Klamath/San Joaquin/Sacramento Hydroclimatic Reconstructions from Tree Rings

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1.Introduction

This is a draft final report for Agreement Number 4600008850, “Klamath/San Joaquin/Sacramento Hydroclimatic Reconstructions”, signed October 13, 2010. Following an extension, signed on May 28, 2013, the contract end date is June 30, 2014. Work includes developing new and updated tree-ring chronologies, reconstructing specified streamflow and/or precipitation records in the Klamath, San Joaquin and Sacramento River Basins, and analyzing the time series properties of the reconstructions. These reconstructions allow assessment of hydrologic variability over centuries to millennia and give context for assessing recent drought events.

Tasks on this project included field collections; laboratory work in sample preparation, dating and measurement; and statistical work in chronology development, reconstruction, and analysis of those reconstructions. The interpretation of the reconstructions includes five main components : 1) place instrumental-period flow statistics in a long-term context, 2) quantify droughts and wet periods, 3) identify cycles in wetness and dryness, 4) check consistency with other paleoclimatic data, and 5) assess reconstructed flow variations in the context of expected scenarios of climate. A total of 16 different hydroclimatic series – 11 flow records and 5 precipitation records, were reconstructed.

This report summarizes the research project products and results. The Data and Methods section of this report describes the field collections and development of tree-ring chronologies, reconstruction modeling, and methods of analyzing reconstructions. The Results section focuses on the interpretation of selected key reconstructions for the Klamath, Sacramento, and San Joaquin basins. Annual time series of the 16 reconstructions are included as products in an appendix and in a digital spreadsheet.

2. Data and Methods

Field collection, chronology development and statistical conversion of chronologies into reconstructed time series of flow or precipitation were done separately by two different research teams for the Klamath (Woodhouse/Malevich) and Sacramento/San Joaquin Basins (Meko/Touchan). Analyses of reconstructions were conducted with the same methods for both sets of basins. The following sections accordingly are subdivided, with separate parts for the Klamath and Sacramento/San Joaquin for Field Collections and Chronology Development and Reconstruction, and one part for Analysis of Reconstructions.

2.1 Field Collections and Chronology Development—Klamath Basin

Field Collections. We updated 12 existing collections and made five new collections in southeastern Oregon and northeastern California. Re-collection sites were identified based on the strength of correlations between pre-existing tree-ring data and flow or precipitation records to be used in the reconstruction models. In addition to the five collections made in the fall of 2010, 12 collections were made in July, 2011. Site information, along with information on tree-species, number of samples, and time coverage are listed in Table 1. Site locations are shown on the map in Figure 1. Two of the new collections found to be too young to be useful so were not developed into chronologies, and are not included in the table or figure.

Chronology Development. These main steps were followed for chronology generation: 1) cross-dating by skeleton plot (Stokes and Smiley 1968), 2) ring measurement using a Velmex sliding stage, 3) quality control on dating using COFECHA (Holmes 1983), 4) quality check and/or reassessment/re-measurement of wood as necessary, and 5) computation of site chronology by the ratio method using R (dplR package, Bunn 2010). After chronologies were developed, the wood samples with unequivocal dating were pin-pricked for archiving such that the dating is hard-coded onto the samples.

For updated chronologies, a subset of samples from previous collections was combined with the new samples. To maintain the length of the original chronologies, ten of the longest tree samples from the original site collections were combined with the updated collection. Samples from the original collections were also chosen to maintain an adequate sample depth (i.e., number of samples). We used the criterion of Expressed Population Signal (EPS) of at least 0.85 (Wigley et al. 1984) to judge whether the sample size is adequate.

Measured tree-ring series were detrended using a 67%N spline, defined as a cubic spline with a frequency response of 0.5 at two-thirds the length of the series (Cook and Peters 1981). Low-lag persistence, when present, was removed from the detrended series by fitting an auto-regressive model with order selected for minimum Akaike Information Criterion (AIC) (Akaike 1974, Box et al. 1994) to generate residual chronologies. Standard chronologies, in which low-order persistence was not removed, were also retained. Tukey's biweight robust mean was used to average the measured, detrended series into both standard and residual site chronologies.

2.2 Field Collections and Chronology Development – Sacramento/San Joaquin Basins

Field Collections. Field collections of tree-ring data were made at 14 different sites for the Sacramento/San Joaquin part of the study between August 2011 and November 2013. Core samples were taken on four trips, and both cores and cross-sections (chainsaw) on one trip. Previous experience with sampling for hydrologic studies in the region (Meko et al. 2001) was used as a guide for site and species selection. Sites collected, along with information on tree-species, number of samples, and time coverage are listed in Table 1. Site locations are shown on the map in Figure 1. All except one site collected is from the Sierra Nevada. The exception is site #26, a *Quercus douglasii* (blue oak), selected for updating because of its demonstrably strong precipitation regional precipitation signal (Meko et al. 2011). Eight of the 14 sites visited were updates aimed a bringing chronologies to present and/or increasing the sample depth in earlier centuries. Six of the sites are new collections.

Chronology Development. Initial steps in chronology development were the same as described above for the Klamath Basin. Measured ring widths were then standardized, or converted to site chronologies, by Matlab tree-ring standardization functions treeprep and treetrim following steps described in Meko et al. (2007) in reconstruction of Colorado River flows. Growth trend was described by fitting a cubic smoothing spline (Cook and Peters 1981) with frequency response 0.95 at twice the series length to each ring-width series, and then was removed by computing core indices as the ratio of measured ring width to the value of the fitted curve in each year. A spline with the identical specifications was then applied to the absolute departures of core indices from their long-term mean to remove trend in variance in the individual core indices (e.g., Meko et al., 1993). The site chronology was then computed as the biweight mean of the core indices available in each year if the sample size is less than six cores, and otherwise by the median of the core indices. Finally, variance-stabilization, following Osborn et al. (1997), was applied to the site chronology to adjust for possible temporal changes of chronology variance associated with changing sample size (number of cores) over time.

2.3 Reconstruction – Klamath Basin

Reconstruction models were developed for

- Klamath River at Keno OR (water year, estimated natural flow, U.S. Bureau of Reclamation, via Maury Roos)
- Trinity River at Lewiston CA(water year streamflow, estimated natural flow, CADWR)

- Klamath Falls climate station (water year precipitation, NOAA's U.S. Historical Climate Network)
- Yreka climate stations (water year precipitation, NOAA's U.S. Historical Climate Network)
- Weaverville climate stations (water year precipitation, NOAA's U.S. Historical Climate Network)

For Klamath Falls precipitation, two reconstruction models were developed using stepwise multiple linear regression. The first of these models was designed to emphasize high model skill (covering 1610 - 2004). The second was designed to emphasize reconstruction length (covering 1000 - 2010). The pool of candidate chronologies for these reconstructions included 10 chronologies from this study and seven moisture-sensitive chronologies from the International Tree-Ring Databank (ITRDB). ITRDB chronologies selected started in 1650 or before, ended in 1996 or later, and were of species known to be sensitive to moisture. The pool was based on residual chronologies that were significantly correlated ($p < 0.05$) with the Klamath Falls precipitation record. Leave-one-out cross-validation (Michaelsen et al. 1987) was used to validate these reconstructions. The final shorter model explains 59% of the total variance (using seven chronologies) and the longer model explains 53% of the variance (using three of the chronologies). The Klamath Falls precipitation reconstruction has been published in the *Journal of Hydrology* (Malevich et al. 2013).

The Trinity River streamflow and Yreka and Weaverville water year precipitation reconstructions were developed using the same methodology as above, with two differences. First, only one reconstruction model was developed for each record. Second, a larger number of chronologies from the ITRDB was used in the pool of candidate chronologies (from a slightly larger geographic area), again based on significant correlations with the instrumental record, for a total of twenty chronologies in the pool for stepwise regression.

The initial Klamath River at Keno streamflow reconstruction was also developed using stepwise regression. Because water year streamflow contained significant low order persistence (that is, a carry-over effect from one year to the next several years), both the set of chronologies (the standard chronologies, in this case) in the predictor pool and the calibration data (streamflow series) were pre-whitened (the persistence was removed) using autoregressive (AR) modeling over the calibration period. The AR models from the calibration period were then fit to the full length chronologies. The pre-whitened chronologies were screened using two criteria: 1) common end date of at least 2000, and 2) significant correlation ($p < 0.05$) with the gage record over the full common period and each half of the period. Nine chronologies passed the screening. The regression model was then fit using all years for the calibration data (1949-2000) and a leave-on-out approach for cross validation (Michaelsen et al. 1987). Two chronology predictors explained 63% of the variance in the gage record (Table 2). Regression assumptions were met for the most part (residuals showed a slight negative trend). The full length reconstruction was generated with the pre-whitened chronologies, extending from 1493-2010. In the final step, persistence was restored to the reconstructed streamflow series using AR equation initially used to prewhiten the series. The correlation between the Keno gage and final reconstruction is $r = 0.75$.

For all of the above reconstructions, 50% confidence intervals were calculated from the RMSE statistic for each model calibration in the cross validation process.

The reconstruction skill for the Klamath models, based on the model calibration, is shown in terms of the variance explained by the reconstruction model (R^2 and R^2 adjusted for the number of predictors in the model, in Table 2, top). The validations statistics for each model (reduction of error, RE, and the root mean squared error) reflect the skill of the reconstruction model when assessed on data withheld from the calibration. In the Klamath basin reconstruction, the model skill for the precipitation reconstructions is slightly lower than for the flow reconstructions. Water-year streamflow is a measure that integrates over space (the watershed) and time (the water year). It also integrates several climatic factors; precipitation mostly but also temperature, and to a lesser degree relative humidity and wind. The net result of these factors over the course of the water year is the annual flow. Tree growth in this region is also integrating the combined influence of a very similar set of climate variables over the water year.

In contrast, the precipitation reconstructions are based on a record that is for a single point and for one variable, and thus, these reconstruction are slightly less skillful (54-60% variance explained versus 63-68% variance explained).

We have recently extended the work on the Klamath River at Keno to include testing sensitivity of the reconstruction to uncertainty in the estimated natural flows used to calibrate the reconstruction described above. In work still in progress, we are exploring the nature of the uncertainty in the gaged flows using an approach that assesses the differences between inflows (Williamson and Sprague Rivers) into Upper Klamath Lake and natural flows estimated for the USGS gage, Klamath at Keno (below Upper Klamath Lake). In doing so, we acknowledge that there is no perfect record of natural flow for this gage, but make an assumption that a likely range of values falls between these two series. In order to evaluate the effect of uncertainty in the observed instrumental record on the reconstructed streamflow, we expand on traditional reconstruction methods which have solely focused on error in the reconstruction model. Using the inflow and outflow records as the range of uncertainty, a Monte Carlo procedure is used to estimate error which may be distributed in the instrumental record. This information is used to create a large number of potential or hypothetical "true" natural instrumental flow series for the Klamath River. Independently calibrated tree-ring reconstructions are then generated for each of these hypothetical natural streamflow series We are currently extending the work to turn the reconstruction probability distributions into confidence intervals and exceedance/non-exceedance probabilities to better compare past and present drought events. A final reconstruction, with confidence intervals, will be generated and compared to the reconstruction described above, and incorporated into regional analyses. These results will be published in a peer-reviewed paper.

2.4 Reconstruction – Sacramento/San Joaquin Basins

Water-year total flows were reconstructed for 10 full natural flow (FNF) series in the Sacramento and San Joaquin River basins (Table 3). All flow data were downloaded from the California Data Exchange Center of the California Department of Water Resources (http://cdec.water.ca.gov/queryTools.html). Water year totals were downloaded for the two summary series -- Sacramento River Runoff and San Joaquin River Runoff. The first is defined as the sum of Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake. The second is defined as the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake. Monthly flows in acre-feet were downloaded and summed in water-year totals for the other eight gages listed in Table 3.

Tree-ring data for the reconstructions were developed by us from our own collections, as described previously, downloaded from the ITRDB, or pulled from data files at the Laboratory of Tree-Ring Research (LTRR). For ITRDB chronologies, the following screening steps were taken: 1) chronologies from California, Oregon and western Nevada in the latitude range of the target watersheds and completely covering the interval 1600-1996 CE were downloaded; 2) log-transformed flow at each of the 10 gages (Table 3) was regressed against each chronology, lagged -1, 0, and +1 years relative to the water year; and 3) a chronology was accepted into the network of candidate sites only if accounted for at least 20% of the variance of water-year flow in the regression model for at least one of the gages. The requirement that the chronology cover the period 1600-1996 CE was relaxed for blue oak (*Quercus douglasii*) sites in the ITRDB, as those are known to have an exceptionally strong moisture signal (e.g., Meko et al. 2001, 2011). Shorter chronologies from other species were deemed unlikely to improve on reconstruction accuracy available from blue oak alone over the past 300 years. Measured ring widths only (no site chronology) were available for some sites in the ITRDB. For those sites, we downloaded the ring widths and generated a site chronology using program ARSTAN to enable us to include the site in the screening exercise.

For ITRDB chronologies passing the screening, the ring widths were downloaded and subjected to additional statistical and graphical quality control using Fortran program COFECHA (Holmes 1983), and Matlab program Lockdown (unpublished, D. Meko). Individual core ring-width series were truncated or deleted as needed to eliminate problems due to questionable dating or measurement, and to reduce temporal changes in sample size in chronologies whose common signal is adequately represented by some reduced set of long ring-width series. The quality-control steps included favoring ring-width series that cover parts of the tree-ring record with low sample replication (e.g., early centuries), have long segment length (number of years), and a strong correlation with other series at the site.

The complete tree-ring network for flow reconstruction in the Sacramento and San Joaquin basins is comprised of the 61 site chronologies at sites shown on the map in Figure 2. Tables with site information and chronology statistics are included in Appendix C. All except one chronology in this network were developed by us from the measured ring widths using the standardization procedure described previously under Chronology Development. The exception, the Kern Composite site chronology of *Pinus Balfouriana* (foxtail pine), was contributed to our study by Dr. Tony Caprio, Fire Ecologist with Sequoia/Kings Canyon National Park. That chronology had been computed by Dr. Caprio using program ARSTAN and conventional detrending choices of negative exponential or straight-line fitted trends (personal communication, Tony Caprio).

Water-year-total flows at each of the 10 target gages (Table 3) in the Sacramento and San Joaquin River basins were reconstructed by locally weighted regression, or Loess (Cleveland 1979; Martinez and Martinez 2002) from subsets of site chronologies in the 61-site network. A Loess reconstruction as we define it is an interpolation of estimated flow from a smoothed scatterplot of observed flow on a single summary tree-ring variable. We used as the predictor, or tree-ring variable, an average over sites of standard chronologies that have first been filtered and scaled to accentuate their statistical signal for the target flow gage. A nested-modeling approach similar to that described by Meko (1997) and applied in reconstruction of Colorado River flow by Meko et al. (2007) was used for reconstructions. The reconstruction method was adapted specifically for this study after exploration of various alternatives, and is described in detail in Appendix D.

The reconstruction method includes cross-validation and split-sample validation to guard against over-fitting and temporal instability of models. Uncertainty in Loess-generated reconstructed values is estimated by the method of “upper and lower smooths” (Martinez and Martinez 2002), which yields an approximate 50% confidence interval around the reconstructed flows. This confidence interval is estimated by Loess modeling separately applied to scatterplots of the positive and negative reconstruction residuals against fitted values (Appendix D).

Summary statistics of reconstruction models for the 10 target gages in the Sacramento and San Joaquin basins are listed in the bottom half of Table 2. The percentage of flow variance accounted for by the “median-accuracy” model ranges from 68% for the Sacramento River (Sacramento River above Bend Bridge) to 78% for the San Joaquin River. Because these reconstructions are done with time-nested models, accuracy varies over time depending on the quality of the available tree-ring chronologies. This feature of the nested models is illustrated for the SJQ4 reconstruction in Figure 3. At the top are time plots of the annual reconstruction, unsmoothed and smoothed by a 30-yr Gaussian filter, 900-2012 CE. At the bottom are time plots of the number of chronologies, N, in the nested models and the percentage of variance, EV, accounted for by the models. Each jog in the time plots of EV and N corresponds to a change in the available set of chronologies and in the nested model. At the start of this tree-ring record, 900 CE, the network consists of just 2 chronologies and the model explains 58% of the flow variance. By the 1700s the number of chronologies in the model has risen to 16 and the EV statistic to 82%. Toward the most recent part of the record, chronologies drop out, and accuracy of reconstruction declines. EV remains at 69% through 2011, but drops sharply in 2012 because of loss of the blue oak chronology at Mt. Diablo from our network.

The high EV for these models indicate strong tracking of observed flows by reconstructions, and this quality is illustrated in the time plot of observed and reconstructed flows, 1901-2011, for San Joaquin River Runoff, or SJQ4 (Figure 4).

A defining characteristic of this system of rivers is the high inter-series correlation of annual flows. Correlation matrices for both the observed and reconstructed flows for the common period 1906-2011 underscore this strong spatial coherence in runoff (Table 4). A comparison of inter-series correlations for the observed and reconstructed flows also shows that the reconstructions slightly overstate the coherence. For example, the correlation between SAC4 and SJQ4 is 0.90 for the observed flows and 0.95 for the reconstructed flows. This is to be expected because reconstruction models for different rivers include some of the same tree-ring chronologies as predictors. The bias in inter-series correlation appears highest for widely separate basins. For example, correlation between the Merced River (MRC) and Sacramento River above Bend Bridge (SBB) is 0.79 for the observed flows and 0.94 for the reconstructions.

2.5 Analysis of Reconstructions

Methods described below address the five main analysis components of the study: (1) Place instrumental-period flow statistics in long-term context, (2) Quantify droughts and wet periods, (3) Identify cycles in wetness and dryness, (4) Check consistency of reconstructions with other paleoclimatic data, and (5) Assess reconstructed flow variations in the context of expected scenarios of climate change.

We address the following statistics of flow in a long-term context: mean, median, variance, skew, and lag-1 autocorrelation coefficient. Statistics of the long-term reconstruction are compared with those of the observed and reconstructed flows for the instrumental period. Selected statistics of the reconstruction are also computed in a moving time window to investigate the long-term variability of the statistics for over numerous available periods the same length as the instrumental period. Empirical cumulative distributions (cdf's) are used to assess the non-exceedance probability of the statistics for the instrumental period. Box plots are used to compare distributions of observed and reconstructed series over common periods of time.

Droughts and wet periods are summarized by two approaches. First is runs analysis, as described by Salas et al. (1980). A run is defined by a sequence of two or more years below the threshold. A measure of drought-duration is the run-length, or the number of years in the sequence.

Runs are summarized in tables listing the start-year, end-year, and run-length. For these tabular summaries we use the median of the time series for the analysis period as the threshold flow. Time series plots of annual reconstructed flows with runs longer than three years color-shaded are used to graphically display the time sequence of runs. The second approach used to summarize droughts and wet periods is running-means analysis. Running means of reconstructed flows are computed and ranked, and the 20 lowest running means of various length are listed in tables. Comparisons are made among the three major flow series. The temporal evolution of droughts and wet periods in terms of running means is shown graphically with color maps, or "flame plots" (Meko et al. 2011; Malevich et al. 2013). The plots, as used here, color code every combination of ending year and *m*-year period, $5 \leq m \leq 50\,yr$, by size of anomaly in flow as a percentage of long-term mean observed flow.

Cycles in the reconstructions are summarized by spectral analysis, cross-spectral analysis, and wavelet analysis. We use the term "cycles" loosely here to include variations that are rhythmic in some sense, but do not necessarily have a regular wavelength or period, and may be present in some parts of the time series and not in others. An example might be droughts that tend to recur at 20-year intervals. Sometimes the interval may be longer or shorter than 20 years, and the intensity – as magnitude of flow anomaly – may be larger or smaller. And the fluctuation may be absent for long segments of the record. Such a "cyclic" pattern can be contrasted with a pure sine wave, which maintains the same period and amplitude at all points in time. Spectral analysis summarizes cycles by displaying the variance of the time series as a function of frequency, or its inverse – wavelength. The variance of a time series can be mathematically split up into contributions from different wavelengths. For the example just mentioned, variance would be high near wavelength 20 years. The plot of the relative variance contributed as a function of wavelength or frequency is the spectrum. Spectral analysis allows some assessment of whether a cyclic component in the data is unexpectedly high (as from some cyclic influence on climate), as opposed to something that may reasonably be expected due to random variability. Cross-spectral analysis extends spectral analysis to multiple time series, and addresses whether cyclic variations in one flow series are related in some sense temporally with those in another flow series. The variations in two series may be in-phase (peaks occurring simultaneously, troughs occurring simultaneously), or out-of-phase (e.g., some time lag between peaks in the two series), or unrelated. In this report, we use spectral analysis to summarize cycles in individual flow series and cross-spectral analysis to summarize relationships between pairs of flow series for different rivers. Spectra and cross-spectra applied in this report use the smoothed-periodogram method (Bloomfield (2000). Prelimary steps include the following: 1) subtract the mean, 2) taper the series (5% of each end), and 3) pad the series with zeros to such that its length is a power of two. The discrete Fourier Transforms, raw periodograms and cross-periodogram are then computed and smoothed with convoluted spans of Daniell filters to achieve spectral and cross-spectral estimates with the desired bandwidth. The mathematical and statistical operations in these methods are described in Bloomfield (2000).

Wavelet analysis (Torrence and Compo, 1998) is used in this report to investigate the temporal evolution of wavelike and possibly cyclic features in the flow series. Wavelet analysis is particularly useful for investigating wavelike features that may localized to parts of a long times series. For example, wavelet analysis can directly address whether some multi-decadal rhythm in wet and dry periods occurs in a long reconstructed streamflow series, and can identify when that rhythm is absent or present, and when the rhythm is weaker or stronger. Time-variation in the relationship between cyclic features in pairs of series is summarized with wavelet cross-coherency (Grinsted et al., 2004). For these analyses we use the Matlab-based wavelet package available for download from the National Oceanography Centre (http://noc.ac.uk/using-science/crosswavelet-wavelet-coherence). Wavelet analysis differs from spectral and cross-spectral analysis in being generally applicable to nonstationary as well as to stationary series, in not relying on the assumption that cyclic variations be sinusoidal in form, and in being specifically intended to study cyclic variations that may “come and go” over the length of the time series.

Consistency of flow reconstructions with other paleoclimatic time series representative of moisture variation is summarized with correlation analysis and smoothed time series plots. Our comparative analysis focuses on a set of hydroclimatic reconstructions from the western US, including gridpoint tree-ring-derived Palmer Drought Severity Index (PDSI) in the North American Drought Atlas (Cook et al., 2009), and flow reconstructions for the Snake (Wise 2010), Yampa (Gray et al. 2011), Colorado (Meko et al. 2007), San Juan (Woodhouse et al. 2006), and Salinas (Griffin 2007) Rivers, as well as lower Colorado River basin tributaries (Salt-Verde-Tonto River (Meko and Hirschboeck 2008). We also use this analysis to show spatial patterns of drought across the western U.S.

The relative importance of reconstructed flow variations to changes expected with climate change scenarios is summarized by comparing the maximum run-lengths (see above) of reconstructed flows, observed flows, and ensemble members of projected full natural flow (FNF) or runoff. For consistency, we used the same six downscaled GCM models, run through the VIC hydrologic model, as were used by CADWR in a 2009 climate change report (Chung et al. 2009), with one run per model, and two climate change scenarios, A2 and B1. Results from projections, 1950-2099, were compared with maximum run-lengths in observed and reconstructed series (for the observed period and full reconstruction). For the Klamath, this assessment was done using a set of downscaled CMIP3 Climate and Hydrology Projections available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#About (USBR 2011, see also Mauer et al. 2007). Because of difference in the units for the model projections (mm of runoff) and the flow series (Acre-feet), all series for the Klamath assessment were first scaled to z-scores using common reference-period (1951-2000) means and standard deviations. A dry year was defined as an annual value below the median for the reference period, and run-length was computed as the number of consecutive years below the threshold. For gages in the Sacramento and San Joaquin Basins, the downscaled projections already in flow units (acre-feet) appropriate for the target basins were obtained from CADWR. For these records we used as the dry-year threshold for observed flows and projections the median of the observed water-year flows for the period 1906-2012, and as the threshold for reconstructed flows the median reconstructed flow for that same 1906-2012 base period. Our procedure was to compare maximum run-length of runs in the projection scenarios with those in the 900-2012 CE reconstructions and 1906-2012 observed flows.

3. Results

Results of application of the methods described in the previous section to the main flow reconstructions for the three basins -- the Klamath at Keno (KLK), Sacramento Four Rivers index (SAC4), and San Joaquin Four Rivers index (SJQ4) are described here. Sections 3.1-3.5 individually address the five main analysis components of the study.

3.1 Instrumental-Period Flow Statistics in Long-Term Context

Statistics of reconstructed flow or precipitation can be used to infer whether the short snapshot of time provided by the instrumental was unusually dry or wet, stable or variable, etc. Statistics are listed in Table 5 for all 16 records reconstructed in this study. Three rows of statistics are shown for each gage. The first two rows for a particular gage allow comparison of statistics of observed and reconstructed series for their common period. This comparison is useful as a baseline to check whether the reconstruction might be biased high or low for a statistic. Some bias is expected, depending on statistic. For example, the standard deviation will generally be lower in a reconstruction than in the observations for the same period because not all variance of flow or precipitation can be explained by regression. On the other hand, when ordinary least squares is used for reconstruction, the means of observed and reconstructed series are forced to be identical over the period used to calibrate the model. This explains, for example, the identical means (1176 kaf) in observed and reconstructed flow for the common period 1949-2000 for the Klamath at Keno. The median is not constrained to be equal for regression, and for the Klamath the median is biased high by 17 kaf (1142 vs 1125 kaf) in reconstruction. The skew is especially prone to negative bias in tree-ring reconstructions of flow or precipitation in semi-arid regions, where observed flow and precipitation are typically highly positively skewed in comparison to the more normally distributed tree-ring data. For example, negative bias in skew is evident for all except the Klamath at Keno reconstruction in Table 5. Lag-1 autocorrelation may or may not be biased in a tree-ring reconstruction depending on the data processing (standard vs residual chronologies) and reconstruction procedure (e.g., use of lagged predictors in models). Autocorrelation is small for all gages studied here except the Klamath at Keno, and for that record the reconstruction closely mirrors the observed autocorrelation (as was the intention in the reconstruction model development).

Reconstruction bias in skew and median, as well as the typical compression of variance by the reconstruction process are evident in box plots of selected reconstructions for the Klamath Basin (Figure 5) and Sacramento/San Joaquin basins (Figure 6).

Because statistics of tree-ring reconstructions are typically biased one way or another relative to those of the observed time series, placement of the hydrologic statistics of the short instrumental period in a long-term context is best restricted to comparisons of reconstructed data. For the statistics listed in Table 5, this comparison would be of the last two rows for a particular gage. Such a comparison allows us to address questions such as whether the modern period has been especially dry or variable in the context of the past few centuries. Restricting the comparison to reconstructed series for this assessment circumvents the problem of reconstruction bias in the statistic. For example, the 1949-2000 instrumental period for the Klamath is inferred wet in a long-term context according to both the mean (1176 vs 1104 kaf) and median (1142 vs 1113 kaf).

This comparison for the Klamath does not address the question of whether some past periods of similar length to the instrumental period were wetter or drier than the instrumental period. A more apt comparison for that objective is of the reconstruction statistic for the *m*-year instrumental period with the large sample of the corresponding statistic for all possible *m*-year periods in the long-term reconstruction.

The empirical cumulative distribution functions (cdfs) for such an assessment of variability of *m*-year mean, median, standard deviation and lag-1 autocorrelation for flow in the three main basins (Klamath at Keno, Sacramento Four Rivers and San Joaquin Four Rivers) in Figures 7-9.

These cdfs, with vertical lines plotted at the value of the statistic for the observed and reconstructed for the instrumental period, highlight especially the large variability of recent flows. For example, on the Klamath, the standard deviation of reconstructed flows for the 52-year period (1949-2000) of overlap of observed and reconstructed flows ranks at about the 75th percentile of the standard deviations for 446 different unique overlapping 52 year periods in the 1507-2003 reconstruction. Recent variability is highlighted even more strongly on the Sacramento and San Joaquin, where the standard deviation for the instrumental period ranks above the 95th percentile in a sample of more than 1000 sample standard deviations computed for 106-year (Sacramento) or 112-year (San Joaquin) periods of the reconstructions.

Whether the instrumental period is judged relatively wet or dry in a long-term context can sometimes hinge on choice of statistic to describe central tendency. For the San Joaquin (Figure 9), for example, the cdf for the mean (upper left) suggests the instrumental period was relatively wet (80th percentile of sample means), while the cdf for the median suggests the instrumental period was relatively dry (40th percentile of sample medians). Such differences can result from variable skew in the annual reconstructed flows for the different time samples. In particular, with positive skew, perhaps due to a few years of very high flow, the mean will be shifted high relative to the median. While the "typical" San Joaquin flow – that exceeded in half the years – may have been relatively low over 1901-2011, a few years with very high flow in that period could result in an arithmetic average, or mean, flow exceeding that of most prior 112-year periods.

3.2 Droughts and Wet Periods

The reconstructed flows in the Klamath, Sacramento, and San Joaquin basins allow an assessment of the instrumental period of record, in terms of drought duration and severity, in a long-term context, The longest run of below median flow years extends to 21 consecutive years in the Klamath River reconstruction, 10 years in the Sacramento and 13 years in the San Joaquin (Figure 10-12, Table 6). Two intervals of 10 years are indicated in the Sacramento: late 1200s and in the 1920s-1930s. In the San Joaquin, the 13-yr run occurs in the late 1400s. The 21-yr run in the Klamath occurs in the mid- to late 1600s. Numerous periods of low flows of four years and more are evident in all three series.

The lowest 20 single-year, 3-, 6-, 10-, 20-, and 50-yr periods are listed in Tables 7, 8, and 9. In both the Sacramento and San Joaquin, flows in the 1920s and 1930s rank among the most extreme in the context of the last millennium, as single years and multi-year periods, as well as multi-decadal periods (e.g., 20 years) of drought. Other 20th century low flows that rank in the lowest 20, are 1977 as a single and as a multi-year drought (1975-77) in both basins, and the 6-year period ending in 1992, which is the longest low flow period that ranks in the lowest 20 multi-year averages over the full reconstructions.

Reconstructions for the Sacramento and San Joaquin flag 1580 an exceptionally dry single year – far drier than any experienced in the instrumental period. On the Sacramento, the reconstructed flow for 1580 is only 45% of that of the reconstructed flow in 1924, the second driest year of the reconstruction (Table 7). The relative severity of low flow in 1580 is almost as great on the San Joaquin, where flow in 1580 is reconstructed at 54% of the flow in 1924 (Table 8). The single-year intensity of tree-ring reconstructed drought in 1580 has been noted previously (Meko et al. 2001). Our results suggest that the drought beginning in the 1570s and including 1580 was of shorter duration in the San Joaquin Basin than in the Sacramento Basin. The 1470s are also a key period of low flow in both basins. At decadal and longer time scales, pre-20th century low flow extremes are dominated by periods in the mid- to late-1100s in the Sacramento basin, while the second half of the 15th century appears to have been more severe in the San Joaquin basin (however, prolonged drought is evident for both of these periods in both basins).

The Klamath at Keno flow reconstruction, starting in 1507, is shorter than the Sacramento and San Joaquin reconstructions, and so does not provide as long a record for instrumental period assessment.

The 1920s and 1930s on the Klamath also appear to be periods of extreme low flow (single to 20-year periods), but rank in the middle to bottom of the lowest 20 periods, in contrast to the higher rankings in the Sacramento and San Joaquin records (Table 9). As in the Sacramento and San Joaquin, the early 1990s is also a period of notable drought in the Klamath basin. The years of the 1570s to early 1580s are markedly dry here as in the other two basins, but the short-term periods (single to 6-year periods) with lowest flows occur in the 1650s and 1660s (Table 9). The decadal and multidecadal periods with lowest flows in the Klamath basin are in the latter half of the 17th century. These are also periods of drought in the Sacramento and San Joaquin basin, but are less severe in those basins in the context of the last 1000 years. If we consider the long Klamath Falls precipitation reconstruction (extends to AD 1000, Malevich et al. 2013), the severe low flow periods of the 1100s in the Sacramento and San Joaquin are evident in this basin as well, although the 17th century periods of low flow are still prominent when assessed in the 1000-year context. The second half of the 11th century also appears to be exceptionally dry in the Klamath Basin (Malevich et al. 2013); this interval is dry in the Sacramento and San Joaquin, but less so than in the Klamath (e.g., Figures 11 and 12).

Flame plots, as described in the Data and Methods, can be used for a quick graphical assessment of the history of dryness and wetness in terms of moving averages of variable length. Moving averages of reconstructed flow for the Sacramento, San Joaquin and Klamath Rivers for window sizes, or moving averages, of *m* years, $5 \le m \le 50$, are graphically summarized by flame plots in Figures 13-15. These plots color-code the moving averages over the full length of the reconstructions as a percentage of normal. For the summary, we define “normal” as the long-term mean of observed flows. The dominant running-mean droughts listed in Tables 7-9 and discussed previously emerge vividly as red colors on the flame plots. At any point on a flame plot, the color indicates the percentage of normal flow for the *m*-year period ending in a given year. Window size increases along the y axis, such that short-duration, intense droughts give dark red colors restricted to the lower part of the plot, while long-duration drought or recurrent dry years over a long period give red colors toward the top of the plot. Colors, from dark red to dark blue, correspond to flow anomalies from 70% to 120% of normal, or from very dry to very wet. Any flow anomalies that happen to be more extreme than those limits are coded with the colors for 70% or 120%. As obvious in Figures 13-15, colors generally become lighter toward the top of the plot because the largest anomalies in terms of extremely high or low percentage of normal are generally found in single years or short moving averages (*m* closest to 5 yr).

Interpretation of the flame plots is illustrated by arrows A, B and C: on the plot for the Sacramento (Figure 13). Arrow A points to the mid-1100s, where red colors indicate 25-year moving averages less than 85% of normal flow. A mid-1100s drought is also a singular persistent event in a tree-ring study of the Colorado River (Meko et al. 2007), and has been flagged as an exceptional case of simultaneously dry conditions on the Sacramento and Colorado Rivers (Meko et al. 2012). The flame plot in Figure 13 indicates that the unusual severity of this drought on the Sacramento extends out to at least an averaging period of 50 years (top of plot). Arrow B points to an extended period of wetness in the 1300s. The dark blue coloring indicates 50-year moving averages of at least 120% of normal at that time. Arrow C points to the intense decadal-scale drought of the 1930s, where the dark red coloring indicates 10-year running means of less than 75% of normal flow. Sacramento River dry periods of ten to 20 years in length during a short interval in the early 20th century were the most severe (i.e. reddest) such periods in the entire record. Comparison of the 1930s drought with the mid-1100s drought on the flame plot in Figure 13 underscores the difference in drought characteristics: less severe short-term flow anomalies but longer duration of low flows in the 1100s than in the 1930s.

Comparison of flame plots in (Figures 13 vs 14) shows that the San Joaquin and Sacramento Basins share many of the major droughts and wet periods. Some differences, however, are evident in relative severity of droughts and wet periods. The 1930s drought appears in both basins, but is more severe in a long-term context in the Sacramento than in the San Joaquin. Both basins have dry conditions in the 1100s, but less so in the San Joaquin. Dry periods on the order of 30-40 years near the end of the 15th century were most severe periods of this length in the San Joaquin record (Figure 14).

In the Klamath River reconstruction, the mid-17th century stands out as a period of severe low flow conditions, from very short time periods to multi-decadal periods, while the late 16th century and the 1930s are notable for drought at periods of less than ten years (Figure 15). The Klamath also exhibits an interesting 18th century recurrence pattern of drought in which a series of short term droughts, marked by low 5-year running means, are interspersed with more normal conditions. As the averaging period is lengthened, those more severe short droughts merge to give running means of less than 90% of normal flow for averaging periods as long as 50 years ending in the latter part of the 1700s (Figure 15, top of plot).

In summary, major periods of extreme low flow are shared among the three basins, although the degree of severity varies. The 1920s and 1930s (up to 20-year periods), 1570 to the early 1580s (mostly at intervals of ten years or less) and the 1100s (prominent at 20- to 50-year intervals) are the most markedly widespread and severe periods of low flow shared across all three basins.

3.3 Cycles in Wetness and Dryness

The spectrum of a time series is the distribution of variance of the series as a function of frequency, or wavelength. A flow series with large-amplitude swings from high flows to low flows over periods of centuries has high variance at centennial timescales, or long wavelengths. A flow series that fluctuates rapidly from dry conditions to wet conditions every other year or several years has high variance at interannual timecales, or high frequencies. Spectral analysis can be used as a descriptive tool to succinctly summarize at which wavelengths or ranges of wavelength the variance of a time series is concentrated. The spectrum of a flow series with a strong, regular cycle at some wavelength (say, 20 years), will show a significant spectral peak at the wavelength of 20 years. The spectrum will show the peak, and spectral analysis will allow testing of the hypothesis that the peak results from random variability as opposed to some internal cyclic feature of the system (e.g., climate) generating the time series. We apply spectral analysis in this study to investigate possible cyclic behavior or rhythms in reconstructed and observed flow series.

The spectra of the observed and reconstructed flows for the Klamath, Sacramento and San Joaquin Rivers computed for the instrumental period are plotted Figures 16-18. These plots represent the relative variance (y axis) of the series as a function of frequency (x axis). The frequency axis ranges from 0 to 0.5 cycles/year. Wavelength is the inverse of frequency, such that a frequency of 0.1 cycles per year corresponds to a wavelength of 10 years. The x axis of the spectrum therefore covers wavelengths from infinity (left end of x axis) to 2 years (right end of x axis). The height of the plotted spectrum is proportional to the variance contributed by a range of wavelengths centered on any given point on the x axis. The spectra plotted in Figures 16-18 indicate several important points about the reconstructed and observed flows. First, the similarity in shapes of spectra for observed and reconstructed flow shows the ability of the tree-ring data to capture the variability of flow at different wavelengths. Second, the major peak in the spectrum (arrow A on Figure 16) indicates that variance in the time series is relatively high at a band of frequencies centered on frequency f=0.0625 cycles/year, or wavelength 16 years (wavelength is inverse of frequency. The location of the highest spectral peak ranges between about 14 years and 16 years for the three flow series (Figures 16-18), and is similar for the reconstructed and observed flows. Third, the spectrum for the reconstructed flows is lower than that for the observed flows. This feature merely reflects the fact that the total variance of reconstructed flow is less than that of observed flow, and is expected because tree-ring data cannot explain all of the variance in observed flow. Fourth, from the shapes of the spectra, it is apparent that the Klamath has proportionally more of its variance at the lower frequencies (longer wavelengths) than the Sacramento or San Joaquin. Spectra for the three basins are broadly similar in shape, with low-frequency variance becoming increasingly important toward the north, as indicated by the shapes of the fitted red-noise spectra (dashed lines).

Ability of the reconstructions to accurately track observed flow variations at various wavelengths or frequencies can be checked further with low-pass smoothing and cross-spectral analysis. Figures 19-

21 show a series of plots from cross-spectral analysis of observed and reconstructed flows for the same three basins discussed above. The top plot in each figure is Gaussian-smoothed observed and reconstructed flows. The smoothed time series plots highlight the synchrony in time series variations of observed and reconstructed flow at decadal-and-longer time scales. Intervals when both smoothed series are simultaneously in their lowest decile (dry) are shaded gray in the smoothed plots. The shading underscores the low-flow conditions of the 1930s and late-1980s to early 1990s. The Klamath observed series, which does not extend back to the earlier of those two droughts, shows a downward trend from the start of record (1949) to the drought peak in the early 1990s (Figure 19).

The smoothed time plots for the observed and reconstructed flow of the Sacramento and San Joaquin Rivers fluctuate greatly from one decade to another, a signature of high inter-decadal variance (Figures 20 and 21, top plots). These fluctuations are large in a practical sense. For the Sacramento (Figure 20), the fluctuations range from about 60% of normal for lowest troughs to 140% of normal for highest peaks. Peaks in wetness are found at 1915, 1941, 1952, 1970, 1983 and 1997. The intervals between peaks are annotated on the plots for the Sacramento (top, Figure 20). The average interval between peaks is 16.4 years. These time series features reflect the near-15-year spectral peak previously noted in the spectral analysis of observed and reconstructed flows for the instrumental period (Figure 17).

The two lower left plots in Figures19-21 show sample spectra of observed and reconstructed series, similar to the spectra plotted in Figures 16-18, but here with a confidence interval (dashed lines) that allows assessment of statistical significance of peaks. A peak is judged significant if the confidence interval around the spectrum at that frequency does not include the horizontal line, which represents the theoretical spectrum of white noise. White noise is a time series with the same variance as the time series analyzed, but with variance distributed evenly over all frequencies. No peak in any of the spectra in Figures 19-21 emerges as statistically significant from white noise. According, we conclude that the observed flows on the Klamath, Sacramento, and San Joaquin do not have statistically significant cycles at any particular frequency or wavelength.

The two lower right plots in Figures 19-21 are the coherency and phase spectra. The coherency is analogous to a correlation coefficient between time series as a function of frequency. The coherency plots here suggest strong correlation of observed and reconstructed series across the full range of frequencies. Coherence is especially high at frequencies for which the variance is high in the individual time series. The phase plot indicates whether the peaks and troughs in reconstructed and observed flows are times such that peaks line up with peaks and troughs with troughs (in-phase). Phase is important in a cross-spectral analysis because it is possible for coherence to be high and two series to be completely in opposition (one indicating wet when the other dry). The phase plots confirm that reconstructed flows are in-phase with observed flows at high and low frequencies in the three basins analyzed. This is especially true for frequencies at which variance is high in the individual series. In summary, the spectral and cross-spectral analysis presented so far support the idea that the tree-ring reconstructions in the three basins can be used to infer variations in observed flow at a low and high frequencies.

The cross-spectral analysis just described confirms that that the reconstructions can effectively track fluctuations in observed flow at high and low frequencies. The full-length reconstructions can therefore be applied to investigate long-term evidence for cycles in wetness and dryness. Although spectral peaks in the flow series (reconstructed and observed) for the instrumental period were found to be not significant, features not significant in a short time series may be significant in a longer time series because, other thing being equal, the width of confidence intervals for statistical tests narrow as sample size increases. The reconstructions generated here extend back to 1507 CE for the Klamath and to 900 CE for the Sacramento and San Joaquin basins. Spectra for the full-length reconstructions for the Klamath, Sacramento and San Joaquin basins are shown in Figures 22-24. These spectra are plotted along with a red noise null continuum and 95% confidence interval to facilitate identification of “significant” peaks – in this case, a peak higher than expected by chance if the series were merely red noise. Small differences in wavelength of peaks should not be interpreted, as the spectral peak is associated with a range of frequencies delineated by the bandwidth annotated on the plots. The spectrum for the full-length Klamath reconstruction shows a small spectral bump near 15 years, but the main peak, and the only peak significantly distinguishable from a red noise spectrum is at the much longer wavelength of 57 years (Figure 22).

Spectra of the full-length Sacramento and San Joaquin reconstructions (Figures 23-24) are much less red (less dominated by low-frequencies) than that of the Klamath. This difference may reflect the greater importance of groundwater to flow of the Klamath, but it should be kept in mind that the time period of analysis for the Klamath differs from that for the other two rivers. For the Sacramento, the major peak – and the only peak statistically distinguishable from red noise – is at 102 years. The second highest peak is at 21 years. No peak in the long-term spectrum is evident at 15 years. The major peak for the San Joaquin is at just a slightly shorter wavelength (93 yr) than that for the Sacramento. Like the peak on the Sacramento, this low-frequency peak is estimated to differ significantly from a red-noise spectrum. The San Joaquin has a secondary spectral peak, which also reaches significance, at 3.7 years. This feature may represent influence of ENSO. The third largest spectral peak for the San Joaquin is at a wavelength of 21 years. The long-term reconstructions for the Sacramento and San Joaquin are alike, therefore in having their two lowest-frequency spectral peaks near 100 years and 21 years.

As described in Section 2.5, wavelet analysis is an alternative to spectral analysis as a way of studying wavelike or cyclic features in a time series, and is especially useful for studying the temporal evolution of any such features. The cross wavelet transform (XWT) and wavelet coherence (WTC) are used in combination with the continuous wavelet transform (CWT) here to graphically summarize the evolution of cyclic features in a pair of observed and reconstructed flow series. We choose for this analysis the most widely separated basins for which we have reconstructions back to 900 CE: the Sacramento River above Bend Bridge (SBB) and the San Joaquin River inflow to Millerton Reservoir (SJF). Analysis for the observed flows, 1906-2012 CE, is summarized in Figures 25-27. Analysis for the reconstructions, 900-2012 CE, is summarized in Figures 28-30.

The CWT, analogous to temporally evolving spectrum, for the observed flows shows a band of high variance near a wavelength of 15 years through the complete observed time series of SBB and SJF, with highest variance concentrated at most recent decades (Figure 25). The XWT shows at what frequencies and times the two series both have high variance, regardless of whether variations in one series are synchronous with those in the other. The XWT in Figure 26 further supports the individual CWTs in identifying the 15-year peak in variance, stronger toward the end of the series (arrow A). The WTC shows whether variations in the two series are coherent (red corresponding to highest coherence) and in-phase or out-of-phase (arrows to right, perfectly in phase; arrows to the left 180° out of phase). The red coloring and right-leaning arrows throughout the time axis near a wavelength of 15 years for the WTC in Figure 27 indicate that variations near the 15-year period in observed flow records for SBB and SJF are approximately in-phase and coherent throughout the observed record, 1906-2012.

The CWTs of the full-length, 900-2012 CE, reconstructions for SBB and SJF suggest that any cyclic tendency near a wavelength of 15 years in the individual observed flow records, 1906-2012, is a transient phenomenon, expressed best in the 20th and 21st centuries (arrow A, Figure 28). The 15-year cycle is completely absent from the first half of the SBB reconstruction (arrow B). Another interesting feature in these CWTs is the high variance near the 100-year wavelength (arrow C, figure 28). For the SBB reconstruction, this long-wave feature is present in the first half of the record, and then re-appears after 1800 CE (arrow D). For the SJF reconstruction, the feature is significant only in about the first quarter of the record. Wavelet analysis complements the spectral analysis results for the Sacramento and San Joaquin basins (Figures 23 and 24) in suggesting that the significant spectral peaks near 100 years in the full reconstruction for the Sacramento and San Joaquin are driven primarily by variations early in the reconstruction record. Some hint of this near-centennial wave is evident in the time series plots of the annual reconstructed flows for SAC4 and SJQ4. For example, the plot for SAC4 shows broad wave-like fluctuations between 900 and 1200 CE, with highs near 900, 1000, 1100 and 1200, and lows approximately midway between those highs (Figure 11).

The cross wavelet functions XWT and WTC reinforce the conclusions above on the 15-year cycle. The strongest evidence for significantly high, in-phase, common variance in SBB and SJF near 15 years is restricted to the most recent 100 years (arrow A, Figure 29). Consistently strong in-phase coherence between the two series near wavelength 15 years is restricted to the second half of the record (arrow A, Figure 30). The XWT and XTC are consistent with the spectral analysis results discussed previously in showing a shift from around 15 years to perhaps nearer 20 years wavelength of relatively high variance before the instrumental period (red pockets centered near 1400 CE and 1800 CE at wavelengths between 16 and 32 years. In summary, this wavelet and cross wavelet analysis suggests that any observed tendency for cycles or quasi-cycles in flow records near a wavelength of 15 years in the instrumental record is not a long-term feature of the hydroclimate of the Sacramento and San Joaquin basins. The analysis also shows that cyclic behavior at very long wavelengths (near 100 years) occurs early (900-1200 CE) in the tree ring record for the Sacramento and San Joaquin Basins, but is not a regular feature over the full record.

3.4 Consistency of Reconstructions with other Paleoclimatic Data

We analyzed the consistency among the Klamath, Sacramento, and San Joaquin reconstructions with others hydroclimatic reconstructions across the western US using a set of existing reconstructions. The reconstructions for the Klamath, Sacramento, and San Joaquin Rivers were augmented with the Trinity River reconstruction to form a transect of gage reconstructions from roughly north to south across the study area. The reconstruction of Klamath Falls precipitation was also included as there is some uncertainty regarding the estimates of natural flow that were available for the reconstruction model calibration. For our assessment with other western US records, we selected a transect of flow reconstructions in the interior West, from north to south: the Snake River, the upper Colorado river basin, (the Yampa, Colorado at Lees Ferry, and San Juan Rivers), and the lower Colorado River basin (Salt and Verde Rivers with Tonto Creek flows to represent the lower Colorado River basin tributaries). We augmented the study area transect with a reconstruction of the Salinas River and several grid point reconstructions of the Palmer Drought Severity Index: 1) central Washington, 2) northeastern Nevada, and 3) southern California (called here the “west coast transect”). We also use this network to examine spatial relationships between the Klamath, Sacramento, and San Joaquin reconstructions and others hydroclimatic reconstructions.

Within the study area, the Sacramento, San Joaquin and Trinity Rivers (observed data) are all highly correlated (Table 10). The Klamath reconstructions (precipitation and flow) are less well correlated, with each other and with the other gage records, but show higher correlations with Sacramento and Trinity Rivers and somewhat lower correlations with the San Joaquin River, as would be expected. The correlations for the reconstructions over the same period reflect a very similar pattern (Table 11).

The relationships between the observed hydroclimatic series (except for PDSI, which has reconstructed values from 1949-1977) for the western US for the years 1949-2000 are shown in Table 12a. All correlations are significant ($p < 0.05$) except between the San Juan River and the lower Colorado River basin tributaries, and the western coast transect (except the San Joaquin River). In addition the correlation between the Klamath and Salinas Rivers is not significant. A comparison of the correlations with the reconstructed time series for 1949-1997 (Table 12b) shows a similar pattern, except correlations with the entire Colorado River basin for the Klamath series are not significant. In addition, the Klamath River reconstruction appears to be unrelated to other series in the west coast transect (see comments on this below).

When the patterns of correlations are examine for the reconstructions over the full common time period, 1591-1997 (Table 13a), all series are significantly correlated except the Klamath River reconstruction, which is not correlated with Colorado River basin or the southern California PDSI grid point reconstructions. In addition, Klamath Falls precipitation is not significantly correlated with the lower Colorado River basin tributaries. The strength of the correlations is as would be expected, with higher correlations among the “west coast transect” reconstructions, and lower values between the west coast and interior west reconstructions. Interestingly, the west coast correlations are highest with the northern-most interior west reconstruction, the Snake River, compared to other interior site correlations.

Correlations by century are show in Tables 13 b, c, d, and e. The pattern that emerges suggests shared hydroclimatic variability across the most of the entire region during all 100-year periods, except between the Klamath/Trinity region and parts of the Colorado River basin. This is most marked in the 17th and 19th centuries and least marked in the 18th century. In the 20th century, only the Klamath reconstructions show a lack of correlations with the Colorado River basin. In all centuries but the 20th century, the Klamath River reconstruction shows broader lack of correlations with other records, especially in comparison with Klamath Falls precipitation. This result may be evidence of the uncertainties in the estimated natural flow data used for the reconstruction calibration. This is something we will continue to investigate.

The coherence of major periods of drought in the north to south transect from central Washington to southern California can be assessed in Figure 31. Notable periods of widespread and persistent drought occurred in the 1930s, 1580s, 1100s, and 1000s (also noted in rankings and flame plots). Other periods of drought appear to have impacted subregions of this transect. For example, drought in late 16th century is evident in from the Trinity River basin and south, while not apparent in the Klamath and central Washington hydroclimatic reconstructions. A similar pattern is suggested around 1300, although the Trinity and Klamath records do not cover this period. In contrast, droughts in the late 1400s, mid 1600s and 1840s appear to have had less impact on the southern end of this transect.

3.5 Reconstructed Flow Variations in Context of Expected Scenarios of Climate Change

A number of approaches may be taken to assess drought characteristics in observed and reconstructed flow series with those in climate change projections. In this report, we chose to assess the longest run of drought. Here, we define a drought run as a consecutive period of years with values below a given threshold. For the Sacramento River at Bend Bridge and San Joaquin River at Millerton Lake, drought years were based on the 1906-2012 medians (reconstruction runs were based on the years below the reconstruction medians; observed and modeled runs were based years on years below the observed median). For the Klamath, all series were converted to z scores using the 1951-2000 period means and standard deviations before runs analysis. Thresholds for Klamath runs are medians for the reference period 1951-2000.

Bar charts (Figure 32) show maximum runs length results for the Sacramento, San Joaquin, and Klamath River reconstructions relative to the observed record in the first three bars. In all three basins, full reconstruction period runs are longer than those of the observed period (in both reconstructed and observed series) although the maximum run for the Sacramento is only slightly longer than for the observed period. The Klamath reconstruction shows a remarkable run of 21 years below the median, exceeding greatly the longest run in the observed period (nine years). The downscaled projections for the Sacramento and Klamath basins are relatively consistent over the six models and two scenarios. Run lengths for the Sacramento projections vary between four and eight years, with none reaching the maximum run length in the instrumental data (ten years). For the Klamath, run lengths vary from five to eight years, almost matching the maximum run length in the observed period, nine years. Runs are slightly longer, on average, for the A2 runs for the Klamath; they are the same, on average, for the Sacramento A2 and B1 runs. The results for the San Joaquin are somewhat different. Maximum run lengths vary widely from five years to 21 years. The average across models within a scenario is eight years for A2 and 8.5 years for B1, longer than the maximum run in the instrumental period (six years), but shorter than the maximum reconstructed run (12 years). Although difficult to gage model performance based on such a small subset of runs, these results suggest the model projections may underestimate maximum runs of drought years in the future. Note: these run lengths are slightly different than those shown in Results section 1 (Figure Runs 2 and 3) because those were based on the entire Sacramento (SAC4) and San Joaquin (SJ4) basin flows (sum of four gages) while these are for specific gages.

4. Conclusions

- Sixteen new tree-ring reconstructions of streamflow and precipitation for use in water-resources planning and operation are provided for the Klamath Basin and Sacramento and San Joaquin Basins. These reconstructions cover centuries to a millennium, and reflect long-term hydroclimatic variability on time scales beyond the reach of instrumental records.
- Reconstructions indicate that the instrumental period – the period covered by gaged flow records -- has been extremely variable in a long-term context. On the other hand, the conclusion on relative wetness of the instrumental period differs depending on whether measured by the mean or median. The median tends to give the instrumental period a drier long-term standing than the mean. This difference perhaps reflects higher positive skewness of flows in the instrumental period.
- Analysis of droughts in the reconstructions for the three basins indicates the 1920s-30s and 1990s contained periods of drought notably severe, even in a centuries- to millennium-context. However, the instrumental period does not contain the driest multi-decadal (50-yr) periods, and in the case of Klamath and San Joaquin, it does not included the longest run of drought years. On the Sacramento and San Joaquin, the instrumental record notably does not contain the record low-flow for individual years. This record-low flow is 1580 CE in both basins, and is reconstructed with only about half the water-year total flow of the driest reconstructed year (1924) of the instrumental period.
- The flow reconstructions examined contain no strong, regular cycles over their full lengths. A significant spectral peak near 100 years was found in the Sacramento and San Joaquin reconstructions. That peak appears to be driven mainly by fluctuations before 1200 CE, with a hint of recurrence in the last century.
- Cyclic variation, with an average wavelength of about 15 years, is evident in both observed and reconstructed flow series over the past 100 years, but is not a long-term feature of the hydroclimate of the basins studied. While some observed flow records have large inter-decadal swings, the near-15-year cycle in those records does not pass spectral analysis tests for statistical significance.
- Comparison of observed and reconstructed hydroclimatic series in the Klamath, Sacramento, and San Joquin basins suggests the reconstructions reflect the spatial relationships in the observed record. When a set of westerns US hydroclimatic records is considered, our reconstructions appear to replicate the spatial relationships in the observed records over the instrumental period. The major exception is the Klamath at Keno reconstruction (also notable over full reconstruction common time period), suggesting a possible problem with this reconstruction.
- Although this is a limited assessment, an evaluation of drought run length in six downscaled GCM flow projections with flow reconstructions suggests that GCMs many projections may not reflect the run lengths that have occurred under natural variability.

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Tables

Table 1. Field collections.

No.	Code	Site Name	Lat	Lon	Elev (ft)	Species	#Samp[a]	#Dated	#Meas	First Year	Last Year
	Klamath										
1	ALU	Antelope Lake (merged), CA	40.11	-120.64	4774	PIPO	48	45	45	1450	2010
2	BCU	Boles Creek (merged)	41.84	-120.88	4948	JUOC	49	39	34	1152	2010
3	CBY	Canby	41.50	-120.99	4892	PIPO	52	34	33	1669	2010
4	DRU	Dalton Reservoir (merged)	41.67	-120.98	5023	PIPO	48	43	41	1357	2010
5	FBK	Frederick Butte (merged)	43.59	-120.44	5249	JUOC	38	37	37	936	2010
6	HRK	Horse Ridge (merged)	43.98	-121.07	3773	JUOC	33	23	19	830	2010
7	ILM	Isn't Likely Mountain	42.12	-120.57	4898	JUOC	71	63	60	1655	2010
8	LVU	Lakeview (merged)	42.12	-120.56	4931	PIPO	52	42	39	1421	2010
9	LCU	Lemon Canyon (merged)	39.58	-120.30	5577	PIJE	48	45	46	1415	2010
10	LJK	Little Juniper Mountain (me	43.13	-119.87	5236	JUOC	38	28	23	1337	2010
11	LTU	Log Cabin (merged)	37.95	-119.15	8199	PIJE	48	41	41	1304	2010
12	PPB	Porcupine Butte	41.43	-121.61	4623	PIPO	52	41	41	1581	2010
13	SMU	Sharp Mt. (merged)	41.72	-121.82	4403	JUOC	51	41	38	1548	2010
14	AGK	Table Rock-Arrow Gap (merge	43.18	-120.90	4652	JUOC	28	28	14	530	2010
15	TMU	Timbered Mountain (merged)	41.72	-120.75	5203	JUOC	49	41	41	1654	2010
	Sacramento/San Joaquin										
16	EVG	Evans Grove	36.78	-118.82	7162	SEGI	40	40	39	1399	2011
17	KAI	Kaiser Pass	37.31	-119.11	8809	JUOC	40	38	39	1161	2011
18	LVF	Leavitt Falls	38.34	-119.55	7218	PIJE	46	42	42	1572	2011
19	UCJ	Upper Casacade Creek Junipe	38.58	-119.81	7766	JUOC	73	62	62	80	2011
20	UCP	Upper Casacade Creek Pine	38.58	-119.80	7766	PIJE	44	42	42	1556	2011
21	STA	Stanislaus River	38.41	-120.05	6657	PIJE	27	27	27	1633	2011
22	EPW	Ebbetts Pass West	38.54	-119.82	8530	JUOC	66	59	59	5	2011
23	LUP	Luther Pass Pine	38.79	-119.95	7949	PIJE	52	52	52	1463	2011
24	CPL	Carson Pass Lower	38.70	-119.99	8323	JUOC	32	31	31	1478	2011
25	SDN	Sardine Point	39.55	-120.20	7441	JUOC	55	53	53	831	2012
26	DIA	Mt Diablo	37.88	-121.97	597	QUDG	15	14	14	1853	2012
27	CSP	Calaveras State Park	38.24	-120.27	4528	SEGI	68	64	64	1522	2012
28	MHM	Mountain Home	36.24	-118.67	6463	SEGI	46	36	36	1584	2012
29	BMN	Black Mountain	36.10	-118.66	6398	SEGI	45	39	39	1516	2012

[a] Number of samples is number of cores; for sites with cross-sections from July 2013 field work, each section counted as a sample

Table 2. Reconstruction model statistics[a]

					Period[f]	
	Re[b]	RMSE[c]	adj R2[d]	R2[e]	calibration	reconstruction
Klamath sites						
Klamath-Keno, Flow	0.58	191	0.61	0.63	1949 – 2000	1507 – 2003
Trinity, Flow	0.64	353	0.66	0.68	1912 – 2003	1584 – 2003
Klamath Falls, P						
short model	0.53	2.50	0.58	0.60	1896 – 2003	1610 – 2004
long model	0.49	2.57	0.52	0.53	1896 – 2010	1000 – 2010
Weaverville, P	0.47	7.880	0.52	0.55	1904 – 2003	1584 – 2003
Yreka, P	0.47	4.258	0.51	0.54	1872 – 2003	1531 – 2003
California sites, Flow						
Feather R.	0.68	1200	N/A	0.70	1906 – 2012	900 – 2012
Yuba R.	0.69	607	N/A	0.71	1901 – 2012	900 – 2012
American R.	0.70	780	N/A	0.72	1901 – 2012	900 – 2012
Sacramento R.	0.65	1953	N/A	0.68	1906 – 2012	900 – 2012
Sacramento 4R	0.70	4238	N/A	0.73	1906 – 2012	900 – 2012
Stanislaus R.	0.72	322	N/A	0.74	1901 – 2012	900 – 2012
Tuolumne R.	0.77	429	N/A	0.78	1901 – 2012	900 – 2012
Merced R.	0.74	276	N/A	0.75	1901 – 2012	900 – 2012
San Joaquin R.	0.76	458	N/A	0.78	1901 – 2012	900 – 2012
San Joaquin 4R	0.75	1480	N/A	0.77	1901 – 2012	900 – 2012

[a] Statistics for California sites are median values for nested models; RMSE for Klamath-Keno is before restoring autocorrelation to flow (model described in text)

[b] Reduction-of-error statistic

[c] Root Mean Square Error of cross-validation; units kaf for flow reconstructions (Flow), and inches for precipitation (P) reconstructions

[d] Adjusted R-squared statistic for Klamath sites; not available for Loess models (Calif. Sites)

[e] Regression R-squared statistic for Klamath sites; equivalent variance-explained statistic for California sites (see text)

[f] First and last year of period for calibration and reconstruction. For nested model (Calif. Sites), end year of calibration period varies between 1989 and 2012 depending on model.

Table 3. Full natural flow records[a] reconstructed in Sacramento and San Joaquin basins.

N	Code[b]	River	Period[c]	Mean(kaf)[d]
1	FTO	Feather	1906-2012	4469
2	YRS	Yuba	1901-2012	2365
3	AMF	American	1901-2012	2734
4	SBB	Sacramento	1906-2012	8443
5	SAC4	Sacramento4	1906-2011	18019
6	SNS	Stanislaus	1901-2012	1175
7	TLG	Tuolumne	1901-2012	1910
8	MRC	Merced	1901-2012	997
9	SJF	San Joaquin	1901-2012	1815
10	SJQ4	San Joaquin4	1901-2011	5926

[a] Full natural flows downloaded 06-Oct-2012 from California Data Exchange Center (cdec)

[b] Gage code in cdec (except SAC4 and SJQ4,which are summary series defined byce cdec as Sacramento River Runoff and San Joaquin River Runoff

[c] Data period (water years) for computation of mean annual flow

[d] Mean annual flow (kaf)

Table 4. Inter-series correlation[a] of observed and reconstructed flows.

	YRS	AMF	SBB	SAC4	SNS	TLG	MRC	SJF	SJQ4
FTO	0.98(0.98)	0.96(0.96)	0.94(0.98)	0.99(0.98)	0.93(0.95)	0.91(0.96)	0.88(0.95)	0.86(0.93)	0.90(0.96)
YRS		0.98(0.98)	0.89(0.97)	0.97(0.98)	0.94(0.96)	0.93(0.96)	0.89(0.94)	0.87(0.93)	0.92(0.96)
AMF			0.85(0.94)	0.95(0.96)	0.97(0.99)	0.96(0.98)	0.93(0.95)	0.90(0.94)	0.95(0.97)
SBB				0.97(0.99)	0.83(0.93)	0.82(0.95)	0.79(0.94)	0.80(0.92)	0.82(0.95)
SAC4					0.92(0.94)	0.91(0.96)	0.88(0.94)	0.87(0.92)	0.90(0.95)
SNS						0.99(0.98)	0.97(0.96)	0.95(0.96)	0.99(0.98)
TLG							0.99(0.99)	0.97(0.98)	1.00(1.00)
MRC								0.99(0.99)	1.00(0.99)
SJF									0.99(0.98)

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[a] first number is for observed flow; number in parentheses is for reconstruction; all correlations for period 1906-2011

Table 5. Flow statistics for instrumental period and full reconstruction

		Statistic[c]				
Time Series[a]	**Period[b]**	**Mean**	**Median**	**StDev**	**Skew**	**r_1**
1 KLK Klamath at Keno Flow	**Obs 1949-2000**	**1176**	**1125**	**357**	**0.05**	**0.44**
	Rec 1949-2000	1176	1142	311	-0.13	0.39
	Rec 1507-2003	1104	1113	284	-0.11	0.40
2 TRN Trinity Flow	**Obs 1912-2003**	**1275**	**1129**	**589**	**0.66**	**0.09**
	Rec 1912-2003	1275	1287	487	0.18	0.23
	Rec 1584-2003	1312	1315	415	-0.18	0.17
3 KFL Klamath Falls Long P	**Obs 1896-2010**	**13.33**	**13.19**	**3.61**	**0.25**	**-0.05**
	Rec 1896-2010	13.32	13.66	2.63	-0.46	-0.11
	Rec 1000-2010	13.34	13.54	2.91	-0.17	-0.08
4 KFS Klamath Falls Short P	**Obs 1896-2004**	**13.42**	**13.39**	**3.66**	**0.20**	**-0.06**
	Rec 1896-2004	13.45	13.74	2.85	-0.41	-0.07
	Rec 1610-2004	13.43	13.62	2.52	-0.17	-0.04
5 WEA Weaverville P	**Obs 1904-2003**	**34.66**	**33.39**	**10.91**	**0.33**	**-0.06**
	Rec 1904-2003	34.66	35.50	8.12	0.14	0.10
	Rec 1584-2003	34.82	35.75	7.43	-0.21	0.04
6 YRK Yreka P	**Obs 1872-2003**	**17.72**	**17.43**	**5.89**	**0.42**	**-0.07**
	Rec 1872-2003	17.72	18.16	4.34	-0.32	0.04
	Rec 1531-2003	17.72	17.89	4.11	-0.14	0.06
7 FTO Feather Flow	**Obs 1906-2012**	**4469**	**3952**	**2098**	**0.55**	**0.07**
	Rec 1906-2012	4539	4333	1755	0.15	0.18
	Rec 900-2012	4565	4364	1519	0.09	0.06
8 YRS Yuba Flow	**Obs 1901-2012**	**2365**	**2252**	**1081**	**0.31**	**0.05**
	Rec 1901-2012	2427	2440	910	-0.13	0.14
	Rec 900-2012	2434	2473	801	-0.23	-0.01
9 AMF American Flow	**Obs 1901-2012**	**2734**	**2588**	**1417**	**0.50**	**0.05**
	Rec 1901-2012	2786	2761	1168	0.10	0.06
	Rec 900-2012	2766	2769	1034	-0.02	-0.01
10 SBB Sacramento Flow	**Obs 1906-2012**	**8443**	**7770**	**3282**	**0.63**	**0.12**
	Rec 1906-2012	8544	8235	2748	0.35	0.27
	Rec 900-2012	8576	8503	2291	0.13	0.14
11 SAC4 Sacramento4 Flow	**Obs 1906-2011**	**18019**	**16315**	**7686**	**0.48**	**0.09**
	Rec 1906-2011	18238	17403	6589	0.16	0.18
	Rec 900-2012	18261	17800	5602	0.04	0.07
12 SNS Stanislaus Flow	**Obs 1901-2012**	**1175**	**1116**	**603**	**0.64**	**0.04**
	Rec 1901-2012	1202	1202	516	0.25	0.11
	Rec 900-2012	1181	1173	449	0.10	0.02
13 TLG Tuolumne Flow	**Obs 1901-2012**	**1910**	**1878**	**903**	**0.62**	**0.03**
	Rec 1901-2012	1946	1868	789	0.35	0.13
	Rec 900-2012	1903	1857	683	0.27	0.04
14 MRC Merced Flow	**Obs 1901-2012**	**997**	**919**	**538**	**0.79**	**0.03**
	Rec 1901-2012	1019	943	473	0.46	0.05
	Rec 900-2012	999	947	404	0.39	-0.02
15 SJF San Joaquin Flow	**Obs 1901-2012**	**1815**	**1679**	**936**	**0.81**	**0.02**
	Rec 1901-2012	1862	1676	851	0.58	0.06
	Rec 900-2012	1798	1699	702	0.46	0.01
16 SJQ4 San Joaquin4 Flow	**Obs 1901-2011**	**5926**	**5610**	**2949**	**0.68**	**0.05**
	Rec 1901-2011	6016	5614	2629	0.45	0.11
	Rec 900-2012	5882	5598	2260	0.37	0.04

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[a] Name of observed (Obs) or reconstructed (Rec) series, preceded by letter code used elsewhere in report to define series; all series are water-year totals of either river flow (Flow) or precipitation (p).

[b] Time period for computation of statistics; for Obs, period is overlap of available data of observations and reconstructions; for Rec, period is full length of reconstruction available beginning with year 900.

[c] Statistics: sample mean, median, standard deveiation, skew, and lag-1 autocorrelation; units for first three statistics are thousands of acre-ft (KAF) for flow, and inches for precipitation; last two statistics are dimensionless.

Table 6. Runs[a] with length ≥4 years in three flow reconstructions

Klamath[b]		Sacramento4[c]		San Joaquin4[d]	
Years	**N**	**Years**	**N**	**Years**	**N**
1515-1522	8	921- 924	4	946- 950	5
1540-1543	4	945- 950	6	977- 981	5
1547-1552	6	975- 981	7	1072-1075	4
1578-1582	5	1072-1075	4	1143-1148	6
1592-1597	6	1130-1136	7	1155-1158	4
1642-1646	5	1143-1148	6	1172-1177	6
1648-1668	21	1150-1158	9	1210-1213	4
1738-1744	7	1170-1177	8	1233-1239	7
1756-1761	6	1233-1239	7	1294-1301	8
1764-1767	4	1292-1301	10	1395-1402	8
1775-1779	5	1390-1393	4	1407-1410	4
1783-1787	5	1395-1400	6	1425-1428	4
1792-1798	7	1407-1410	4	1450-1461	12
1843-1846	4	1425-1432	8	1463-1466	4
1848-1852	5	1451-1457	7	1471-1483	13
1873-1876	4	1475-1483	9	1505-1508	4
1880-1884	5	1515-1521	7	1518-1523	6
1912-1915	4	1540-1543	4	1540-1545	6
1917-1920	4	1569-1572	4	1569-1572	4
1924-1935	12	1578-1582	5	1578-1582	5
1987-1992	6	1592-1595	4	1592-1595	4
		1636-1639	4	1629-1632	4
		1645-1648	4	1645-1648	4
		1652-1655	4	1652-1655	4
		1753-1760	8	1688-1691	4
		1780-1783	4	1753-1757	5
		1843-1846	4	1780-1783	4
		1856-1859	4	1793-1796	4
		1917-1922	6	1843-1846	4
		1926-1935	10	1855-1859	5
		1946-1951	6	1928-1931	4
		1959-1962	4	1946-1950	5
		1987-1992	6	1959-1962	4
				1987-1992	6
				2000-2004	5

[a] runs defined as consecutive years below median

[b] Klamath at Keno, 1507-2003; median =1113 kaf

[c] Sacramento R. Runoff, 900-2012, median=17800 kaf

[d] San Joaquin R. Runoff, 900-2012, median=5598 kaf

Table 7. Ranked moving average of reconstructed flow, Sacramento River Runoff (series SAC4), 900-2012 CE. Moving averages of length 1, 3, 6, 10, 20, 25 and 50 years ranked from driest (1) to 20th driest (20). Rank listed in first column, Flow in kaf followed by last year of moving average in remaining columns.

N	1	3	6	10	20	50
1	2399 (1580)	8747 (1580)	10864 (1934)	12341 (1933)	13691 (1936)	15601 (1175)
2	5329 (1924)	8837 (1581)	11734 (1992)	12405 (1935)	13807 (1935)	15670 (1177)
3	5339 (1729)	9228 (1796)	11778 (1933)	12661 (1934)	13867 (1937)	15682 (1179)
4	5973 (1977)	9361 (1931)	11808 (1846)	13015 (1931)	13881 (1158)	15710 (1178)
5	6071 (1829)	9832 (1655)	11905 (1931)	13079 (1932)	14304 (1934)	15768 (1176)
6	6128 (1841)	9862 (1977)	11935 (1935)	13216 (1936)	14331 (1162)	15768 (1180)
7	6161 (1783)	10023 (1778)	12225 (1480)	13552 (1580)	14338 (1157)	15834 (1174)
8	6209 (1795)	10759 (1783)	12562 (1481)	13554 (1482)	14385 (1159)	15866 (1172)
9	6231 (1931)	10875 (1845)	12600 (1932)	13561 (1937)	14459 (1939)	15940 (1173)
10	6633 (1571)	11019 (981)	12642 (1929)	13648 (1148)	14517 (1156)	15968 (1181)
11	6732 (1126)	11100 (1146)	12673 (1845)	13846 (1483)	14616 (1938)	16037 (1183)
12	6799 (1532)	11369 (1961)	12719 (1148)	13881 (1481)	14695 (1160)	16037 (1187)
13	6913 (1864)	11433 (1481)	12745 (1156)	13933 (1783)	14702 (1161)	16038 (1171)
14	6918 (1529)	11491 (1757)	12792 (1520)	13934 (1152)	14817 (1148)	16070 (1170)
15	7357 (1632)	11495 (1156)	12835 (1157)	13993 (1929)	14859 (1164)	16119 (1188)
16	7441 (1285)	11527 (1846)	12845 (981)	14055 (1849)	14874 (1152)	16148 (1168)
17	7489 (957)	11567 (1992)	12953 (1521)	14089 (1157)	14886 (1154)	16156 (1189)
18	7512 (1691)	11591 (1145)	12958 (1580)	14110 (1480)	14903 (1940)	16157 (1182)
19	7596 (1579)	11600 (1933)	12966 (1844)	14112 (1159)	14925 (1155)	16161 (1185)
20	7616 (1976)	11650 (980)	13021 (1158)	14115 (1158)	14934 (1163)	16163 (1186)

Table 8. Ranked moving average of reconstructed flow, San Joaquin River Runoff (series SJQ4), 900-2012 CE. Moving averages of length 1, 3, 6, 10, 20, 25 and 50 years ranked from driest (1) to 20th driest (20). Rank listed in first column, Flow in kaf followed by last year of moving average in remaining columns.

N	1	3	6	10	20	50
1	575 (1580)	2292 (1655)	3377 (1846)	3825 (1933)	4390 (1465)	4940 (1500)
2	1064 (1924)	2376 (1796)	3429 (1931)	3904 (1461)	4424 (1466)	4973 (1499)
3	1185 (1795)	2402 (1580)	3438 (1934)	3939 (1934)	4447 (1468)	4987 (1501)
4	1277 (1532)	2499 (1931)	3505 (983)	3941 (1459)	4466 (1469)	5016 (1483)
5	1284 (1126)	2590 (1581)	3600 (1480)	3968 (1460)	4519 (1935)	5023 (1492)
6	1453 (1729)	2663 (1778)	3668 (1845)	3971 (1935)	4522 (1936)	5026 (1480)
7	1473 (1829)	2725 (1845)	3686 (981)	3978 (1482)	4574 (1467)	5029 (1497)
8	1564 (1864)	2782 (1783)	3700 (982)	4004 (1931)	4602 (1937)	5038 (1502)
9	1593 (957)	2836 (1961)	3729 (1933)	4011 (1783)	4614 (1158)	5041 (1479)
10	1666 (1632)	2940 (980)	3732 (1783)	4019 (1932)	4632 (1464)	5042 (1481)
11	1687 (1841)	2976 (981)	3759 (980)	4056 (1483)	4634 (1463)	5048 (1498)
12	1687 (1931)	3068 (1846)	3765 (1782)	4060 (984)	4646 (1934)	5060 (1495)
13	1697 (1783)	3082 (1757)	3766 (1992)	4064 (1481)	4660 (1462)	5066 (1493)
14	1719 (1579)	3102 (1977)	3769 (1929)	4099 (1480)	4670 (1461)	5067 (1482)
15	1768 (1782)	3111 (1858)	3784 (1481)	4145 (1784)	4676 (1483)	5070 (1485)
16	1834 (1655)	3131 (1654)	3858 (1461)	4197 (1465)	4687 (1157)	5077 (1486)
17	1893 (1777)	3194 (979)	3875 (1457)	4238 (986)	4703 (1482)	5081 (1491)
18	1902 (1059)	3201 (1737)	3877 (1459)	4275 (1462)	4704 (1156)	5085 (1496)
19	1908 (954)	3205 (1824)	3887 (1670)	4275 (1849)	4717 (1159)	5097 (1487)
20	1967 (1529)	3217 (1795)	3908 (1844)	4279 (983)	4717 (1859)	5100 (1484)

Table 9. Ranked moving average of reconstructed flow, Klamath at Keno (series KLK), 1507-2003 CE. Moving averages of length 1, 3, 6, 10, 20, 25 and 50 years ranked from driest (1) to 20th driest (20). Rank listed in first column, Flow in kaf followed by last year of moving average in remaining columns.

N	1	3	6	10	20	50
1	252 (1655)	405 (1656)	492 (1660)	591 (1661)	712 (1667)	955 (1668)
2	324 (1666)	454 (1657)	504 (1659)	599 (1662)	713 (1668)	955 (1674)
3	379 (1575)	521 (1581)	579 (1661)	612 (1663)	745 (1669)	957 (1667)
4	384 (1656)	530 (1660)	583 (1658)	614 (1660)	753 (1670)	957 (1675)
5	390 (1659)	557 (1661)	591 (1657)	646 (1664)	757 (1671)	959 (1673)
6	396 (1992)	565 (1655)	638 (1656)	663 (1659)	759 (1666)	960 (1676)
7	428 (1667)	581 (1668)	653 (1662)	689 (1667)	771 (1672)	964 (1671)
8	465 (1918)	588 (1580)	684 (1582)	707 (1658)	775 (1662)	964 (1672)
9	468 (1581)	588 (1582)	692 (1934)	719 (1666)	777 (1663)	965 (1669)
10	474 (1616)	596 (1667)	696 (1663)	719 (1668)	782 (1661)	965 (1677)
11	478 (1889)	597 (1933)	697 (1580)	725 (1665)	784 (1673)	966 (1670)
12	495 (1933)	601 (1658)	712 (1581)	735 (1657)	787 (1664)	972 (1679)
13	503 (1860)	603 (1659)	734 (1583)	754 (1933)	787 (1665)	973 (1666)
14	510 (1660)	641 (1778)	735 (1664)	763 (1934)	808 (1660)	975 (1678)
15	515 (1776)	641 (1934)	740 (1655)	775 (1935)	814 (1674)	976 (1665)
16	546 (1579)	659 (1920)	743 (1933)	792 (1583)	842 (1936)	977 (1664)
17	548 (1580)	665 (1992)	744 (1935)	797 (1584)	845 (1934)	979 (1680)
18	570 (1926)	673 (1919)	754 (1667)	798 (1582)	846 (1659)	979 (1681)
19	575 (1639)	677 (1926)	781 (1936)	799 (1656)	850 (1935)	982 (1663)
20	578 (1654)	703 (1662)	782 (1668)	823 (1581)	854 (1937)	991 (1662)

Table 10. Correlations for observed flow and precipitation in the Klamath, Sacramento, and San Joaquin basins, 1949-2000. All values significant at $p < 0.05$.

	Klamath Falls P	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Klamath Falls P	1.000				
Klamath R.	0.752	1.000			
Trinity R.	0.719	0.674	1.000		
Sacramento R.	0.773	0.678	0.941	1.000	
San Joaquin R.	0.689	0.515	0.840	0.927	1.000

Table 11. Correlations for reconstructed flow and precipitation in the Klamath, Sacramento, and San Joaquin basins, 1949-2000. All values significant at $p < 0.05$.

	Klamath Falls P	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Klamath Falls P	1.000				
Klamath R.	0.671	1.000			
Trinity R.	0.699	0.724	1.000		
Sacramento R.	0.715	0.640	0.950	1.000	
San Joaquin R.	0.641	0.481	0.880	0.952	1.000

Table 12. Correlations for observed flow and precipitation in the Klamath, Sacramento, and San Joaquin basins, with other hydroclimatic series in the western US. PDSI records are reconstructions up to 1978, then are instrumental data. Common period is 1949-2000, except for Snake R. which starts in 1958. N = 48 because of four missing values in the Salinas River record. Red values are not significant at $p < 0.05$. b. Correlations for reconstructed series.

a. observed	Klamath Falls P	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Snake R.	0.651	0.697	0.497	0.624	0.592
Yampa R.	0.554	0.409	0.504	0.588	0.647
Colorado R.	0.449	0.336	0.454	0.542	0.650
San Juan R.	*0.139*	*0.012*	*0.170*	*0.225*	0.363
lower CO tributaries	*0.054*	*-0.167*	*0.202*	*0.196*	0.404
PDSI-C. WA	0.596	0.523	0.497	0.520	0.494
PDSI-NE NV	0.539	0.330	0.486	0.595	0.696
Salinas R.	0.451	*0.264*	0.757	0.737	0.847
PDSI-S. CA	0.596	0.523	0.497	0.520	0.494

b. reconstructed	Klamath Falls	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Snake R.	0.394	0.340	0.614	0.618	0.550
Yampa R.	*0.179*	*0.190*	0.464	0.496	0.494
Colorado R.	*0.194*	*0.202*	0.505	0.533	0.549
San Juan R.	*0.011*	*-0.036*	*0.244*	0.307	0.381
Lower CO tribs.	*0.025*	*-0.147*	*0.219*	*0.252*	0.348
PDSI-C.WA	0.570	0.543	0.595	0.572	0.456
PDSI-NE NV	0.324	*0.256*	0.604	0.646	0.655
Salinas R.	0.369	*0.208*	0.676	0.719	0.821
PDSI-S.CA	0.310	*0.090*	0.565	0.632	0.721

Table 13. Correlations for reconstructed water year precipitation and streamflow for Klamath, Sacramento, and San Joaquin basins and other hydroclimatic reconstructions in the western US. For the full common period, a.1591-1997, and for b. 1600s, c. 1700s, d. 1800s, and e. 1900s to 1997. Red values are not significant at $p < 0.05$

a. 1591-1997	Klamath Falls	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Klamath Falls	1.000				
Klamath R.	0.589	1.000			
Trinity R.	0.581	0.476	1.000		
Sacramento R.	0.590	0.399	0.914	1.000	
San Joaquin R.	0.542	0.334	0.864	0.957	1.000
Snake R.	0.332	0.193	0.399	0.412	0.400
Yampa R.	0.128	*0.083*	0.205	0.283	0.315
Colorado R.	0.156	*0.065*	0.255	0.337	0.361
San Juan R.	0.152	*-0.008*	0.250	0.322	0.351
Lower CO tribs.	*0.092*	*-0.053*	0.207	0.261	0.303
PDSI-C.WA	0.582	0.385	0.475	0.488	0.420
PDSI-NE NV	0.373	0.221	0.503	0.588	0.590
Salinas R.	0.288	0.123	0.716	0.786	0.843
PDSI-S.CA	0.320	*0.088*	0.609	0.697	0.737

b. 1600-1699	Klamath Falls	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Klamath Falls	1.000				
Klamath R.	0.581	1.000			
Trinity R.	0.507	0.360	1.000		
Sacramento R.	0.538	0.295	0.877	1.000	
San Joaquin R.	0.493	0.223	0.808	0.953	1.000
Snake R.	0.336	*0.192*	0.257	0.266	0.254
Yampa R.	*0.169*	*0.135*	*0.179*	0.255	0.303
Colorado R.	*0.144*	*0.054*	*0.164*	0.258	0.270
San Juan R.	*0.170*	*0.020*	*0.189*	0.251	0.249
Lower CO tribs.	*0.136*	*0.006*	0.271	0.282	0.297
PDSI-C.WA	0.505	0.264	0.371	0.421	0.349
PDSI-NE NV	0.343	*0.179*	0.511	0.612	0.633
Salinas R.	0.220	*0.070*	0.685	0.787	0.837
PDSI-S.CA	0.247	*0.000*	0.571	0.697	0.736

c. 1700-1799	Klamath Falls	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Klamath Falls	1.000				
Klamath R.	0.621	1.000			
Trinity R.	0.498	0.426	1.000		
Sacramento R.	0.508	0.343	0.926	1.000	
San Joaquin R.	0.510	0.322	0.896	0.969	1.000
Snake R.	0.314	*0.069*	0.411	0.456	0.450
Yampa R.	0.228	*0.092*	0.277	0.418	0.386
Colorado R.	0.207	*0.066*	0.286	0.426	0.409
San Juan R.	0.201	*0.040*	0.312	0.449	0.441
Lower CO tribs.	*0.091*	*-0.038*	*0.194*	0.290	0.309
PDSI-C.WA	0.560	0.410	0.524	0.492	0.456
PDSI-NE NV	0.397	0.198	0.427	0.570	0.563
Salinas R.	0.276	*0.091*	0.765	0.843	0.864
PDSI-S.CA	0.302	*0.071*	0.569	0.703	0.722

d. 1800-1899	Klamath Falls	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Klamath Falls	1.000				
Klamath R.	0.470	1.000			
Trinity R.	0.629	0.331	1.000		
Sacramento R.	0.598	0.247	0.895	1.000	
San Joaquin R.	0.529	0.226	0.859	0.958	1.000
Snake R.	0.373	*0.168*	0.439	0.435	0.440
Yampa R.	*0.040*	*0.073*	*0.104*	*0.183*	0.253
Colorado R.	*0.135*	*0.035*	*0.191*	0.273	0.329
San Juan R.	*0.178*	*-0.046*	0.258	0.312	0.346
Lower CO tribs.	*0.110*	*-0.094*	*0.178*	0.248	0.283
PDSI-C.WA	0.636	0.312	0.441	0.455	0.421
PDSI-NE NV	0.394	0.214	0.504	0.550	0.552
Salinas R.	0.287	*-0.013*	0.701	0.783	0.846
PDSI-S.CA	0.405	*0.089*	0.727	0.761	0.775

e. 1900-1997	Klamath Falls	Klamath R.	Trinity R.	Sacramento R.	San Joaquin R.
Klamath Falls	1.000				
Klamath R.	0.682	1.000			
Trinity R.	0.710	0.719	1.000		
Sacramento R.	0.712	0.659	0.946	1.000	
San Joaquin R.	0.634	0.532	0.890	0.951	1.000
Snake R.	0.350	0.356	0.507	0.499	0.465
Yampa R.	*0.097*	*0.070*	0.297	0.317	0.348
Colorado R.	*0.171*	*0.153*	0.391	0.410	0.447
San Juan R.	*0.069*	*0.001*	0.268	0.298	0.386
Lower CO tribs.	*0.062*	*-0.101*	0.240	0.277	0.358
PDSI-C.WA	0.619	0.571	0.560	0.575	0.450
PDSI-NE NV	0.374	0.307	0.586	0.628	0.615
Salinas R.	0.383	0.291	0.714	0.742	0.832
PDSI-S.CA	0.356	0.205	0.615	0.660	0.730

Figures

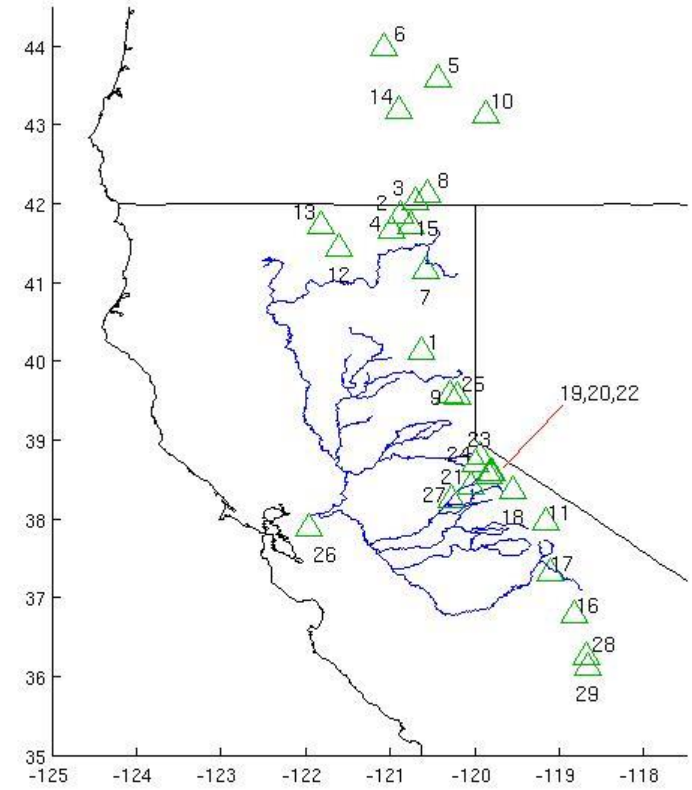

Figure 1. Map showing locations of the 29 tree-ring sites for field collections on this project. Species and other information on the sites are listed in Table1.

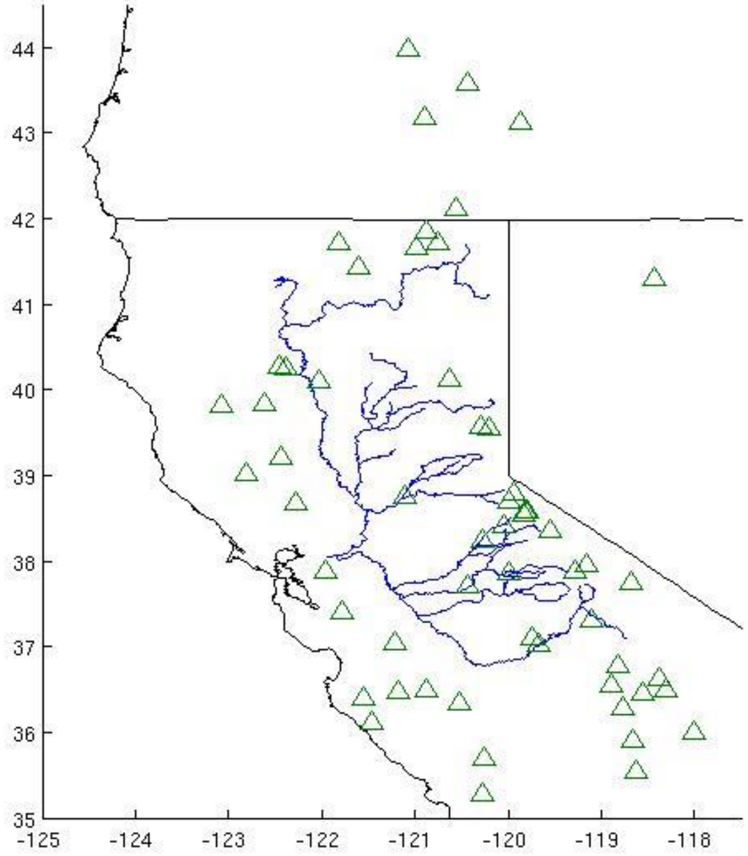

Figure 2. Map showing 6l-site tree-ring network for reconstruction modeling of Sacramento and San Joaquin River basins. Reconstruction of any flow record draws on a subset of these sites, whose names, site information, and basic chronology statistics are listed in Appendix C.

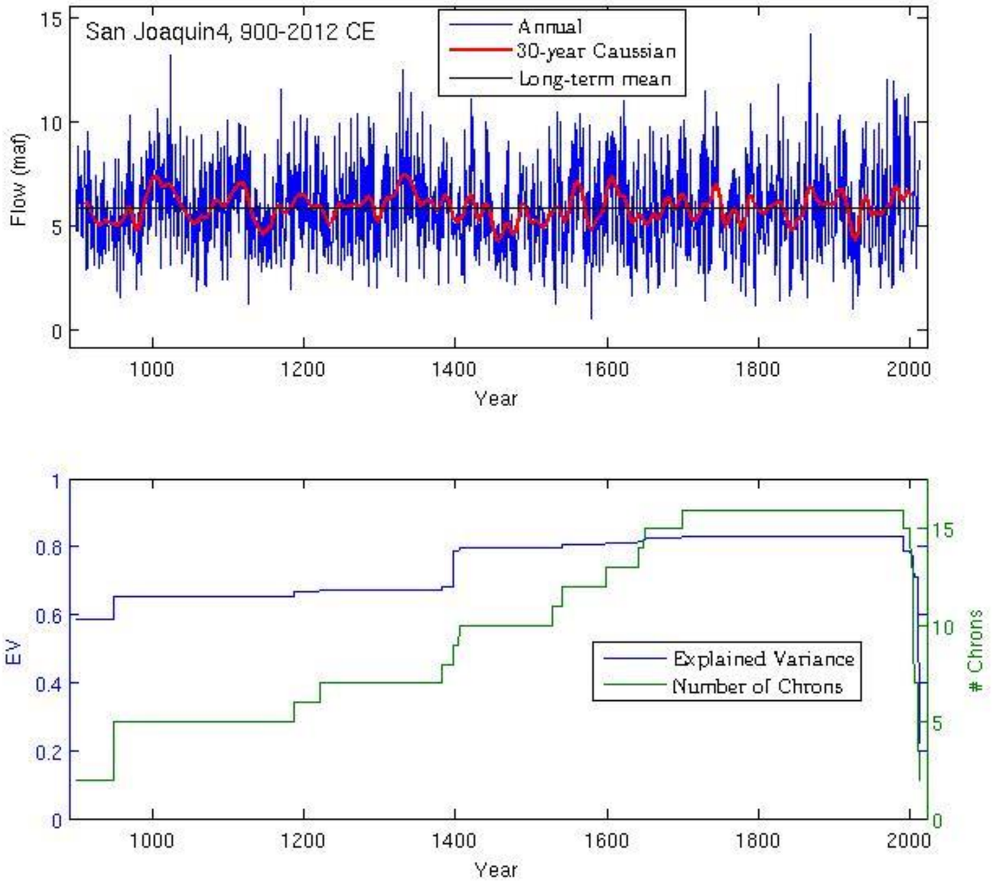

Figure 3. Reconstruction time series for San Joaquin River Runoff, 900-2012 CE. Top: annual and 30 yr Gaussian-smoothed reconstructed flow. Bottom: number of chronologies (N) in nested Loess model and decimal fraction of variance of flow explained (EV) by model.

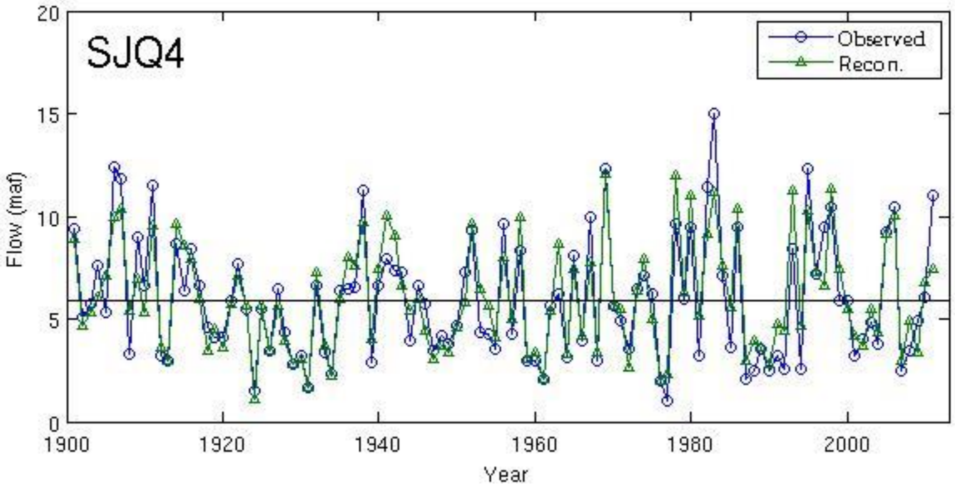

Figure 4. Time plots of observed and reconstructed flow, San Joaquin River Runoff, 1901-2011. Horizontal line at observed mean. For reconstruction statistics, see last line of Table 2.

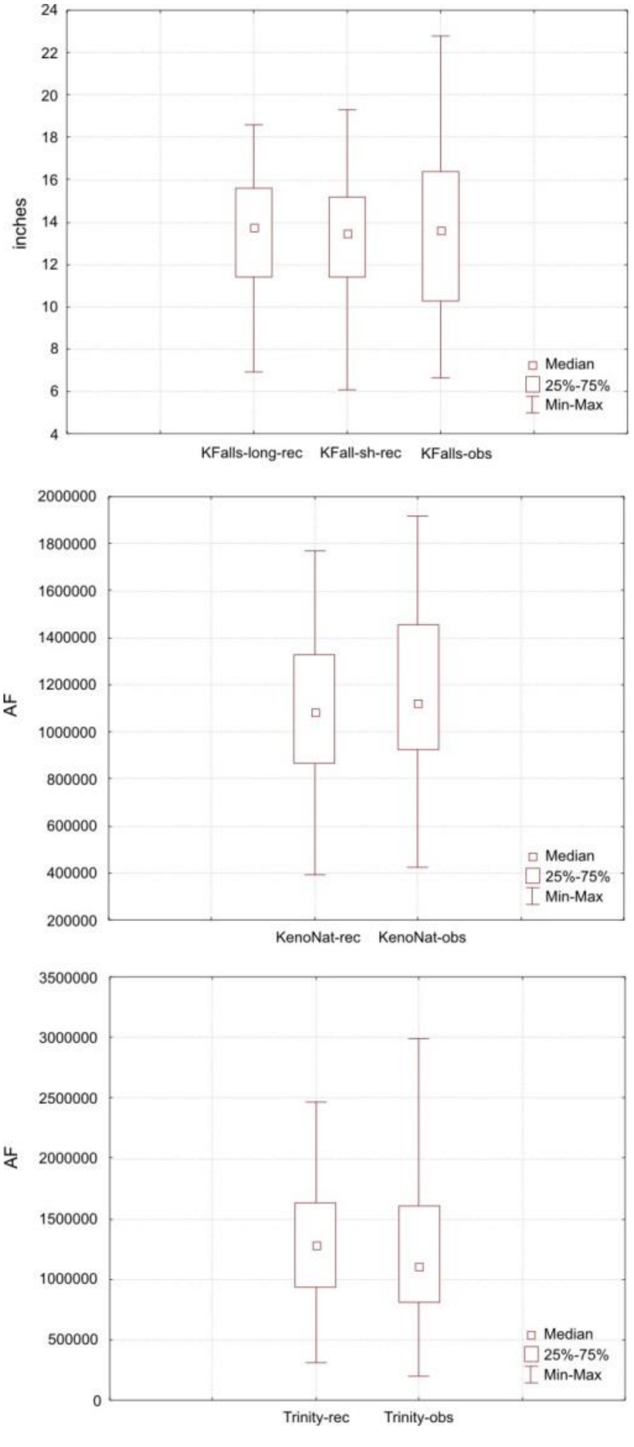

Figure **5**. Box plots for Klamath Falls water year precipitation (1912-2000), Klamath at Keno estimated natural water year flow (1949-2000), and Trinity River water year flow (1912-2000), reconstructions and observed series. Plots show median (center square) 25th and 75th percentiles (rectangle) and extreme high and low values. For the Klamath at Keno, results for the two reconstruction models are shown (one starting in 1000 and one in 1610).

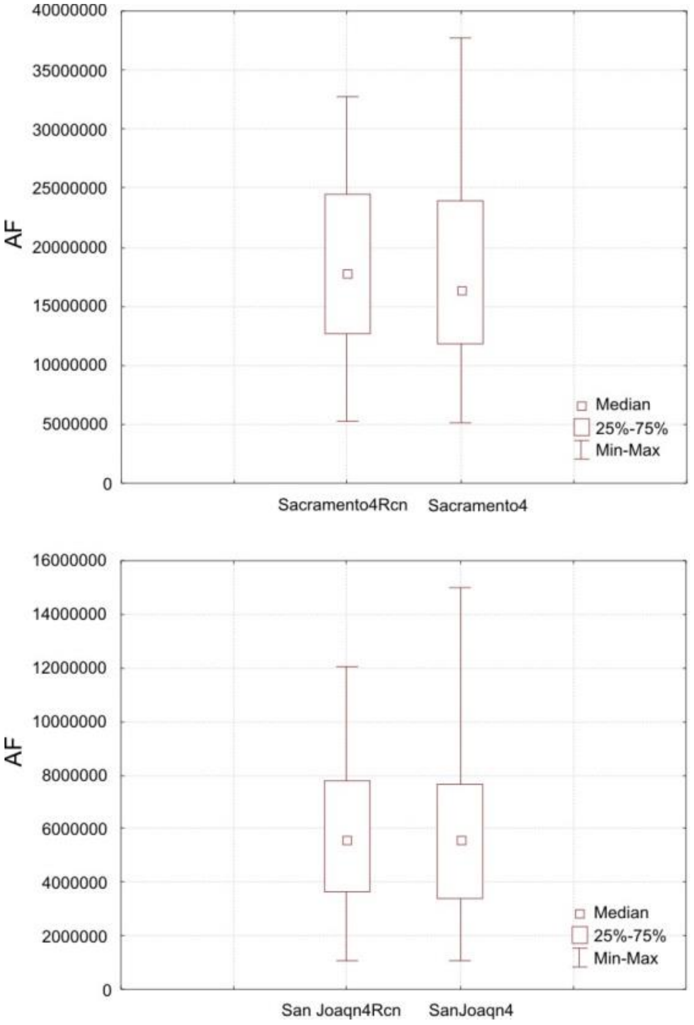

Figure 6. Box plots for Sacramento (4 rivers average) and San Joaquin (4 rivers averages) water streamflow, (1906-2011), reconstructions and observed series. Plots show median (center square) 25th and 75th percentiles (rectangle) and extreme high and low values.

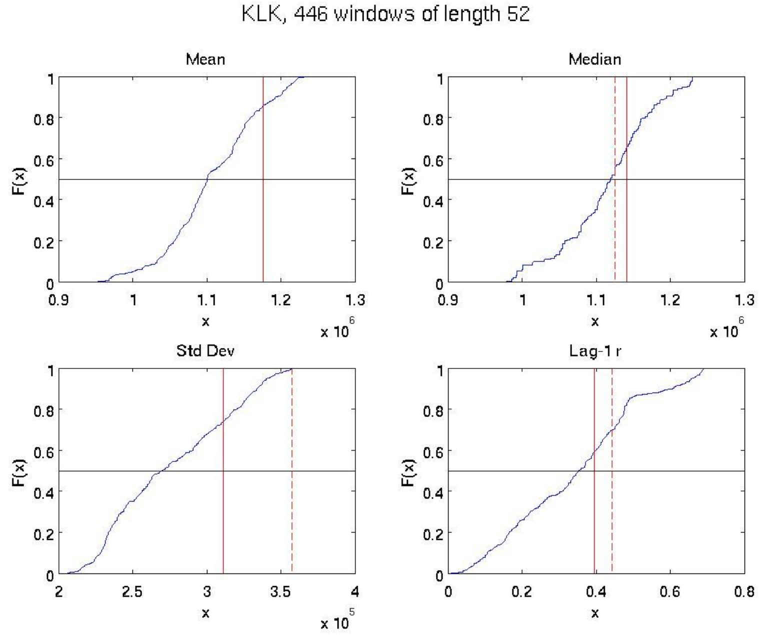

Figure 7. Cumulative distribution functions of hydrologic statistics in *m*-year overlapping windows offset by one year for Klamath River (KLK) flow reconstruction. Statistics, clockwise from upper right are mean, median, standard deviation and lag-1 autocorrelation. X-axis units are flow in acre-ft for first three statistics, and dimensionless for the last. Y-axis is non-exceedance probability of the statistic at given value of x. Vertical lines mark the value of the statistic for the reconstruction (solid) or observations (dashed) for the single *m*-year period of overlap of observed and reconstructed series. If only solid vertical line, the statistic is identical for the two series. Offset of vertical lines shows the bias in reproducing the calibration-period value of the statistic. For standard deviation this offset also reflects unexplained variance in the reconstruction. Annotated at top of figure are the number of windowed-periods and the length (years) of the window. For example, the 52-year overlap period of observed and reconstructed flows was relatively wet: the reconstructed sample mean for this period, about 1.15 million acre-feet, ranks near the 80th percentile of 446 sample means computed for a total of 446 overlapping 52-year periods.

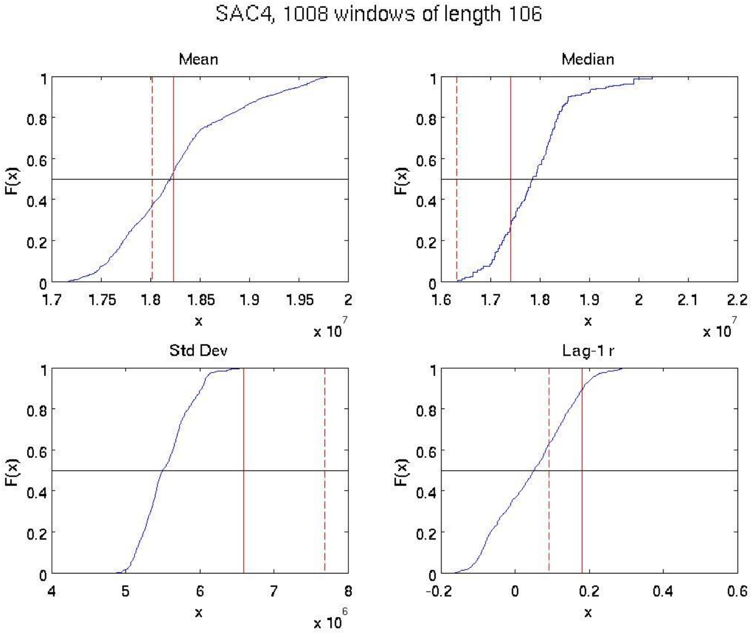

Figure 8. Cumulative distribution functions of hydrologic statistics in *m*-year overlapping windows offset by one year for long-term reconstruction of Sacramento (SAC4) reconstructed flows. Components of plots described in caption to Figure 7.

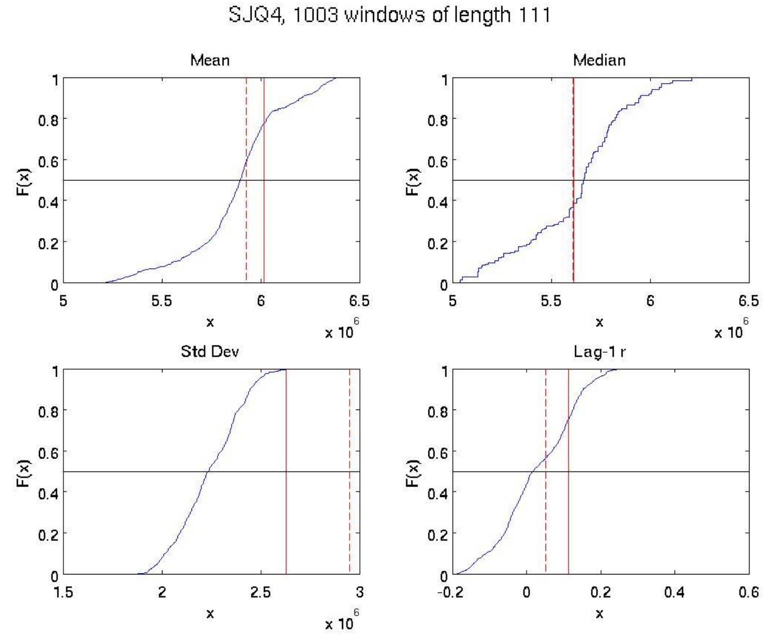

Figure 9. Cumulative distribution functions of hydrologic statistics in *m*-year overlapping windows offset by one year for long-term reconstruction of San Joaquin (SJQ4) reconstructed flows. Components of plots described in caption to Figure 7.

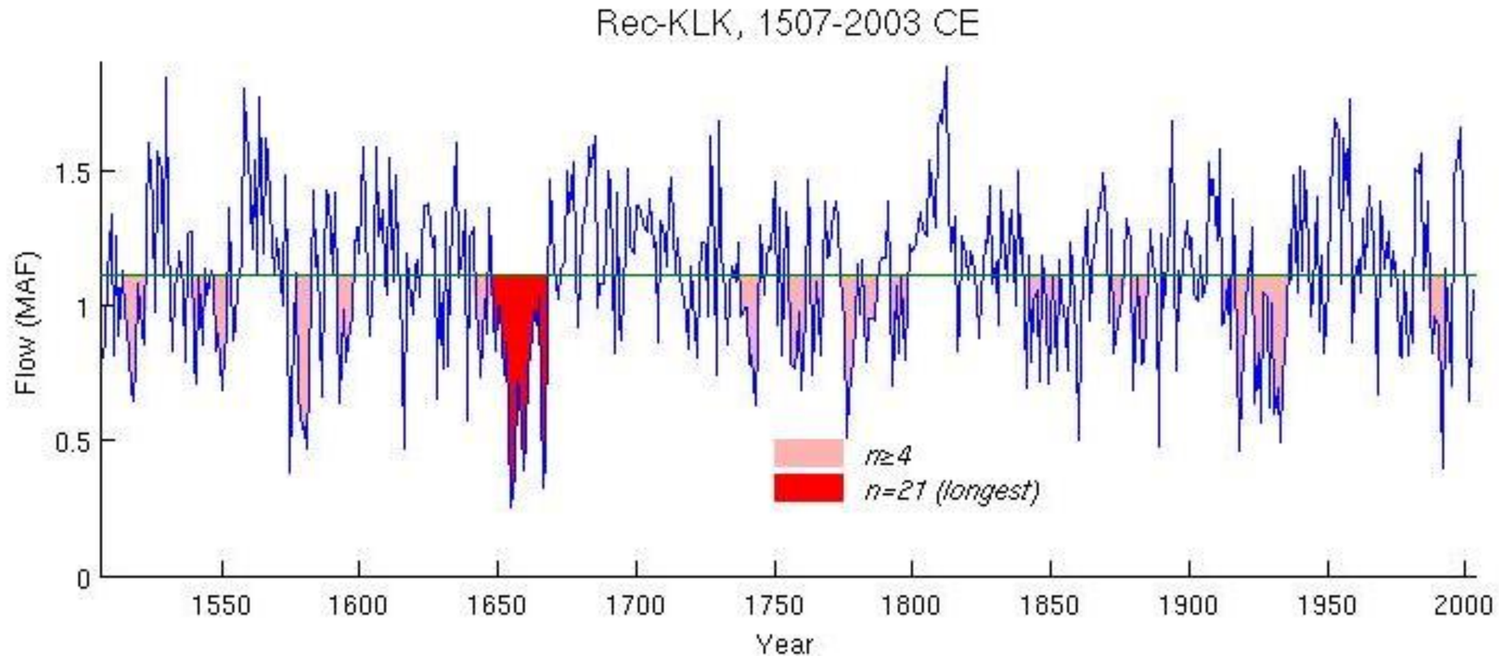

Figure 10. Reconstructed flows of Klamath River, 1507-2003. Horizontal line at median. Color-shading marks longest run and all other runs greater than specified length.

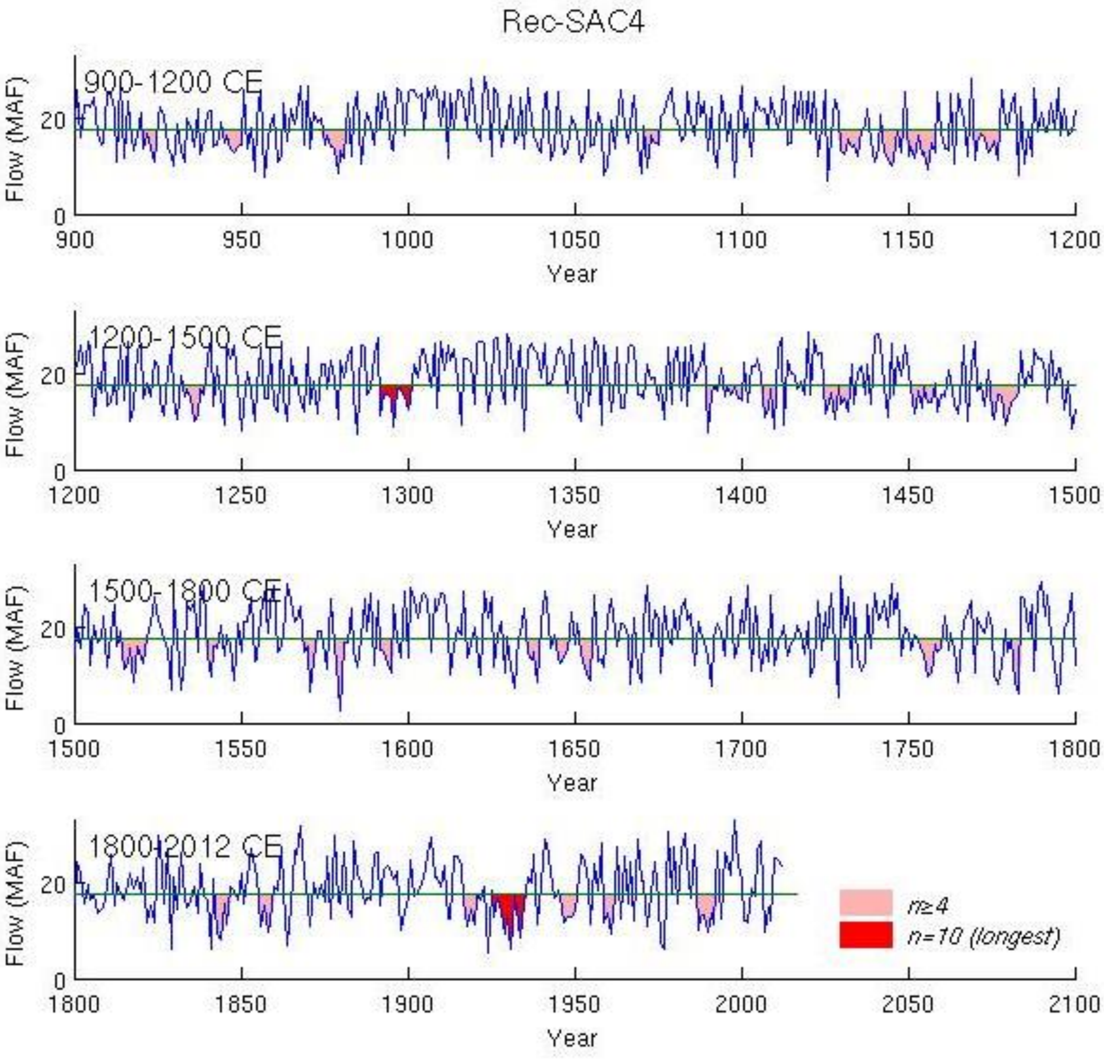

Figure 11. Reconstructed flows of Sacramento River (SAC4), 900-2010 CE. Horizontal line at median. Color-shading marks longest run and all other runs greater than specified length.

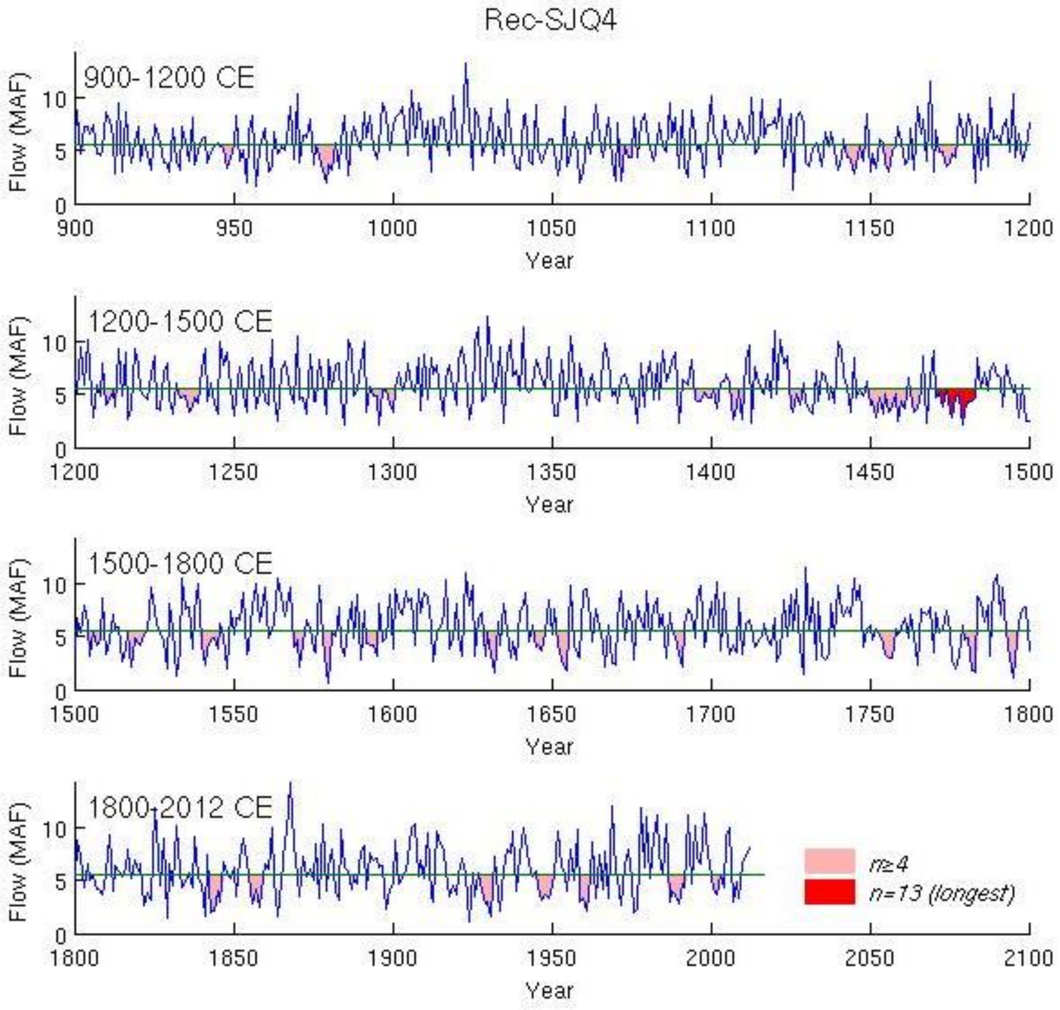

Figure 12. Reconstructed flows of San Joaquin River (SAC4), 900-2010 CE. Horizontal line at median. Color-shading marks longest run and all other runs greater than specified length.

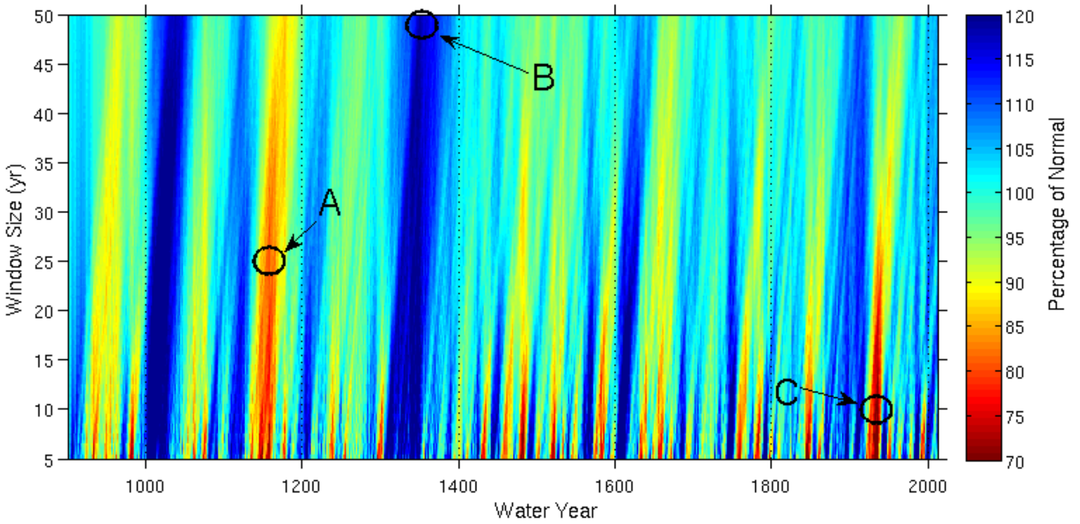

Figure 13. Color-mapped running means of reconstructed flows of Sacramento River (SAC4), 900-2012 CE. Anomaly in *m*-year moving-average flow, where *m* is the window size, is color-coded as percentage of long-term normal observed flow. Time axis (x axis) is ending year of the *m*-year window. Key at right associates colors with flow anomaly – lower flow toward red and higher flows toward blue. Any *m*-year flows lower than 70% or higher than 120% of mean are assigned same color as 70% and 120%. For example, arrow A marks a period in the 1100s (x axis) with 25-yr means (y axis) less than 85% of long-term mean (color key at right). Similarly, arrow B marks a 50-yr period ending in mid-1300s with unmatched wetness (more than 120% of long-term mean), and arrow C highlights the unprecedented dryness of the 1930s in terms of low ten-year-mean flow.

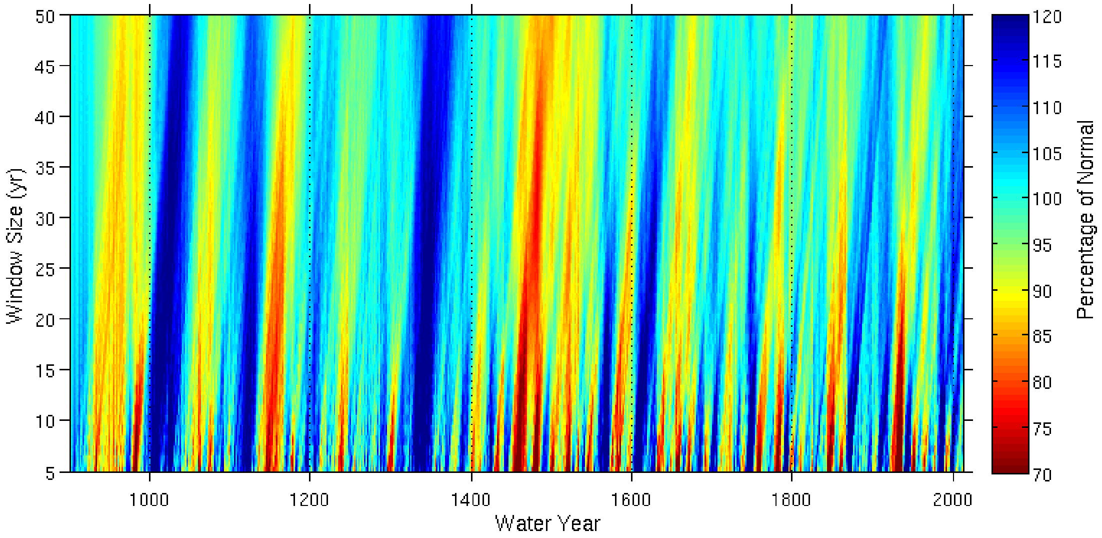

Figure 14. Color-mapped running means of reconstructed flows of San Joaquin River (SJQ4), 900-2012 CE. Interpretation of colors explained in caption for Figure 13.

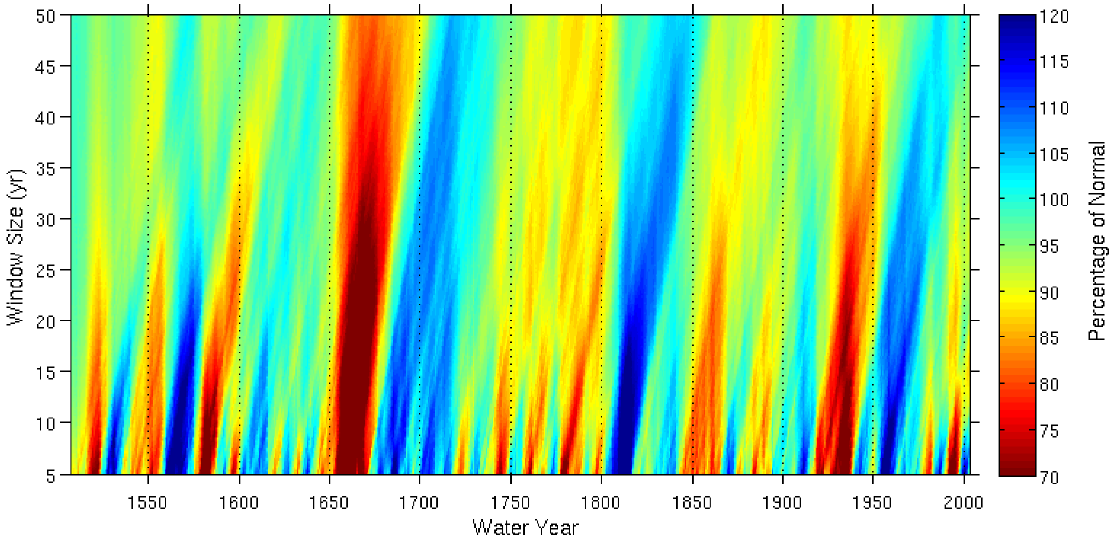

Figure 15. Color-mapped running means of reconstructed flows of Klamath River (KLK), 1507-2003 CE. Interpretation of colors explained in caption for Figure 13.

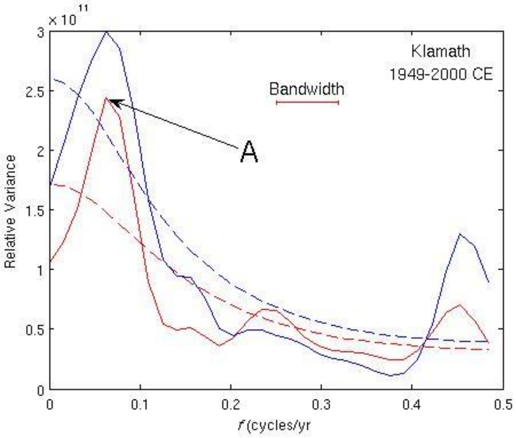

Figure 16. Spectra of observed (blue) and reconstructed (red) Klamath flows for calibration period. Red noise background dashed. Difference in total areas under spectrum reflects variance unexplained by tree rings. Spectra by smoothed periodogram method. Highest peak at frequency *f*=0.0625, which corresponds to a wavelength of about 16 years (annotated peak A).

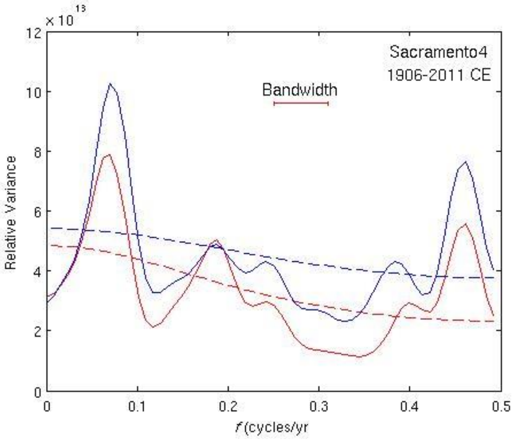

Figure 17. Spectra of observed (blue) and reconstructed (red) Sacramento4 flows for calibration period. Highest peak at wavelength of about 14 years. Remainder of caption as in Figure 16.

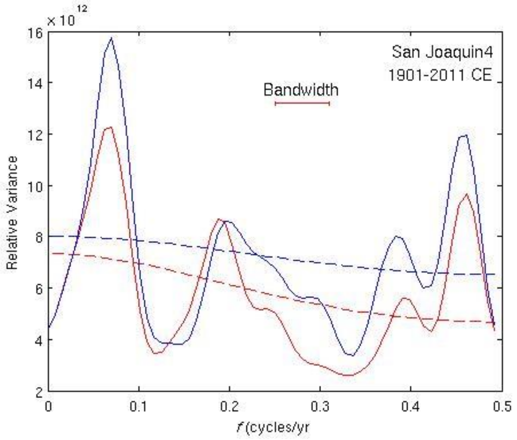

Figure 18. Spectra of observed (blue) and reconstructed (red) San Joaquin4 flows for calibration period. Highest peak at wavelength of about 14 years. Remainder of caption as in Figure 16.

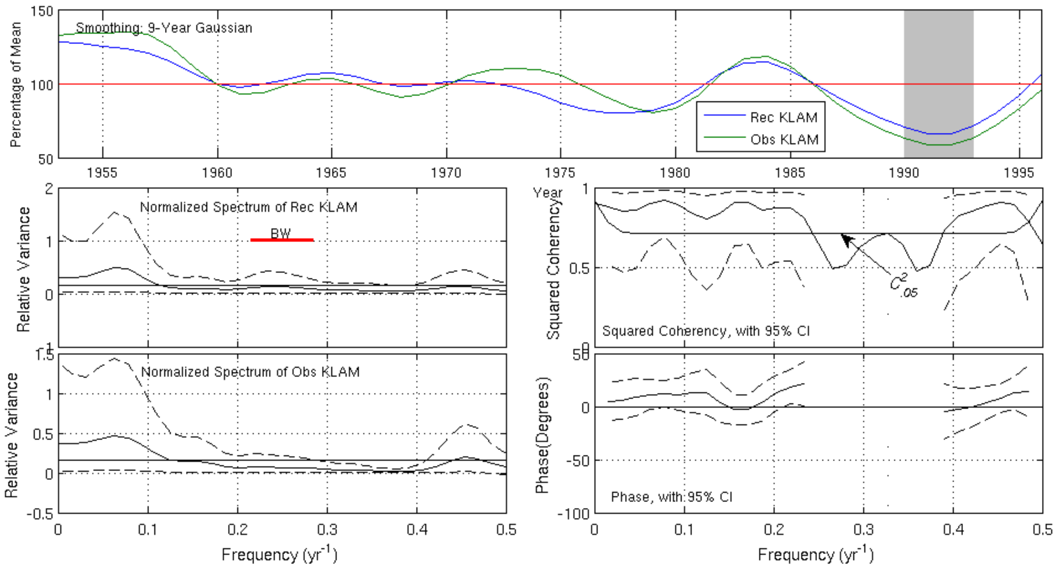

Figure 19. Smoothed time series and cross-spectral output for Klamath River. Analysis for overlap period of reconstructed and observed flows, 1949-2000. Top: Gaussian smoothed reconstructed and observed flow as percentage of mean. Left bottom two: normalized spectra of reconstructed and observed flows with 95% confidence interval. Right bottom two: squared coherency and phase series describing frequency properties of covariation of reconstructed and observed flows. Shading in top plots marks period both smoothed series in driest decile. Gaussian filter weights for smoothing the annual flows to produce the time series at top are as follows: [0.0135 0.0477 0.1172 0.2012 0.2408 0.2012 0.1172 0.0477 0.0135].

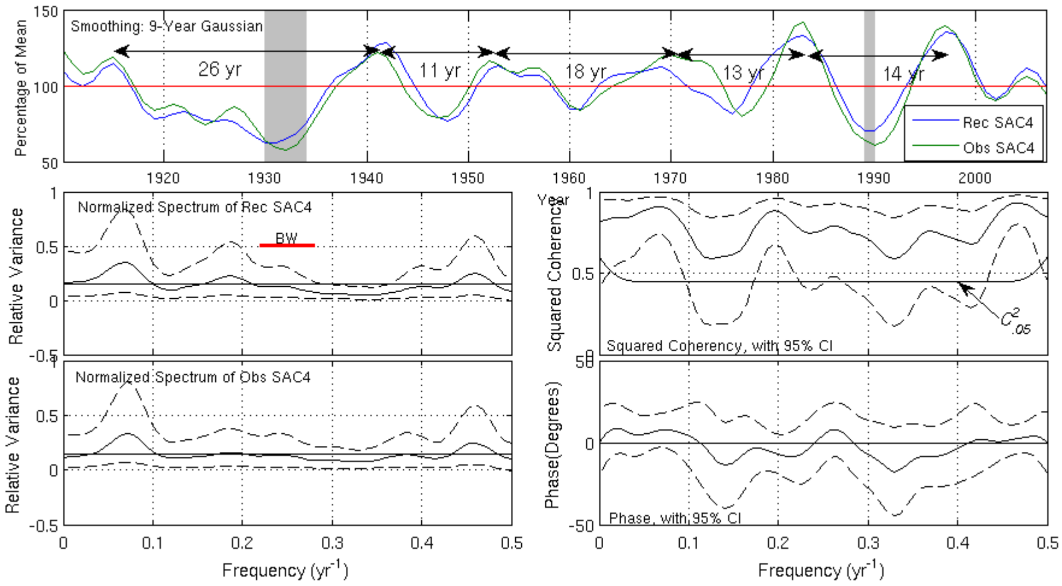

Figure 20. Smoothed time series and cross-spectral output for Sacramento River (SAC4). Analysis for overlap period of reconstructed and observed flows, 1906-2012. Double arrows (top) mark approximate intervals between peaks in smoothed flows. Average interval is 16.4 yr. Remainder of caption as in Figure 19.

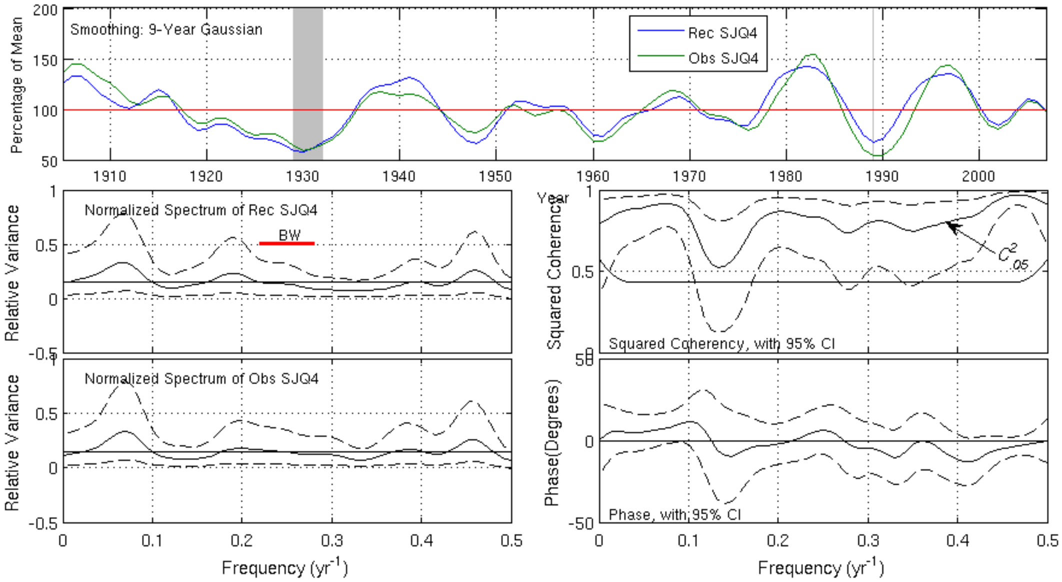

Figure 21. Smoothed time series and cross-spectral output for San Joaquin River (SJQ4). Analysis for overlap period of reconstructed and observed flows, 1901-2012. Remainder of caption as in Figure 19.

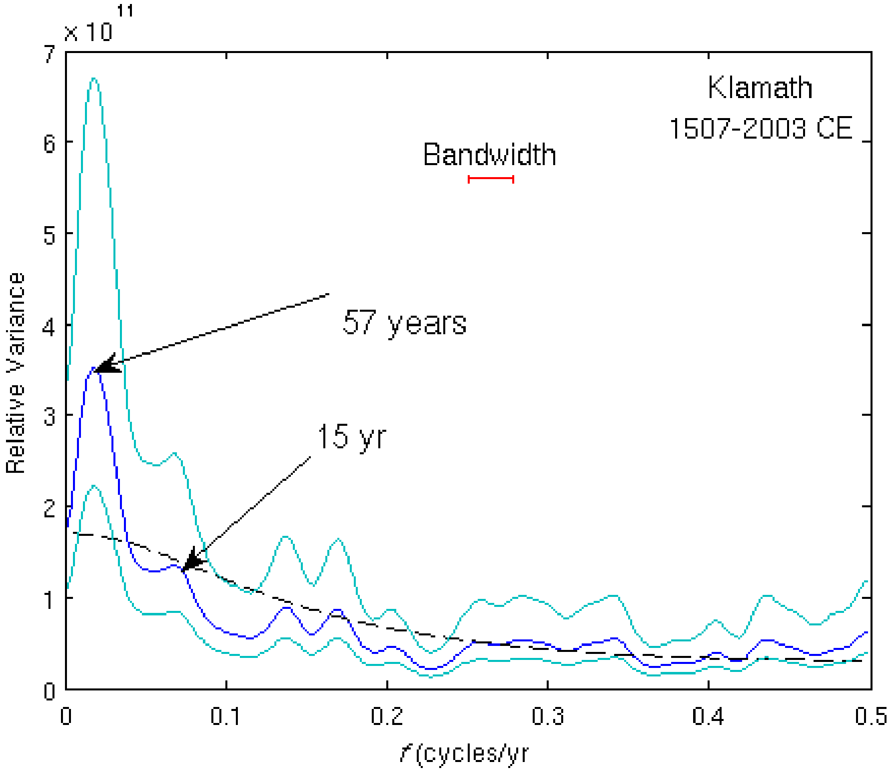

Figure 22. Spectrum with 95% confidence interval and red-noise null continuum for long-term reconstruction of Klamath reconstructed flows. Period of analysis and bandwidth for smoothed-periodogram spectrum annotated. Major peak is at 57 years. Next low-frequency peak is at 15 years. The null hypothesis of a red noise spectrum is rejected at a *p*-value of 0.05 (95% significance) only if the red noise spectrum (dashed line) falls outside the indicated confidence interval (light blue) around the estimated spectrum (dark blue).The spectal peak at 57 years is the only peak significantly different from a red noise spectrum.

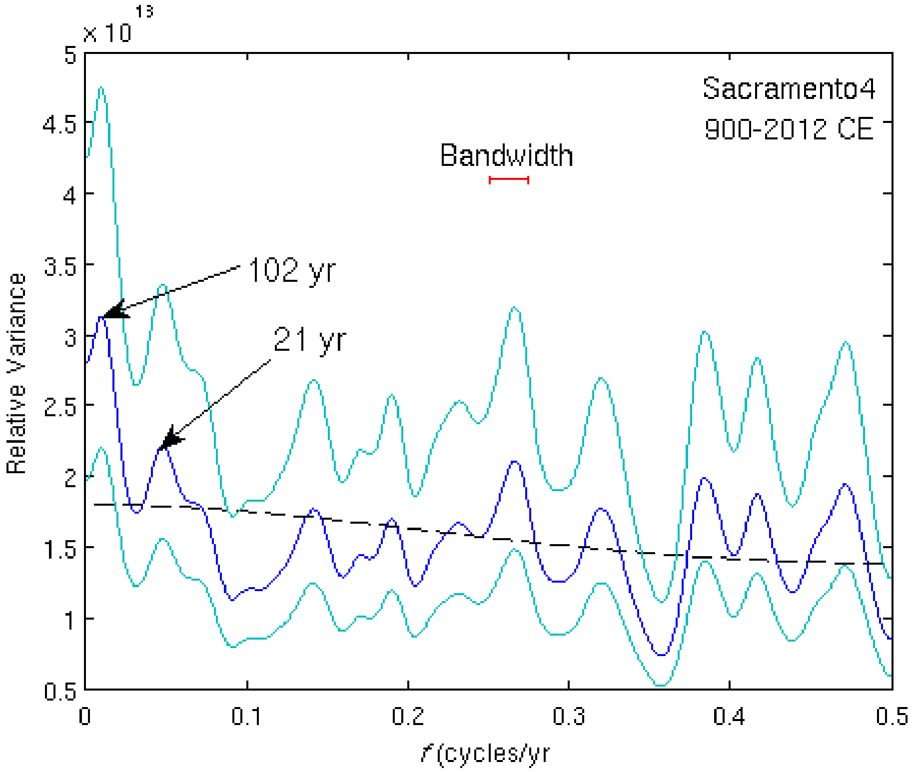

Figure 23. Spectrum with 95% confidence interval and red-noise null continuum for long-term reconstruction of Sacramento (SAC4) reconstructed flows. Period of analysis and bandwidth for smoothed-periodogram spectrum annotated. Major spectral peak is at 102 years, and secondary peak at 21 years. Only the major peaks differs significantly from red noise (dashed line). See caption of Figure 22 for how significance is judged.

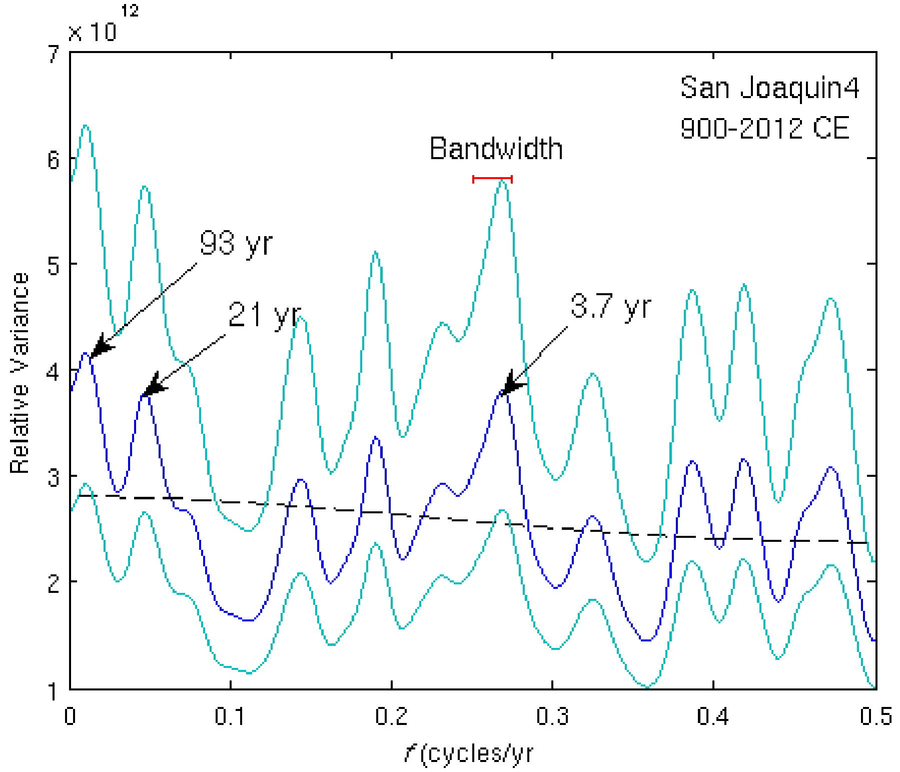

Figure 24. Spectrum with 95% confidence interval and red-noise null continuum for long-term reconstruction of San Joaquin (SJQ4) reconstructed flows. Period of analysis and bandwidth for smoothed-periodogram spectrum annotated. Major spectral peak is at 93 years. Second highest peak is at 3.7 years, and third highest at 21 years. Only the peak at 93 years and 3.7 years are significantly different (barely) from the red noise spectrum . See caption of Figure 22 for how significance is judged.

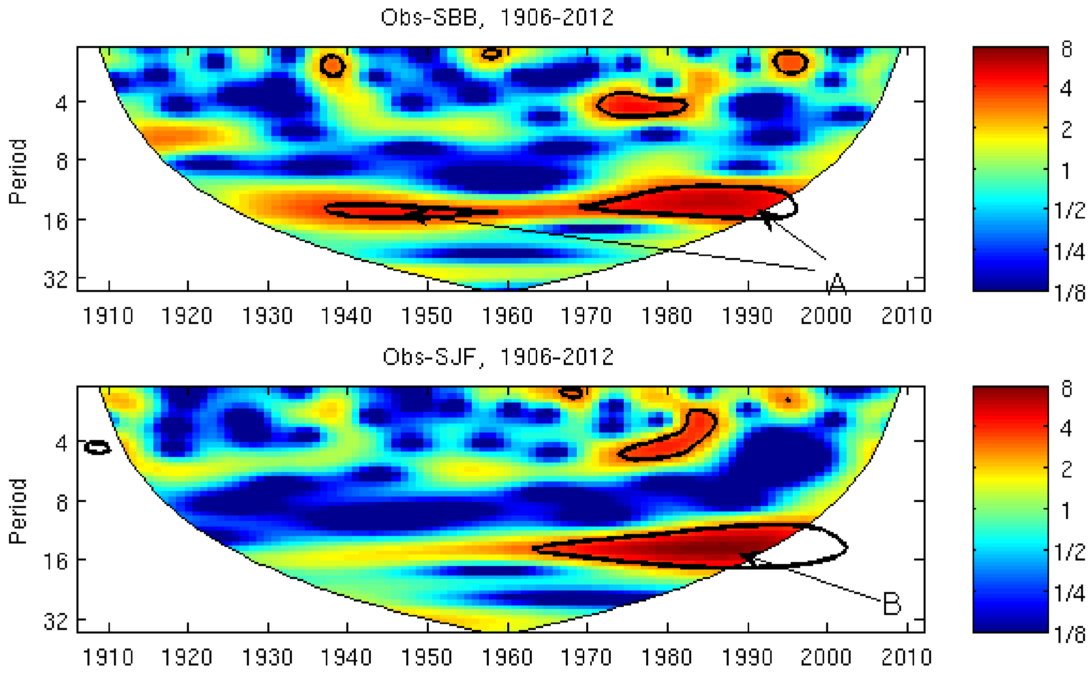

Figure 25. Continuous wavelet transforms(CWT) of observed flows of Sacramento River at Bend Bridge (SBB) and San Joaquin River inflow to Millerton Reservoir (SJF) , 1906-2012. These are the two most widely separated watersheds in the study for which we have millennial-length reconstructions. Color scale at right codes relative variance, with darkest red indicating 8 times the variance as blue-green (#1), and darkest blue indicating 1/8 the variance of blue-green. Thick black line delineates areas with variance significantly greater than expected for red noise at 95% confidence. Period on y axis at left is in years. The cone of influence (COI), the area in white outside the vase shaped region, marks parts of time-frequency space in which edge effects might distort the picture. Central year of period for which a particular color applies is given along the x axis. Spectra show high variance near a wavelength of 15 years throughout the observed record for SBB (arrow A), and in the most recent decades for SJF (arrow B).

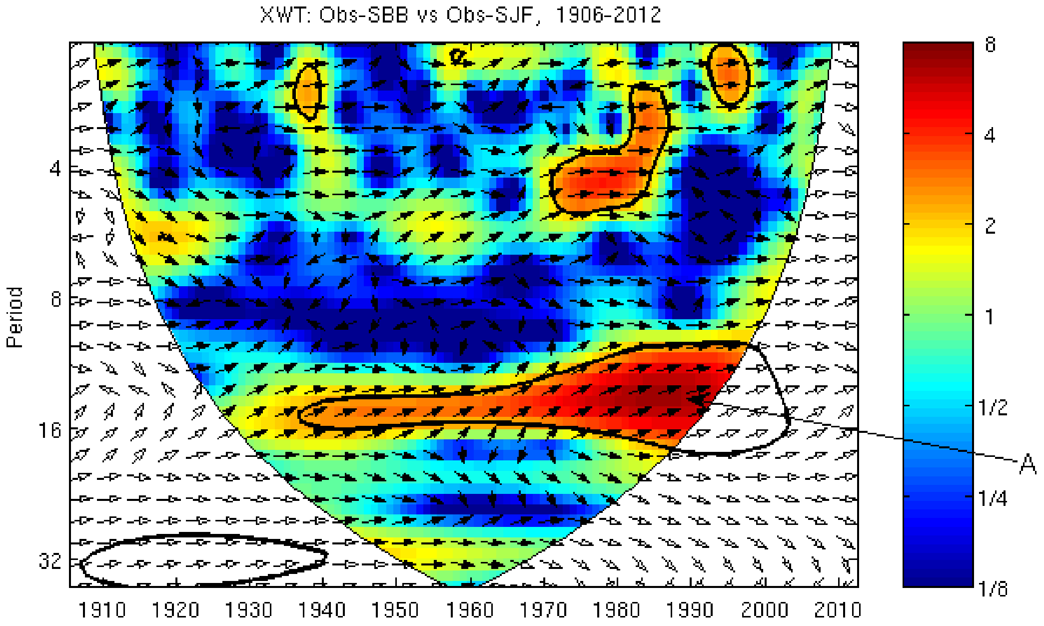

Figure 26. Cross wavelet transform (XWT) of observed flows of Sacramento River at Bend Bridge (SBB) and San Joaquin River inflow to Millerton Reservoir (SJF) , 1906-2012. Colors on the XWT code areas in time-frequency space in which variance is high in both series. Red indicates high variance, and blue indicates low variance. Thick black line indicated areas with significant (95%) common variance. The cone of influence (COI), the area in white outside the vase shaped region, marks parts of time-frequency space in which edge effects might distort the picture. Direction of arrows indicates phase relationship of variations: 0° (arrow to right) is perfectly in phase; 180° (arrow to left) is opposite phase, or peaks opposite troughs. Number of years of offset corresponding to a specific phase angle depends on the period in years (y axis). For example, at period of 15 years, 180°, or opposite phase, is an offset of 7.5 years, while for a period of 32 years, opposite phase is an offset of 16 years. Red region marked with arrow A indicates period when SBB and SJF both have much power (high variance) at wavelengths near 15 years. This high common high variance is concentrated toward the latter part of the observed record. For example, the arrow points to a period centered on about 1990. At wavelengths or periods near 15 years, the black arrows have an angle from the horizontal of about 30°. Near wavelength 15 years, 180° corresponds to an offset of 7.5 years, and 30° corresponds to an offset of only about a year. The 15-year fluctuations in SBB and SJF can therefore be considered approximately in phase. That the arrows on this band near a period of 15 years have about the same angle across the plot from the start to the end of the record (left to right) indicates the variations near that period are phase-locked through time.

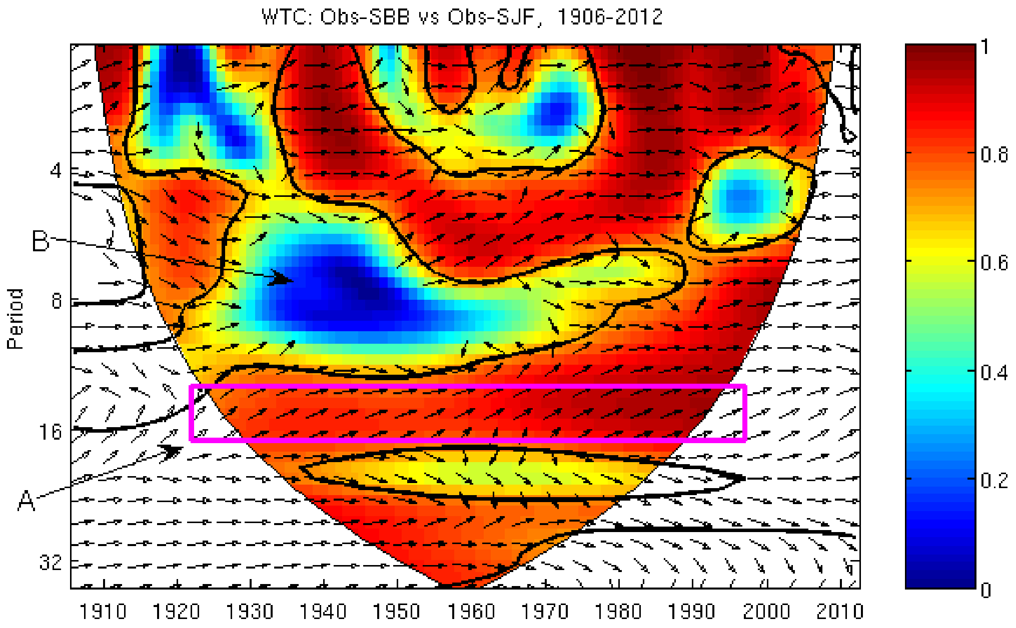

Figure 27. Wavelet coherence (WTC) between observed flows of Sacramento River at Bend Bridge (SBB) and San Joaquin River inflow to Millerton Reservoir (SJF) , 1906-2012. The WTC is analogous to correlation between two series as a function of time and frequency. The cone of influence (COI), the area in white outside the vase shaped region, marks parts of time-frequency space in which edge effects might distort the picture. The thick black line delineates areas with Monte Carlo significance of coherence at 95% or greater. Arrows indicate phase of relationship: arrow to right, perfectly in-phase (0 degrees); arrow to left, perfectly out of phase (180 degrees), or troughs at that wavelength in one series timed with peaks in the other (see caption for Figure 26). For these two series, coherence is significant over most of the figure. Area of low coherence (blue) coincides with periods with low variance at the indicated wavelength (Figure 25). A belt of in-phase significant coherence extends through the time series near the 15-year wavelength (arrow A). A region of low coherence, centered near 1945 and wavelength 8 years is marked by arrow B. Such a feature can be explained by the low variance in the individual series at that time (Figure 26).

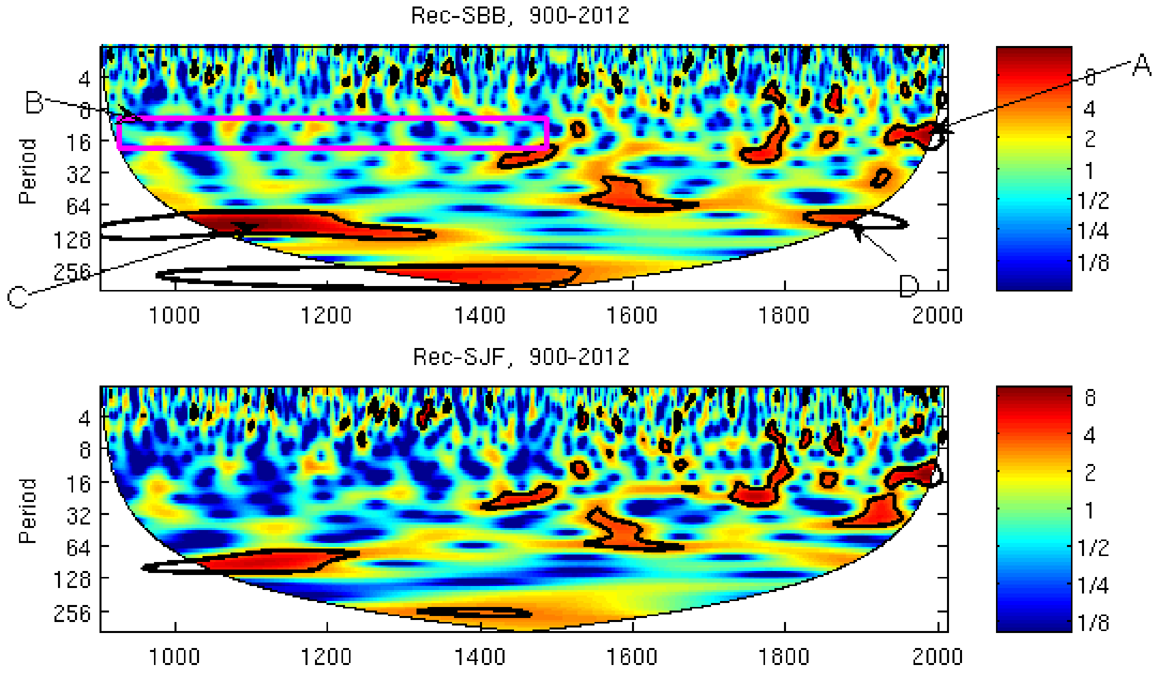

Figure 28. Continuous wavelet transforms (CWT) of reconstructed flows of Sacramento River at Bend Bridge (SBB) and San Joaquin River inflow to Millerton Reservoir (SJF) , 900-2012 CE. For interpretation of colors, axes, etc., refer to caption for Figure 25, which has plots for the observed flows. CWT for these reconstructions show that the high variance near a wavelength of 15 years that was evident in the much shorter records of observed flows is not consistent over centuries. The strongest evidence for cyclic behavior near wavelength 15 years is restricted to the period beginning in the 20th century (arrow A on plot for SBB). For a long stretch of time from the beginning of record till about 1500 CE, evidence of high variance near the 15-year wavelength is completely lacking (arrow B). The early part of the reconstruction shows cyclic behavior at very long wavelengths; such behavior is not consistent through the long reconstruction but does appear again until the 19th century (arrows C and D).

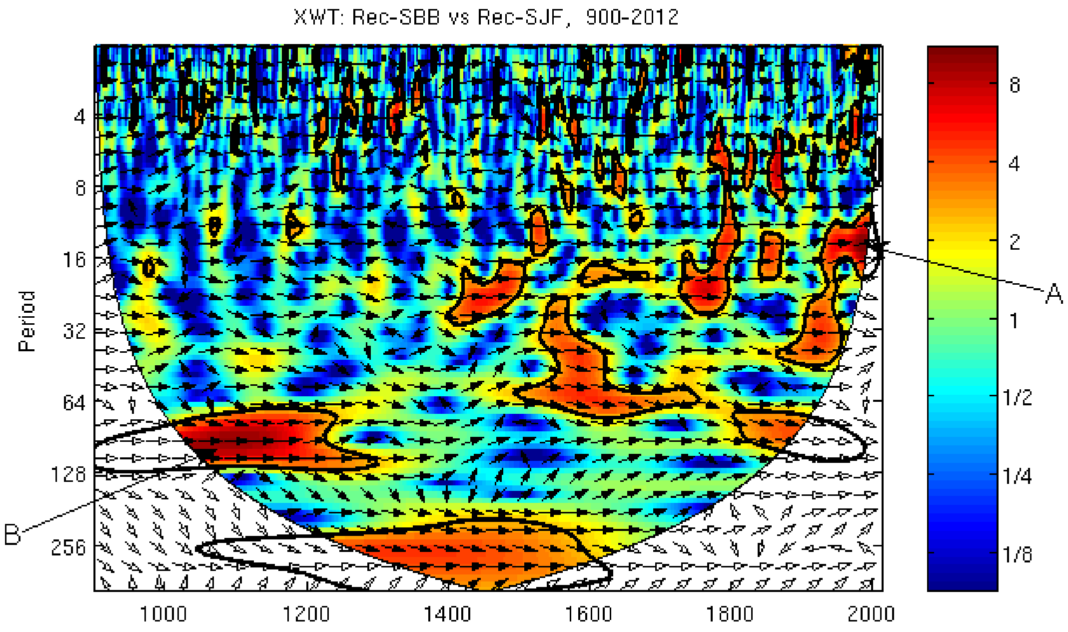

Figure 29. Cross wavelet transform (XWT) of reconstructed flows of Sacramento River River at Bend Bridge (SBB) and San Joaquin River inflow to Millerton Reservoir (SJF) , 900-2012 CE. For general interpretation of XWT features, see caption for figure 26. The XWT indicates when two series have high variance in particular wavelength-ranges, and if the variations at a particular frequency are in phase or not (arrows). This XWT shows that the high common variance in SBB and SJF near wavelength 15 years is present mainly in the 20th century (arrow A). Variance is high and in-phase in both series near a wavelength of 100 years prior to 1200 (arrow B).

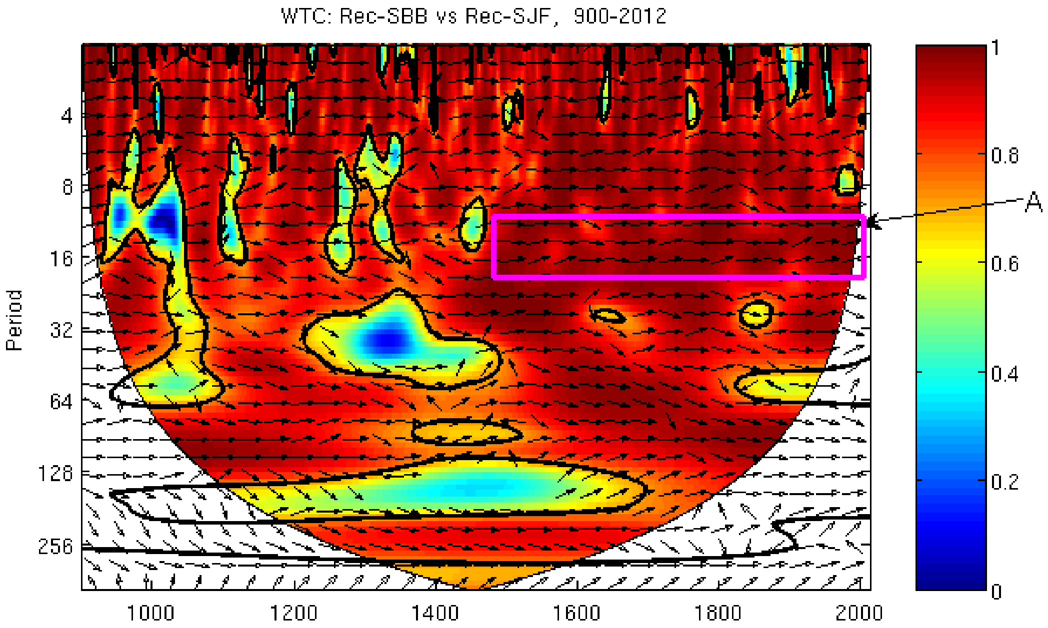

Figure 30. Wavelet coherence (WTC) between reconstructed flows of Sacramento River at Bend Bridge (SBB) and San Joaquin River inflow to Millerton Reservoir (SJF), 900-2012. Black line delineates Monte Carlo significance of coherence at 95%. See caption to Figure 27 for general point on interpretation of WTC. Coherence between these two reconstructions is significant over most of the time-frequency mapped in this figure (small areas of non-significant coherence are blue). A belt of high coherence and in-phase variations near wavelength of 15-25 years extends from present back to about 1500 (arrow A and purple box), but disappears in earlier centuries. Wavelength of strongest

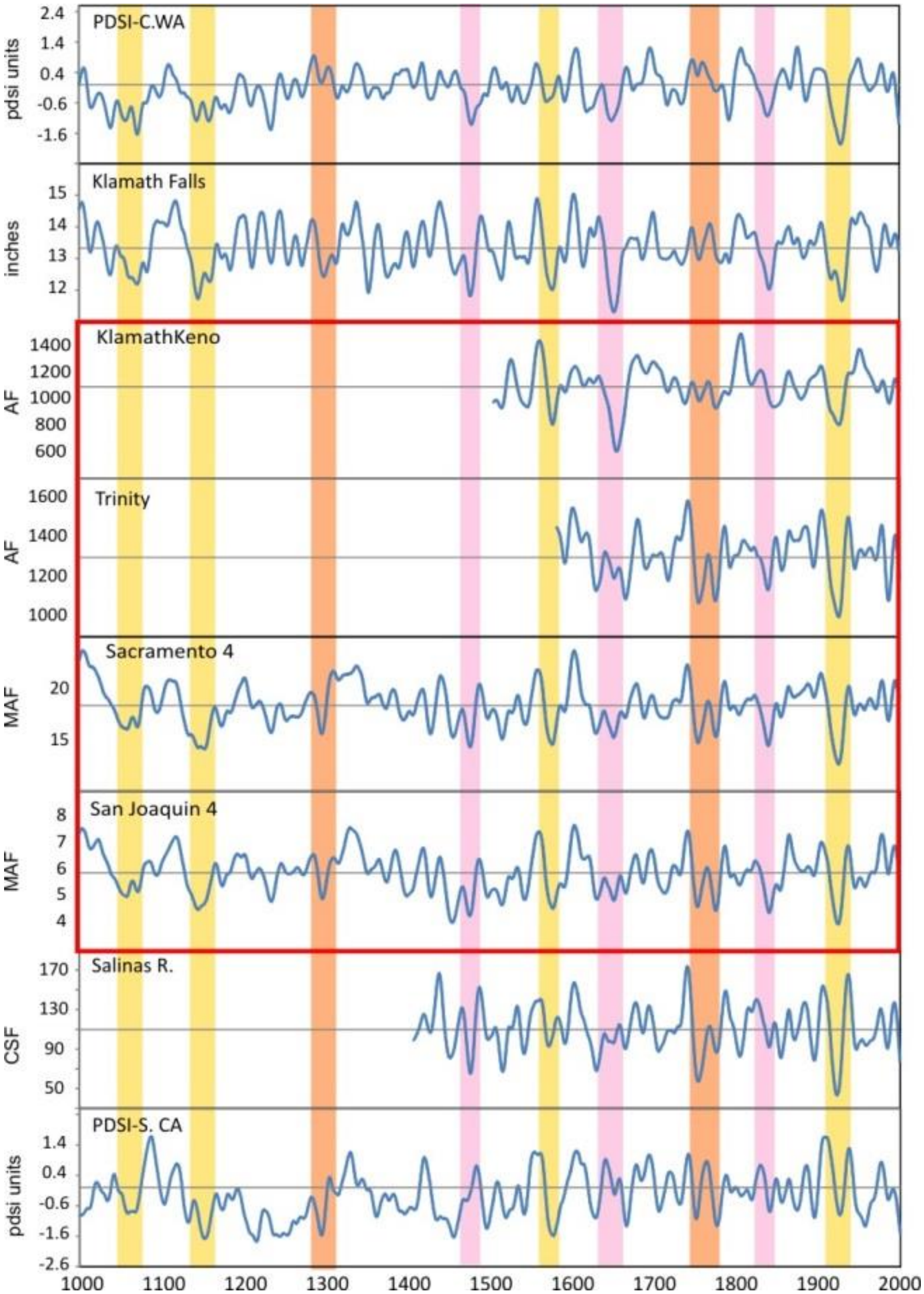

Figure 31. Klamath (Klamath Falls precipitation, Klamath at Keno and Trinity flow), Sacramento (4 rivers average), and San Joaquin (4 rivers average) with other western hydroclimate reconstructions, smoothed with a 20 year spline. Series are arranged from north to south. Major region-wide droughts are indicated with yellow bars, dry south-wet north are orange, and dry north-wet south are pink. Start dates are variable, all end in 2003.

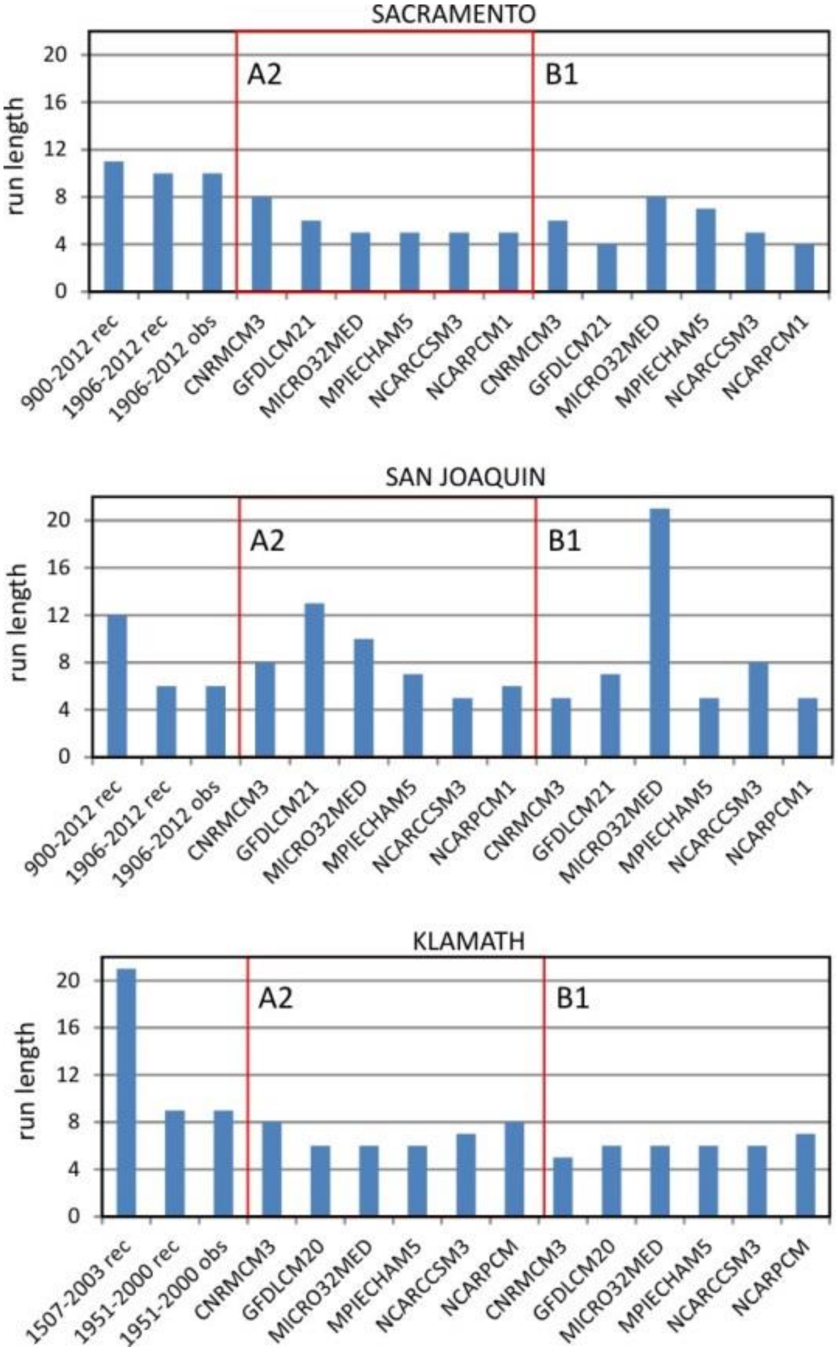

Figure 32. Maximum runs of drought years for Sacramento (top), San Joaquin (middle), and Klamath (bottom) flows; reconstructed (full and instrumental periods), observed series, and projected flows from a variety of downscaled GCMs for A2 and B1 scenarios, water years 1950-2099 (1951 start for Klamath).

Appendix A. Reconstructed Flow and Precipitation

```
Data listed 10 years per row in units indicated in the table below.
All series are water-year sum

 1  KLK  Klamath R. at Keno, OR, natural flows (rec); multiply by 1000 to get AF
 2  TRN  Trinity R. at Lewiston, CA,  flows (rec); multiply by 1000 to get AF
 3  KFL  Klamath Falls-long precipitation (rec); mult by 1E-2 to get inches
 4  KFS  Klamath Falls-short, precipitation (rec); mult by 1E-2 to get inches
 5  WEA  Weaverville, precipitation (rec); mult by 1E-2 to get inches
 6  YRK  Yreka, precipitation (rec); mult by 1E-2 to get inches
 7  FTO Feather River inflow to Lake Oroville (rec); multiply by 1000 to get AF
 8  YRS Yuba River at Smartville (rec); multiply by 1000 to get AF
 9  AMF American River inflow to Lake Folsom (rec); multiply by 1000 to get AF
10  SBB Sacramento River above Bend Bridge (rec); multiply by 1000 to get AF
11  SAC4 Sacramento River Four Rivers unimpaired runoff(rec); mult by 1000 to get AF
12  SNS Stanislaus River inflow to New Melones (rec); multiply by 1000 to get AF
13  TLG Tuolumne River inflow to New Don Pedro (rec); multiply by 1000 to get AF
14  MRC Merced River inflow to New Exchequer (rec); multiply by 1000 to get AF
15  SJF San Joaquin River inflow to Millerton (rec); multiply by 1000 to get AF
16  SJQ4 San Joaquin River Four Rivers unimpaired runoff(rec); mult by 1000 to get AF

KLK  Klamath R. at Keno, OR, natural flows (rec); multiply by 1000 to get AF

KLK  1500    NaN    NaN    NaN     NaN    NaN    NaN     NaN    809    882   1113
KLK  1510   1339    817   1261     890   1133    974     927    693    647    781
KLK  1520   1082    907    857    1308   1608   1373     977   1572   1511   1104
KLK  1530   1850   1258    834    1086   1092   1205    1065    793   1264   1277
KLK  1540    784    711   1110     858   1143   1044    1129   1109    835    896
KLK  1550    688    845    888    1363    871    941    1084   1163   1809   1640
KLK  1560   1578   1215   1545    1116   1778   1198    1618   1552   1225   1127
KLK  1570   1253   1178   1001    1485   1098    379     915   1124    668    546
KLK  1580    548    468    747    1427   1149   1189     668   1150   1425   1404
KLK  1590   1126   1425   1013     640    987    790     870    965   1215   1291
KLK  1600   1192   1589   1347    1051    892   1161    1589   1263   1357   1107
KLK  1610   1042   1551   1093    1482   1141   1106     474   1197   1100    969
KLK  1620   1146   1169   1036    1373   1371   1384    1223   1261    659   1100
KLK  1630    771   1350    776    1157   1449   1609    1110   1211   1353    575
KLK  1640   1260   1296    965     942    738   1025     898   1362    972    830
KLK  1650    996   1004    742     865    578    252     384    727    690    390
KLK  1660    510    772    825     987    926   1035     324    428    990   1473
KLK  1670   1154   1082   1024    1134   1169   1499    1349   1534   1176    924
KLK  1680   1134   1366   1374    1593   1514   1629     998   1080   1086   1228
KLK  1690   1502   1441    821    1425    950    872    1232   1510   1224   1198
KLK  1700   1371   1376   1349    1283   1273   1399    1221   1234    868   1313
KLK  1710   1259   1145   1416    1478   1117   1251    1115   1020    971    845
KLK  1720   1145    931    809    1110   1232   1228     960   1628   1191    744
KLK  1730   1685   1192   1048     856   1061   1148    1092   1232    965    993
KLK  1740    992    786    815     633    881   1302    1039   1189   1223   1208
KLK  1750   1465    928   1362     815   1348   1247     781    768    839    980
KLK  1760    692    977   1466    1267    747   1093     969    818   1385   1180
KLK  1770   1196   1303   1387    1320   1114    937     515    685    723    929
KLK  1780   1157    970   1173     792    956    953     946   1083   1159   1177
KLK  1790   1179   1387   1095     705   1076    828    1109    799   1038   1227
KLK  1800   1204   1233   1311    1352   1288   1263    1540   1454   1295   1665
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KLK  1810   1708   1681   1892    1400   1205   1330     831    935   1256   1186
KLK  1820   1099   1202   1186    1043    884   1053    1246   1235   1445   1086
KLK  1830   1161    930   1429    1281   1093   1298    1355   1003   1502   1194
KLK  1840   1250    693   1185     797   1021   1059     721   1187   1002    711
KLK  1850    934   1110    759    1170   1035    941     757   1235   1156    860
KLK  1860    503    933   1119    1360    947   1149    1262   1367   1364   1492
KLK  1870   1306    936   1281     827    940    987    1025   1322   1275   1259
KLK  1880    689   1104    975     787    789   1123    1281   1171   1057    478
KLK  1890   1264    991   1171    1347   1683    762    1128   1053   1178   1317
KLK  1900   1212   1248   1040    1019   1184   1035    1102   1533   1411   1469
KLK  1910   1248   1582    929     949   1096    842    1394    857    465    697
KLK  1920    816   1136   1128    1296    638    824     570   1048   1034    626
KLK  1930   1008    598    698     495    730    939    1228   1102   1487   1053
KLK  1940   1514   1134   1505    1222    959   1048    1403    904   1191    821
KLK  1950   1076   1409   1560    1692   1645   1083    1624   1410   1767    867
KLK  1960   1090   1173   1050    1327   1142   1447    1300   1263    674   1388
KLK  1970   1286   1139   1280    1073   1205   1064     822    811   1133    815
KLK  1980    979    865   1512    1495   1564   1062    1391   1013    826    964
KLK  1990    933    667    396    1142    870    702    1478   1576   1660   1357
KLK  2000   1275    647    907    1060    NaN    NaN     NaN    NaN    NaN    NaN

TRN  Trinity R. at Lewiston, CA,  flows (rec); multiply by 1000 to get AF

TRN 1580    NaN    NaN    NaN     NaN   1545   1127    1221   1685   1544   1934
TRN 1590   1222   1922    788    1127    914    666    1552   1306   1094   1983
TRN 1600   1080   2215   1796    1436   1398   1650    1789   1178   1292   1547
TRN 1610   1695   1649   1478     716   1106   1480    1239   1830   1227   1541
TRN 1620   1462   1343   1083    1948   1469   1828     868   1582   1296    600
TRN 1630   1343    733    744    1314   1514   1638     846   1168   1192     75
TRN 1640   1431   2095   1859    1282   1392   1129    1020   1326   1167   1252
TRN 1650   1641   1588   1067    1063    515    847    1902   1008   1316    905
TRN 1660   1516   1678   1409    1098   1446   1292    1108    217   1337    834
TRN 1670    710   1507   1566     940   1263   1541     775   1702   1226   1109
TRN 1680   1581   1378   1674    1678   1720   1860    1071   1537   1302   1484
TRN 1690   1168    489   1293    1483   1333    785    1474   1720   1031   1098
TRN 1700   1494   1230   1944     747   1700   1320     713   1445   1112   1803
TRN 1710    942   1272   1462    1619   1165   1430    1445   1496   1227    710
TRN 1720   1212    596    884    1749   1296   1461    1047   1781   1094    684
TRN 1730   2397   1750   1657     659   1709   1284    1069   1033   1785    949
TRN 1740   1793   1555   1516    1580   1490   2035    1719   1858   1092   1630
TRN 1750   1456   1185   1348    1158   1301   1043     548    906   1136   1116
TRN 1760   1098   1389   1228    1348    887    413    1301   1523   1678   1934
TRN 1770    638   1634   1350    1631   1530   1112     169    605   1186   1537
TRN 1780    997   1301    694     359   1850   1843    1440   1347    994   2030
TRN 1790   2037   1645   1896    1226    560    418     695   1488   1622   1770
TRN 1800    833   1750   1511    1219   1395   1136    1270   1091   1153   1122
TRN 1810   1629   1855   1466    1429   1159   1337    1293   1439   1393   1530
TRN 1820   1317   1237    899    1223   1004   2187    1807   1244   1557    318
TRN 1830   1370   1111   1772    1265   1214   1474    1410    907   1518   1399
TRN 1840   1314    563   1560     711    492   1379    1093   1547   1386   1156
TRN 1850   1634   1348   1507    1972   1644   1485     912   1096    953    874
TRN 1860   1260   1357   1666    1174    488   1157    1750   1687   2333   1726
TRN 1870   1186    694   1585    1229   1292   1251    1518   1345   1941   1464
TRN 1880    996   1290   1046    1170   1954   1577    1732   1273    963   1223
TRN 1890   2054   1725   1259    1641   1569   1300    1212   1123    658    896
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TRN 1900   1315   1690   1312    1145   1332   1562    1639   2188   1569   1496
TRN 1910   1452   1804    849    1033   1926   1492    1712   1112    588   1107
TRN 1920    653   1506   1298    1541    443   1308    1004   1375   1163    630
TRN 1930   1034    534   1192     723    822   1457    1632   1464   1916    879
TRN 1940   1665   2129   1941    1565   1289   1357    1071    697    979    906
TRN 1950    966   1248   2073    1796   1413    645    1727   1298   2055    935
TRN 1960    894    958   1297    1739   1007   1620    1268   1591    857   1937
TRN 1970   1596   1284    964    1236   1692   1275     312    391   2269   1356
TRN 1980   1725   1176   1934    2461   1724   1035    1711    644    485    745
TRN 1990    789    996    589    1630    788   1472    1860   1678   2419   1526
TRN 2000   1494    487    840    1367    NaN    NaN     NaN    NaN    NaN    NaN

KFL  Klamath Falls-long precipitation (rec); mult by 1E-2 to get inches

KFL 1000   1358   1201   1591    1811   1634   1169    1657   1197   1709   1594
KFL 1010   1339   1390    610    1583   1189   1311    1469    980   1425   1732
KFL 1020   1512   1232   1465    1858   1201   1228    1398   1429   1240   1083
KFL 1030   1626   1894    776    1476   1193   1185    1571   1000   1240   1071
KFL 1040    839   1413   1618    1409   1138   1736    1583   1059   1335   1319
KFL 1050   1185   1232    846    1602   1807   1039    1217   1697   1220    795
KFL 1060   1217   1394   1039     992   1728   1472    1067    882   1795   1031
KFL 1070   1008   1508    846    1260   1154    969    1508   1390   1744   1476
KFL 1080   1327   1020   1118     819   1492   1063    1197   1476   1433   1598
KFL 1090   1138   1961   1244     890   1724   1516    1626   1264   1181   1276
KFL 1100   1528   1594   1524     937   1862   1492    1366   1303   1280   1051
KFL 1110   1646   1500   1409    1843   1106   1276    1657   1594   1469   1724
KFL 1120   1276   1402   1894    1146   1193   1465     614   1937   1776   1760
KFL 1130    850   1106   1185    1602   1543    780    1362   1476   1760   1417
KFL 1140    713   1028   1236    1492   1283    673     913   1461   1185   1276
KFL 1150   1142   1291   1362    1406   1472    937    1413   1165   1205   1154
KFL 1160   1421    846   1504     846    941   1551    1571   1650   1327   1776
KFL 1170    984   1457   1039    1413    740   1453    1252   1370   1512   1488
KFL 1180   1417   1339   1555     764   1272    780    1634    969   1728   1252
KFL 1190   1220   1181   1685    1614   1063   1839    1449   1425   1055   1331
KFL 1200   1567   1051   1996    1346   1657   1827     850   1217   1516   1394
KFL 1210    949   1118   1031    1016   1862   1323    1787    815   1134   1768
KFL 1220   1685   1689   1201     909   1697   1843    1327   1496   1492   1366
KFL 1230   1146    882   1646    1398   1177   1339     925   1374   1228    937
KFL 1240   1807   1925   1224    1744   1079    858    2075   1776   1728   1417
KFL 1250    799   1138   1614    1102    945   1626    1201   1311    858   1909
KFL 1260    965   1091   1858    1429   1177   1571    1638   1421   1154   1055
KFL 1270   1846    787    969     839   1768   1429    1492   1764   1047    638
KFL 1280   1579   1531   1547    1618   1650    858    1343   1791   1563   1161
KFL 1290   1323   1752   1106    1240    850   1720    1094   1197   1492    988
KFL 1300    890   1500   1496    1327    906   1535    1417    728   1870   1315
KFL 1310   1555   1496   1055     961   1492    906    1000   1256   1760   1555
KFL 1320   1114   1724   1984    1535    594   1461    1319   1866    760   1256
KFL 1330   1579   1461   1728    1138   1575    630    1657   1720   1823   1791
KFL 1340    843   2217   1189    1236    732   1492    1622   1476   1358   1705
KFL 1350   1567    685    740    1189    965   1335    1272   1382    843   1618
KFL 1360   1776   1260   1177    1520   1268   1453    1669   1516   1516   1028
KFL 1370   1370   1193   1232    1528   1024    917    1531   1031   1571    768
KFL 1380   1646   1319   1146    1409    866   1618    1433   1496   1303   1091
KFL 1390    811   1476   1193    1268   1480   1000    1504   1472   1323   1453
KFL 1400   1520   1594   1240    1433   1193   1760     929   1075   1142   1122
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KFL 1410	1004	1732	1768	811	1575	1244	1425	1598	1181	1402
KFL 1420	1709	1272	1913	1343	1327	839	1378	1516	681	1602
KFL 1430	1425	1425	909	1370	1646	1783	1331	1252	1638	980
KFL 1440	1961	1689	1768	1252	638	1705	1551	1465	1496	1488
KFL 1450	1236	1394	1138	1295	1000	1476	1457	1496	949	976
KFL 1460	1146	1343	1453	1563	1280	843	1323	1370	1079	1425
KFL 1470	1634	1402	1559	1240	1205	811	992	1213	1287	1205
KFL 1480	972	1354	1165	1075	1598	1421	1307	1315	1508	1370
KFL 1490	1791	1437	1307	1449	1244	1484	1563	1252	1488	1106
KFL 1500	843	1626	1071	1697	1524	862	1705	1583	862	1213
KFL 1510	1185	1484	1614	1016	1429	969	1232	965	1004	1406
KFL 1520	1232	1425	1551	1677	1559	1469	1492	1370	1366	827
KFL 1530	1890	1307	681	1437	1205	1445	1496	992	1677	1646
KFL 1540	850	693	1677	1547	1610	1291	1366	1110	965	1335
KFL 1550	945	1520	1583	1650	870	1146	1500	1811	1646	1697
KFL 1560	1717	1114	1535	945	2146	752	1650	1386	1386	1004
KFL 1570	1374	945	1028	1831	1465	681	1150	1717	1087	945
KFL 1580	764	1248	1437	1480	1256	1535	1220	1724	1425	1280
KFL 1590	1039	1429	1610	654	1165	1024	1567	1587	1205	1768
KFL 1600	1083	1677	1583	1685	1445	1429	1764	992	2039	1213
KFL 1610	1201	1705	1028	1236	1232	1142	894	1882	929	1189
KFL 1620	1343	1760	1039	1689	1858	1591	1075	1441	886	1260
KFL 1630	1122	1657	969	2004	1736	1689	969	1476	1445	886
KFL 1640	1492	1736	1449	1209	1087	1075	1102	1433	1311	917
KFL 1650	1295	1083	976	1303	1134	850	1445	1091	1236	941
KFL 1660	882	1657	1516	1543	1484	1465	913	870	1547	1701
KFL 1670	1031	1339	1681	1272	1354	1417	1307	1339	1390	850
KFL 1680	1484	1689	1646	1461	1366	1256	736	1386	1268	1299
KFL 1690	1417	1276	1205	1657	1516	1035	1402	1469	1083	1394
KFL 1700	1843	1980	1500	941	1661	1323	1051	1402	799	1528
KFL 1710	1480	1201	1339	1520	1028	1453	1413	988	1425	1382
KFL 1720	1315	1252	1323	1020	1327	1500	1252	1945	1228	638
KFL 1730	1728	992	1520	1205	1583	906	1244	1272	1496	1213
KFL 1740	1591	1079	1130	1185	1252	1626	1575	1386	1480	1480
KFL 1750	1689	1075	1429	972	1484	1370	1067	1146	1445	1213
KFL 1760	1185	1535	1646	1543	961	1264	1421	1134	1673	1618
KFL 1770	1303	1469	1307	1736	1441	1244	921	1362	1114	1307
KFL 1780	1563	1429	1327	898	1449	1150	1224	1291	1240	1697
KFL 1790	1606	1587	1169	791	1004	1039	1654	1327	1512	1618
KFL 1800	811	1681	1571	1520	1429	1429	1571	1110	1256	1657
KFL 1810	1539	1551	1622	1079	1039	1339	1382	1366	1709	1209
KFL 1820	1299	1433	1213	1469	1264	1677	1606	1413	1283	709
KFL 1830	1524	1264	1571	1134	1043	1630	1421	1067	1445	1291
KFL 1840	1291	724	1496	870	1323	1252	988	1366	1315	1283
KFL 1850	1496	1531	1209	1630	1335	1268	1150	1555	1130	1189
KFL 1860	1272	1516	1677	1358	902	1453	1819	1567	1614	1193
KFL 1870	1220	1020	1437	1126	1406	1177	1535	1795	1457	1335
KFL 1880	1185	1512	1091	1059	1272	1512	1248	1264	1291	1039
KFL 1890	1469	1787	1402	1291	1693	823	1343	1539	1071	1480
KFL 1900	1256	1295	1417	1201	1594	1531	1579	1531	1315	1413
KFL 1910	1161	1547	1102	1138	1563	1106	1480	1043	705	1220
KFL 1920	1335	1618	1295	1480	807	1728	988	1579	1236	724
KFL 1930	1366	846	1394	1094	933	1248	1327	1236	1516	1004
KFL 1940	1563	1433	1720	1748	1433	1260	1465	906	1496	1209
KFL 1950	1425	1512	1571	1685	1657	689	1862	1657	1594	783

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KFL 1960   1402   1398   1323    1728   1193   1795    1378   1402    752   1563
KFL 1970   1476   1307   1150     980   1484   1126     929   1394   1685   1075
KFL 1980   1421   1291   1583    1650   1614   1339    1571    984   1390   1299
KFL 1990   1130   1378    902    1681   1311   1492    1559   1402   1760   1303
KFL 2000   1173   1016   1098    1272   1335   1512    1469   1008   1110   1335
KFL 2010   1244    NaN    NaN     NaN    NaN    NaN     NaN    NaN    NaN    NaN

KFS  Klamath Falls-short, precipitation (rec); mult by 1E-2 to get inches

KFS 1610   1091   1638   1063    1295   1114   1114    1051   1642   1114    988
KFS 1620   1201   1772   1157    1476   1535   1469     858   1394    949   1083
KFS 1630   1213   1319   1161    2004   2075   1539     909   1594   1315    740
KFS 1640   1366   1508   1547    1398   1126   1098     961   1528   1382   1000
KFS 1650   1311   1035   1059    1185   1413   1000    1524   1020   1350   1028
KFS 1660    945   1732   1508    1476   1374   1354    1189    980   1720   1657
KFS 1670   1319   1551   1559    1461   1402   1413    1083   1457   1366   1256
KFS 1680   1406   1681   1295    1398   1594   1122     894   1378   1433   1402
KFS 1690   1591   1098   1118    1598   1594   1118    1449   1457   1012   1394
KFS 1700   1685   1811   1650     902   1642   1350    1098   1594    894   1480
KFS 1710   1390   1319   1421    1673   1106   1748    1524   1047   1343   1390
KFS 1720   1201   1138   1315    1232   1370   1551    1409   1866   1157    799
KFS 1730   1579   1079   1650    1256   1598   1126    1169   1492   1638   1087
KFS 1740   1240   1146   1327    1260   1256   1697    1512   1504   1343   1516
KFS 1750   1638   1126   1488     972   1327   1465     933   1118   1445   1232
KFS 1760   1339   1681   1378    1433   1043   1390    1339   1150   1630   1390
KFS 1770   1287   1398   1449    1705   1272   1413     996   1398   1264   1307
KFS 1780   1488   1374   1386     854   1457   1004    1232   1378   1244   1728
KFS 1790   1551   1681   1205     874   1055   1276    1591   1362   1398   1453
KFS 1800    811   1677   1575    1598   1358   1480    1402   1130   1406   1780
KFS 1810   1531   1531   1650    1134   1256   1252    1465   1350   1685   1331
KFS 1820   1209   1476   1248    1295   1197   1744    1492   1331   1299    685
KFS 1830   1630   1295   1602    1075   1205   1846    1484   1146   1220   1154
KFS 1840   1323   1059   1516    1126   1280   1421    1126   1283   1232   1291
KFS 1850   1398   1630   1287    1496   1323   1272    1248   1539   1154   1157
KFS 1860   1496   1602   1449    1331   1031   1260    1701   1496   1587   1071
KFS 1870   1197   1035   1374    1244   1244   1264    1417   1823   1398   1350
KFS 1880   1134   1646   1154    1114   1370   1638    1280   1311   1394    917
KFS 1890   1413   1626   1307    1398   1831    898    1287   1646   1016   1496
KFS 1900   1551   1366   1362    1433   1504   1437    1520   1665   1437   1287
KFS 1910   1185   1500   1272    1551   1374   1150    1441   1028    610   1236
KFS 1920   1248   1661   1126    1484    764   1685    1035   1500   1335    713
KFS 1930   1366    949   1299     980    965   1185    1307   1142   1516    878
KFS 1940   1606   1516   1933    1728   1264   1378    1433   1055   1492   1256
KFS 1950   1488   1579   1512    1717   1579    736    1870   1642   1642    819
KFS 1960   1315   1386   1465    1760   1134   1890    1268   1350    787   1732
KFS 1970   1484   1480   1252     972   1421   1098    1004   1224   1866   1087
KFS 1980   1425   1272   1650    1571   1657   1276    1465    854   1280   1409
KFS 1990   1150   1236    783    1720   1138   1323    1606   1512   1799   1453
KFS 2000   1335    776   1236    1476   1539    NaN     NaN    NaN    NaN    NaN

WEA  Weaverville, precipitation (rec); mult by 1E-2 to get inches

WEA 1580    NaN    NaN    NaN     NaN   3629   3581    2940   4078   3936   4347
WEA 1590   3438   3975   2490    2932   2622   2223    4130   3849   3127   4970
WEA 1600   2634   5213   4172    3935   3950   4439    4725   2894   3716   3594
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WEA 1610   4114   4143   3751    2088   2923   3217    2995   4732   3176   3725
WEA 1620   3580   3997   3093    4615   3686   4379    2266   4012   3583   2308
WEA 1630   3619   2448   2556    4120   4217   4167    2327   3348   3153    961
WEA 1640   3437   4821   4456    3621   3410   2784    3101   3413   3159   3166
WEA 1650   3915   3672   2780    3262   2570   2954    5000   2651   3621   2756
WEA 1660   3756   4477   3594    3307   3798   3611    3125   1346   3626   2751
WEA 1670   2318   4187   4328    2462   3456   3506    3139   3866   3558   2884
WEA 1680   3766   3507   3945    3924   4335   4421    2767   4225   3439   3958
WEA 1690   3157   1644   3658    3832   3500   2343    3802   3870   2342   2758
WEA 1700   4126   3658   4838    2098   4288   3057    2316   4108   3209   4603
WEA 1710   2839   3375   3860    4107   2807   3869    4120   3190   3140   2287
WEA 1720   3287   2271   3264    3940   3431   3796    3616   4652   3166   2412
WEA 1730   5419   3776   3756    2285   4255   3462    2738   3013   4759   3050
WEA 1740   4517   3563   3696    4155   3733   4456    4387   4192   2906   3899
WEA 1750   4004   3392   3620    3349   3603   2800    2071   3090   3417   3137
WEA 1760   3466   3873   3410    3450   2571   2249    4176   3904   3850   4732
WEA 1770   2375   3903   2826    4239   3650   2868    1445   2602   3424   3608
WEA 1780   2924   3885   2685    1999   4617   4169    4133   3415   3069   4795
WEA 1790   4431   3668   3985    3207   2016   2318    3050   3874   4016   4009
WEA 1800   2019   4486   3764    3510   3981   3271    3606   3075   3459   2919
WEA 1810   4599   4377   3478    3687   3540   3432    3048   3419   3752   3692
WEA 1820   3468   2959   2798    3524   3083   4777    3990   2945   3377   1663
WEA 1830   4119   3073   4007    3107   3187   4034    4058   2648   3611   3636
WEA 1840   3595   2174   4085    2325   2420   3914    3385   3839   3569   3011
WEA 1850   3823   3714   3569    4756   4271   4101    2941   3217   2864   2953
WEA 1860   3819   3631   3953    2864   1989   3164    4646   3702   4511   3886
WEA 1870   3138   2513   4122    3292   3478   3350    3859   3977   4263   3915
WEA 1880   2535   3627   2829    3346   4362   3922    3909   3202   2889   3736
WEA 1890   4601   4119   3181    3984   4117   3118    3703   3321   2533   3268
WEA 1900   3882   4204   3664    3064   4135   3879    3946   4757   3644   3637
WEA 1910   3583   4352   2627    3134   4391   3892    3846   2969   2192   3231
WEA 1920   2599   4535   3410    4023   2032   3802    2775   3621   3216   2022
WEA 1930   3339   2249   3188    2555   2792   3647    3954   3027   4436   2475
WEA 1940   4073   4629   4587    3826   2948   3604    3095   2816   3424   2865
WEA 1950   3099   3622   4744    4757   3729   2234    4581   3585   4572   2641
WEA 1960   2708   3232   3103    4669   2789   4070    3685   3445   2424   4201
WEA 1970   4309   3287   3143    2731   4157   3293    1788   2332   5356   3187
WEA 1980   3832   3551   4053    5600   4131   2982    4035   2261   2132   2490
WEA 1990   2644   3327   2312    3817   2677   3722    4589   3934   4966   3803
WEA 2000   3548   2280   2854    3836    NaN    NaN     NaN    NaN    NaN    NaN

YRK  Yreka, precipitation (rec); mult by 1E-2 to get inches

YRK 1530    NaN   1564    951    1883   1758   2207    2360   1003   2174   1938
YRK 1540    817    841   2104    1772   1985   1446    1631   1370   1386   1790
YRK 1550   1259   2068   1589    1913   1090   1601    1682   2474   2250   2270
YRK 1560   2583   1518   1505    1570   2436   1361    1881   1686   1394   1292
YRK 1570   1482   1169   1449    2394   1920   1022    1221   2583   1717    854
YRK 1580   1085   1804   2263    2728   1994   1938    1672   2470   2223   2038
YRK 1590   1392   2293   1804    1416   1543   1115    2317   2139   1402   2261
YRK 1600   1319   2696   2128    2106   2099   2346    2372   1275   2026   1966
YRK 1610   1475   2013   1345    1481   1277   1538     992   2138   1175   1157
YRK 1620   1508   2008   1488    2406   2182   2126    1188   1840   1418   1553
YRK 1630   1816   1652   1521    2457   2776   2450    1317   2062   1864    771
YRK 1640   2070   2847   1992    1541   1564   1429    1474   2159   1700   1468
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YRK 1650   1765   1749   1177    1567   1259   1391    2093   1401   1795   1386
YRK 1660   1394   2014   1931    1727   1971   2160    1436    921   2287   2081
YRK 1670   1572   1886   2160    1669   1620   2006    1594   2048   1708   1503
YRK 1680   1824   1861   2068    2193   2181   1948    1058   1650   1519   1810
YRK 1690   1807   1649   1417    2138   1877   1127    1857   2296   1483   1532
YRK 1700   2297   2167   2447    1356   2138   1734    1355   2131   1383   2360
YRK 1710   1554   1616   1821    2310   1497   2214    2093   1772   1806   1625
YRK 1720   1773   1265   1285    1805   1879   1879    1561   2377   1743   1101
YRK 1730   2531   1766   2093    1484   1977   1583    1572   1753   1872   1535
YRK 1740   2049   1845   1883    1800   1671   2218    1847   1935   1669   1876
YRK 1750   2066   1382   1974    1268   1896   1552    1114   1427   1573   1660
YRK 1760   1461   2033   1838    1789   1306   1545    1840   1705   2285   2180
YRK 1770   1161   2034   1957    2372   1892   1480     862   1475   1635   1979
YRK 1780   1770   1979   1642     884   2069   1653    1599   1693   1547   2462
YRK 1790   2240   2252   1959    1167   1025   1337    2021   2174   2335   2131
YRK 1800    920   2349   2032    1767   1805   1636    1829   1644   1785   2216
YRK 1810   2167   2266   2157    1697   1205   1864    1775   1889   1953   1868
YRK 1820   1806   1700   1471    1789   1522   2608    2274   1854   1757    956
YRK 1830   2171   1896   2427    1448   1535   2539    2111   1395   1822   1807
YRK 1840   1765   1174   2193    1479   1463   1972    1449   1968   1744   1484
YRK 1850   1904   1994   1600    2212   1596   1464    1634   1987   1601   1570
YRK 1860   1754   1934   2142    2051   1002   1770    2335   2215   2316   1600
YRK 1870   1683   1212   2008    1478   1579   1467    1908   2156   2237   1935
YRK 1880   1422   2071   1529    1475   1844   1829    1942   1700   1432   1309
YRK 1890   2421   2263   1923    2130   2428   1298    1763   1941   1240   1787
YRK 1900   2024   1849   1800    1844   2010   1835    2093   2233   1557   1477
YRK 1910   1493   2127   1192    1365   1735   1476    2050   1380    695   1580
YRK 1920   1464   2028   1812    2080   1020   2020    1319   2172   1742    870
YRK 1930   1734   1308   1650    1337   1272   1669    1843   1923   2432   1215
YRK 1940   2222   2202   2401    2067   1542   1737    1803    896   1820   1481
YRK 1950   1752   1952   2204    2396   1959    819    2379   2071   2277   1099
YRK 1960   1686   2032   1967    2386   1619   2518    1741   2046   1158   2421
YRK 1970   2177   1845   1629    1350   2193   1714     996   1167   2724   1568
YRK 1980   2004   1591   2473    2607   1989   1428    2182    982   1042   1569
YRK 1990   1541   1566   1045    2285   1464   1844    2221   2183   2482   2029
YRK 2000   1902    609   1481    2099    NaN    NaN     NaN    NaN    NaN    NaN

FTO Feather River inflow to Lake Oroville (rec); multiply by 1000 to get AF

FTO  900   3889   6521   3937    5756   5770   5569    6190   4165   3430   3641
FTO  910   6341   6381   5391    2534   7116   2766    5952   4872   3151   4097
FTO  920   5255   3286   4114    3391   2571   5074    5611   5267   3334   2990
FTO  930   2332   4613   3142    2591   4977   4558    3344   5476   2971   3714
FTO  940   5255   5438   3334    3478   4822   3536    4027   3266   3057   3310
FTO  950   3482   6698   3272    4412   2116   4975    6698   1699   3744   4476
FTO  960   5147   2605   2982    5935   3668   5532    4603   5286   6856   3488
FTO  970   6843   3295   5276    4773   4990   3495    4023   3404   3316   1932
FTO  980   3220   2814   5864    2847   5445   6618    2511   4459   5327   4690
FTO  990   3455   6364   4416    6609   5315   3272    3220   6719   6615   3974
FTO 1000   6580   6699   6698    6188   6456   4310    6746   6080   6807   6652
FTO 1010   4542   6603   2804    6408   4361   6715    6590   5874   4360   7171
FTO 1020   5307   4200   3690    7257   6529   2858    6754   6369   3389   4494
FTO 1030   4364   6265   3622    4112   6249   3287    6781   4886   3992   3508
FTO 1040   3070   6535   6563    2667   3283   6593    4394   2978   3331   5015
FTO 1050   4445   4195   2595    3215   6655   3347    3481   5269   4523   1865
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FTO 1060	2398	4852	3360	4538	6694	4479	3548	4626	6300	3538
FTO 1070	1997	4594	2290	3996	3549	3504	5011	5330	6443	6714
FTO 1080	5005	4949	3699	4085	6573	4754	3947	6543	5041	6003
FTO 1090	3211	5688	3202	2250	6364	5071	3713	5258	1770	4970
FTO 1100	6891	3855	4962	2861	6180	5836	5421	5477	4291	6245
FTO 1110	5170	4399	5433	6819	3442	3568	6627	4733	6599	4340
FTO 1120	6573	4081	6556	2938	4379	6660	1499	3985	6100	5283
FTO 1130	3162	3039	3812	3398	3528	2915	4272	4464	5613	3702
FTO 1140	2580	3314	5182	3146	2846	2390	2757	4311	3053	6584
FTO 1150	2923	3412	2845	3995	3017	3124	2190	3552	3104	6583
FTO 1160	4149	3353	3189	6526	2418	6515	5225	5057	2853	7186
FTO 1170	2650	3699	4055	3858	3091	3429	3726	2717	6688	4865
FTO 1180	4229	5697	6518	1815	5730	2477	4295	2836	6733	4166
FTO 1190	5293	4170	4200	5885	4294	6734	4008	5504	4018	4249
FTO 1200	5376	5392	6666	5040	6836	6721	2670	4760	3922	6625
FTO 1210	3217	3385	4762	3356	6714	3533	6828	2379	3226	6367
FTO 1220	6752	3571	4373	3719	5799	5427	3471	2723	5171	6596
FTO 1230	3596	2472	4924	3686	4113	3720	2412	2622	4073	3830
FTO 1240	5924	7062	3180	5515	3659	2122	6707	5881	6673	4302
FTO 1250	1888	3238	5041	4012	2339	4291	6591	3585	3559	6461
FTO 1260	3280	2907	6822	3701	2378	5893	4345	4830	3517	2844
FTO 1270	6600	3266	4640	2812	5471	5571	4055	5763	4604	2506
FTO 1280	5693	4689	5913	6628	3864	1683	6685	6548	3801	4098
FTO 1290	6074	7028	2742	3800	3819	3635	2033	4075	4052	3700
FTO 1300	2944	3599	5506	4688	6517	6541	5235	4234	6776	3064
FTO 1310	6817	5182	6660	5772	6539	4592	2105	5868	5847	5636
FTO 1320	3305	6734	6850	6732	2849	4291	6954	7001	4199	3272
FTO 1330	7205	6702	3495	6081	6719	1843	6535	6743	6400	6197
FTO 1340	4719	6767	4333	4337	5120	6461	6591	6114	3855	6936
FTO 1350	4038	2850	2419	6666	3159	4226	6987	6584	2154	6667
FTO 1360	5036	2853	4918	6623	3137	3050	6560	6636	6592	3745
FTO 1370	3818	3613	5537	4610	4758	3514	4310	2511	6627	3257
FTO 1380	5678	6580	3503	6609	3147	6695	4443	5257	5357	6736
FTO 1390	1732	3892	4333	3967	5341	3700	4258	3787	4115	3618
FTO 1400	3527	5702	3351	5449	5408	5881	4946	2599	3081	4066
FTO 1410	2048	6478	7000	2230	5753	4954	4924	4144	4435	3792
FTO 1420	7267	3762	6903	6131	6240	2842	3127	3868	2469	4154
FTO 1430	3300	3547	2863	5512	3319	5127	5420	3791	5569	3253
FTO 1440	7072	7223	6740	4309	2611	6749	3821	6105	4910	6695
FTO 1450	5050	4260	2753	3941	3099	4235	3363	3380	4314	2850
FTO 1460	3712	3648	5135	4759	3276	2781	4855	6629	2387	5476
FTO 1470	6802	4000	4458	3156	5111	2911	2504	3733	3684	2227
FTO 1480	2592	3401	3548	3870	6410	4261	5058	4496	6418	5814
FTO 1490	5981	5087	3345	6394	4268	5383	5356	2993	4523	1991
FTO 1500	2968	4912	3749	6379	5890	2921	5145	4053	4299	5670
FTO 1510	2856	4564	6308	3814	4750	2702	3003	3771	1928	3810
FTO 1520	3311	2934	4380	5193	6707	5496	5142	4222	3667	1601
FTO 1530	6521	4338	1586	3225	6442	6036	6590	3559	6515	7281
FTO 1540	3374	2274	3794	3758	5027	3334	4519	4048	2160	5220
FTO 1550	3615	5337	5280	6732	3058	3320	5443	6990	4660	6474
FTO 1560	7324	3623	4008	4430	7328	6389	5329	5415	6254	3615
FTO 1570	3870	1530	3147	4749	4707	3503	2729	6690	4013	1791
FTO 1580	475	4000	4063	6214	3741	2707	4351	6631	4736	6985
FTO 1590	2900	6538	3673	3543	3011	2503	6362	4331	3278	7137
FTO 1600	3357	7306	6636	5582	6778	6707	6574	3582	6694	6066

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FTO 1610   7029   6895   4866    2360   3884   5053    4552   7066   3323   4117
FTO 1620   4936   3977   2383    6894   5626   6786    2812   4575   5348   2462
FTO 1630   4268   2814   1688    4339   4499   6092    3534   3173   3659   1995
FTO 1640   5594   7069   6532    3658   4332   3220    3241   3299   3745   5437
FTO 1650   3857   5268   3511    2729   2000   2172    6804   3234   3146   2710
FTO 1660   5290   6591   4840    3839   5252   5237    4188   1898   5324   2529
FTO 1670   1939   4878   7061    3848   5738   5160    2530   5924   4503   3994
FTO 1680   6202   4176   6021    6312   5194   5684    2614   5299   4575   3974
FTO 1690   3190   1877   4284    5297   4866   3359    5426   6790   3282   3929
FTO 1700   6065   4868   7331    2677   6440   4974    2575   3880   3010   6924
FTO 1710   2941   4221   4729    5138   3185   3971    4222   4924   4644   3346
FTO 1720   5200   2184   2913    6601   3721   6190    4264   6817   3901   1326
FTO 1730   7350   4914   6849    2815   6568   3469    2452   3128   6303   3516
FTO 1740   6781   5718   5455    6526   4780   7450    5807   6972   3431   4811
FTO 1750   4663   3719   4638    4034   3695   3372    2201   2612   4103   3670
FTO 1760   3771   5828   3739    4558   3836   2082    4411   5101   6084   6743
FTO 1770   2561   5851   4808    4600   5844   4795    2257   1865   2867   5018
FTO 1780   3598   4699   2193    1359   6698   6749    4678   6504   2642   7000
FTO 1790   7438   6070   6844    4506   2686   1486    2497   5272   5587   7123
FTO 1800   2858   6318   5393    3951   4939   3979    4538   3354   3395   3480
FTO 1810   4687   6668   3844    5100   4198   3948    4854   5728   4502   5348
FTO 1820   4302   5980   2837    3794   2779   7470    7138   3756   6756   1449
FTO 1830   5460   3715   6967    4406   3611   4047    4926   3361   5907   4116
FTO 1840   4143   1475   5370    2167   1814   3778    2701   4988   4624   3950
FTO 1850   5864   3936   5441    6875   5994   5465    2623   3710   2230   2988
FTO 1860   4556   4414   7097    4595   1528   3628    6840   6623   8029   5975
FTO 1870   3901   2645   5166    4074   5032   3861    6651   3027   7437   3876
FTO 1880   3910   6628   3317    3073   7155   5516    5276   3631   3961   3946
FTO 1890   6597   6667   3670    5989   5729   5654    5189   5719   2221   3471
FTO 1900   4203   6216   4255    4408   4783   5273    6674   7442   5108   5203
FTO 1910   4467   6232   2923    2874   6358   6486    5799   4145   2485   3423
FTO 1920   2641   4182   4122    4747   1115   4477    2985   3931   3502   2119
FTO 1930   3047   1371   4059    2888   1876   3789    5201   5158   6800   2536
FTO 1940   5069   7237   7232    5703   4079   4446    4032   2721   3193   3084
FTO 1950   3508   4333   6616    6370   4827   2650    6215   4427   7243   2693
FTO 1960   3261   2125   4235    7163   2871   6520    3620   6393   2951   7404
FTO 1970   5250   5374   2507    4385   6315   4091    1794   1402   7769   4486
FTO 1980   6929   3847   6694    7615   6498   4116    7170   2314   3180   3150
FTO 1990   2180   3435   2662    6963   3123   6670    6206   5079   8012   5814
FTO 2000   5152   2762   2926    4580   4135   5659    6221   2498   2753   2846
FTO 2010   6075   6856   5851     NaN    NaN    NaN     NaN    NaN    NaN    NaN

YRS Yuba River at Smartville (rec); multiply by 1000 to get AF

YRS  900   2033   3405   2031    2948   2920   2797    3066   1975   1782   2085
YRS  910   3369   3230   2590    1227   3779   1252    3266   2583   1583   2315
YRS  920   2823   1664   2273    1905   1311   2892    2993   2564   1619   1542
YRS  930   1225   2739   1636    1365   2816   2498    1672   2987   1500   2033
YRS  940   2863   2917   1707    1873   2542   1871    2164   1743   1640   1796
YRS  950   2050   3098   1547    2299    981   2503    3115    769   1874   2802
YRS  960   2805   1160   1418    2945   2167   2205    2045   2127   3413   1489
YRS  970   3611   1711   2808    3306   3467   1544    3042   2187   1489    942
YRS  980   2383   1349   2353    1402   2815   3221    1196   2602   2975   2566
YRS  990   2394   3260   3052    3398   2493   1896    2631   3439   2855   2369
YRS 1000   3307   3199   3388    3475   3051   2439    3662   2733   3396   3373
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YRS 1010   2418   3359   1351    3403   2683   3482    3375   2737   2446   3654
YRS 1020   3084   2398   2388    3757   3309   1420    3468   3005   2250   2695
YRS 1030   2473   3418   2060    3099   3300   1614    3479   2452   2461   1776
YRS 1040   1610   3366   3199    1384   1790   3401    2363   1731   2205   2468
YRS 1050   1947   2549   1317    1831   3396   1432    2228   2789   1999   1004
YRS 1060   1145   2757   1757    2004   3398   2668    1822   2662   3348   1710
YRS 1070   1061   3377   1217    2271   2071   1760    2784   2045   1558   3121
YRS 1080   2357   2677   1866    2470   2395   2184    1584   3305   2469   3230
YRS 1090   1535   3473   1851     926   3471   2916    2600   2622   1196   2486
YRS 1100   3486   2516   2802    1346   3439   2927    2102   2601   2597   2989
YRS 1110   2705   2294   2840    3493   1663   2381    3491   2606   3359   3241
YRS 1120   3125   2505   3576    1401   2398   3465     741   3303   3463   3290
YRS 1130   1563   1647   2776    2238   2336   1514    2900   1857   2858   2232
YRS 1140   1373   1803   2275    1938   1749   1247    1444   2754   1494   3112
YRS 1150   1390   1799   1540    2906   2500   1806    1585   2294   1925   3393
YRS 1160   2381   1791   1771    3296   1200   3486    3113   3200   1925   3757
YRS 1170   1424   3020   2044    2175   1562   1210    2368   1283   3130   2450
YRS 1180   2270   3162   2925     953   3378   1202    3013   1321   3468   2371
YRS 1190   2880   2562   2830    3356   2472   3686    2186   2693   2351   2918
YRS 1200   3160   1679   3354    2583   3441   3417    1281   2196   2572   3205
YRS 1210   1818   1738   2556    1961   3377   1459    3414   1111   1348   3380
YRS 1220   3348   2517   2256    2060   3180   3411    2142   1361   2943   3365
YRS 1230   1854   1193   3190    1879   1887   1985    1396   1450   2120   1975
YRS 1240   2866   3198   1643    2661   1843   1267    3492   2712   3373   2639
YRS 1250    947   2133   3320    2063   1093   2573    3115   1900   1919   3345
YRS 1260   1437   1464   3507    1966   1370   3388    3253   3341   1976   1521
YRS 1270   3654   1746   2750    1378   3407   2730    1872   3318   2334   1231
YRS 1280   3295   2504   3180    3432   3097    741    3596   3455   2484   2164
YRS 1290   2962   3580   1212    2606   2201   2649    1110   2592   2819   1942
YRS 1300   1370   2546   3102    2186   3181   3115    2511   2385   3171   1710
YRS 1310   3459   2293   3458    2822   3189   2381    1040   3357   3361   2985
YRS 1320   1844   3420   3393    3328   1280   2133    3478   3544   1864   2166
YRS 1330   3698   3377   2044    2822   3579    890    3422   3524   2936   3204
YRS 1340   2478   3754   2730    2462   2763   3408    3413   2833   2654   3592
YRS 1350   2694   1385   1244    3462   1707   2476    3513   3346    998   3532
YRS 1360   3336   1780   3121    3537   2232   1593    3399   3393   3265   2059
YRS 1370   3231   2116   3015    3142   2413   1814    2740   1102   3505   1691
YRS 1380   3228   3381   1716    3389   1483   3518    2525   2361   2921   3435
YRS 1390    872   2128   2487    2325   2763   1553    2190   1986   2428   1977
YRS 1400   1827   2911   1700    2859   2768   3288    2831   1369   1535   2444
YRS 1410    872   3432   3636     985   3230   2594    2241   2389   2450   2082
YRS 1420   3629   1966   3581    3187   3033   1268    1675   2446   1112   2653
YRS 1430   1860   2094   1447    2956   1821   3045    2860   2091   2978   1684
YRS 1440   3655   3454   3425    2245   1335   3639    2086   3336   2747   3443
YRS 1450   3044   2327   1427    2143   1707   2212    1841   1842   2358   1458
YRS 1460   2242   1944   2671    2709   1865   1444    2511   3407   1093   2957
YRS 1470   3457   2224   2382    1585   2741   1294    1222   2234   2049   1032
YRS 1480   1440   1935   1972    2088   3368   2168    2737   2617   3359   2789
YRS 1490   3210   2762   1829    3278   2248   2861    3036   1571   2671    826
YRS 1500   1687   3006   1989    3359   3355   1521    2999   1990   2080   2508
YRS 1510   1399   2330   3367    2110   2663   1328    1648   2193    900   2254
YRS 1520   1917   1569   2650    3037   3365   2922    2625   2505   2181    692
YRS 1530   3479   2555    684    1867   3407   3006    3402   1614   3405   3690
YRS 1540   1658   1050   2365    2037   2946   1815    2495   2527    945   2977
YRS 1550   1859   2782   2858    3470   1516   1808    2844   3512   2516   3425
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YRS 1560   3653   1990   2326    2331   3754   2620    2957   2874   3104   2002
YRS 1570   2315    686   1862    2725   2633   1995    1421   3474   2262    877
YRS 1580     97   2405   2357    3339   2189   1404    2327   3481   2728   3573
YRS 1590   1616   3361   2212    2012   1643   1274    3357   2659   1704   3827
YRS 1600   1751   3750   3420    2944   3410   3364    3456   1876   3610   2802
YRS 1610   3554   3596   2749    1179   2199   2802    2188   3722   1894   2141
YRS 1620   2613   2350   1165    3504   3075   3616    1435   2374   2905   1103
YRS 1630   2388   1490    761    2626   2568   3220    1943   1724   2191    815
YRS 1640   2844   3637   3400    2175   2529   1852    1779   1891   2134   2813
YRS 1650   2246   2843   1981    1384    953    963    3521   1610   1477   1363
YRS 1660   2644   3427   2886    2079   2716   2582    2407    781   3120   1339
YRS 1670    950   2940   3697    2120   2872   3028    1211   3403   2613   2311
YRS 1680   2833   2354   2926    3277   2860   3120    1461   2834   2548   2401
YRS 1690   1879    798   2397    3085   2828   1717    2738   3618   1709   2295
YRS 1700   3175   2561   3725    1188   3339   2796    1112   2227   1537   3620
YRS 1710   1460   2154   2633    3103   1750   2326    2550   2934   2194   1660
YRS 1720   2726    996   1512    3144   2048   3131    2014   3761   2179    472
YRS 1730   4018   2572   3568    1366   3511   1918    1429   1533   3065   1925
YRS 1740   3503   2685   2844    3401   2661   3727    3007   3680   1794   2451
YRS 1750   2612   2100   2554    2266   2234   1712    1037   1380   2357   2074
YRS 1760   2168   3098   2113    2695   2019    894    2589   2731   3126   3511
YRS 1770   1307   2872   2566    2701   3237   2734     971    833   1492   2828
YRS 1780   1975   2482    996     633   3622   3278    2529   3083   1387   3669
YRS 1790   3886   2779   3631    2433   1324    501    1238   2782   2988   3541
YRS 1800   1438   3497   2970    1958   2705   2232    2630   1808   1846   1837
YRS 1810   2815   3599   2034    2930   2357   2469    2461   2835   2433   2879
YRS 1820   2606   2849   1407    2087   1396   3833    3646   2049   3524    492
YRS 1830   2940   1906   3627    2485   2018   2378    2716   1792   3034   2245
YRS 1840   2276    622   3170     987    877   2117    1432   2685   2562   2187
YRS 1850   2675   1970   2718    3613   2922   2935    1341   2113   1141   1513
YRS 1860   2465   2507   3577    2481    644   2088    3481   3412   3985   2951
YRS 1870   1980   1224   2877    2467   2663   2139    3491   1540   3882   2174
YRS 1880   2116   3536   1991    1649   3746   2839    3038   2102   2324   2215
YRS 1890   3361   3628   1995    3316   3079   2845    2929   2994   1072   2008
YRS 1900   2317   3406   2460    2520   2788   2784    3403   3753   2680   2846
YRS 1910   2561   3188   1461    1407   3044   3262    3291   2452   1264   1905
YRS 1920   1411   2558   2236    2810    416   2684    1677   2428   1962   1090
YRS 1930   1811    672   2376    1512    977   2119    2744   2531   3505   1200
YRS 1940   2725   3513   3671    3066   2167   2402    2157   1340   1705   1550
YRS 1950   1830   2245   3430    3115   2633   1392    3355   2394   3766   1507
YRS 1960   1730   1006   2257    3662   1476   3429    1985   3598   1578   3815
YRS 1970   2828   2744   1234    2295   3355   2242     650    598   3918   2320
YRS 1980   3696   2035   3583    4017   3398   2258    3883   1081   1480   1492
YRS 1990   1080   1923   1242    3437   1610   3345    3378   2990   4039   3269
YRS 2000   2825   1502   1699    2717   2372   3342    3704   1347   1983   1728
YRS 2010   2842   3559   3045     NaN    NaN    NaN     NaN    NaN    NaN    NaN

AMF American River inflow to Lake Folsom (rec); multiply by 1000 to get AF

AMF  900   2269   4157   2265    3450   3409   3219    3588   2180   2010   2355
AMF  910   4055   3817   2958    1284   4687   1313    3953   2991   1732   2638
AMF  920   3310   1815   2709    2128   1386   3394    3493   2870   1740   1664
AMF  930   1287   3194   1782    1453   3291   2821    1808   3594   1628   2279
AMF  940   3365   3414   1862    2062   2890   2084    2449   1954   1797   1982
AMF  950   2329   3646   1668    2622   1064   2828    3616    792   2119   3232
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AMF	960	3224	1225	1522	3525	2477	2568	2299	2492	4116	1590
AMF	970	4564	1820	3196	3870	4211	1631	3498	2435	1587	987
AMF	980	2666	1432	2628	1510	3354	3879	1278	2969	3444	2997
AMF	990	2729	3901	3571	4089	2797	2092	2974	4249	3373	2720
AMF	1000	3945	3942	4111	4280	3538	2765	4748	3176	4097	4032
AMF	1010	2708	4045	1469	4114	3112	4359	4117	3279	2812	4749
AMF	1020	3617	2733	2717	4929	3956	1518	4300	3538	2537	3155
AMF	1030	2810	4119	2353	3649	3929	1764	4294	2852	2817	1968
AMF	1040	1814	4061	3755	1471	1975	4090	2623	1869	2465	2777
AMF	1050	2194	2902	1416	2016	4067	1533	2530	3192	2237	1062
AMF	1060	1213	3176	1956	2317	4096	3037	2031	3112	3975	1863
AMF	1070	1112	4071	1291	2586	2357	1994	3213	2266	1689	3689
AMF	1080	2703	3133	2054	2989	2747	2522	1755	3949	2819	3810
AMF	1090	1652	4238	1973	963	4262	3371	2916	2933	1266	2857
AMF	1100	4295	2834	3194	1439	4178	3377	2367	2947	2925	3567
AMF	1110	3086	2583	3273	4272	1838	2704	4296	2927	4007	3783
AMF	1120	3648	2839	4456	1478	2744	4225	770	3906	4205	3787
AMF	1130	1670	1775	3167	2503	2596	1624	3383	2042	3248	2476
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SBB Sacramento River above Bend Bridge (rec); multiply by 1000 to get AF

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SAC4 1130  13022  12465  15472   13957  14496  12023   17412  18115  21964  15194
SAC4 1140  10761  13607  20604   12942  11776  10055   11468  17494  12579  25305
SAC4 1150  11998  13999  11723   16266  12429  12816    9240  14539  12835  25273
SAC4 1160  16962  13737  13181   24998  10277  24986   20848  20347  11919  28054
SAC4 1170  11027  15176  16546   15857  12659  13924   15118  11324  25803  19538
SAC4 1180  17298  22474  24939    7937  22320  10411   17509  11820  26035  17074
SAC4 1190  20911  17082  17267   22837  17558  25979   16419  21681  16435  17237
SAC4 1200  21345  21444  25636   20299  26503  25910   11119  19225  16070  25507
SAC4 1210  13275  13987  19014   13748  25916  14509   26402  10059  13266  24844
SAC4 1220  26027  14695  17859   15197  22717  21508   14145  11307  20673  25333
SAC4 1230  14801  10417  19593   15160  16677  15249   10142  11007  16626  15638
SAC4 1240  23249  27426  13097   21532  14997   9080   25859  22955  25727  17290
SAC4 1250   8200  13298  20153   16353   9916  17530   25335  14665  14586  24940
SAC4 1260  13521  12107  26374   15034  10094  22976   17800  19244  14364  11834
SAC4 1270  25380  13458  18429   11697  21744  21968   16557  22668  18706  10495
SAC4 1280  22476  19002  23361   25440  15611   7441   25746  25153  15622  16803
SAC4 1290  23917  27304  11368   15569  15636  14826    8717  16608  16595  15142
SAC4 1300  12198  14825  21799   18981  24976  25138   20881  17180  26172  12663
SAC4 1310  26420  20653  25635   22773  25099  18549    9080  22956  22985  22285
SAC4 1320  13644  26026  26534   26016  11852  17551   27068  27288  17012  13548
SAC4 1330  28224  25880  14438   23776  25865   8044   25081  26075  24829  24140
SAC4 1340  19045  26201  17672   17792  20467  24961   25360  23925  15911  26973
SAC4 1350  16537  11829  10198   25625  13034  17391   27213  25312   9273  25689
SAC4 1360  20076  11859  19732   25476  12906  12609   25218  25592  25348  15356
SAC4 1370  15617  14904  21853   18853  19034  14476   17523  10574  25495  13399
SAC4 1380  22600  25289  14427   25436  13077  25797   18132  21004  21274  25952
SAC4 1390   7617  15892  17628   16315  21123  15149   17346  15556  16960  14849
SAC4 1400  14447  22364  13813   21512  21571  22812   19661  10849  12698  16698
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SAC4 1410   8636  25023  27308    9352  22781  19787   19619  16758  18262  15639
SAC4 1420  28597  15415  26767   23664  24228  11706   12918  15988  10268  17013
SAC4 1430  13644  14691  11857   21810  13685  20127   21546  15596  21705  13407
SAC4 1440  27598  28160  25970   17457  10945  26276   15672  23439  19566  25908
SAC4 1450  20075  17222  11508   16259  12809  17142   13839  13897  17735  11815
SAC4 1460  15432  15024  20541   18998  13548  11602   19458  25784   9975  21507
SAC4 1470  26520  16322  17973   12989  20464  12012   10455  15458  15159   9349
SAC4 1480  10915  14036  14705   15904  24718  17049   20209  18181  24817  22841
SAC4 1490  23067  20223  13813   24684  17382  21162   21102  12408  18420   8393
SAC4 1500  12277  19925  15465   24503  23004  12099   20382  16533  17475  22162
SAC4 1510  11680  18509  24501   15747  19077  11214   12453  15451   8272  15719
SAC4 1520  13644  12180  17743   20485  26082  21525   20323  17328  15096   6918
SAC4 1530  25266  17703   6799   13381  25018  23325   25478  14549  25219  28399
SAC4 1540  13886   9608  15738   15553  20194  13761   18276  16474   8901  20722
SAC4 1550  14806  20984  21055   26124  12579  13604   22266  27337  18590  24956
SAC4 1560  28514  14853  16328   18135  28756  25198   20878  21344  24342  14763
SAC4 1570  15815   6633  13193   19067  18875  14350   11289  25868  16246   7596
SAC4 1580   2399  16515  16667   23933  15287  11407   17785  25658  18893  27057
SAC4 1590  12111  25264  15065   14563  12528  10591   24642  17589  13368  27449
SAC4 1600  13740  27973  25623   21796  26605  26942   25747  14687  25781  23472
SAC4 1610  27083  26500  19229   10125  15861  19748   18120  27194  13674  16509
SAC4 1620  19987  16274  10026   27350  21938  26013   11626  18258  21032  10249
SAC4 1630  17733  11648   7357   17692  18163  23708   14623  13192  14594   8283
SAC4 1640  21049  27303  25224   15407  18384  13782   12558  13845  14962  22974
SAC4 1650  16244  20658  14807   11769   9046   8682   26661  12770  13125  11524
SAC4 1660  21688  25843  18961   15820  20698  20248   18043   7904  21752  10897
SAC4 1670   8386  20826  28318   16068  23326  21342   10376  24005  17911  16289
SAC4 1680  23412  18031  23783   25800  21586  22729   12068  21124  19158  16941
SAC4 1690  13988   7512  17941   20660  18469  13936   21551  26018  13607  16824
SAC4 1700  23206  18550  28405   10763  24354  20574   10763  16132  12677  26415
SAC4 1710  11965  16770  18674   20422  14077  16573   17556  20301  18316  14240
SAC4 1720  21095   9433  11800   25534  14954  22922   17376  26853  15647   5339
SAC4 1730  30567  19720  26220   11689  25036  13768   10686  12725  24629  15463
SAC4 1740  27008  21503  22076   25479  19855  28924   22744  27063  13900  19791
SAC4 1750  18604  15311  18311   16927  14887  14374    9618  10481  16438  14598
SAC4 1760  15530  22213  15149   18664  15400   8619   17985  21117  23164  25434
SAC4 1770  10542  22000  19877   18712  23008  19860   10000   8188  11883  19439
SAC4 1780  14674  17534   8583    6161  26100  25784   19156  24678  10974  26979
SAC4 1790  29375  22317  26708   17735  11468   6209   10005  20024  21472  26874
SAC4 1800  11879  24351  21809   15692  19593  16358   17659  13378  14245  14656
SAC4 1810  19549  25752  15259   19747  17524  16489   19757  21686  18728  21193
SAC4 1820  17570  22867  11394   14975  11501  29764   27597  15403  26806   6071
SAC4 1830  21041  14508  26183   16615  14698  16449   19240  13661  23847  17120
SAC4 1840  16485   6128  20804    9334   7926  15364   11292  18869  18204  16145
SAC4 1850  21767  15501  21044   26723  23058  21379   10844  15237   9599  11874
SAC4 1860  18979  18295  27414   18299   6913  14971   26408  25734  31632  22298
SAC4 1870  15477  10918  19683   16883  19511  15918   25525  12372  29750  15820
SAC4 1880  15458  26155  14778   12741  28377  21954   20302  15414  16658  16265
SAC4 1890  25759  26155  15195   22722  23276  22353   20653  22359   9933  14073
SAC4 1900  17269  24650  17180   18012  19848  21148   25772  29110  21039  20843
SAC4 1910  19073  23333  12260   12400  25209  25455   23200  16494  10641  14273
SAC4 1920  11147  17622  16302   19004   5329  18081   12774  16557  14020   9093
SAC4 1930  12758   6231  16943   11627   8530  15519   20884  20010  25625  11124
SAC4 1940  20022  28750  28184   22299  16520  18076   17030  11639  12874  12721
SAC4 1950  14253  17412  25832   24546  19402  11282   23596  18261  28080  11534
```

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SAC4 1960  13490   9082  17355   27389  12246  25258   15427  24254  12172  28767
SAC4 1970  20081  20237  10808   17394  24336  15996    7616   5973  30538  17861
SAC4 1980  27187  15378  26574   29901  24535  16666   27678   9906  12709  13086
SAC4 1990   9755  13612  11333   26440  12484  26061   24931  21256  32698  23689
SAC4 2000  20758  11994  11763   18523  16928  26323   28393   9470  14623  12034
SAC4 2010  25015  24627  23524     NaN    NaN    NaN     NaN    NaN    NaN    NaN
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SNS Stanislaus River inflow to New Melones (rec); multiply by 1000 to get AF
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```
SNS  900    972   1773    964    1480   1459   1356    1518    936    887   1024
SNS  910   1731   1621   1259     558   1907    576    1718   1294    764   1138
SNS  920   1436    790   1191     930    605   1462    1454   1188    746    722
SNS  930    566   1376    775     626   1413   1178     776   1583    717    990
SNS  940   1207   1250    767     953   1088   1137    1079   1027    651    849
SNS  950   1104   1675    780     977    339   1345    1671    277   1008   1210
SNS  960   1470    565    723    1350    907   1084     997   1234   1818    839
SNS  970   2019    798   1364    1320   1679    728    1145    892    593    353
SNS  980    724    612   1150     632   1186   1686     513   1305   1526   1224
SNS  990   1002   1731   1330    1696   1068    825    1138   1884   1719   1009
SNS 1000   1550   1682   1734    1830   1351    925    2061   1299   1893   1766
SNS 1010   1106   1632    579    1641   1086   1690    1668   1313    898   2005
SNS 1020   1230   1109   1173    2390   1637    623    1795   1678    918   1130
SNS 1030   1242   1794    775    1494   1408    904    1928   1302   1025    660
SNS 1040    613   1660   1702     803    729   1839    1039    759    976   1266
SNS 1050   1260   1022    490     879   1820    693     965   1411    939    336
SNS 1060    565   1267    921    1238   1855   1290     856   1162   1659    824
SNS 1070    407   1546    395    1059    855    846    1635    888   1577   1714
SNS 1080   1487   1044    782    1196   1578   1080     971   1865   1284   1658
SNS 1090    657   1773    694     456   1761   1337    1049   1145    454   1397
SNS 1100   1945   1396   1260     697   1705   1550    1260   1192   1264   1629
SNS 1110   1473   1178   1402    1952    950   1034    1924   1308   1550   1557
SNS 1120   1664   1490   1955     691   1419   1716     214   1654   1752   1607
SNS 1130    774    671   1022    1190   1076    680    1393   1125   1419   1074
SNS 1140    596    840   1250     859    823    536     719   1090    802   1705
SNS 1150    593    928    653    1231   1183    773     587    997   1049   1484
SNS 1160   1215    728    866    1420    614   1796    1373   1624    809   2174
SNS 1170    586   1415    976     983    657    769     909    862   1714   1399
SNS 1180   1143   1704   1429     359   1497    603    1464    661   1941   1225
SNS 1190   1315   1178   1504    1633    974   1995     891   1356    783   1024
SNS 1200   1587   1059   1911    1227   1965   1610     535   1186    981   1628
SNS 1210    764    885   1050     749   1850    985    1798    515    724   1830
SNS 1220   1625   1124    972     891   1434   1742     717    741   1461   1702
SNS 1230    980    615   1450     980    947   1120     633    711   1134    792
SNS 1240   1424   1819    871    1155    786    663    1834   1464   1780   1275
SNS 1250    561    906   1511    1006    633   1438    1756    648    906   1691
SNS 1260    821    742   1911    1087    470   1395    1518   1508   1084    779
SNS 1270   1896    858   1093     592   1746    832     827   1679   1304    608
SNS 1280   1636   1151   1547    1720    877    396    1899   1755    924   1035
SNS 1290   1665   1931    664    1196    906   1049     345   1008   1027    795
SNS 1300    669   1112   1404    1025   1251   1593    1173    936   1734    682
SNS 1310   1730    832   1545    1489   1687   1002     643   1176   1543   1120
SNS 1320    822   1549   1736    1377    459    889    1774   1965    906    946
SNS 1330   2086   1830   1213    1275   1864    601    1686   1900   1435   1541
SNS 1340   1010   2006   1070    1040   1162   1669    1714   1526   1094   1827
SNS 1350   1233    595    666    1740    946    910    1933   1483    502   1657
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SNS 1360	1343	810	1664	1329	905	809	1724	1792	1624	1022
SNS 1370	1188	788	1339	1422	1658	876	1395	423	1512	786
SNS 1380	1320	1657	917	1625	880	1765	1307	1534	1666	1768
SNS 1390	554	1196	1466	1251	1863	946	855	855	1087	942
SNS 1400	922	1184	715	1165	1273	1566	1310	555	720	1167
SNS 1410	473	1687	1878	405	1544	1210	793	1026	1459	859
SNS 1420	2025	1031	1973	1812	1745	683	618	1032	821	1520
SNS 1430	998	719	613	1430	900	1623	1419	903	1137	832
SNS 1440	2014	1749	1309	1217	742	1811	947	1259	1112	1292
SNS 1450	901	816	585	914	610	924	650	868	949	451
SNS 1460	951	689	1344	1224	660	745	986	1734	414	1314
SNS 1470	1800	972	1143	816	953	560	550	1000	1025	367
SNS 1480	771	987	868	830	1850	1208	1488	1190	1325	1517
SNS 1490	1352	1459	927	1582	1420	1035	1429	582	1231	587
SNS 1500	425	1427	1035	1640	1345	782	1090	732	744	1513
SNS 1510	727	816	1384	1325	1186	498	745	1345	417	913
SNS 1520	929	874	1166	1148	1810	1719	1287	1159	1244	443
SNS 1530	1754	1222	309	645	1859	1548	1311	632	1490	1976
SNS 1540	740	416	856	839	1074	735	1173	1184	354	1495
SNS 1550	925	1246	1393	1857	615	690	1771	1795	1353	1654
SNS 1560	1810	991	1319	1342	2011	1566	1474	1566	1789	828
SNS 1570	998	432	946	1303	1274	909	654	1769	1090	365
SNS 1580	65	1291	844	1600	985	730	999	1642	1142	1843
SNS 1590	684	1720	899	935	881	548	1710	1172	1032	1883
SNS 1600	877	1986	1592	1408	1688	1739	1740	829	1840	1322
SNS 1610	1758	1910	1447	522	1173	1524	1226	2143	987	1086
SNS 1620	1415	1120	564	1859	1432	2180	600	1241	1464	539
SNS 1630	1099	595	296	1328	934	1423	1133	647	919	375
SNS 1640	1420	1693	1796	957	1291	918	912	819	1169	1549
SNS 1650	1144	1510	1016	611	412	323	1851	727	593	584
SNS 1660	1584	1800	1268	966	1333	1117	1094	326	1346	484
SNS 1670	436	1544	2031	950	1458	1414	521	1671	1359	1182
SNS 1680	1482	1137	1533	1721	1308	1495	647	1445	1277	1183
SNS 1690	799	329	1224	1517	1368	872	1399	1949	820	1249
SNS 1700	1640	1022	1951	561	1631	1478	617	979	729	1758
SNS 1710	621	1046	1348	1368	817	965	1146	1404	970	701
SNS 1720	1365	498	655	1575	992	1654	1030	2004	901	232
SNS 1730	2392	1258	1713	501	1735	827	664	734	1604	961
SNS 1740	1810	1461	1456	1633	1282	2097	1553	1974	711	1245
SNS 1750	1230	1036	1234	1180	947	740	480	601	1151	962
SNS 1760	1204	1456	946	1368	935	372	1366	1390	1439	1647
SNS 1770	618	1333	1203	1255	1558	1215	501	288	659	1231
SNS 1780	914	1060	327	272	1837	1643	1258	1491	602	1921
SNS 1790	2154	1304	1996	1187	566	189	501	1298	1392	1717
SNS 1800	734	1822	1525	899	1376	1083	1171	870	830	829
SNS 1810	1371	1947	901	1490	1425	1232	1262	1493	1097	1405
SNS 1820	1247	1284	532	801	571	1979	1901	862	1831	207
SNS 1830	1411	794	2040	1287	961	1122	1298	828	1664	1126
SNS 1840	1004	290	1500	418	336	1054	573	1295	1248	987
SNS 1850	1197	711	1466	1858	1403	1382	524	939	502	676
SNS 1860	1317	1240	1797	1125	324	949	1757	1680	2245	1622
SNS 1870	1196	592	1466	1142	1250	1089	1728	646	2180	969
SNS 1880	1089	1860	998	665	1925	1447	1398	957	1221	1009
SNS 1890	1625	1899	840	1576	1510	1520	1431	1406	510	833
SNS 1900	1149	1876	1063	1051	1340	1260	1813	2066	1204	1390

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SNS 1910   1170   1815    654     598   1686   1735    1690   1299    633    948
SNS 1920    649   1288   1200    1358    146   1227     783   1132    831    506
SNS 1930    716    346   1261     657    428   1100    1530   1227   1876    652
SNS 1940   1369   1775   1820    1462   1006   1219     941    629    754    635
SNS 1950    898   1119   1809    1408   1220    774    1624   1131   2009    716
SNS 1960    645    419   1026    1889    661   1577     858   1709    678   2298
SNS 1970   1296   1232    552    1110   1620   1115     322    334   2241   1216
SNS 1980   2083    999   1947    2289   1699   1014    2119    583    599    647
SNS 1990    613    954    719    2001    858   1816    1702   1361   2177   1498
SNS 2000   1356    740    769    1240    975   1673    2148    651    943    764
SNS 2010   1328   1578   1484     NaN    NaN    NaN     NaN    NaN    NaN    NaN

TLG Tuolumne River inflow to New Don Pedro (rec); multiply by 1000 to get AF

TLG  900   1593   2849   1571    2351   2307   2131    2374   1531   1482   1709
TLG  910   2768   2520   1981     973   3122    995    2751   2068   1297   1863
TLG  920   2305   1333   1917    1566   1057   2381    2285   1877   1257   1245
TLG  930   1007   2260   1323    1087   2302   1893    1307   2551   1231   1658
TLG  940   1960   1994   1292    1587   1771   1848    1772   1697   1132   1449
TLG  950   1796   2623   1320    1635    649   2162    2618    556   1687   1926
TLG  960   2281    990   1251    2133   1523   1759    1661   1945   2906   1396
TLG  970   3291   1314   2106    2048   2568   1226    1831   1487   1048    688
TLG  980   1249   1085   1864    1110   1892   2641     917   2060   2364   1893
TLG  990   1640   2698   2040    2629   1711   1385    1809   2989   2660   1631
TLG 1000   2397   2589   2700    2865   2059   1518    3342   1998   3024   2754
TLG 1010   1748   2494   1009    2559   1735   2598    2549   2011   1485   3235
TLG 1020   1917   1768   1845    4129   2455   1068    2839   2594   1501   1789
TLG 1030   1946   2831   1289    2322   2179   1490    3111   1993   1664   1142
TLG 1040   1079   2610   2662    1321   1246   2954    1671   1283   1617   1983
TLG 1050   1966   1679    886    1488   2917   1191    1618   2208   1567    652
TLG 1060   1018   2035   1540    1947   2982   1988    1423   1845   2579   1363
TLG 1070    759   2412    736    1751   1443   1425    2535   1470   2430   2699
TLG 1080   2310   1698   1331    1874   2457   1747    1612   2990   1982   2562
TLG 1090   1127   2804   1180     836   2820   2084    1691   1833    826   2217
TLG 1100   3166   2129   1945    1186   2676   2391    1957   1890   1989   2510
TLG 1110   2272   1849   2191    3156   1546   1683    3099   2002   2394   2375
TLG 1120   2569   2265   3099    1161   2199   2687     449   2578   2746   2437
TLG 1130   1285   1160   1685    1867   1718   1162    2170   1786   2196   1730
TLG 1140   1041   1420   1956    1436   1374    949    1231   1777   1347   2655
TLG 1150   1035   1544   1123    1956   1851   1287    1015   1670   1711   2323
TLG 1160   1917   1240   1459    2224   1077   2880    2131   2500   1340   3626
TLG 1170   1021   2208   1602    1626   1139   1302    1541   1442   2709   2177
TLG 1180   1822   2671   2206     681   2373   1051    2287   1140   3170   1925
TLG 1190   2062   1872   2328    2518   1600   3240    1450   2113   1317   1670
TLG 1200   2432   1701   3055    1934   3210   2440     952   1907   1625   2549
TLG 1210   1299   1487   1719    1281   2978   1601    2862    921   1247   2947
TLG 1220   2501   1780   1606    1491   2249   2718    1217   1192   2288   2489
TLG 1230   1561   1070   1990    1529   1533   1596    1089   1296   1527   1399
TLG 1240   2394   2974   1456    1859   1347   1131    3216   2461   2679   1977
TLG 1250   1016   1735   2503    1754   1104   2520    2716   1175   1659   2542
TLG 1260   1479   1384   3180    1453    812   2162    2605   2416   1760   1426
TLG 1270   3332   1541   1573    1127   2815   1341    1221   2700   1911   1148
TLG 1280   2693   1955   2553    2533   1643    766    3246   2985   1597   1860
TLG 1290   2577   3197   1080    1953   1697   1737     741   1514   1653   1231
TLG 1300   1126   1741   2279    1703   2065   2531    2037   1750   2761   1193
```

TLG 1310	2816	1594	2706	2118	2519	1542	1067	1979	2598	1720
TLG 1320	1352	2529	3057	2284	766	1345	2647	3404	1184	1542
TLG 1330	3892	2854	1790	2371	3051	938	2754	3243	2179	2452
TLG 1340	1728	3428	1859	1591	1966	2721	2622	2245	1879	3009
TLG 1350	1647	1076	1038	2643	1570	1530	3314	2400	975	2624
TLG 1360	2053	1397	1854	2227	1544	1402	2677	3119	2649	1582
TLG 1370	1871	1424	2170	2137	1820	1580	1941	858	2552	1251
TLG 1380	2194	2598	1494	2515	1512	2967	2107	2409	2660	2872
TLG 1390	947	2159	2045	1966	2529	1589	1412	1427	1751	1570
TLG 1400	1606	1901	1253	1922	2107	2181	1882	924	1358	1813
TLG 1410	938	2639	3031	790	2447	2056	1662	1754	2244	1613
TLG 1420	3418	1690	3240	2482	2764	1297	1206	1730	1218	2075
TLG 1430	1429	1112	1012	2101	1363	2346	2132	1488	1956	1337
TLG 1440	3132	2965	2176	1925	1046	2683	1490	1912	1690	2019
TLG 1450	1365	1491	1051	1633	1058	1705	1120	1405	1606	944
TLG 1460	1371	1279	2176	1768	1087	1185	1761	2582	864	2207
TLG 1470	2878	1605	1802	1175	1729	1084	960	1498	1666	749
TLG 1480	1122	1471	1414	1527	2742	1858	2346	1852	2318	2508
TLG 1490	2266	2104	1386	2483	2025	1607	2013	1047	1929	755
TLG 1500	780	2217	1796	2583	2085	1154	1871	1472	1600	2700
TLG 1510	1174	1605	2363	1942	1975	872	1320	1876	692	1681
TLG 1520	1542	1459	1675	1746	3079	2493	2094	1816	1713	753
TLG 1530	2679	1842	448	1142	2955	2306	2366	1315	2450	3164
TLG 1540	1280	743	1392	1339	1650	1242	1857	1592	742	2303
TLG 1550	1712	2243	2103	2893	1025	1259	2620	2950	2175	2388
TLG 1560	3130	1471	1976	2097	3236	2571	2394	2477	2998	1272
TLG 1570	1675	820	1448	2018	2038	1369	1195	2850	1698	713
TLG 1580	210	1940	1391	2750	1598	1033	1763	2545	1593	2830
TLG 1590	1092	2652	1416	1375	1339	962	2653	1686	1646	2860
TLG 1600	1253	3126	2616	2353	2862	2681	2727	1452	2851	2187
TLG 1610	2958	3048	2195	978	1882	2157	2382	3200	1414	1646
TLG 1620	2285	1685	1026	3044	2512	3078	1009	2086	2310	991
TLG 1630	1713	1093	535	2020	1442	2495	1942	985	1529	902
TLG 1640	2345	2545	2808	1649	2026	1450	1489	1267	1850	2587
TLG 1650	1742	2413	1494	1025	769	570	3155	1285	1097	1027
TLG 1660	2656	2796	1993	1629	2298	1827	1619	676	2038	907
TLG 1670	861	2352	2906	1532	2302	2088	933	2483	2158	1831
TLG 1680	2629	1623	2385	2659	2053	2289	1070	2333	2009	1723
TLG 1690	1163	697	1938	2415	2110	1505	2627	3237	1346	2052
TLG 1700	2694	1857	3258	1084	2702	1933	1111	1355	1217	2771
TLG 1710	1180	1813	2230	2118	1328	1618	1795	2150	1579	1375
TLG 1720	2231	917	1168	2690	1791	2887	1908	2979	1433	414
TLG 1730	3338	1787	2706	956	2724	1103	1063	1175	2616	1620
TLG 1740	2858	2322	2311	2668	2172	3401	2534	3239	1326	1933
TLG 1750	2009	1697	1955	1839	1492	1145	858	993	1723	1408
TLG 1760	1744	2258	1574	2143	1515	777	2303	2097	2356	2478
TLG 1770	1188	2353	1972	1943	2414	1894	884	563	1036	1830
TLG 1780	1560	1619	618	583	2816	2633	1990	2472	1063	3163
TLG 1790	3322	2155	3148	1957	1014	440	998	2053	2374	2607
TLG 1800	1268	2848	2319	1499	2272	1746	1816	1455	1444	1357
TLG 1810	1965	2907	1508	2199	2088	1875	2110	2409	1697	2264
TLG 1820	2000	2158	901	1301	1033	3322	3046	1553	2860	511
TLG 1830	2161	1402	3284	2041	1549	1706	1966	1547	2670	1881
TLG 1840	1694	599	2232	713	723	1409	959	2051	1902	1708
TLG 1850	1913	1182	2408	2870	2190	1913	991	1493	889	1254

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TLG 1860   1996   2033   2917    1646    655   1619    2686   2868   4072   2739
TLG 1870   1882   1108   2295    1829   1858   1644    2623   1187   3129   1357
TLG 1880   1774   2558   1372    1106   3341   1959    2216   1494   1862   1472
TLG 1890   2421   2719   1406    2460   2284   2366    2026   2136    892   1404
TLG 1900   1714   2753   1596    1645   1954   2001    2932   3251   1903   2349
TLG 1910   1749   2884   1242    1055   2909   2670    2665   1987   1178   1503
TLG 1920   1213   1920   2117    1999    350   1864    1207   1856   1303    906
TLG 1930   1096    611   2030    1111    713   1771    2484   2262   3143   1260
TLG 1940   2363   2983   3071    2299   1824   2040    1575   1090   1243   1123
TLG 1950   1406   1873   2984    2151   1800   1302    2527   1780   3176   1087
TLG 1960   1111    755   1781    2861   1201   2466    1379   2700   1131   3780
TLG 1970   1974   1875    974    2017   2428   1674     693    739   3649   1928
TLG 1980   3320   1668   2786    3554   2511   1697    3083   1013   1164   1121
TLG 1990   1005   1523   1331    3417   1482   3126    2499   2317   3516   2339
TLG 2000   1900   1312   1300    1828   1534   2947    3252   1059   1633   1231
TLG 2010   2363   2385   2473     NaN    NaN    NaN     NaN    NaN    NaN    NaN

MRC Merced River inflow to New Exchequer (rec); multiply by 1000 to get AF

MRC  900    798   1523    785    1251   1216   1101    1243    756    757    882
MRC  910   1485   1325   1019     468   1634    475    1486   1090    645    972
MRC  920   1240    661   1033     799    517   1302    1208    948    616    622
MRC  930    495   1240    661     537   1258    978     645   1421    613    855
MRC  940   1031   1038    637     802    904    960     919    880    561    736
MRC  950    924   1413    653     840    315   1152    1403    253    877    996
MRC  960   1189    476    622    1155    776    905     846   1007   1574    685
MRC  970   1818    631   1077    1051   1347    593     935    742    511    327
MRC  980    632    536    960     550    994   1425     440   1074   1231    983
MRC  990    828   1449   1034    1390    855    688     923   1653   1404    818
MRC 1000   1262   1388   1445    1535   1034    754    1875   1014   1632   1455
MRC 1010    869   1328    490    1377    882   1422    1367   1035    747   1817
MRC 1020    975    896    931    2361   1278    512    1558   1372    741    917
MRC 1030    990   1516    638    1227   1137    739    1704   1021    844    562
MRC 1040    537   1432   1421     642    614   1610     832    631    816   1012
MRC 1050   1004    857    432     756   1582    585     829   1152    794    310
MRC 1060    501   1079    792    1007   1624   1008     705    959   1370    671
MRC 1070    358   1320    348     907    730    726    1355    733   1282   1449
MRC 1080   1211    890    665    1002   1301    893     816   1639   1011   1352
MRC 1090    550   1514    571     398   1553   1072     851    934    394   1179
MRC 1100   1755   1078    981     577   1438   1243     993    967   1022   1349
MRC 1110   1171    931   1146    1718    767    857    1692   1003   1259   1229
MRC 1120   1360   1160   1663     555   1143   1442     200   1391   1464   1251
MRC 1130    626    570    870     950    857    571    1137    896   1132    868
MRC 1140    508    715   1012     715    682    459     615    912    669   1440
MRC 1150    499    783    554    1010    945    637     505    861    880   1262
MRC 1160    979    616    733    1211    529   1595    1104   1317    667   2064
MRC 1170    493   1162    806     819    567    656     788    724   1460   1128
MRC 1180    925   1443   1143     317   1285    513    1209    572   1724    963
MRC 1190   1063    981   1191    1355    968   1828     822   1140    847   1000
MRC 1200   1259    903   1637     999   1767   1459     490    972    898   1306
MRC 1210    710    782    900     688   1582    762    1522    426    691   1587
MRC 1220   1347    928    885     751   1294   1440     606    555   1233   1285
MRC 1230    756    503   1044     784    745    790     479    598    855    666
MRC 1240   1221   1611    683    1085    696    453    1717   1239   1546   1021
MRC 1250    409    841   1413     810    503   1341    1434    629    875   1475
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MRC 1260	662	624	1773	774	488	1277	1310	1297	831	691
MRC 1270	1802	750	869	516	1511	902	816	1379	1011	459
MRC 1280	1374	1008	1324	1322	895	388	1803	1542	829	876
MRC 1290	1306	1734	487	926	813	961	392	1018	998	831
MRC 1300	572	948	1162	916	1103	1377	954	938	1410	630
MRC 1310	1547	899	1520	1141	1398	905	459	1191	1278	1053
MRC 1320	737	1483	1651	1326	485	845	1807	1986	692	804
MRC 1330	2258	1479	860	1175	1616	369	1561	1723	1107	1166
MRC 1340	922	2048	902	894	969	1406	1391	1075	902	1898
MRC 1350	876	474	497	1459	740	918	1834	1179	415	1419
MRC 1360	1010	639	1079	1326	722	657	1413	1659	1321	791
MRC 1370	918	736	1079	1306	935	724	962	422	1495	724
MRC 1380	1293	1449	718	1374	705	1578	1034	1163	1372	1503
MRC 1390	347	1039	1114	954	1472	849	872	873	923	902
MRC 1400	883	998	554	1095	1050	1196	1079	496	657	948
MRC 1410	418	1487	1607	382	1303	1007	996	829	1177	868
MRC 1420	1916	804	1754	1415	1498	616	623	905	668	1009
MRC 1430	671	677	547	1308	693	1198	1168	786	1062	643
MRC 1440	1721	1569	1135	920	529	1499	804	932	837	1148
MRC 1450	741	875	502	847	553	919	550	645	914	412
MRC 1460	709	664	1097	879	546	559	1022	1436	362	1118
MRC 1470	1545	761	844	598	975	538	462	880	787	358
MRC 1480	554	728	748	801	1459	899	1171	933	1281	1285
MRC 1490	1086	1065	594	1323	1007	965	961	437	949	364
MRC 1500	480	1261	884	1356	981	539	904	770	907	1477
MRC 1510	542	807	1291	933	969	477	646	993	381	842
MRC 1520	721	653	919	1071	1715	1212	1050	963	795	285
MRC 1530	1539	908	216	733	1831	1317	1348	742	1351	1775
MRC 1540	669	385	714	765	833	615	1066	841	349	1316
MRC 1550	863	1131	1104	1519	581	710	1362	1720	998	1257
MRC 1560	1651	762	936	999	1910	1502	1070	1306	1620	725
MRC 1570	845	286	749	1025	1095	664	622	1540	890	342
MRC 1580	98	1230	938	1499	795	453	985	1454	774	1696
MRC 1590	386	1417	646	777	701	493	1495	744	835	1534
MRC 1600	617	1644	1331	1117	1562	1445	1364	747	1511	1227
MRC 1610	1540	1481	971	403	967	1014	1282	1659	602	840
MRC 1620	1365	782	479	1847	1197	1596	509	1190	1225	498
MRC 1630	942	549	263	1029	733	1471	901	473	830	449
MRC 1640	1417	1321	1548	694	995	736	725	628	901	1547
MRC 1650	782	1439	686	494	304	336	1854	686	553	534
MRC 1660	1576	1587	1167	730	1336	981	688	370	1251	378
MRC 1670	309	1342	1618	731	1256	1061	435	1490	1066	906
MRC 1680	1614	804	1370	1454	959	1195	456	1276	935	812
MRC 1690	595	318	1101	1375	1116	845	1521	1635	622	1099
MRC 1700	1381	909	1833	563	1626	1021	506	706	596	1592
MRC 1710	532	1127	1167	990	640	782	833	1177	823	700
MRC 1720	1239	404	557	1611	853	1563	860	1605	630	232
MRC 1730	2024	973	1508	441	1555	551	445	558	1505	898
MRC 1740	1720	1228	1139	1344	1130	1804	1336	1679	633	1009
MRC 1750	1102	784	930	956	697	525	481	501	992	822
MRC 1760	977	1055	825	1111	834	332	1374	1181	1203	1334
MRC 1770	511	1339	949	890	1340	923	435	316	600	1230
MRC 1780	793	893	280	255	1736	1476	1010	1517	480	1832
MRC 1790	1806	1073	1691	959	468	179	511	1257	1380	1395
MRC 1800	577	1592	1142	666	1227	804	933	682	664	552

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MRC 1810    963   1627    642    1124    992    894    1086   1391    871   1228
MRC 1820    982   1248    478     684    530   2082    1586    745   1659    242
MRC 1830   1192    777   1789    1001    726    786     943    726   1573    919
MRC 1840    803    226   1411     280    350    652     497   1269   1036    924
MRC 1850   1180    574   1285    1580   1095    932     429    670    359    685
MRC 1860   1089    990   1813     801    232    913    1413   1681   2325   1358
MRC 1870    871    592   1179     927   1070    819    1568    491   1875    600
MRC 1880   1111   1389    646     546   1853    998    1227    698    944    836
MRC 1890   1522   1448    709    1461   1009   1242    1004   1060    329    691
MRC 1900    745   1530    775     883    926   1141    1655   1774    941   1223
MRC 1910    913   1522    578     483   1714   1467    1327    978    597    737
MRC 1920    623    901   1143     947    180    945     565    963    657    430
MRC 1930    479    254   1323     608    334   1063    1397   1369   1647    608
MRC 1940   1246   1784   1540    1099    934    967     745    470    586    595
MRC 1950    726    894   1772    1048    928    664    1440    833   1727    504
MRC 1960    556    311    997    1472    492   1285     708   1472    500   2150
MRC 1970    886    894    381    1280   1315    818     326    330   2172   1059
MRC 1980   1866    824   1532    1880   1152    890    1652    443    652    558
MRC 1990    449    810    752    1995    729   1770    1207   1106   1966   1162
MRC 2000    954    719    593    1023    542   1579    1722    487    968    530
MRC 2010   1576   1197   1294     NaN    NaN    NaN     NaN    NaN    NaN    NaN
```

SJF San Joaquin River inflow to Millerton (rec); multiply by 1000 to get AF

```
SJF  900   1493   2741   1472    2384   2310   2120    2412   1450   1412   1622
SJF  910   2731   2577   1923     898   2961    955    2689   1939   1232   1800
SJF  920   2276   1262   1810    1466    970   2420    2278   1821   1163   1147
SJF  930    918   2276   1241     956   2334   1818    1206   2584   1173   1578
SJF  940   1907   1948   1208    1456   1661   1806    1700   1586   1055   1357
SJF  950   1684   2597   1243    1557    595   1992    2505    520   1562   1797
SJF  960   2110    913   1142    2078   1435   1623    1555   1778   2797   1296
SJF  970   3131   1228   1973    1900   2443   1143    1717   1388    985    632
SJF  980   1109    988   1737    1035   1680   2300     869   1922   2227   1724
SJF  990   1502   2496   1845    2415   1579   1284    1676   2563   2318   1469
SJF 1000   2123   2000   2072    2324   1826   1333    2637   1705   2698   2464
SJF 1010   1591   2007    923    2291   1477   1760    1613   1454   1258   2289
SJF 1020   1521   1459   1645    3639   1839    990    2370   2252   1379   1565
SJF 1030   1810   2776   1213    2162   2010   1384    2926   1794   1547   1079
SJF 1040   1012   2335   2478    1227   1172   2909    1563   1200   1498   1869
SJF 1050   1845   1599    831    1325   2879   1113    1514   2101   1477    589
SJF 1060    883   1930   1438    1840   2961   1883    1347   1722   2440   1276
SJF 1070    710   2220    709    1627   1344   1340    2404   1385   2274   2625
SJF 1080   2222   1686   1241    1681   2360   1650    1512   2937   1920   2443
SJF 1090   1063   2733   1099     760   2743   1959    1589   1729    759   2117
SJF 1100   3172   1992   1841    1108   2585   2274    1862   1801   1884   2313
SJF 1110   2136   1750   2131    3183   1437   1604    3048   1904   2235   2253
SJF 1120   2457   2111   3117    1085   2096   2664     419   2380   2706   2341
SJF 1130   1215   1070   1572    1730   1597   1089    2009   1671   2073   1610
SJF 1140    974   1322   1810    1329   1271    887    1143   1674   1257   2426
SJF 1150    964   1429   1015    1819   1723   1215     912   1525   1599   2285
SJF 1160   1807   1172   1350    2121   1010   2886    2042   2372   1293   3857
SJF 1170    961   2085   1503    1511   1080   1161    1388   1269   2665   2080
SJF 1180   1722   2638   2128     629   2278    975    2150   1074   3212   1844
SJF 1190   2020   1754   2253    2532   1551   3328    1368   2022   1257   1568
SJF 1200   2249   1589   3035    1858   3299   2371     884   1783   1532   2443
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SJF 1210	1231	1415	1674	1226	2897	1497	2831	858	1143	2913
SJF 1220	2474	1659	1529	1432	2124	2635	1141	1087	2174	2393
SJF 1230	1456	993	1849	1433	1444	1491	1008	1185	1454	1338
SJF 1240	2260	2946	1358	1828	1292	971	3132	2347	2834	1758
SJF 1250	894	1542	2281	1568	1060	2320	2609	1132	1541	2311
SJF 1260	1380	1277	3346	1464	739	2210	2450	2341	1618	1283
SJF 1270	3356	1425	1469	1007	2644	1364	1336	2552	1832	998
SJF 1280	2547	1740	2411	2515	1430	645	3147	2868	1505	1659
SJF 1290	2437	3218	1033	1719	1531	1530	620	1629	1638	1259
SJF 1300	1055	1689	2226	1653	1846	2295	1765	1429	2575	1072
SJF 1310	2546	1392	1895	1886	2341	1426	968	1932	2357	1668
SJF 1320	1253	2440	2875	2072	836	1476	2842	3505	1373	1498
SJF 1330	3651	2478	1588	2265	2988	773	2495	3050	2007	2177
SJF 1340	1502	3456	1705	1542	1701	2428	2411	1973	1674	2601
SJF 1350	1594	965	942	2558	1394	1440	3075	2054	818	2458
SJF 1360	1914	1251	1841	1774	1359	1332	2584	2826	2506	1523
SJF 1370	1680	1266	1912	2010	1760	1404	1726	697	2352	1167
SJF 1380	1921	2402	1427	2374	1418	2954	1913	2259	2616	2726
SJF 1390	733	1957	1831	1792	2610	1507	1360	1366	1558	1431
SJF 1400	1458	1681	1132	1789	1913	2132	1939	831	1208	1647
SJF 1410	840	2643	3005	712	2467	1755	1615	1567	2131	1454
SJF 1420	3508	1407	3283	2520	2778	1187	1039	1525	1282	1862
SJF 1430	1311	1088	970	2284	1284	2220	2139	1259	1751	1279
SJF 1440	3174	2893	2056	1744	1060	2573	1418	1697	1498	1905
SJF 1450	1236	1380	898	1428	996	1574	1036	1240	1588	780
SJF 1460	1298	1176	2030	1570	1041	1126	1677	2637	705	2050
SJF 1470	2907	1324	1581	1195	1700	1022	903	1445	1485	678
SJF 1480	1071	1306	1328	1405	2737	1713	2259	1667	2209	2400
SJF 1490	2074	2069	1205	2518	1884	1551	1767	881	1732	774
SJF 1500	710	2091	1630	2557	1838	1001	1619	1285	1447	2724
SJF 1510	1048	1453	2178	1742	1784	827	1207	1709	652	1457
SJF 1520	1351	1269	1527	1648	3146	2262	1941	1661	1430	603
SJF 1530	2474	1673	394	1119	3241	2412	2514	1208	2264	3087
SJF 1540	1319	715	1230	1412	1445	1201	1892	1508	631	2322
SJF 1550	1598	2073	2010	2852	993	1210	2512	3137	1917	2266
SJF 1560	3009	1435	1752	1908	3206	2867	2018	2479	3026	1218
SJF 1570	1439	617	1345	1828	2111	1245	1171	2835	1700	584
SJF 1580	113	2011	1447	2703	1366	913	1801	2578	1394	2986
SJF 1590	822	2517	1255	1361	1235	905	2734	1411	1553	2795
SJF 1600	1162	3022	2386	2010	2835	2589	2401	1168	2780	2259
SJF 1610	2682	2572	1725	844	1751	1803	2407	2957	1245	1618
SJF 1620	2246	1479	965	3260	2172	2919	957	2378	2115	1007
SJF 1630	1455	956	471	1868	1293	2500	1703	894	1440	921
SJF 1640	2550	2266	2781	1350	1908	1368	1284	1172	1759	2776
SJF 1650	1473	2470	1332	880	608	541	3148	1225	1074	1055
SJF 1660	2789	2948	2083	1409	2363	1678	1361	664	1962	705
SJF 1670	643	2342	2883	1426	2341	2026	844	2565	1883	1566
SJF 1680	3050	1479	2662	2843	1887	2201	943	2427	1807	1573
SJF 1690	1058	618	1995	2474	2118	1547	2772	2842	1244	1967
SJF 1700	2557	1718	3454	1070	2916	1716	979	1258	1116	2751
SJF 1710	1069	2007	2189	1819	1196	1421	1575	2051	1533	1382
SJF 1720	2027	842	1029	2814	1530	2740	1699	2915	1155	463
SJF 1730	3633	1552	2667	851	2737	1028	881	1093	2606	1445
SJF 1740	3060	2397	2113	2493	1934	3436	2528	3127	1188	1871
SJF 1750	2088	1544	1696	1587	1257	1035	926	891	1794	1452

```
SJF 1760   1845   1951   1514    1933   1452    675    2496   2164   2267   2397
SJF 1770   1045   2507   1772    1744   2462   1732     892    576   1024   1980
SJF 1780   1431   1466    474     493   2854   2602    1784   2466    940   3281
SJF 1790   3141   1970   3101    1588    854    308     907   2145   2467   2639
SJF 1800   1129   2851   2053    1284   2269   1541    1647   1309   1252   1146
SJF 1810   1747   3058   1310    1937   1843   1682    2084   2596   1692   2232
SJF 1820   1750   2118    844    1124    930   3862    2760   1377   2875    403
SJF 1830   2038   1305   3251    1773   1404   1471    1766   1382   2812   1762
SJF 1840   1497    510   2270     588    654   1113     970   2084   1892   1642
SJF 1850   1931   1062   2374    2909   1862   1693     808   1190    725   1220
SJF 1860   1944   1840   3079    1498    489   1495    2491   2991   4318   2465
SJF 1870   1736   1084   2193    1621   1784   1527    2696   1028   3234   1167
SJF 1880   2051   2386   1222     954   3444   1693    2047   1276   1631   1463
SJF 1890   2549   2465   1279    2439   1856   2327    1960   1806    707   1232
SJF 1900   1423   2866   1410    1575   1702   2191    3166   3267   1710   2396
SJF 1910   1624   2918   1164     961   3142   2610    2484   1671   1111   1364
SJF 1920   1153   1657   2081    1669    315   1549    1055   1701   1101    810
SJF 1930    912    525   2125    1052    688   1846    2454   2344   2994   1242
SJF 1940   2251   3179   2690    2019   1726   1778    1374    912   1168   1085
SJF 1950   1373   1631   3239    1807   1705   1274    2501   1507   3240    971
SJF 1960    959    614   1873    2591   1033   2385    1289   2723   1009   4079
SJF 1970   1630   1623    794    2300   2270   1448     607    699   3936   1726
SJF 1980   3457   1511   2823    3584   2138   1681    3112    922   1226   1091
SJF 1990    879   1455   1379    3583   1394   3322    2153   1831   3580   1849
SJF 2000   1748   1315   1101    1631   1311   2941    2898    958   1672    957
SJF 2010   2751   2333   2389     NaN    NaN    NaN     NaN    NaN    NaN    NaN

SJQ4 San Joaquin River Four Rivers unimpaired runoff(rec); mult by 1000 to get AF

SJQ4  900   4822   8860   4760    7363   7212   6632    7427   4642   4516   5184
SJQ4  910   8641   7910   6167    2900   9525   2973    8613   6435   3906   5722
SJQ4  920   7209   4014   5996    4726   3156   7445    7129   5791   3786   3746
SJQ4  930   3002   7053   3982    3254   7213   5827    3940   8067   3701   5037
SJQ4  940   6058   6171   3893    4805   5414   5704    5433   5187   3385   4376
SJQ4  950   5548   8272   3983    4983   1908   6708    8223   1593   5176   5950
SJQ4  960   7144   2935   3751    6754   4640   5383    5030   6037   9080   4203
SJQ4  970  10375   3935   6467    6335   8029   3657    5591   4489   3105   1988
SJQ4  980   3726   3216   5679    3314   5832   8315    2721   6426   7342   5995
SJQ4  990   4994   8621   6329    8246   5188   4188    5589   9571   8411   4992
SJQ4 1000   7513   8180   8485    9088   6364   4572   10629   6222   9507   8643
SJQ4 1010   5359   7805   3014    8027   5319   8214    8029   6299   4466  10203
SJQ4 1020   5882   5438   5655   13203   7832   3171    8962   8204   4563   5530
SJQ4 1030   6004   8926   3909    7318   6835   4549    9819   6313   5114   3408
SJQ4 1040   3210   8251   8416    4030   3733   9349    5049   3866   4914   6134
SJQ4 1050   6139   5124   2633    4466   9145   3573    4928   6829   4769   1902
SJQ4 1060   3004   6322   4766    6104   9413   6225    4317   5759   8074   4170
SJQ4 1070   2215   7639   2158    5358   4358   4361    8062   4419   7585   8460
SJQ4 1080   7290   5282   4003    5922   7702   5386    4920   9577   6221   8072
SJQ4 1090   3380   8796   3528    2451   8874   6478    5129   5643   2420   6952
SJQ4 1100  10113   6660   6047    3578   8367   7500    6057   5792   6175   8011
SJQ4 1110   7047   5661   6850    9962   4745   5184    9841   6198   7475   7389
SJQ4 1120   8157   7180   9790    3494   6958   8507    1284   8056   8657   7646
SJQ4 1130   3911   3466   5157    5786   5247   3514    6799   5465   6775   5295
SJQ4 1140   3133   4314   6114    4320   4197   2842    3734   5432   4110   8461
SJQ4 1150   3074   4688   3341    6040   5803   3928    3024   5122   5316   7343
```

SJQ4	1160	5951	3747	4379	7063	3227	9160	6654	7908	4066	11598
SJQ4	1170	3049	6952	4917	4904	3433	3910	4670	4402	8506	6830
SJQ4	1180	5591	8532	6886	1987	7453	3170	7166	3436	10052	6000
SJQ4	1190	6472	5812	7278	8025	4964	10311	4375	6594	4008	5150
SJQ4	1200	7590	5232	9567	5965	10187	7609	2834	5854	4924	7958
SJQ4	1210	3946	4546	5334	3899	9362	4877	8966	2731	3750	9311
SJQ4	1220	7873	5431	4928	4577	6959	8575	3665	3572	7135	7888
SJQ4	1230	4740	3202	6118	4653	4664	4836	3260	3912	4675	4246
SJQ4	1240	7383	9313	4410	6124	4192	3128	9950	7730	9012	5764
SJQ4	1250	2925	5124	7547	5097	3413	7709	8532	3633	5261	7815
SJQ4	1260	4363	4071	10207	4812	2417	7239	8060	7478	5193	4169
SJQ4	1270	10449	4599	4715	3198	8771	4445	4324	8310	6261	3167
SJQ4	1280	8235	5716	7844	7956	4685	2117	10250	9235	4840	5392
SJQ4	1290	7995	9963	3343	5671	4961	4932	2056	5409	5374	4178
SJQ4	1300	3403	5518	7193	5397	6392	7934	5957	5219	8499	3511
SJQ4	1310	8826	4545	8487	6937	7863	5133	3075	6586	7866	5789
SJQ4	1320	3992	8267	9497	7283	2628	4753	9888	11431	4363	4922
SJQ4	1330	12503	8967	5182	7151	9531	2390	8774	10162	6744	7261
SJQ4	1340	5320	11458	5646	5198	5941	8374	8022	6618	5534	9509
SJQ4	1350	5145	3042	3008	8346	4560	4746	10532	7277	2559	7992
SJQ4	1360	6289	4038	6469	6867	4629	4320	8510	9871	8156	4868
SJQ4	1370	5541	4152	6512	6890	5742	4554	5611	2230	7879	3854
SJQ4	1380	6686	8068	4490	7888	4502	9244	6212	7207	8266	8993
SJQ4	1390	2314	6417	6249	5856	8292	4761	4380	4388	5148	4628
SJQ4	1400	4682	5575	3658	6008	6322	6927	6115	2721	4001	5455
SJQ4	1410	2657	8300	9642	2331	7694	6220	5213	5131	6932	4758
SJQ4	1420	11106	5011	10236	7967	8685	3828	3391	5050	4063	6150
SJQ4	1430	4288	3578	3140	7209	4304	7094	6810	4459	5815	4150
SJQ4	1440	10049	9377	6830	5687	3398	8512	4712	5598	4909	6239
SJQ4	1450	4076	4403	2910	4758	3181	5040	3336	4028	5128	2549
SJQ4	1460	4346	3764	6620	5182	3355	3663	5402	8592	2363	6628
SJQ4	1470	9130	4707	5255	3859	5566	3259	2885	4826	4874	2211
SJQ4	1480	3545	4365	4395	4635	8534	5569	7181	5468	7242	7936
SJQ4	1490	6799	6608	3932	7851	6325	5268	5940	2826	5833	2498
SJQ4	1500	2426	6775	5424	8000	6205	3250	5536	4244	4834	8669
SJQ4	1510	3312	4768	7142	5773	5861	2622	3870	5628	2111	4886
SJQ4	1520	4451	4174	5166	5538	9759	7672	6273	5449	4761	1967
SJQ4	1530	8219	5702	1277	3726	10494	7700	7869	3873	7519	10007
SJQ4	1540	4289	2277	4085	4661	4897	3861	6173	5134	2041	7370
SJQ4	1550	5207	6792	6544	9094	3286	3979	8040	9971	6479	7252
SJQ4	1560	9652	4850	5783	6190	10459	8820	6953	7918	9684	3946
SJQ4	1570	4741	2111	4289	6605	5903	3710	3594	9851	4911	1719
SJQ4	1580	575	5477	4978	7828	4248	3166	6037	8225	4905	9058
SJQ4	1590	2829	7425	4354	4231	4268	3119	8085	4588	4887	9068
SJQ4	1600	3774	9501	7811	7059	9352	8320	8626	4150	9543	7238
SJQ4	1610	9246	8736	5923	2696	5372	5824	7178	10304	3780	4842
SJQ4	1620	8160	5243	3101	11080	7974	9768	3192	6816	7228	3142
SJQ4	1630	5317	3375	1666	6430	4236	8068	5591	3031	4503	2811
SJQ4	1640	7393	8071	9178	4473	6049	4065	4267	3690	5422	8443
SJQ4	1650	5152	7572	4350	2881	2162	1834	9781	4163	3417	3058
SJQ4	1660	9263	9546	6649	4545	7660	5837	4533	2089	6124	2492
SJQ4	1670	2250	6732	9263	4731	7477	6171	2831	7904	6544	5598
SJQ4	1680	9404	4717	7888	8659	5954	7032	2996	7277	5550	5091
SJQ4	1690	3347	2168	6011	7686	7160	4897	8601	9806	3992	6068
SJQ4	1700	8260	5884	10123	3625	9211	5983	3387	4266	3595	8683

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SJQ4 1710   3375   6214   6550    5949   3992   4676    5067   6232   4963   4116
SJQ4 1720   6784   2738   3463    8498   5109   9059    5578   9430   4096   1453
SJQ4 1730  11520   5560   8733    2778   8340   3206    2883   3514   8178   5057
SJQ4 1740   9833   7495   6874    7851   6959  10506    8414   9795   3988   5737
SJQ4 1750   6039   4755   5654    5296   4438   3314    2921   3009   5654   5251
SJQ4 1760   5847   6774   4967    7053   5143   2264    7687   7324   7171   7778
SJQ4 1770   3461   7292   5447    5782   7409   5612    2797   1893   3300   6016
SJQ4 1780   4732   4881   1768    1697   8756   8329    6386   7964   3142  10153
SJQ4 1790  10892   7080   9595    5549   2918   1185    3026   6351   7668   7830
SJQ4 1800   3685   8778   7344    4373   6674   4984    5652   4196   4098   3700
SJQ4 1810   5770   9369   4058    6408   5951   5416    6304   7920   5282   6954
SJQ4 1820   5950   6647   2658    3788   3169  11830    9785   4613   9067   1473
SJQ4 1830   6674   4489  10262    5886   4359   4962    5711   4409   9209   5472
SJQ4 1840   4765   1687   7383    1987   2154   4033    3016   6758   5770   5196
SJQ4 1850   6315   3442   7193    8996   6699   5562    2776   4121   2435   4045
SJQ4 1860   6674   6111  10027    5182   1564   4931    8948   9640  14251   8463
SJQ4 1870   5430   3465   7205    5314   6062   4975    8486   3287  10386   4040
SJQ4 1880   6268   7983   4019    3214   9782   6238    5923   4126   5413   4733
SJQ4 1890   7803   8291   4131    7541   6904   7073    6275   6487   2343   4169
SJQ4 1900   4843   8872   4685    5347   6019   7111    9982  10369   5381   6972
SJQ4 1910   5286   9551   3596    2991   9620   8546    7951   5985   3452   4501
SJQ4 1920   3613   5701   7104    5614   1064   5688    3457   5669   3950   2788
SJQ4 1930   3023   1687   7253    3672   2203   6012    7995   7593   9703   4009
SJQ4 1940   7443  10063   9062    6636   5367   5974    4446   3087   3670   3380
SJQ4 1950   4568   5797   9628    6425   5629   4091    7985   5025   9920   3078
SJQ4 1960   3344   2086   5383    8677   3271   7468    4172   7786   3351  12040
SJQ4 1970   5668   5464   2613    6399   7899   4996    2023   2286  11985   6313
SJQ4 1980  11024   5140   9129   11149   7619   5564   10332   2929   3957   3630
SJQ4 1990   2842   4792   4448   11240   4671  10277    7251   6604  11323   7462
SJQ4 2000   5510   4186   3692    5484   4329   9176   10019   3002   4922   3339
SJQ4 2010   6817   7411   8151     NaN    NaN    NaN     NaN    NaN    NaN    NaN
```

Appendix B. Observed Flows and Precipitation

Data listed 10 years per row in units indicated in the table below.
All series are water-year sums.

1 KLK Klamath R. at Keno, OR, natural flows (obs); multiply by 1000 to get AF
2 TRN Trinity R. at Lewiston, CA, flows (obs); multiply by 1000 to get AF
3 KF Klamath Falls, precipitation (obs); mult by 1E-2 to get inches
4 WEA Weaverville, precipitation (obs); mult by 1E-2 to get inches
5 YRK Yreka, precipitation (obs); mult by 1E-2 to get inches
6 FTO Feather River inflow to Lake Oroville(obs); multiply by 1000 to get AF
7 YRS Yuba River at Smartville(obs); multiply by 1000 to get AF
8 AMF American River inflow to Lake Folsom(obs); multiply by 1000 to get AF
9 SBB Sacramento River above Bend Bridge(obs); multiply by 1000 to get AF
10 SAC4 Sacramento River Four Rivers unimpaired runoff(obs); mult by 1000 to get AF
11 SNS Stanislaus River inflow to New Melones(obs); multiply by 1000 to get AF
12 TLG Tuolumne River inflow to New Don Pedro(obs); multiply by 1000 to get AF
13 MRC Merced River inflow to New Exchequer(obs); multiply by 1000 to get AF
14 SJF San Joaquin River inflow to Millerton(obs); multiply by 1000 to get AF
15 SJQ4 San Joaquin River Four Rivers unimpaired runoff(obs); mult by 1000 to get AF

KLK Klamath R. at Keno, OR, natural flows (obs); multiply by 1000 to get AF

KLK	1940	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	909
KLK	1950	1052	1461	1639	1697	1716	1079	1916	1581	1880	1090
KLK	1960	1014	888	1018	1346	1028	1611	1065	1218	719	1078
KLK	1970	1088	1486	1402	951	1596	1349	1161	819	1233	717
KLK	1980	918	668	1527	1581	1637	1263	1294	864	718	997
KLK	1990	717	574	425	1031	548	927	1242	1386	1421	1450
KLK	2000	1163	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

TRN Trinity R. at Lewiston, CA, flows (obs); multiply by 1000 to get AF

TRN	1910	NaN	NaN	1029	1073	2030	2155	1506	651	603	1150
TRN	1920	408	1795	784	686	266	1499	808	1826	1058	528
TRN	1930	815	402	720	803	683	966	1025	999	2105	573
TRN	1940	1613	2547	1804	1108	654	1047	1415	732	1205	1096
TRN	1950	854	1610	1817	1612	1585	735	2027	1083	2694	1042
TRN	1960	1025	1218	1043	1597	796	1695	1345	1653	1012	1751
TRN	1970	1591	1667	1158	1390	2648	1405	671	200	2055	853
TRN	1980	1473	864	2017	2990	1559	838	1586	881	943	1064
TRN	1990	719	487	900	1767	522	2267	1475	1479	2684	1401
TRN	2000	1551	734	1228	1841	NaN	NaN	NaN	NaN	NaN	NaN

KF Klamath Falls, precipitation (obs); mult by 1E-2 to get inches

KF	1890	NaN	NaN	NaN	NaN	NaN	NaN	1339	1453	1063	1315
KF	1900	1091	1327	1091	1248	1736	1020	1307	1689	1035	1421
KF	1910	1457	1453	1713	1630	1398	1047	1220	1012	874	1024
KF	1920	795	1402	1291	1394	720	1839	661	1941	1272	807
KF	1930	1228	803	1146	965	894	1307	1528	1213	1772	902
KF	1940	1929	1760	1319	1827	1098	1346	1500	1173	1811	1201
KF	1950	1197	1539	1874	1583	1535	752	2280	1799	2055	827
KF	1960	925	1291	1224	1520	1189	1945	1008	1409	858	1366
KF	1970	1492	1854	1425	878	1461	1358	1091	839	1445	1028

```
KF 1980   1571    988   2067    1665   1803   1398    1567    933   1122   1528
KF 1990   1469    929    732    2024    760   1713    1898   1701   1957   1638
KF 2000   1350    760   1161    1539   1126   1260    1504    917   1165   1087
KF 2010   1067    NaN    NaN     NaN    NaN    NaN     NaN    NaN    NaN    NaN

WEA  Weaverville, precipitation (obs); mult by 1E-2 to get inches

WEA 1900    NaN    NaN    NaN     NaN   5757   3406    4109   4276   3019   4772
WEA 1910   2875   3108   3748    2874   4545   4353    3566   2574   2447   3694
WEA 1920   2036   4962   2548    3018   1780   4768    2548   5119   3272   1999
WEA 1930   2899   2205   2756    2801   2586   3393    3806   2595   5269   2528
WEA 1940   4588   5239   4005    3807   2394   3210    3618   2821   3671   2473
WEA 1950   3075   4642   4656    3989   4599   2247    5334   3339   6145   3023
WEA 1960   2704   3495   2886    4212   2695   4632    2925   4032   3572   2863
WEA 1970   3723   3902   2782    2728   4764   3322    2172    912   5005   2396
WEA 1980   2454   1718   4909    6543   3702   3047    3338   2526   3050   3826
WEA 1990   2067   1252   2279    3833   1523   4970    3977   3266   5069   4080
WEA 2000   3791   2473   3826    4495    NaN    NaN     NaN    NaN    NaN    NaN

YRK  Yreka, precipitation (obs); mult by 1E-2 to get inches

YRK 1870    NaN    NaN   1431    1209   1233   1027    2338   1279   1975   1249
YRK 1880   1735   2148   1283    1217   1746   1858    1954   1917   1501   1025
YRK 1890   3144   1219   1381    1739   2991   2049    2363   1892   1295   1244
YRK 1900   1970   1771   1831    1518   3209   1859    2208   2516   1352   1253
YRK 1910    466   1463   1262    1111   1963   1378    1807   1151   1397   1758
YRK 1920    981   2052   1482    1603    689   2785    1029   2750   1447   1074
YRK 1930   1672   1197   1524    1386   1228   1384    1919   1390   2745   1151
YRK 1940   2140   2054   2219    2134   1186   1482    1768   1222   2107   1181
YRK 1950   1384   2430   2396    2333   2126    689    2672   1509   2489    995
YRK 1960   1370   2049   1586    2269   1459   2497    1183   1854   1514   2074
YRK 1970   2392   2580   1996    1189   2803   1917    1824    935   2684   1233
YRK 1980   2236   1327   3327    2505   1996   1805    1964   1182   1603   2282
YRK 1990   1584   1640   1176    2216    958   2509    2730   3001   2826   2295
YRK 2000   1901    897   1688    2128    NaN    NaN     NaN    NaN    NaN    NaN

FTO Feather River inflow to Lake Oroville(obs); multiply by 1000 to get AF

FTO 1900    NaN    NaN    NaN     NaN    NaN    NaN    6856   9492   3639   7517
FTO 1910   4638   7114   2289    2798   6990   5445    6204   4673   2703   3628
FTO 1920   2216   5953   5065    3096   1295   3076    3098   5670   4172   1844
FTO 1930   3952   1443   3324    2000   2017   4270    4290   3166   8604   1857
FTO 1940   5675   6482   6652    5620   2872   3736    4185   2532   3854   2595
FTO 1950   3841   5691   7962    5216   4230   2472    7974   3624   6970   2851
FTO 1960   3223   2637   3659    6266   2588   6912    2856   6283   3458   7069
FTO 1970   6269   5958   3233    4741   8363   4854    1849    994   5685   3023
FTO 1980   5533   2478   8998    9418   5767   2642    6760   2227   2049   3687
FTO 1990   2171   2057   1898    5713   1891   9280    5783   6754   7199   5278
FTO 2000   4245   2041   3084    4693   3800   4266    8212   2540   2239   3147
FTO 2010   3586   6579   2858     NaN    NaN    NaN     NaN    NaN    NaN    NaN

YRS Yuba River at Smartville(obs); multiply by 1000 to get AF

YRS 1900    NaN   2871   2694    2438   4190   2489    3721   4544   1691   3968
YRS 1910   2756   3606   1209    1492   3061   2690    3300   2530   1348   1976
```

```
YRS 1920   1298   3168   2972    2073    603   2123    1606   3542   2435   1010
YRS 1930   1818    641   2114    1078    987   2241    2589   1858   4034    907
YRS 1940   2860   3138   3406    3133   1395   2112    2401   1365   2010   1485
YRS 1950   2219   3539   4118    2554   1917   1285    3962   1959   3529   1235
YRS 1960   1695   1125   1924    3275   1482   3883    1424   3299   1573   3669
YRS 1970   2915   2857   1714    2660   3984   2372     791    369   2985   1727
YRS 1980   3186   1100   4926    4699   3163   1319    3472    883    919   2262
YRS 1990   1238   1179    912    2903    878   4570    3247   3729   3622   2744
YRS 2000   2229    922   1723    2370   1684   2376    4221   1226   1213   1694
YRS 2010   1838   3855   1535     NaN    NaN    NaN     NaN    NaN    NaN    NaN

AMF American River inflow to Lake Folsom(obs); multiply by 1000 to get AF

AMF 1900    NaN   3396   2592    2515   5390   2174    4838   5786   1526   4624
AMF 1910   3614   5554   1338    1513   4045   3154    3940   2923   1503   2229
AMF 1920   1467   3204   3279    2751    543   2717    1386   3652   2521   1147
AMF 1930   1652    715   2595    1269   1124   2583    3397   2328   4511   1046
AMF 1940   3406   3145   3917    3875   1462   2516    2866   1417   2239   1857
AMF 1950   2664   4631   4976    2653   1997   1564    4645   2137   4090   1226
AMF 1960   1680   1045   2069    3552   1632   4484    1392   3967   1699   4445
AMF 1970   3163   2972   1874    3008   4272   2620     801    349   3224   2042
AMF 1980   3871   1128   6124    6382   3901   1574    4653    880    853   2247
AMF 1990   1118   1195    901    3399    811   5549    3668   4704   4398   3316
AMF 2000   2658   1022   2025    2305   1600   3278    5349   1298   1195   1953
AMF 2010   2205   4842   1710     NaN    NaN    NaN     NaN    NaN    NaN    NaN

SBB Sacramento River above Bend Bridge(obs); multiply by 1000 to get AF

SBB 1900    NaN    NaN    NaN     NaN    NaN    NaN   11292  13881   7916  14571
SBB 1910   9109  10108   6574    7044  13716  12568   10697   7134   5441   7824
SBB 1920   4217  11476   6666    5287   3294   8078    5674  10971   7634   4399
SBB 1930   6096   3296   5082    4591   4502   7493    7075   5979  14677   4370
SBB 1940  10493  14314  11261    8497   4703   6699    8169   5074   7650   6033
SBB 1950   5718   9086  11544    9668   9283   5663   13306   7170  15121   6737
SBB 1960   6459   7165   7463    9899   5218  10360    7278  10510   6909  11797
SBB 1970  11711  10785   6606    9639  15876   9387    4763   3412  12024   5617
SBB 1980   9736   6392  13361   17180   9520   5507   10945   5280   5410   6622
SBB 1990   4738   4013   5157   10191   4226  15147    9591  10230  16176   9855
SBB 2000   9769   5828   7770    9944   8957   8627   14303   5216   5631   6226
SBB 2010   8378   9937   5716     NaN    NaN    NaN     NaN    NaN    NaN    NaN

SAC4 Sacramento River Four Rivers unimpaired runoff(obs); multiply by 1000 to get AF

SAC4 1900    NaN    NaN    NaN     NaN    NaN    NaN   26710  33700  14770  30680
SAC4 1910  20120  26380  11410   12850  27810  23860   24140  17260  10990  15660
SAC4 1920   9200  23800  17980   13210   5740  15990   11760  23830  16760   8400
SAC4 1930  13520   6100  13120    8940   8630  16590   17350  13330  31830   8180
SAC4 1940  22430  27080  25240   21130  10430  15060   17620  10390  15750  11970
SAC4 1950  14440  22950  28600   20090  17430  10980   29890  14890  29710  12050
SAC4 1960  13060  11970  15110   22990  10920  25640   12950  24060  13640  26980
SAC4 1970  24060  22570  13430   20050  32500  19230    8200   5120  23920  12410
SAC4 1980  22330  11100  33410   37680  22350  11040   25830   9270   9230  14820
SAC4 1990   9260   8440   8870   22210   7810  34550   22290  25420  31400  21190
SAC4 2000  18900   9810  14600   19310  16040  18550   32090  10280  10280  13020
SAC4 2010  15940  25130    NaN     NaN    NaN    NaN     NaN    NaN    NaN    NaN
```

```
SNS Stanislaus River inflow to New Melones(obs); multiply by 1000 to get AF

SNS 1900    NaN   1686    960    1124   2047    976    2414   2834    620   1926
SNS 1910   1406   2357    600     594   1769   1301    1668   1377    828    768
SNS 1920    743   1262   1430    1130    261   1224     606   1364    950    517
SNS 1930    732    315   1353     609    424   1214    1322   1109   2045    526
SNS 1940   1400   1338   1485    1565    676   1277    1178    634    898    745
SNS 1950   1076   1694   1919     967    888    681    1883    894   1678    584
SNS 1960    594    404    995    1268    643   1757     703   1932    640   2210
SNS 1970   1320   1074    776    1281   1560   1242     371    155   1590   1164
SNS 1980   1804    591   2345    2952   1434    678    1936    372    378    778
SNS 1990    469    511    486    1557    455   2348    1489   1759   2085   1348
SNS 2000   1162    565    853     974    751   1692    2201    565    625    985
SNS 2010   1101   2231    623     NaN    NaN    NaN     NaN    NaN    NaN    NaN

TLG Tuolumne River inflow to New Don Pedro(obs); multiply by 1000 to get AF

TLG 1900    NaN   2921   1590    1877   2439   1631    3610   3750   1024   2669
TLG 1910   2132   3422   1051    1081   2624   2045    2498   2223   1462   1347
TLG 1920   1342   2018   2471    1786    543   1932    1110   2051   1525    979
TLG 1930   1148    602   2114    1104    807   2103    2160   1997   3424    981
TLG 1940   2213   2489   2356    2370   1295   2086    1879   1094   1409   1246
TLG 1950   1546   2475   2982    1525   1429   1124    3153   1418   2638    990
TLG 1960   1052    732   1766    2041   1130   2738    1306   3105   1007   3852
TLG 1970   1962   1683   1207    2031   2239   2033     671    383   2903   1914
TLG 1980   3045   1056   3806    4631   2471   1229    2971    656    821   1312
TLG 1990    843   1099    835    2624    885   3922    2316   3224   3338   2127
TLG 2000   2019   1034   1401    1627   1321   3006    3313    849   1129   1665
TLG 2010   1888   3524    875     NaN    NaN    NaN     NaN    NaN    NaN    NaN

MRC Merced River inflow to New Exchequer(obs); multiply by 1000 to get AF

MRC 1900    NaN   1554    826     980   1093    898    2035   2126    518   1475
MRC 1910   1066   2115    515     440   1416   1093    1455   1126    831    682
MRC 1920    687   1014   1420     942    252    910     610   1084    737    486
MRC 1930    513    262   1113     516    361   1171    1152   1215   2080    477
MRC 1940   1095   1454   1287    1289    684   1097     942    564    688    638
MRC 1950    719   1225   1563     626    668    534    1675    648   1409    455
MRC 1960    483    312    928     984    447   1360     669   1716    426   2188
MRC 1970    883    733    550    1108   1133   1108     298    150   1756   1075
MRC 1980   1646    501   1947    2787   1181    567    1558    298    415    534
MRC 1990    406    560    448    1531    375   2173    1209   1749   1845    905
MRC 2000    974    521    636     816    608   1684    1741    413    617    837
MRC 2010   1067   1927    424     NaN    NaN    NaN     NaN    NaN    NaN    NaN

SJF San Joaquin River inflow to Millerton(obs); multiply by 1000 to get AF

SJF 1900    NaN   3228   1704    1727   2062   1795    4368   3114   1163   2901
SJF 1910   2042   3586   1044     879   2883   1966    2760   1936   1467   1298
SJF 1920   1322   1604   2355    1654    444   1439    1161   2001   1154    862
SJF 1930    859    480   2047    1111    692   1923    1853   2208   3688    921
SJF 1940   1881   2652   2254    2054   1265   2138    1730   1126   1215   1164
SJF 1950   1310   1859   2840    1227   1314   1161    2960   1327   2631    949
SJF 1960    829    647   1924    1945    922   2272    1299   3232    862   4040
```

```
SJF 1970   1446   1418   1039    2047   2190   1796     629    362   3402   1830
SJF 1980   2973   1068   3316    4642   2049   1129    3031    758    862    939
SJF 1990    743   1034    809    2673    826   3878    2203   2782   3160   1527
SJF 2000   1742   1065   1171    1450   1131   2830    3181    684   1117   1455
SJF 2010   2029   3305    832     NaN    NaN    NaN     NaN    NaN    NaN    NaN

SJQ4 San Joaquin River Four Rivers unimpaired runoff(obs); multiply by 1000 to get AF

SJQ4 1900    NaN   9390   5080    5710   7640   5300   12430  11820   3320   8970
SJQ4 1910   6640  11480   3210    3000   8690   6400    8380   6660   4590   4090
SJQ4 1920   4090   5900   7680    5510   1500   5510    3490   6500   4370   2840
SJQ4 1930   3250   1660   6630    3340   2280   6410    6490   6530  11240   2900
SJQ4 1940   6590   7930   7380    7280   3920   6600    5730   3420   4210   3790
SJQ4 1950   4650   7250   9300    4350   4300   3500    9670   4290   8360   2980
SJQ4 1960   2960   2100   5610    6240   3140   8130    3980   9980   2940  12290
SJQ4 1970   5610   4910   3570    6470   7120   6180    1970   1050   9650   5980
SJQ4 1980   9470   3220  11410   15010   7130   3600    9500   2080   2480   3560
SJQ4 1990   2460   3200   2580    8380   2540  12320    7220   9510  10430   5910
SJQ4 2000   5900   3180   4060    4870   3810   9210   10440   2510   3490   4940
SJQ4 2010   6090  11020    NaN     NaN    NaN    NaN     NaN    NaN    NaN    NaN
```

Appendix C. Tree-Ring Chronology Metadata and Statistics

This Appendix includes information on the 61 tree-ring chronologies forming the base network for the flow reconstructions for the Sacramento and San Joaquin Basins. Two tables are included:

Table C1. Chronology Metadata (p. 2, with keys on pp 3-4)
Table C2: Chronology statistics (p.5-6)

Table C1. Chronology Metadata[a].

N	CODE	FIRST	LAST	FILE	SITE_NAME	PI	SPECIES	LAT	LONG	ELEV	RAW_DATA
1	CPE	-420	2011	CPEM.rwl	Carson Pass East Merged	b	JUOC	38.70	-119.99	2537	Our files; ITRDB
2	KAI	720	2011	KAIM.rwl	Kaiser Pass Merged	g	JUOC	37.31	-119.11	2685	Our files; Caprio
3	UCJ	647	2011	UCJ#e.rwl	Upper Cascade Creek Juniper	a	JUOC	38.58	-119.81	2367	Our files
4	EPW	710	2011	EPW#e.rwl	Ebbetts Pass West Juniper Edited	a	JUOC	38.54	-119.82	2600	Our files
5	LVF	1505	2011	LVF.rwl	Leavitt Falls	a	PIJE	38.34	-119.55	2200	Our files
6	STA	1633	2011	STAE.rwl	Stanislaus River	a	PIJE	38.41	-120.05	2029	Our files
7	UCP	1556	2011	UCP.rwl	Upper Cascade Creek Pine	a	PIJE	38.58	-119.80	2361	Our files
8	EVG	-350	2011	EVGM.rwl	Evans Grove Merged	i	SEGI	36.78	-118.82	2183	Our files
9	LTU	1304	2010	LTU#e.rwl	Log Cabin Mine (update)	i	PIJE	37.95	-119.15	2499	Our files; ITRDB
10	ALU	1450	2010	ALU#e.rwl	Antelope Lake (update)	e	PIJE	40.11	-120.64	1455	Our files; ITRDB
11	BCU	1152	2010	BCU#e.rwl	Boles Creek (update)	f	JUOC	41.84	-120.88	1508	Our files; ITRDB
12	DRU	1357	2010	DRU#e.rwl	Dalton Reservoir (update)	k	JUOC	41.67	-120.98	1531	Our files; ITRDB
13	FBK	870	2010	FBK#e.rwl	Frederick Butte (update)	e	JUOC	43.59	-120.44	1600	Our files; ITRDB
14	HRK	898	2010	HRK#e.rwl	Horse Ridge (update)	e	JUOC	43.98	-121.07	1150	Our files; ITRDB
15	LVU	1421	2010	LVU#e.rwl	Lakeview (update)	k	PIPO	42.12	-120.56	1503	Our files; ITRDB
16	LJK	1337	2010	LJK#e.rwl	Little Juniper Mountain (update)	k	JUOC	43.13	-119.87	1596	Our files; ITRDB
17	LUP	1466	2011	LUPc.rwl	Luther Pass	a	PIJE	38.79	-119.95	2423	Our files
18	LCU	1415	2010	LCU#e.rwl	Lemon Canyon (update)	k	PIJE	39.58	-120.30	1700	Our files; ITRDB
19	PPB	1581	2010	PPB#e.rwl	Porcupine Butte	d	PIPO	41.43	-121.61	1409	Our files
20	SMU	1675	2010	SMU#e.rwl	Sharp Mt. (update)	k	JUOC	41.72	-121.82	1342	Our files; ITRDB
21	AGK	530	2010	AGK#e.rwl	Table Rock-Arrow Gap (update)	f	JUOC	43.18	-120.90	1418	Our files; ITRDB
22	TMU	1654	2010	TMU#e.rwl	Timbered Mountain (update)	k	JUOC	41.72	-120.75	1586	Our files; ITRDB
23	AC2	1475	2004	ca614c.rwl	American Canyon	h	QUDG	35.28	-120.27	561	ITRDB
24	BVB	1546	2004	ca649c.rwl	Bear Valley Buttes	h	QUDG	39.21	-122.44	468	ITRDB
25	CL2	1620	2004	ca615c.rwl	Clear Lake State Park:	h	QUDG	39.01	-122.81	427	ITRDB
26	DMS	1448	2003	ca653c.rwl	Dead Mule Saddle	h	QUDG	35.91	-118.67	1237	ITRDB
27	DEN	1596	2003	ca651c.rwl	Dennison Peak	h	QUDG	36.29	-118.78	1132	ITRDB
28	DIB	1519	2004	ca652c.rwl	Dibble Creek	h	QUDG	40.25	-122.38	218	ITRDB
29	DON	1531	2005	ca616c.rwl	Don Pedro Reservoir and Green Valley	h	QUDG	37.71	-120.43	274	ITRDB
30	DYE	1601	2005	ca654c.rwl	Dye Creek Preserve:	h	QUDG	40.09	-122.03	143	ITRDB
31	EEL	1535	1996	ca617.rwl	Eel River	h	QUDG	39.82	-123.08	610	ITRDB
32	FIG	1293	2003	ca656c.rwl	Figueroa Mountain	h	QUDG	34.74	-120.00	1036	ITRDB
33	AR2	1636	2003	ca620c.rwl	Folsom Lake State Rec Area American R	h	QUDG	38.76	-121.11	167	ITRDB
34	HAS	1460	2004	ca657c.rwl	Hastings Reservation	h	QUDG	36.39	-121.55	755	ITRDB
35	KR2	1585	2003	ca621c.rwl	Kern River	h	QUDG	35.53	-118.63	715	ITRDB
36	LOB	1333	2004	ca660c.rwl	Los Lobos Creek	h	QUDG	34.92	-119.24	1051	ITRDB
37	B24	1786	2003	ca645c.rwl	Marys Ranch	h	QUDG	37.40	-121.78	475	ITRDB
38	DI2	1582	2012	ca623c.rwl	Mt. Diablo State Park	h	QUDG	37.88	-121.97	182	ITRDB
39	MUR	1532	2004	ca661c.rwl	Murphy Ranch	h	QUDG	39.84	-122.61	342	ITRDB
40	KAW	1494	2004	ca659c.rwl	North Fork Kaweah River	h	QUDG	36.55	-118.89	701	ITRDB
41	PP2	1510	2003	ca625c.rwl	Pacheco Pass State Park	h	QUDG	37.04	-121.21	434	ITRDB
42	PPC	1538	2004	ca662c.rwl	Palo Prieto Canyon	h	QUDG	35.69	-120.26	558	ITRDB
43	PN2	1577	2003	ca626c.rwl	Pinnacles National Monument:	h	QUDG	36.48	-121.18	487	ITRDB
44	PUT	1534	2004	ca663c.rwl	Putah Creek, Lake Berryessa	h	QUDG	38.67	-122.27	180	ITRDB
45	B27	1379	2003	ca646c.rwl	Rock Springs Ranch	h	QUDG	36.49	-120.88	1067	ITRDB
46	SJR	1557	2004	ca664c.rwl	San Joaquin Experimental Range	h	QUDG	37.09	-119.75	345	ITRDB
47	JOA	1710	1996	ca627c.rwl	San Joaquin River Millerton Lake	h	QUDG	37.03	-119.68	137	ITRDB
48	COT	1674	2004	ca650c.rwl	South Fork Cottonwood Creek	h	QUDG	40.28	-122.45	213	ITRDB
49	IND	1494	2003	ca658c.rwl	The Indians	h	QUDG	36.12	-121.46	646	ITRDB
50	TOU	1408	2005	ca665c.rwl	Tuolumne River	h	QUDG	37.87	-119.98	1194	ITRDB
51	B32	1409	2003	ca647c.rwl	Wright Mountain	h	QUDG	36.34	-120.52	1219	ITRDB
52	SND	831	2012	SND#ec.rwl	Sardine Point	l	JUOC	39.55	-120.20	2268	ITRDB
53	CSP	-40	2012	CSP#e.rwl	Calaveras State Park	m	SEGI	38.24	-120.27	1380	Our files
54	MPK	885	1996	ca605#e.rwl	Mammoth Peakk	n	PIAL	37.87	-119.28	3300	ITRDB
55	GMT	680	2000	ca633#e.rwl	Glass Mountain	n	PIFL	37.75	-118.68	2990	ITRDB
56	JKN	975	1998	nv518#e.rwl	Jackson Mountains	n	JUOC	41.30	-118.44	2097	ITRDB
57	BFA	831	1992	ca636#e.rwl	Boreal Plateau	o	PIBA	36.45	-118.55	3420	ITRDB
58	UWL	-225	1992	ca637#e.rwl	Upper Wright Lakes	o	PIBA	36.62	-118.37	3519	ITRDB
59	MHC	1297	2012	MHC#e.rwl	Mountain Home	p	SEGI	36.24	-118.67	1970	Our files
60	BMC	-210	2012	BMC#e.rwl	Black Mountain	p	SEGI	36.10	-118.66	1950	Our files
61	KNC	325	1990	kerncmp.crn	Kern Composite	q	PIBA	36.50	-118.30	33307	Our files

[a] Columns of table defined are in key on next page

KEY TO COLUMNS OF TABLE C1

N: reference number (1-61) of chronology. This number is cross-referenced and used in intermediate output tables to identify chronologies as used in Loess modeling

C: three-character code for chronology

FIRST, LAST: first and last year of data in ring-width (rwl) or chronology (crn) file in next column

FILE: name of ascii computer file with the ring widths (if rwl) or standard site chronology (crn). For all sites except Kern Composite we began with a file of ring widths and standardized those into site chronologies by procedures described in the report. The compute files listed are al available as digital Appendix Z2 (a zip file) to this report. Files names beginning with a state code followed by a 3-digit number (e.g., ca632) were downloaded from the International Tree-Ring Data Bank (ITRDB). We started with the ring-width file from the ITRDB, and often altered it by screening out series with weak common signal, truncating segments with questionable data or very weak common signal, etc. When an ITRDB chronology was altered in any way, the rwl file name listed in the table contains appended letters ("#e", "c", or "ec"). This indicate that the file is not identical to that in the ITRDB. We include a zip file with all .rwl files, and the one .crn file, in Table C1 as digital Appendix Z2;

SITE NAME: name of the tree-ring site

PI: letter code to last names of individual or individuals responsible for developing tree-ring data for the site (see next page).

SPECIES: four letter species code: JUOC=*Juniperus occidentalis*; PIJE=*Pinus jeffreyi*; SEGI=*Seqouia giganteum*; PIPO=*Pinus ponderosa*; QUDG=*Quercus douglasii*; PIAL=*Pinus albicaulis*; PIBA=*Pinus balfouriana*

LAT, LONG: decimal degrees north latitude and east longitude (negative indicates west longitude)

ELEV: elevation of site above mean sea level, in meters

RAW DATA: how we acquired the data. "Our files" means data on file at the Laboratory of Tree-Ring Research because we or one of our colleagues there collected the site and developed the measured ring widths. "ITRDB" means data downloaded from the International Tree-Ring Data Bank. "Caprio" means data directly provided by Dr. Tony Caprio, Fire Ecologist, Sequoia Kings Canyon NP. Note that data many individuals are often responsible and deserving of credit for data available from sources such as the ITRDB. We attempt to acknowledge those individuals in the "PI", Principal Investigator" column of this table.

Letter codes of “PI” column of Table C1.

a	Meko, Touchan and others, this project
b	Meko, Touchan and others, this project; Meko, Sacramento River Project
c	Meko, Touchan and others, this project; Meko, Sacramento River Project; Fritts 1980s
d	Woodhouse and others, this project
e	Woodhouse and others, this project, Meko Sacramento River Project; Fritts 1980s
f	Woodhouse and others, this project, Meko Sacramento River Project
g	Woodhouse and others, this project; Caprio 1990s; Fritts 1980s
h	Stahle and others, blue oak project
i	Woodhouse and others, this project; Ferguson and others, 1964
j	Meko and others, this project; Hughes and others, 1992
k	Woodhouse and others, this project; Fritts 1980s
l	Meko Sacramento River Project
m	Meko, Touchan and others, this project; Baisan/Swetnam
n	King and others
o	Graumlich and others
p	Meko, Touchan and others, this project; Hughes
q	Caprio

First group is most recent collection

Table C2. Summary statistics chronologies 1-60 in Table C1. Statistics computed with aid of ARSTAN program (Cook & Holmes, 1999; Cook & Krusic, 2005). Chronology statistics were computed from ring-width (rwl) files, such that none are provided for site 61 (Kern Composite) in Table C1. The original COFECHA output file (provided by Tony Caprio) for Kern Composite, however, indicates the site has an extremely strong common signal.

Site Code		**Total Chronology**				**Common Interval**		
	MSSL[a]	Std[b]	SK[c]	KU[d]	1st Year EPS[e]>0.85	Time Span	MCAR[f]	Ev[g] PC1 (%)
CPE	419	0.21	0.49	1.08	1395	1669-1996	0.30	33
KAI	320	0.21	0.22	0.32	1351	1784-1981	0.31	33
UCJ	329	0.24	0.92	2.75	1269	1686-2001	0.39	43
EPW	355	0.24	1.42	6.20	1620	1837-2010	0.35	38
LVF	317	0.23	0.09	0.51	1646	1720-2008	0.39	42
STA	272	0.19	0.47	0.30	1740	1796-2011	0.37	40
UCP	289	0.17	0.56	1.15	1713	1804-2011	0.38	40
EVG	579	0.23	2.18	17.93	1399	594-1754	0.28	36
LTU	326	0.27	0.22	1.16	1608	1778-1964	0.45	47
ALU	304	0.24	0.03	0.71	1567	1790-1980	0.35	38
BCU	307	0.25	0.44	0.29	1414	1810-1993	0.41	45
DRU	244	0.28	0.14	1.37	1631	1695-1975	0.46	50
FBK	326	0.40	-0.00	-0.41	983	1807-1982	0.56	59
HRK	392	0.47	0.04	-0.43	1076	1777-1982	0.59	61
LVU	233	0.23	-0.03	0.04	1691	1805-1964	0.51	54
LJK	250	0.36	0.05	-0.11	1504	1743-1992	0.55	57
LUP	446	0.18	0.30	0.40	1651	1630-2002	0.30	35
LCU	272	0.25	0.03	0.81	1592	1831-1980	0.40	42
PPB	247	0.21	0.14	0.46	1739	1792-2010	0.32	36
SMU	182	0.27	0.03	0.81	1739	1821-1981	0.48	51
AGK	467	0.47	0.12	-0.27	530	1812-1996	0.66	68
TMU	166	0.27	0.16	0.07	1751	1852-1980	0.45	48
AC20	258	0.38	0.25	0.07	1585	1700-1979	0.58	62
BVB	153	0.34	0.33	0.33	1745	1904-2001	0.55	58
CL20	234	0.22	0.09	0.61	1673	1715-1996	0.40	45
DMS	242	0.29	0.36	0.47	1675	1804-1994	0.49	53
DEN	202	0.24	0.25	0.28	1666	1690-1800	0.47	50
DIB	163	0.29	0.266	-0.33	1739	1890-2004	0.43	47
DON	205	0.29	0.24	0.65	1681	1892-2005	0.46	49
DYE	196	0.21	0.92	2.64	1785	1872-2004	0.32	36
EEL	219	0.22	0.10	0.71	1760	1818-1989	0.42	45
FIG	233	0.39	0.50	1.65	1515	1862-2003	0.68	70
AR2	244	0.26	0.22	0.21	1863	1740-1990	0.34	39
HAS	197	0.32	0.78	1.64	1665	1835-1997	0.46	49
KER	184	0.50	0.96	1.47	1683	1872-1994	0.68	69
LOB	226	0.51	0.66	0.53	1396	1474-1650	0.67	69
B24	136	0.30	0.82	1.23	1873	1887-2003	0.43	48
DI2	157	0.40	0.25	-0.25	1659	1901-1997	0.61	63
MUR	146	0.35	0.78	2.22	1780	1876-2004	0.43	47
KAW	206	0.32	0.16	0.00	1567	1886-2004	0.53	56
PP20	234	0.44	0.45	0.26	1650	1726-1996	0.55	59
PPC	183	0.51	0.62	0.09	1667	1805-1982	0.72	75
PN2	227	0.40	0.31	0.02	1665	1752-1994	0.54	57
PUT	249	0.30	-0.04	0.53	1597	1780-1950	0.51	54
B27	203	0.44	0.32	-0.22	1471	1676-1839	0.68	70
SJR	201	0.31	0.02	-0.01	1650	1840-2004	0.58	60
JOA	192	0.40	0.34	-0.43	1751	1833-1988	0.60	63
COT	146	0.27	1.26	3.71	1913	1913-2004	0.44	50
IND	216	0.25	-0.13	0.94	1718	1812-1949	0.37	42
TOU	301	0.17	0.17	0.26	1566	1785-2005	0.31	35
B32	208	0.45	0.46	0.06	1446	1880-2003	0.70	71

SND	508	0.21	0.18	0.22	1339	1600-1992	0.33	38
CSP	375	0.14	0.12	2.71	1876	1132-1750	0.18	25
MPK	216	0.25	0.89	4.38	1790	1850-1996	0.26	31
GMT	447	0.15	0.11	0.80	1550	1650-2000	0.18	22
JKN	424	0.29	0.01	0.22	1242	1667-1981	0.45	47
BFA	435	0.21	0.14	0.15	1200	1672-1991	0.35	37
UWL	423	0.21	-0.15	0.31	-2	1450-1991	0.42	45
MHC	300	0.13	-0.41	2.66	1675	1690-1987	0.20	26
BMC	411	0.27	1.77	11.39	850	1785-1991	0.28	31

[a] MSSL is Mean Sample Segment Length
[b] Std is Standard Deviation
[c] SK is skewness
[d] KU is Kurtosis
[e] EPS is Expressed Population Statistic (Wigely et al., 1984)
[f] MCAR is Mean Correlation Among Radii
[g] EV is Explained Variance

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Appendix D. Loess Reconstruction Method

The Loess reconstruction model as used in this project is an extension on the time-nested (TN) reconstruction modeling described by Meko (1997). TN modeling is a means of adapting reconstruction models to the time-changing makeup of tree-ring networks and individual tree-ring chronologies. Single-site reconstructions (or SSRs) as intermediate variables in reconstruction of climatic or flow series, is also used in this study. That approach was first described by Meko (1997), and was successfully applied in Colorado River reconstruction (Meko et al. 2007).

Loess, or locally weighted regression (Cleveland 1979) has not been widely used before in tree-ring reconstruction of flow. We adopted Loess for this study based on observations of curvature in the relationship between tree-ring indices and flow for several of the target flow time series in the Sacramento/San Joaquin Basins. Trial-and-error analysis suggested the Loess model is more appropriate than ordinary least squares linear regression for describing the relationships observed.

The steps in reconstruction of flows in the Sacramento/San Joaquin part of the project are described in detail below. The same approach was taken for each of the 10 flow records reconstructed.

1. Assume a target time series of observed full natural flows, or “flow”, and an available tree-ring network with tree-ring chronologies likely to be related to runoff variations in the watershed.
2. Build an initial time series matrix of standard site chronologies. The years covered by the individual chronologies (columns of the matrix) will typically vary, but all are assumed to overlap the flow record a sufficient number of years (e.g., 50 yr) for calibration of reconstruction models. The matrix may contain many more chronologies than will actually be used in the reconstruction.
3. Filter and scale each chronology individually by regressing flow against the chronology in a distributed-lag model, or a model in which the current value of the predictand may depend on the values of the predictor (chronology) in years lagged forward or backwards from the year of the predictand. The approach initially used was to allow for various types of transformation on predictand (flow) and predictors (tree-ring indices). We eventually simplified this to log-transformation of flow and optional squared transformation on the tree-ring index. A regression model is estimated, and the fitted model is then applied to get estimates of log-transformed flow. These estimates, based on one chronology, are essentially a filtered and scaled tree-ring chronology in transformed flow units. After back-transformation to original units, this is a “single-site reconstruction, or “SSR”. The regression statistics may indicate no significant relationship between flow and the chronology, and in that case the regression modeling serves the additional purpose of screening out weak chronologies. More details of the single-site reconstruction are listed as 3.1-3.5.

    3.1. Consider the standard chronology and chronology squared at times t-1, t, t+1 to make up pool of potential predictors. The pool of potential predictors therefore nmbers 6. The predictand is log-transformed flow.
    3.2. Set the initial calibration period for the regression as the overlap of years of flow with the chronology. This overlap may or may not include all years of the flow record. For example even if flow and tree-ring index have the same last year, the calibration can extend only through the next-to-last year because of the need for a lag t+1 predictor in the model.
    3.3. Run a preliminary regression, with selection of the predictors, from lags -1, 0, and +1 of the tree-ring index made by stepwise regression with *p*-to-enter of 0.05 and *p*-to-remove of 0.10. This preliminary stepwise regression identifies a “step” at which the regression should be terminated..
    3.4. Repeat the stepwise regression with leave-5-out cross validation (Michaelsen 1987), truncating

entry at any point that cross-validation reduction-of-error statistic (RE; Fritts et al. 1990) fails to increase. Note that this cross-validation excerise can dictate cutting of the entry of predictors at fewer steps than suggested in (3.3) above.

3.5. Re-calibrate the regression model using the predictors and calibration period indicated from the previous step, but with a possibly expanded calibration period to take into account that either or both of the lags on the tree-ring index may not be needed in the model. Also repeat the leave-n-out cross-validation and the split-sample validation (Snee 1977), and apply the model to earlier tree-ring data to get a long-term reconstruction of flow. This time the number left out in cross-validation is not necessarily five, but is computed from the lags in the final model. The number left out is n=1+2*m, where m is the sum of the largest negative lag and largest positive lag. For example, if lags -1 and 1 are included, n = 1+2*2=5 are left out in cross-validation.

4. Back-transform the reconstructed flows (SSRs) – generated for the different chronologies by the steps just described – from log-transformed to original flow units, and organize the SSRs as columns of a time series matrix. The series in this matrix will generally have variable start and end years, such that any specific subset of the SSRs covers just part of the entire tree-ring record.

5. Generate a single final reconstruction of flow by combining the information from the SSRs by locally weight regression, or Loess (Cleveland, 1979). The Loess model is a smoothed scatterplot of observed flow on the arithmetic average of SSRs from some set of sites. The procedure consists of averaging over sites (columns of the matrix of SSRs) followed by re-calibration of the average into a flow estimate by linear interpolation with the fitted Loess curve. A loess model in this context is essentially a smoothed scatterplot of observed flow on an average of SSRs over some subset of of sites. The models must be time-nested (Meko, 1997) because subsets of SSRs are restricted to the time period for which not data is missing at any of the sites in the subset. Details are given below:

5.1. Identify the subsets of SSRs for use in the time-nested models. This is done by exploratory loess modeling using various possible combinations of SSRs. The selection proceeds forward chronologically from the first year of the SSR matrix. The loess modeling uses local-linear modeling and a smoothing parameter of $\alpha = 0.6$ 0.if that smoothing parameter gives a monotonically increasing loess curve. If the curve is not monotonically increasing, α is incremented in steps of 0.1 until the curve is monotonic.

5.2. For the first year in any of the SSRs (earliest year of the tree-ring network), averages over all possible subsets of available SSRs are tested as predictors. Subsets are identified that satisfy two conditions: 1) the fitted loess curve is monotonic increasing, and 2) split-sample calibration-validation (first half and last half) yields positive RE on both calibration halves. The model satisfying those conditions and explaining the most flow variance according to an explained-variance statistic, EV, is selected as the model for the first year. EV is analogous to regression R^2, and is computed as EV=1-SSE/SST, where SSE is the sum-of-squares of departures of observed flow from the fitted Loess curve, and SST is the sum-of-squares of departures of observed flow from its sample mean over the period used to estimate the Loess curve. This model (particular set of available SSRs) arrived at by this assessment of first year of tree-ring data is set as the "current" model.

5.3. The matrix of SSRs for the following year is then checked for a change in makeup, defined as any of the SSRs in the current model dropping out, or any new SSRs becoming available. Assume N_c SSRs in the current model, N_d of those dropping out in the change-year, and N_a new series becoming available. The next action depends on those numbers:

5.3.1. $N_l=N_c$+Na-N_d<=4: try all possible subsets of the N_l SSRs as possible predictors

5.3.2. $N_l=N_c$+Na-N_d>4:

5.3.2.1. $N_a=0$: use the average over the remaining N_c-N_d as the updated set

5.3.2.2. $N_a>0$: try combinations appending to the set of N_c in-model variables all possible subsets of the N_a new variables

5.3.3. $N_d=N_c$**:** as in the first year of the SSR matrix, try all possible combinations of SSRs available

An additional constraint is that all possible subsets is used for initial model until some model gives an explained variance of a least 1/3 the flow variance.

5.4. Proceed chronologically by the above procedure (repeat step 5.3) through the entire time coverage of the SSR matrix. The result is complete coverage of the the tree-ring record by time-nested subsets of SSRs chosen for relatively high strength of statistical relationship with flow. In the preceding two steps the scatterplots for the exploratory loess modeling are based on the overlap of flow data and the all of the candidate subsets of SSRs for a particular subperiod. The SSR (or tree-ring chronology) with shortest overlap with flow therefore sets the overlap for the assessment of "best" subset. This method was adopted to avoid comparing accuracy statistics of SSR subset models built on different calibration periods, as the some periods of the flow record may be better than others for relationship with tree-ring indices.

5.5. Re-fit each time-nested (TN) loess model again, this time with leave-n-out cross-validation and split-sample validations, and storage of calibration and validation statistics, and application of the model to reconstruct flow for segment of the tree-ring record covered by the SSRs. The reconstruction is done by linear interpolation from a lookup table derived from the fitted loess curve. The loess curve is extended linearly to allow interpolation of flows outside the range of x data in the calibration period.

5.6. Build an approximate 50% confidence interval around the reconstructed flows by the method of upper and lower smooths (Martinez and Martinez 2002). In this method, the positive and negative cross-validation residuals are modeled separately by conservative loess models (alpha=0.95), and the fitted curves are adopted as the upper and lower intervals.

5.7. Splice the TN reconstructions together into a final reconstruction. Because some TN models overlap, a criterion of assignment is needed when a year has reconstructed flows by more than one model. The criterion we use that the final reconstructed flow for any year should be the flow provided by the model with the highest EV in its calibration period. One shortcoming of this criterion is that the EV for competing models (competing groups of SSRs) is not necessarily based on the same calibration period.

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Appendix E. Description of Digital Data Products

Digital data are included on the file CADWR_4600008850.zip

That zip file includes the descriptive ascii file readme.txt and two other files:

1) Reconstructions.xlsx: MS Excel file with the 16 reconstruction (See Appendix A) and their upper and lower 50% confidence intervals.
2) RingwidthData.zip : Measured ring-width series (.rwl files) for all chronologies used in the reconstructions for the Sacramento and San Joaquin Basin.

Following is a listing of readme.txt:

```
readme.txt -- Contents of this zip file CADWR_Agreement_4600008850.zip

This zip file contains two files

1)  Reconstructions.xlsx:  MS Excel spreadsheet with the 16 reconstructions and 50%
confidence intervals for the 16 reconstructions produced on the project (see Appendix
A).  The spreadsheet has a header row identifying each each reconstruction.  Following
rows have data for each year, as follows:

     col 1: year
     col 2-48:  16 sets of of 3 columns;
             -Reconstructed flow in acre-ft
             -Lower 50% confidence interval
             -Upper 50% confidence interval

       Series included are listed below, and correspond to those in Appendix A:

        1  KLK  Klamath R. at Keno, OR, natural flows (rec);  AF
        2  TRN  Trinity R. at Lewiston, CA,  flows (rec);  AF
        3  KFL  Klamath Falls-long precipitation (rec);  inches
        4  KFS  Klamath Falls-short, precipitation (rec);  inches
        5  WEA  Weaverville, precipitation (rec);  inches
        6  YRK  Yreka, precipitation (rec);  inches
        7  FTO Feather River inflow to Lake Oroville (rec); AF
        8  YRS Yuba River at Smartville (rec);  AF
        9  AMF American River inflow to Lake Folsom (rec);  AF
       10  SBB Sacramento River above Bend Bridge (rec); AF
       11  SAC4 Sacramento River Four Rivers unimpaired runoff(rec);  AF
       12  SNS Stanislaus River inflow to New Melones (rec);  AF
       13  TLG Tuolumne River inflow to New Don Pedro (rec);  AF
       14  MRC Merced River inflow to New Exchequer (rec);  AF
       15  SJF San Joaquin River inflow to Millerton (rec);  AF
       16  SJQ4 San Joaquin River Four Rivers unimpaired runoff(rec);  AF
```

2) RingwidthData.zip: ring-width files (.rwl files) for the chronologies used in the reconstructions for the Sacramento and San Joaquin Basins. The filenames match the names in the "FILENAME" column of the table of chronology metadata included as Table C1 in Appendix C.