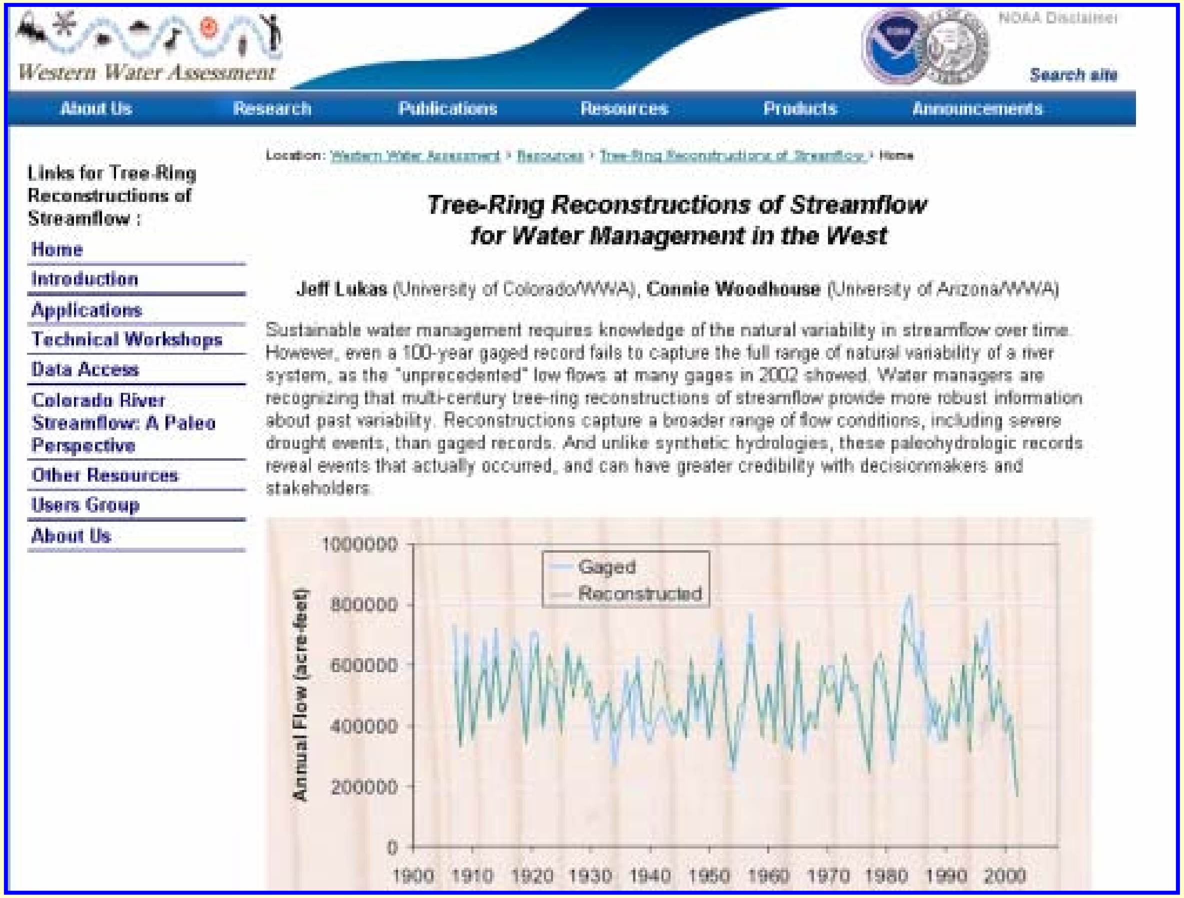


Figure 5. Demands & Supplies: 15% Reduced Flow Hydrology, Current Trends Scenario (demand = 31,700 AF/year).

Decision support

Web resource for streamflow reconstructions



- Technical workshops
- Descriptions of applications
- Access to data
- Other resources
- Colorado River Streamflow: A Paleo Perspective

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

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*

Who's using streamflow reconstructions?

Colorado	Colorado Water Conservation Board (2) Denver Water (2) Northern Colorado Water Conservancy District (1,2) Colorado River Water Conservation District (2) Rio Grande Water Conservation District (1) U.S. Bureau of Reclamation – Aspinall Unit (2) City of Boulder (2) City of Westminster (1)
New Mexico	New Mexico Interstate Stream Commission (2)
Arizona	Salt River Project (Phoenix) (2) City of Chandler (1)
California	California Department of Water Resources (2)
Multi-state	U.S. Bureau of Reclamation - Lower Colorado (2)

- *This list is skewed towards type 2 applications; we don't hear about many type 1 applications*

Web survey of workshop participants, 4/08 (n = 30)

4. How have tree-ring data been used by you, your organization, or organizations that you consult for? (select all that

	Response Percent
To broaden understanding of hydrologic variability	75.0%
To educate users/public	46.4%
To educate board or other decision-makers	50.0%
As input into a water system model or other model	25.0%
For quantitative analysis, but not in a modeling environment	14.3%
To inform planning and decision-making	53.6%
I have not used tree ring data in my organization	17.9%

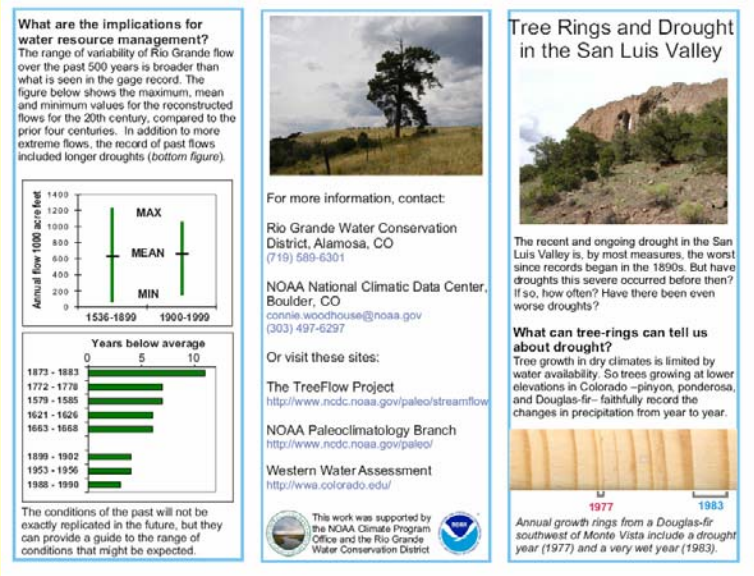
Web survey of workshop participants, 4/08 (n = 30)

7. Do you or individuals in your organization have any of the following concerns that might limit use of tree ring data? (
that apply)

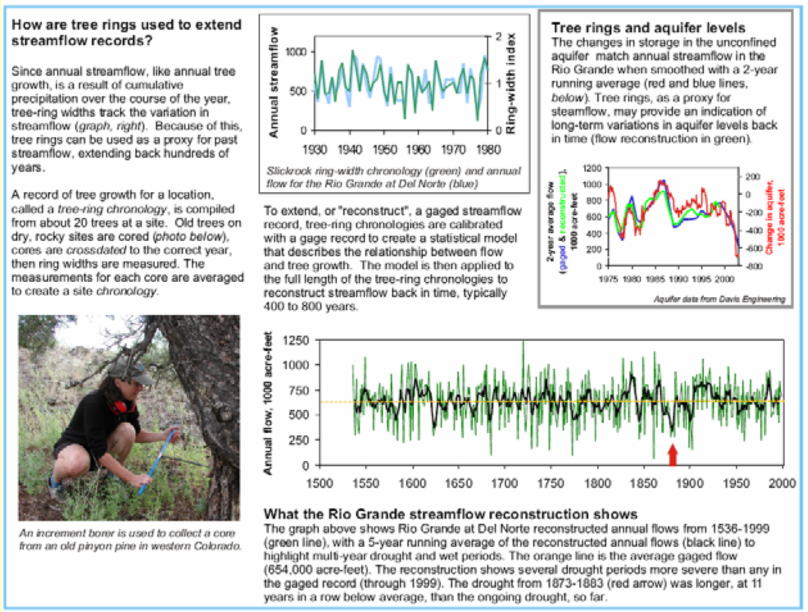
	Response Percent
Tree ring data are too uncertain/not credible	22.2%
Stakeholders/public may not accept/understand use of tree ring data	**37.0%**
Observed/gaged record is sufficient for our planning needs	14.8%
It is difficult to use tree-ring data in qualitative or quantitative assessments with gage data	22.2%
It is difficult to incorporate information related to tree-ring data into decision-making	29.6%
None of the above	**37.0%**

1) Provide long-term context for the gage record

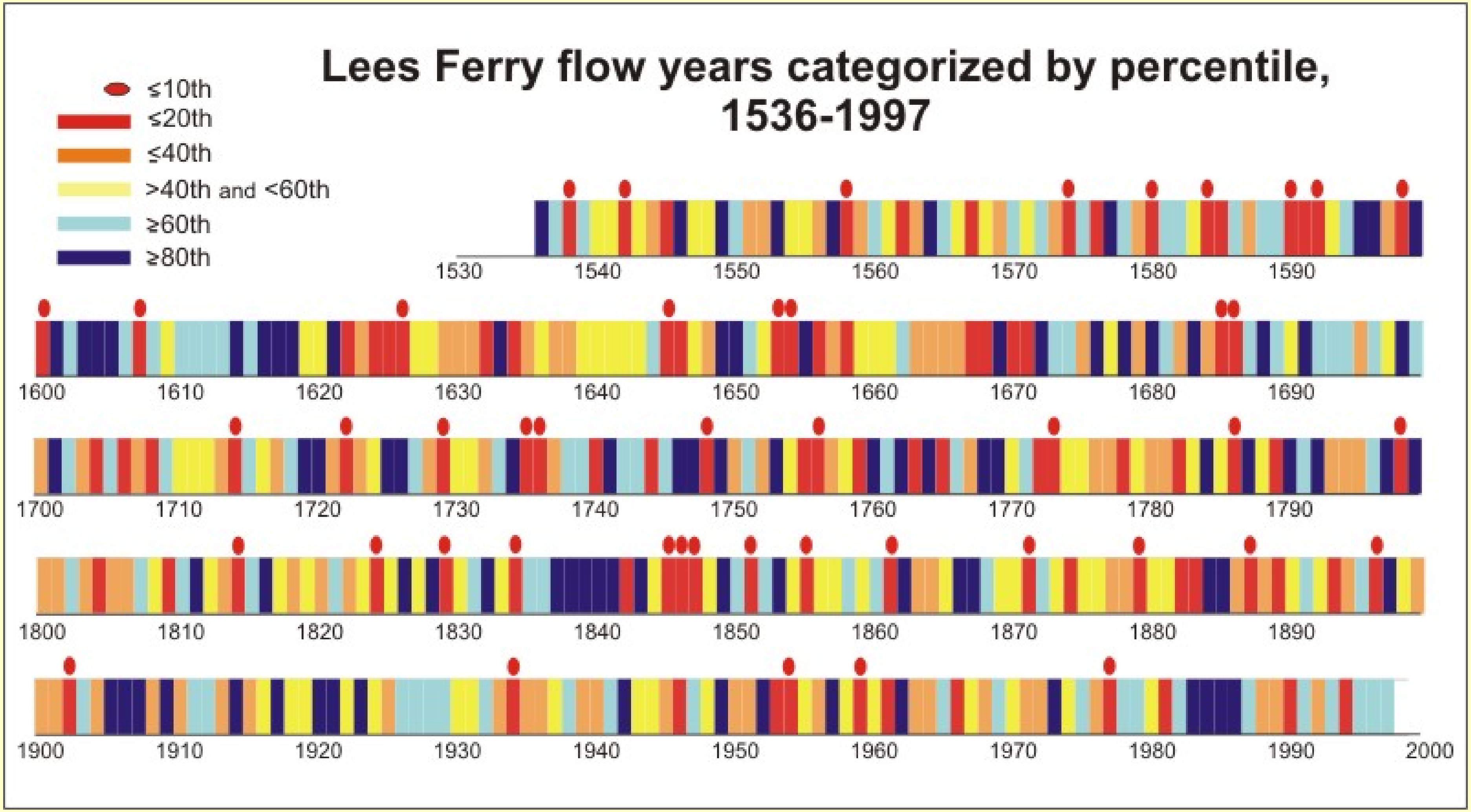
Communicating to water users, stakeholders, decisionmakers



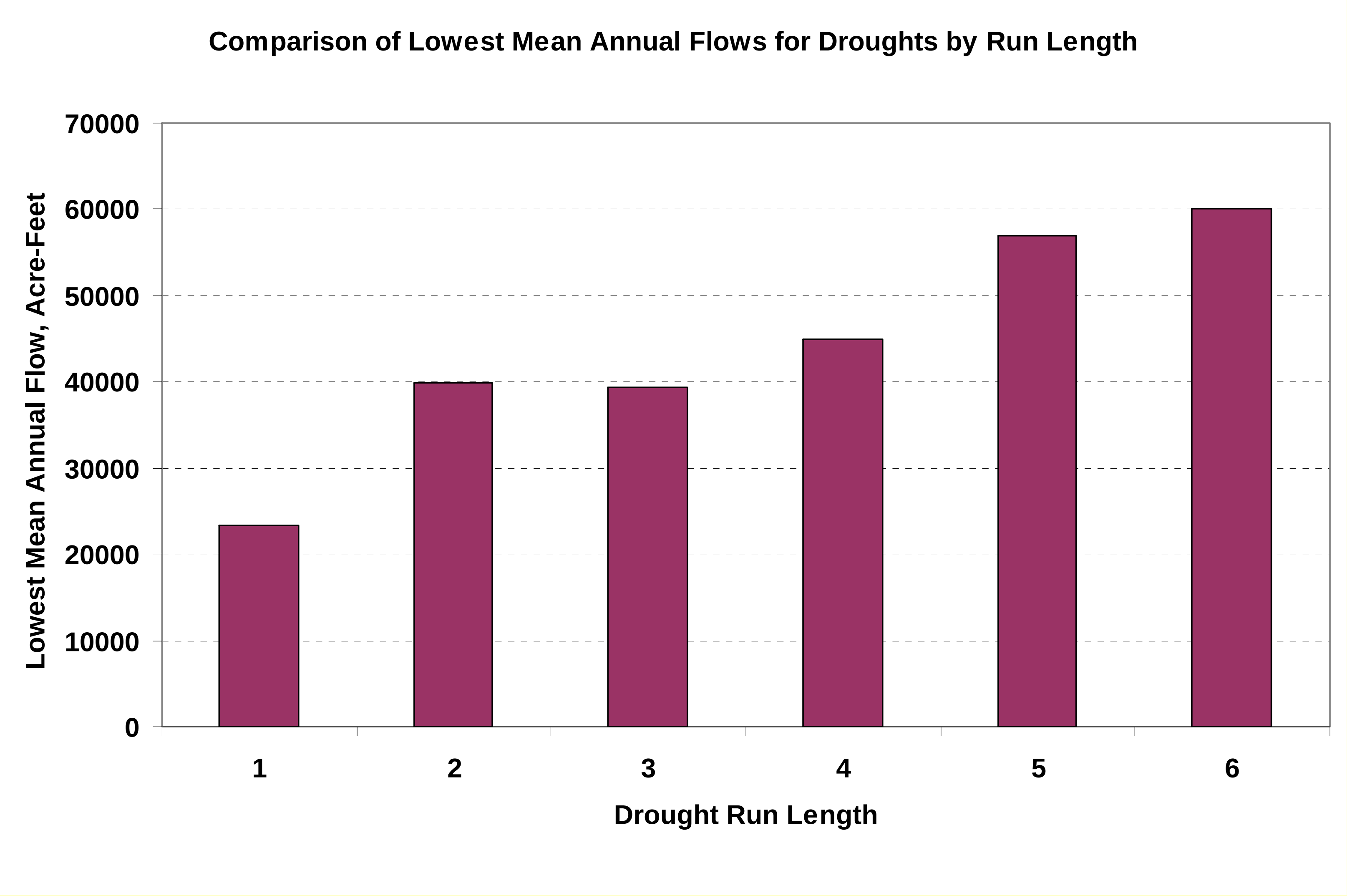
Tri-fold brochure developed for Rio Grande Water Conservation District to educate water users about long-term variability in water supply



A colorful visualization of reconstructed flows for the Colorado at Lees Ferry



Analysis of lowest mean reconstructed flows for *n*-length droughts, Boulder Creek, 1566-2002



Graphic by Lee Rozaklis, AMEC Earth and Environnmental

(2) Input into a system model to assess management scenarios

Denver Water - water supply yield analyses

Challenge:

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

Tree-ring reconstructions of *annual* flow for 2 gage locations (Colorado R.; South Platte R.)

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

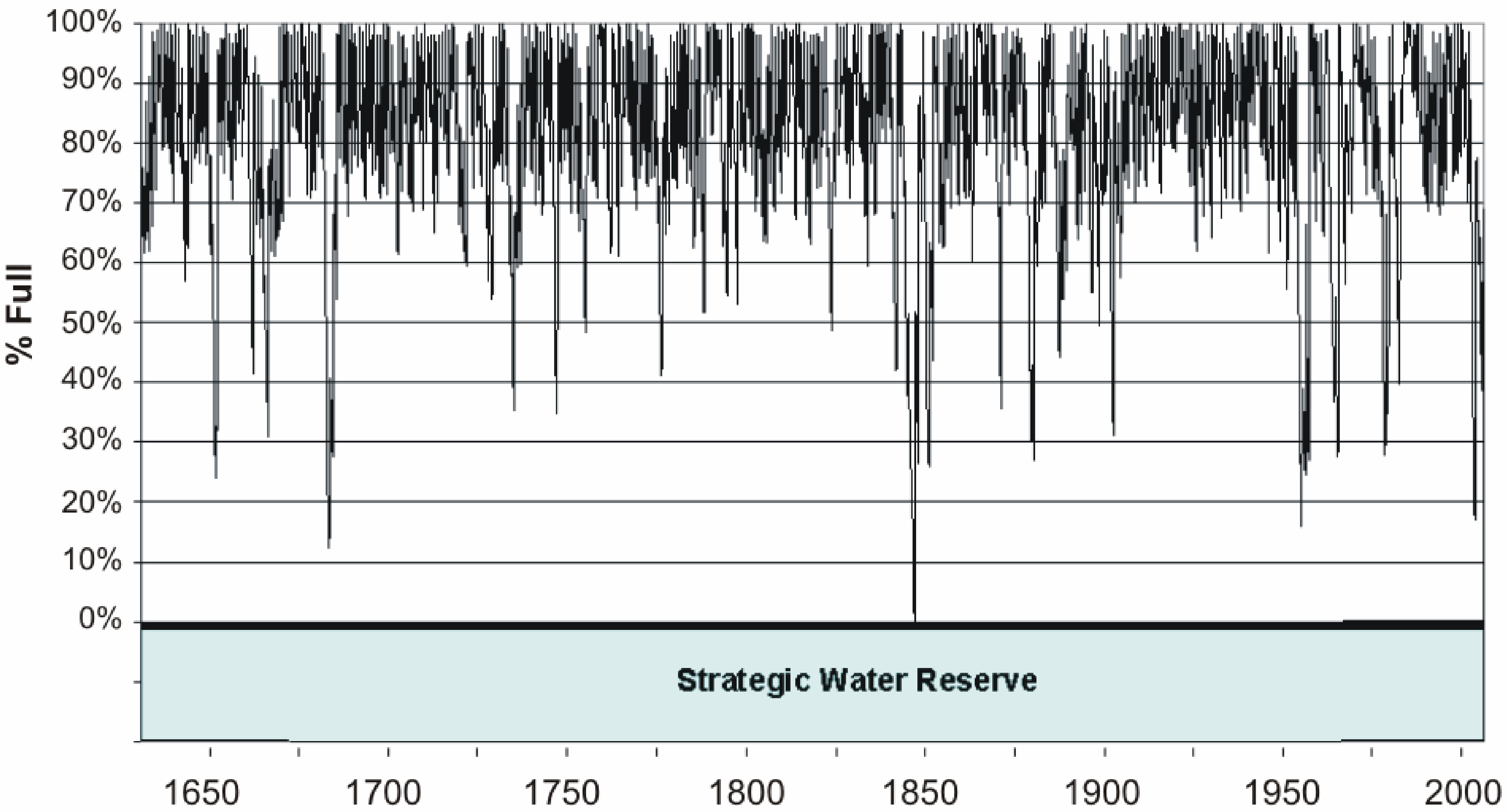
• Years with more extreme wet/dry values are scaled accordingly

• Data are assembled as new sequences of model years

•PACSM is used to simulate the entire tree-ring period, 1634-2002

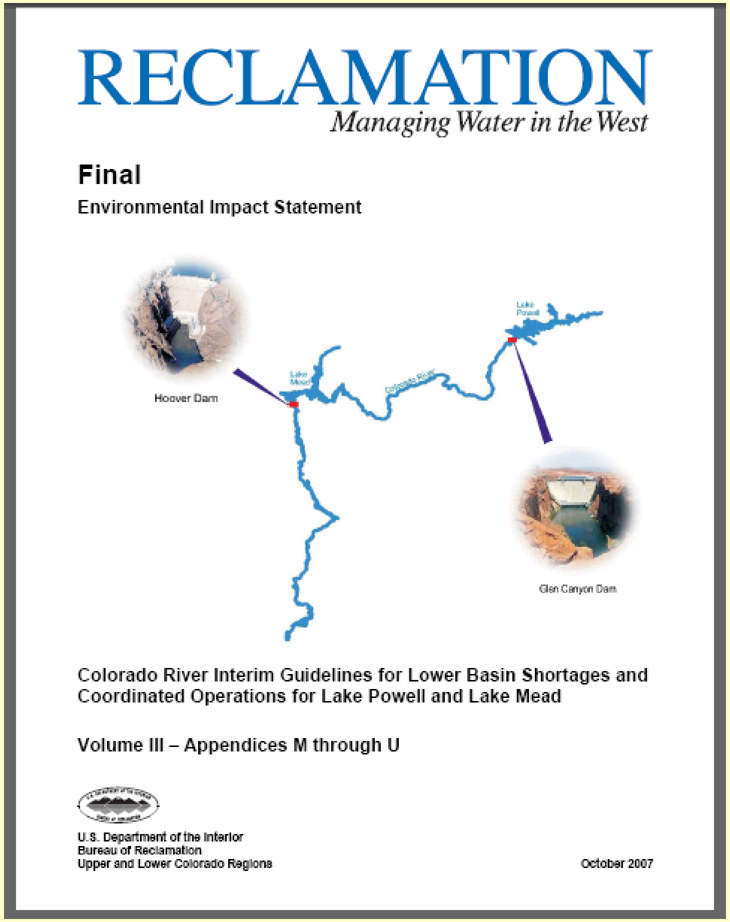
Denver Water - water supply yield analyses

Reservoir contents with 345 KAF demand and progressive drought restrictions



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

Reclamation - analyses for Colorado River Shortage EIS



Appendix N

Analyses of Hydrologic Variability Sensitivity

"…to evaluate the potential effects to the hydrologic resources of alternative hydrologic inflow sequences."

Alternative hydrologies:

- Two hydrologies based on tree-ring reconstructions of Lees Ferry flow

- Block resampling of observed flow

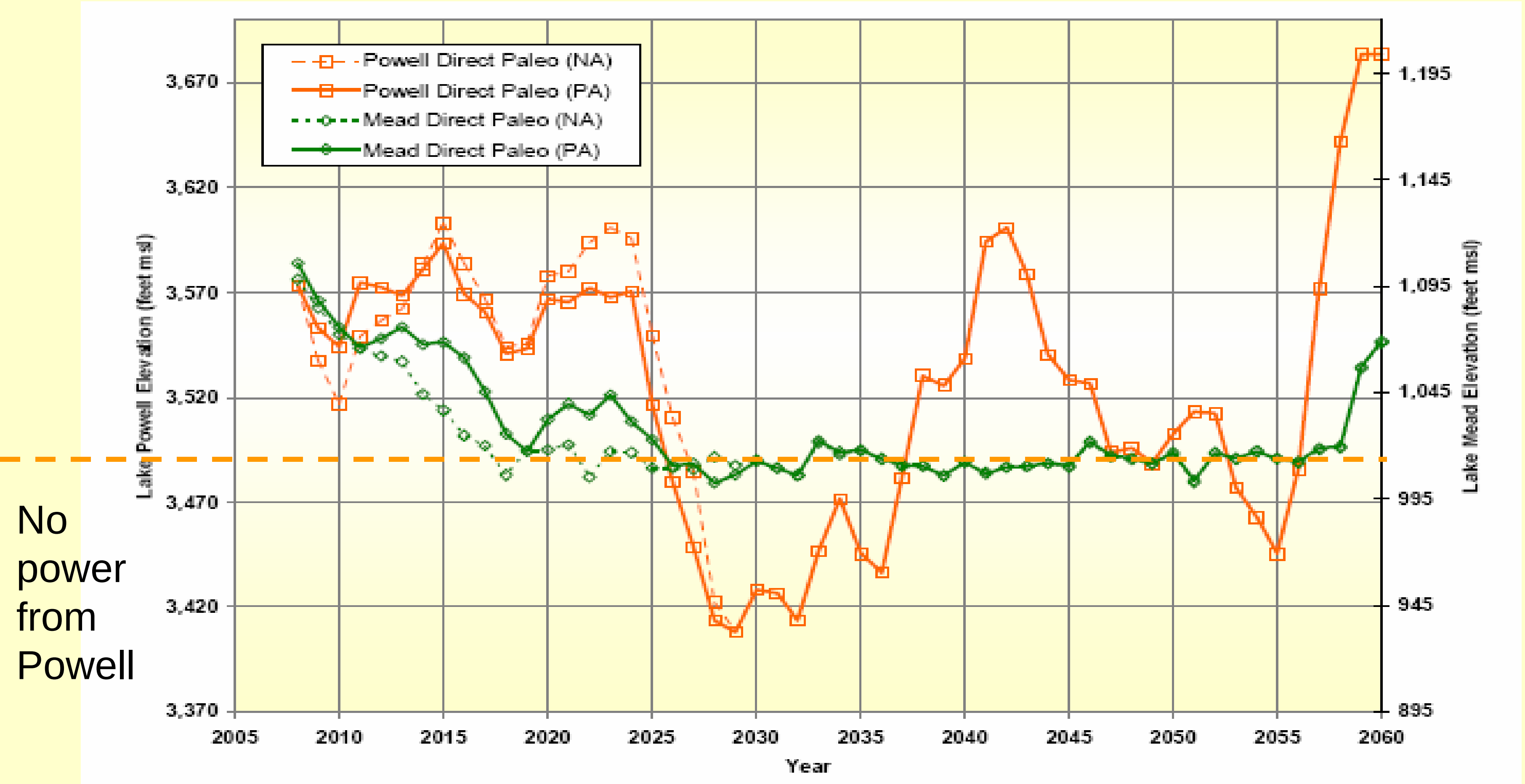
- Stochastic manipulation of observed flow

Model output from Reclamation "Shortage" EIS, 2007

Hydrology based on Meko et al. Lees Ferry reconstruction, yrs 1130-1182

Modeled Powell (orange) and Mead (green) year-end elevations

No Action (dashed) and Preferred Alternative (solid)



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 Animas 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

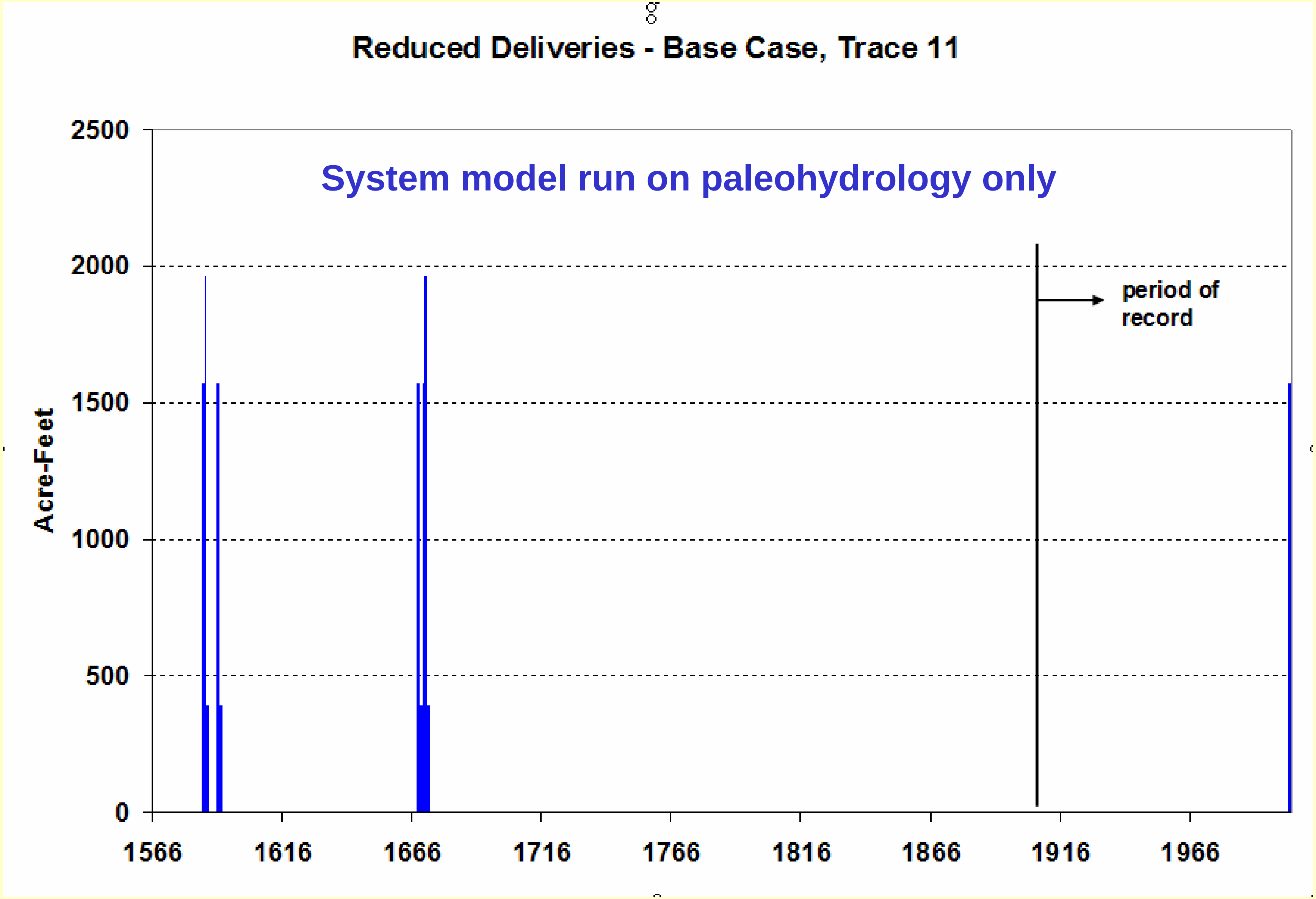
- Was 2000+ drought the first salvo?

Paleohydrology + GCM output: best of both worlds?

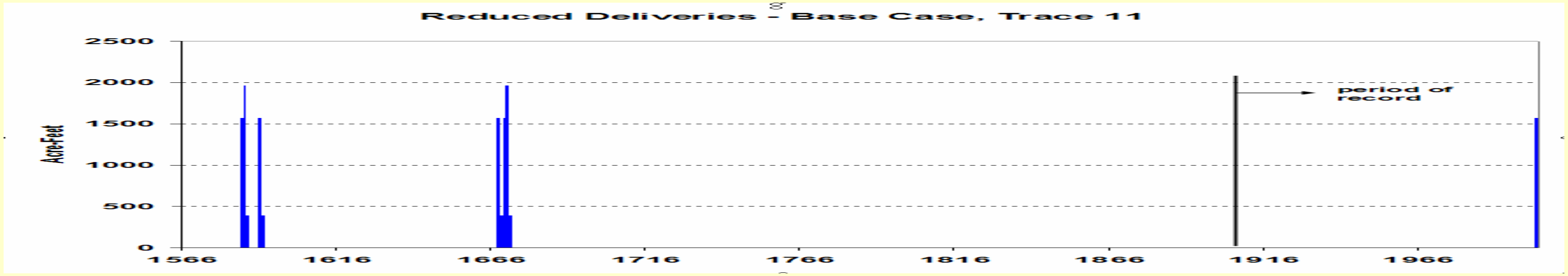
- **Paleohydrology** – captures full range of natural variability better than gage records, but can't predict the future
- **GCM output** (with hydrologic downscaling) - represents future trends (at least temp.), but poorly simulates interannual and interdecadal variability
- Combine via hydrologic modeling = 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

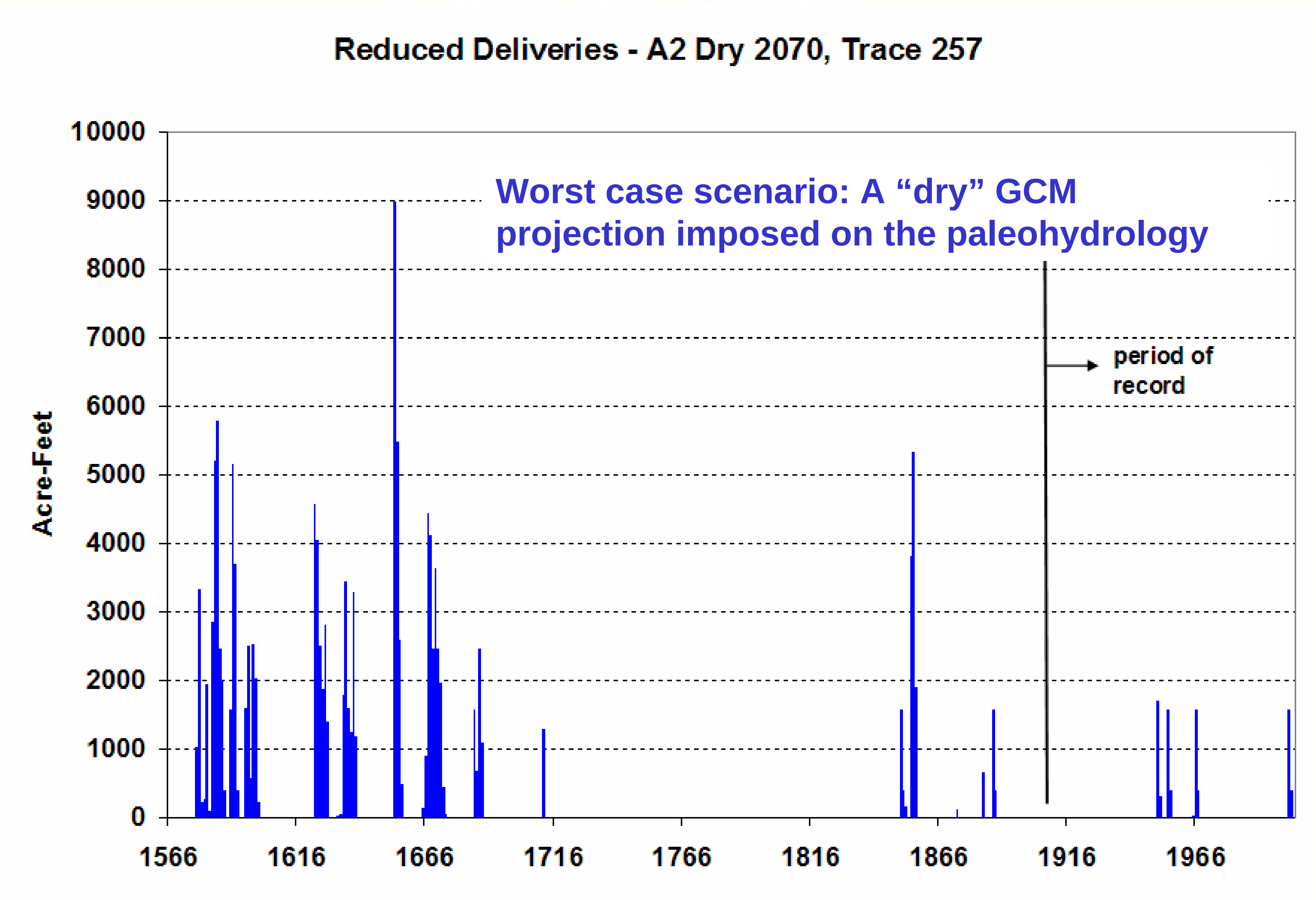


Lee Rozaklis, AMEC Earth and Environmental



Lee Rozaklis, AMEC Earth and Environmental

A "Worst Case" Scenario



Lee Rozaklis, AMEC Earth and Environmental

Discussion:

1) How to best use the streamflow reconstructions?

2) What other climate-based information do you need in preparing for an uncertain hydrologic future?

Thank you