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Lawrence P. Smith and Charles W. Stockton[2]

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INTRODUCTION

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BASIN CHARACTERISTICS

The Salt and Verde basins encompass approximately 13,000 square miles in central Arizona (Figure 1). The Verde joins the Salt at Granite Reef to form the largest tributary of the Gila River which flows southwestward to its junction with the Colorado. With the exception of the Colorado, the Salt and Verde yield the greatest amount of runoff of any streams in the state.

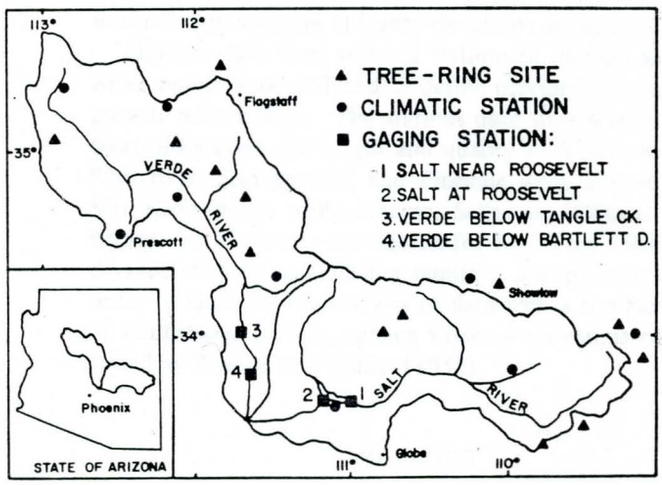

Figure 1. Location Map of the Salt and Verde River Basins, Arizona.

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ABSTRACT: The Salt and Verde Rivers of central Arizona provide the water supply for metropolitan Phoenix and a considerable acreage of irrigated agriculture. Rapid urbanization has caused concern over future water supply and aggravated flooding in the already flood-prone Salt River Valley. Tree-ring data were used as a proxy source to extend the annual and seasonal runoff records back to A.D. 1580 and thus to determine whether the period of record for annual discharge adequately represents the long term flow characteristics of the two rivers. Results show that several periods of extended low flow have occurred during the past 400 years, many of which were more severe then any comparable period since 1890. The low flow periods appear to have a recurrence interval of about 22 years. Also the gaged records contain an above average number of high seasonal and annual flows when compared to the entire 400 years. The reconstructions contain important implications for future water supply and flood potentials in the Salt River Valley. (KEY TERMS: Salt and Verde Rivers, Arizona; tree-ring reconstructions; annual and seasonal flows; flood potential.)

INTRODUCTION

Water from the Salt and Verde Rivers is the main source of supply for the metropolitan Phoenix area and, in addition, supports a large area of irrigated agriculture. Hydroelectricity is generated at four of the six major dams on the two rivers and all of the impoundments provide a wide variety of opportunities for water based recreation. Both the power and water resources are managed by the Salt River Project (SRP), the oldest multipurpose reclamation project in the nation. Altogether, SRP delivers water to 250,000 acres of land and electricity to more than 280,000 customers (SRP, 1980).

Rapid urbanization since World War II has escalated the demand for water. Flooding, always a threat in the Salt River Valley, has become an even greater problem as agricultural land has been replaced by homes, driveways, streets, and parking lots. Since population growth shows no signs of decreasing, there is a growing concern over both the future water supply and flooding potential. A basic tenet in both issues is whether the period of gaged records, although relatively long, adequately represents the long term flow characteristics of the rivers. The importance of this point is underscored by experience on the Colorado River. Here the long term flow of the river was considerably overestimated because the period of record upon which water was allocated to the upper and lower basins was unusually wet (Stockton, 1975). We have addressed this problem on the Salt and Verde Rivers by using information derived from tree rings to reconstruct their flows back to A.D. 1580. Results of this study are presented and discussed in this paper. The procedures are similar to those described by Stockton (1975) and Stockton and Boggess (1980) for a similar study on the Upper Colorado River.

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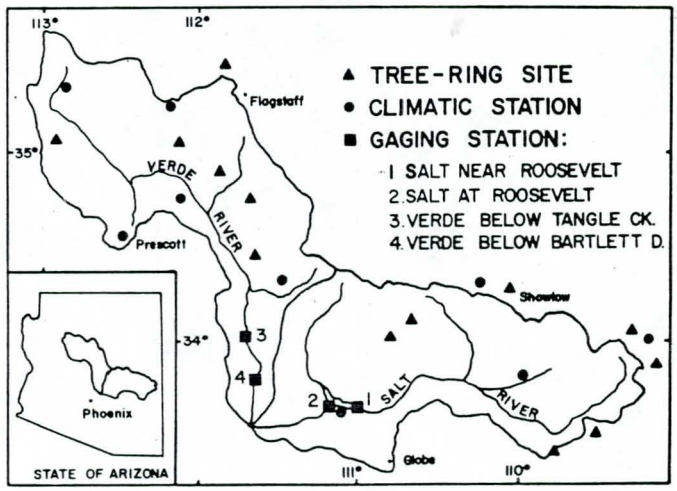

Figure 1. Location Map of the Salt and Verde River Basins, Arizona.

[1] Paper No. 81140 of the *Water Resources Bulletin*. Discussions are open until August 1, 1982.
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Both rivers originate at high elevations, with the extreme altitudes approaching or exceeding 12,000 feet above sea level. Precipitation in quite variable over the basins, ranging from about 8 inches in the more arid portions to more than 32 inches in the higher mountains. Precipitation occurs in both winter and summer. Winter storms are from large scale cyclonic systems moving in from the Pacific Ocean. Summer rains occur largely as convective thunderstorms associated with the movement of Gulf of Mexico moisture across the state. The latter make minimal contributions to stream flow.

Several reservoirs have been constructed in the Salt and Verde basins to provide a reliable water supply. Roosevelt Dam, the first project constructed by the Bureau of Reclamation, forms the principal reservoir on the Salt River. Three additional dams are located downstream from Roosevelt, namely Horse Mesa, Mormon Flat, and Stewart Mountain. These, along with Roosevelt, serve to store and regulate the flow of the Salt River and all are equipped to develop hydroelectric power. Records of the Salt River Project (SRP, 1980) give the combined usable storage capacity of the four reservoirs as 1,754,000 acre feet.

Two small reservoirs in the upper Verde basin, used by the City of Prescott and the Chino Valley Irrigation District, have an estimated capacity of about 5,000 acre-feet. Two larger storage reservoirs were constructed by the Salt River Project in the lower basin, Bartlett Dam in the late 1930's and Horseshoe Dam in the mid-1940's; these reservoirs have a combined capacity of 317,423 acre feet (SRP, 1980).

Water supply from the two basins is distributed by Granite Reef Diversion Dam, located just below the confluence of the two rivers. The combined storage capacity of the entire system is approximately 2.08 million acre feet (maf). This is about twice the average combined annual discharge of 1.19 maf, or about four times the median combined annual discharge of 0.51 maf (based on the period from 1914 to 1979).

It should be emphasized that the dams mentioned above were constructed for water supply and hydropower generation. Flood control was not a design objective. The relatively small reservoir capacity, coupled with somewhat erratic annual flows and high demands for water and electricity, dictate that the first priority must be given to filling reservoirs following drawdown during the dry months when runoff is minimal. Under these constraints, flood control is strictly coincidental with drawdown through use, rather than by design.

DATA

The locations of the climatic and stream gaging stations and the tree-ring sites used in this study are shown on Figure 1. The gage on the Salt River above Roosevelt Lake, near the town of Roosevelt, was put into operation in 1914 and has an associated drainage area of approximately 4306 square miles. An earlier gage, about 16 miles downstream from the one "near Roosevelt" operated from 1901 to 1913 and records were published as the "Salt River at Roosevelt." It included the discharge of Tonto Creek and had a drainage area of approximately 5830 square miles. Runoff for the period 1888 to 1900 was estimated from records at McDowell and Arizona Dam. Because this gage has a significantly larger drainage area than the one "near Roosevelt," their records could not be combined; thus the "near Roosevelt" data were used to calibrate the stream flow records. Since the period from 1888 to 1913 contained some of the largest discharges ever recorded, these early data were valuable because they could be used to verify the relative magnitudes of reconstructed discharges outside of the 1914-1979 calibration period.

The gage on the Verde River below Bartlett Dam was put into operation in 1895. Monthly discharges for water years 1889-1894 and 1900 were estimated from the discharge of the Salt River at Arizona Dam (United States Geological Survey, 1954). The flow of the Verde River below Bartlett Dam has been regulated by Bartlett and Horseshoe Reservoirs since their completion in 1939 and 1945, respectively. The record of monthly discharge after 1939 was corrected by adding the monthly changes in reservoir contents as published by the USGS to the reported monthly flow at the gage. A gage was opened on the Verde River below Tangle Creek in 1945, and represents the inflow to the Verde River reservoir system. The drainage area between the two gages is insignificant, so the Tangle Creek gage was used after 1945 to avoid the errors in estimating the reservoir contents associated with the gage below Bartlett Dam.

Tree-ring samples consisting of two cores each from at least ten trees per site were collected from 13 locations within the Salt and Verde River basins (Figure 1) according to procedures described by Stokes and Smiley (1968). Each site was selected to maximize both the climatic sensitivity of the trees (i.e. only open grown trees on exposed sites with shallow soils receiving moisture only from precipitation were sampled) and length of the tree-ring series. The species selected for analysis were either ponderosa pine (*Pinus ponderosa* Laws.) or pinyon pine (*Pinus edulis* Engelm.). Sampling of ponderosa pine was restricted to the lower forest border region, since this species is usually not sensitive at higher elevations in central Arizona.

Climatic data from selected stations in the Salt and Verde River basins were analyzed to define precipitation-runoff-tree growth relationships. The stations used were selected on the basis of location and length and quality of record; Roosevelt, Whiteriver, Springerville, and Pinedale were selected for the Salt River basin; while Jerome, Seligman, Williams, Natural Bridge, and Prescott were chosen for the Verde. Many of the climatic stations had missing monthly precipitation data. In order to facilitate the analysis of data with a common period of continuous record, missing values were estimated as described by Paulhus and Kohler (1952).

METHODS

The sample cores from each site were prepared, dated, and measured as described by Stokes and Smiley (1968). Tree ring indices were derived from the measured ring widths which in their raw form, are generally unsatisfactory for climatic reconstructions because ring width usually decreases as a tree increases in circumference and age. This trend was removed by

fitting a modified negative exponential decay curve to the time series of ring widths and dividing the measured width by the value of the fitted curve for the same year. The resulting series, which is essentially stationary in time, is the tree-ring index. The indices from all cores from a given site and year were averaged to obtain a single index value for that year. These procedures are discussed in detail by Fritts (1976, Ch. 6). Since the standard error of estimation increases with decreasing sample size, the reliability of indices based on only a few cores is usually poor. Thus, indices used in our analysis were based on a minimum of four cores.

Under maximum stress conditions, tree growth for a particular year largely depends on that year's moisture input alone. More commonly, a combination of soil moisture and biological carryovers result in a lag effect, with a particular year's growth being influenced by moisture from the previous one or two years. This autocorrelation (the relationship between a given year's response and that for a previous year) is estimated in a manner similar to a product-moment correlation coefficient, except that instead of determining the relationship between two variables, x and y, the relationship between x and x-i is calculated, where i is the amount of lag. Autocorrelation (or persistence) may be removed from certain time series by regressing the response at time t with that at time t-i, and then subtracting the estimated effect of input at time t-i on response at time t from the known response at time t (Box and Jenkins, 1976). Meko (1981) has discussed in detail how the resulting autoregressive (AR) process can be applied to tree ring series to remove the effects of soil moisture and biological carryovers.

The reconstruction of stream discharge from tree-ring data assumes that the sample trees are responding to and recording the same climatic input that influences discharge. To determine this, the relationships between climate and discharge, climate and tree growth were derived using principal components analysis (PCA). The PCA method allows a large field of highly correlated data to be expressed as a smaller number of uncorrelated variables called eigenvectors. A spatial array of M stations each having the same number, N, of data points will yield the smaller of either M or N eigenvectors. Each eigenvector will contain M components corresponding to the number of stations, or variables, and will account for a portion of the total variance (Cooley and Lohnes, 1971). The sum of the products of an eigenvector generated by the PCA with the values of its components for a given year yields a value called an amplitude for that year (Kutzbach, 1967).

Three aspects of PCA are especially important in the analysis of climatic data. First, it groups the components of each eigenvector into combinations, or modes, which occur within the data field through time (Stockton, 1975). The first eigenvector will reflect the most common mode of occurrence, the second eigenvector the next most common, and so on. Secondly, each eigenvector generated by the analysis is orthogonal to the other eigenvectors, so that they are truly independent variables. The third, and perhaps the most important, benefit of PCA relates to the analysis of precipitation data alone. The amplitudes derived from the eigenvectors of monthly precipitation are a representation of the total precipitation for a given year. Since tree growth is influenced by precipitation throughout the year, the width of each growth ring is also a function of total annual precipitation. Therefore, the amplitudes generated by PCA can be used to independently verify the discharge – tree-growth relationship.

The amplitudes corresponding to the eigenvectors of monthly climatic data for several stations within the Salt and Verde River basins represent modes of temperature and precipitation which are independent in time and weighted spatially over each of the basins. These amplitudes were entered as predictor variables in a multiple linear regression (MLR) analysis with the $\log_{10}$ transform of annual discharge to determine water balance models. A $\log_{10}$ transform was performed because the original discharge data were log-normally distributed and their use in an MLR with normalized predictor variables would have resulted in the estimation of negative values for low flow years. The use of the transform increased thevariance explained by a few percent for each of the models, most likely because of the dampening in variance resulting from the $\log_{10}$ transformation.

The precipitation and temperature amplitudes were also regressed against each of the tree-ring series in order to determine the climate – tree-growth relationship. The results of the water balance and tree-growth analyses are presented in detail by Smith (1981).

Since discharge and tree growth responded to climatic stimuli in a similar manner, the record of past climate contained within the tree-ring series was substituted as proxy data to reconstruct records of annual runoff. Stream flow records were reconstructed by using the tree-ring series from the respective basins as independent predictors in a multiple linear regression with the $\log_{10}$ discharge data for the period of gaged record. The results were used to predict discharge back in time to 1580. In all of the multiple linear regressions, only those variables which were significant at the 99 percent confidence level and which resulted in an increase in R^2 [adjusted for the loss of a degree of freedom caused by entering that variable (Kutzbach and Guetter, 1980)] were entered in the prediction equations.

The stream flow reconstructions were analyzed for periodic components using spectral analysis methods (Jenkins and Watts, 1966). The series were lagged by 100 years and the Parzen weighting function was employed, as detailed in the computer program of Aarons and Reagan (1977). The confidence limits for the spectral density function were determined in accordance with techniques described in Chatfield (1975).

RESULTS AND DISCUSSION

Salt River Basin

The results of the calibration of Salt River discharge and tree-ring data for the 1914-1979 period are summarized in Column A of Table 1. Since the most important precipitation influencing both discharge and tree growth occurs in the

winter months, two separate calibrations were performed to reconstruct October through April and December through March discharge in addition to total annual flow. Not all of the tree ring series were of the same length, so that separate prediction equations were developed for each of the common data periods in order to maximize the length of the reconstructed records. The reconstructed annual discharge is plotted with the actual gaged data in Figure 2.

TABLE 1. Results of Regressions Between Actual Gaged Data and Predicted Flows for the Salt River Near Roosevelt (see text for a description of columns).

		Regression Model						
		A	B		C		D	
Season	Common Period	R^2	R^2	SE	R^2	SE	R^2	SE
Annual	1702-1979	0.728	0.593	336	0.757	260	0.730	221
	1630-1979	0.666	0.435	396	0.617	326	0.637	257
	1620-1979	0.643	0.387	413	0.558	350	0.579	276
	1580-1979	0.535	0.390	411	0.564	348	0.534	290
October to April	1702-1979	0.717	0.586	293	0.729	237	0.712	191
	1680-1979	0.704	0.480	328	0.673	260	0.750	178
	1630-1979	0.686	0.525	314	0.679	258	0.708	192
	1620-1979	0.641	0.425	345	0.513	317	0.614	221
	1580-1979	0.527	0.361	364	0.540	308	0.524	246
December to March	1702-1979	0.665	0.497	240	0.706	184	0.724	132
	1680-1979	0.633	0.342	275	0.577	220	0.703	138
	1620-1979	0.604	0.425	257	0.522	227	0.630	154
	1580-1979	0.490	0.341	275	0.498	240	0.517	176

Notes: SE = standard error of estimation in thousand acre-feet.
R^2 values are adjusted for loss in degrees of freedom.

The reconstructed values were tested against actual gaged flow in simple linear regression using both the early independent data from 1895-1907 and from 1911 to 1913, and the data from the 1914 to 1979 calibration period (Column B). A reduction in R^2 from the original prediction equation occurred in every case. This reduction was due to the underestimation of major flows in 1905 and 1916, and also to the fact that the early data were for a larger drainage area. The flows predicted for 1908 and 1920 were of the same magnitude as those for 1905 and 1916, respectively, implying an apparent lag in prediction of three to four years for those two high flows. A likely explanation for this lag is that the 1899 to 1904 period was shown to be very dry by both precipitation and stream flow records. Also, cores from sample trees experienced minimal or no measurable diameter growth during portions of the period. Although 1905 was a wet year, the annual ring widths did not show maximum response to this moisture until 1908. This lag was undoubtedly caused by an exhaustion of food reserves in the trees during the six years of hot, dry weather. The two years prior to 1916 were also very dry, with many of the sample trees experiencing only minimal diameter growth. During such extended dry periods, photosynthesis is inhibited by the lack of moisture while the rate of respiration is increased by high temperatures. This combination results in a depletion of the food reserves available for growth. Once moisture is again available, these depleted food reserves must be replenished before ring widths show a maximum response. The longer period lag associated with these two high flows was not removed by the time series analysis because it was unrelated to the autocorrelation structure associated with a more common one or two year lag. Instead, it appears to be a nonstationarity associated only with very wet years following drier periods.

Since the predicted values for 1908 and 1920 most likely represent moisture conditions in 1905 and 1916, respectively, they were substituted for those years and the regressions were performed again (Column C). In each case, the value of R^2 was much closer to that obtained in the $\log_{10}$ prediction equation for the 1914-1979 period. Separate regressions were performed between the gaged and reconstructed data for the period from 1921 to 1979 and the results are shown in Column D. The R^2 values obtained were in good agreement with those derived from both the original prediction equation and the regressions with the two high flows transposed, also indicating that the longer period lag of the two high flows was responsible for the majority of the reduction in R^2.

The standard errors of estimation derived from each of the regressions are included in Table 1. The values for the 82 year regression with the high flows transposed (Column C) are probably most representative of the standard errors of the estimated flows themselves. The values obtained without transposing the two high flows (Column B) are more representative of the standard error associated with the predicted value for a particular year. Since the magnitude of a high historical flow is more important in terms of design that the year in which it occurred, the standard errors in Column C are probably a more realistic estimate of the standard error in magnitude for flows estimated outside the calibration period.

Statistical analyses were performed on the gaged and predicted discharge records and the results for the annual reconstruction are shown in Table 2. The first four moments of the actual and predicted records for the period from 1914-1979 were very nearly identical for each of the models, indicating that the reconstructions provide reliable estimates of the distribution of annual and seasonal flows. Frequency distributions of both gaged and predicted records for the 1914-1979 period are shown on Figure 3. From a design standpoint, the problems associated with the lag in prediction of certain high seasonal flows are not important when the distributions alone are considered.

The means for the 80-year periods from 1740-1819 and 1900-1979 were significantly greater than those for the three remaining periods at at least the 80 percent confidence level, yet were not significantly greater than the 400-year means. This has important implications for water supply planning because it suggests that although the mean from the period of gaged record from 1914-1979 was not significantly different from the 400-year mean, it may not be a reliable estimator of the dependable annual supply. The mean annual flow from

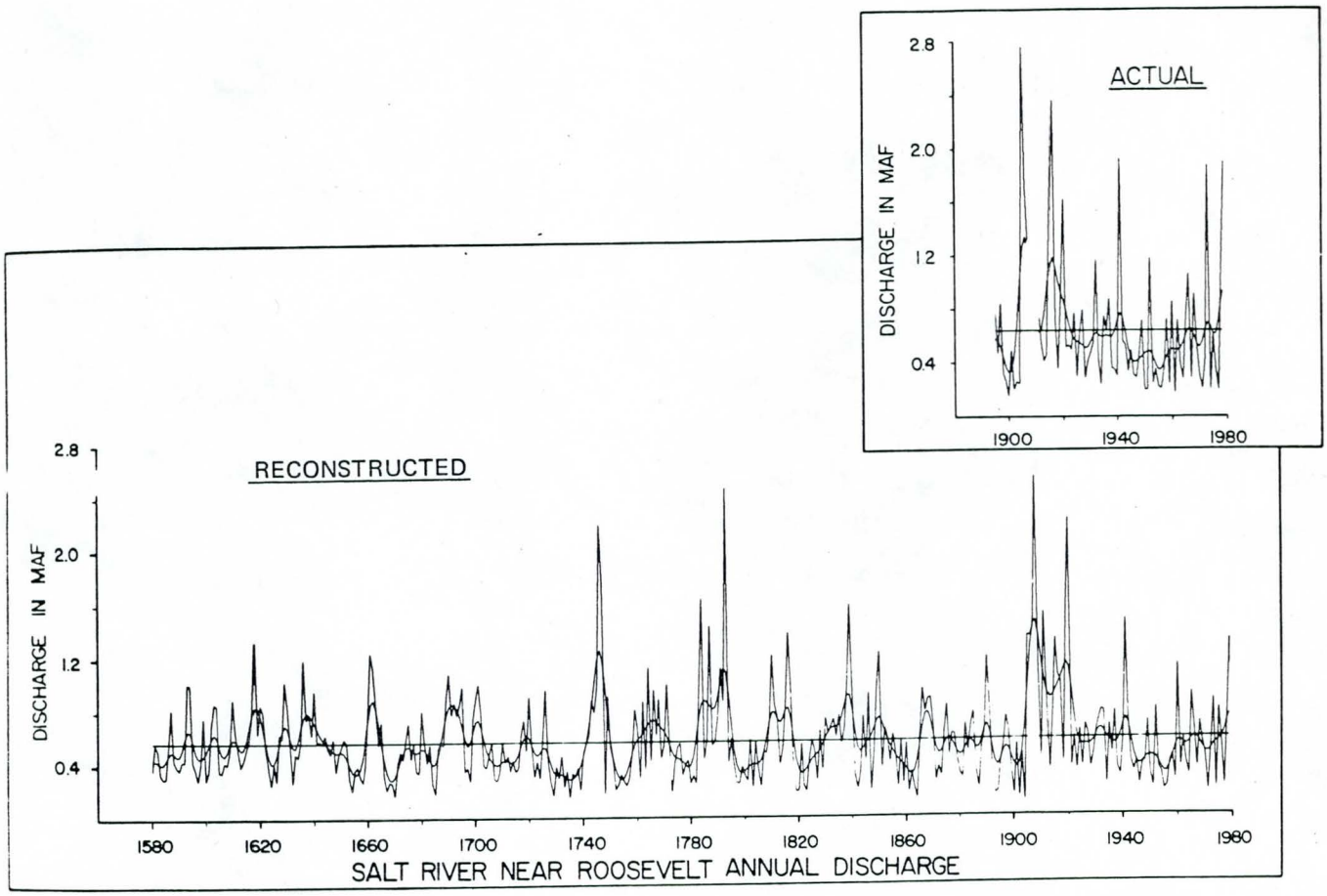

Figure 2. Reconstructed and Actual Discharge ofthe Salt River Near Roosevelt (calibration period is from 1914-1979).

the three 80-year periods of lower flow (1580-1659, 1660-1739, 1820-1899) may represent a more realistic value.

TABLE 2. Results of Statistical Analyses of Reconstructed and Actual Discharge of the Salt River Near Roosevelt.

Season	Data	Period	Mean	Standard Deviation	Skewness	Kurtosis
Annual	Actual	1914-1979	626.8	480.0	1.81	3.11
	Reconstructed	1914-1979	588.1	371.9	1.89	5.01
		1580-1979	576.6	343.9	2.02	9.64
		1580-1659	547.4	227.4	1.12	4.29
		1660-1739	514.9	249.1	0.84	3.12
		1740-1819	623.3	431.3	2.01	8.12
		1820-1899	544.4	274.3	0.94	4.74
		1900-1979	639.1	451.4	1.81	7.21

Notes: Mean and standard deviation in thousand acre-feet.

Several periods of sustained high and low flows are evident throughout the 400-year reconstructions. The period from 1905 to 1920 was the wettest period in the entire reconstruction, with almost all of the predicted flows being above the 400-year mean. The only other period that approached the early 1900's in magnitude was from the mid-1780's through the mid-1790's.

Moving averages of two, five, ten, twenty-five, and fifty years were calculated in order to analyze the short and long term trends in the reconstructions. High flows in the early 1900's dominated the short and long term means of each seasonal reconstruction. The driest five-year period ended in 1670. This drought is known to have occurred over the entire southwest and resulted in severe hardship for the Pueblo people living in the area (Page, 1980). A sustained low flow period lasting from 1728 until 1739 dominated the long term low flow means. During this 12-year period the average annual discharge was only 43 percent of the 400-year mean, and in no year did the discharge exceed the mean value. The recurrence of such an extended dry period would have devastating consequences.

The spectral density function for the October-April reconstruction is shown on Figure 4. The only significant value occurred at 22.2 years and reflects the return period of extended low flow periods. This is important from a water supply standpoint, because it implies that there is a tendency toward deficient stream flow every 22 years. Mitchell, *et al.* (1979), found a 22-year periodicity in drought occurrence in the western United States and related it to the Hale Solar Cycle. A similar periodic component in gaged stream flow

records for the entire United States has been noted by W. B. Langbein and J. R. Slack (1980). This periodic low flow tendency of the Salt River discharge should be incorporated in future water supply planning efforts.

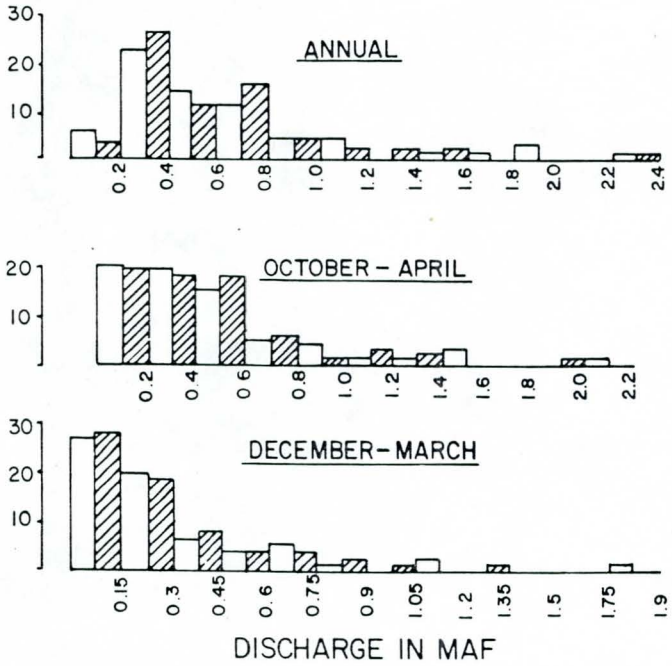

Figure 3. Frequency Distributions of Actual (open) and Reconstructed (hachured) Stream Flow of the Salt River Near Roosevelt, 1914-1979.

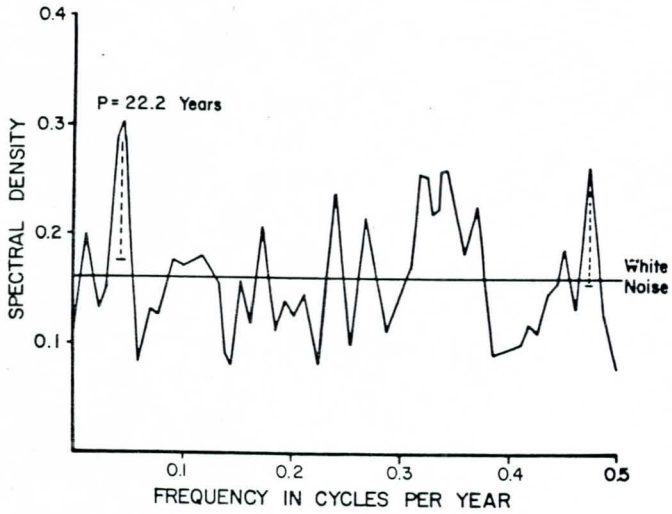

Figure 4. Spectral Density Function for the October-April Discharge of the Salt River Near Roosevelt, With the Lower 90 Percent Confidence Level Plotted for Two of the Frequencies. The white noise line is the spectral density function of a normally distributed random variable. Only the 22.2 year periodicity is significant at the 90 percent confidence level.

In terms of high discharge events, water year 1979 was particularly troublesome for the city of Phoenix, with the gaged October through April discharge of 1.59 maf for 1979 being equaled or exceeded only three times since 1900. A high discharge value was predicted for this year in all of the reconstructions. The predicted discharge was 1.12 maf and was equaled or exceeded 12 times over the past 400 years. On the average, then, a seasonal flow of this magnitude was recorded in the actual data once every 27 years, and in the reconstructed records once every 30 years, indicating that the 1979 gaged flow was not anomalous. In general, there was an above average number of high seasonal flows during the 1900-1979 period, when compared to the long term reconstruction. A summary of comparisons between flows from the periods of gaged and reconstructed records is shown in Table 3.

TABLE 3. Comparison of Selected Actual and Reconstructed Flows of the Salt River Near Roosevelt.

Flow Year	Season	Actual (MAF)	Average Actual Occurrence	Reconstructed (MAF)	Average Reconstructed Occurrence
1905	Annual	2.76*	1 in 80	2.52	1 in 400
	Oct-Apr	2.28*	1 in 80	2.17	1 in 200
	Dec-Mar	1.51*	1 in 40	1.39	1 in 400
1916	Annual	2.36	1 in 40	2.21	1 in 133
	Oct-Apr	2.08	1 in 40	1.88	1 in 100
	Dec-Mar	1.78	1 in 80	1.26	1 in 200
1941	Annual	1.93	1 in 27	1.45	1 in 40
	Oct-Apr	1.42	1 in 20	1.38	1 in 57
	Dec-Mar	1.08	1 in 16	0.99	1 in 100
1979	Annual	1.91	1 in 20	1.30	1 in 22
	Oct-Apr	1.59	1 in 27	1.12	1 in 31
	Dec-Mar	1.08	1 in 20	0.80	1 in 57

Notes: Average occurence is the number of times the flow was equaled or exceeded divided by the period of record. Actual period of record is 1900-1979, reconstructed period is 1580-1979.

*Includes the discharge of Tonto Creek.

Verde River Basin

The results of the calibration of Verde River discharge and tree-ring data for the 1895-1979 period are summarized in Column A of Table 4. Because of surface water diversion for agriculture in the Verde basin, only the discharges for the periods from October through April and December through March were modeled. The reconstructed October-April discharge is plotted with the gaged data on Figure 5.

The predicted values were tested against actual gaged data in a manner similar to the analyses for the Salt River basin. The values of R^2 from the regression between the predicted values and the actual data again shows a marked reduction due to the lag in prediction of the 1905 and 1916 high flows (Column B). The growth response in the original tree-ring data was lagged by three to four years. Filtering by the AR2 process reduced the lag to one year in most of the series, so that the high flows

were predicted for 1906 and 1917. When these high flows were substituted for 1905 and 1916, respectively, the values of R^2 obtained were much closer to the values estimated by the original $\log_{10}$ prediction equation (see Column C). Separate regressions were performed for the period from 1920-1979, and the results are shown in Column D. The values for R^2 obtained were in good agreement with those from the original $\log_{10}$ prediction equation and from the regression with the high flows transposed. The standard errors of estimation derived from each of the regression models are included in Table 4.

The statistical analyses for the gaged and reconstructed October-April discharge of the Verde River are summarized in Table 5. Frequency distributions of both the gaged and predicted records for the 1900-1979 period are shown on Figure 6. Although the first four moments of the actual and predicted records for the period from 1900-1979 were very similar, minor differences were evident, most notably in the low flow end of the October-April reconstruction. A likely explanation for this difference is that the base flow of the Verde River is controlled by the discharge of springs, rather than by climatic factors (B. N. Aldridge, USGS, Tucson, Arizona, personal communication, 1981). This dominance is less pronounced over a shorter seasonal period, as is evident in the December-March distributions.

TABLE 4. Results of Regressions Between Actual Gaged Data and Predicted Flows for the Verde River Below Tangle Creek (1895-1979) (see text for explanation of columns).

		Regression Model						
		A	B		C		D	
Season	Common Period	R^2	R^2	SE	R^2	SE	R^2	SE
October to April	1702-1979	0.744	0.562	195	0.723	155	0.764	134
	1685-1979	0.725	0.544	199	0.683	166	0.694	152
	1648-1979	0.704	0.505	207	0.629	180	0.709	148
	1641-1979	0.699	0.521	204	0.645	176	0.691	153
	1580-1979	0.465	0.280	250	0.319	243	0.455	204
December to March	1702-1979	0.701	0.444	179	0.686	134	0.667	123
	1685-1979	0.680	0.415	183	0.625	147	0.583	138
	1648-1979	0.655	0.400	185	0.592	153	0.578	139
	1641-1979	0.681	0.416	183	0.598	152	0.580	139
	1580-1979	0.469	0.236	209	0.325	197	0.491	153

Notes: SE = Standard error of estimation in thousand acre-feet.
R^2 values are adjusted for loss in degrees of freedom.

Moving averages were also calculated for the Verde River reconstructions. High flows during the early 1900's dominated the five to twenty-five year means, while the greatest fifty-year

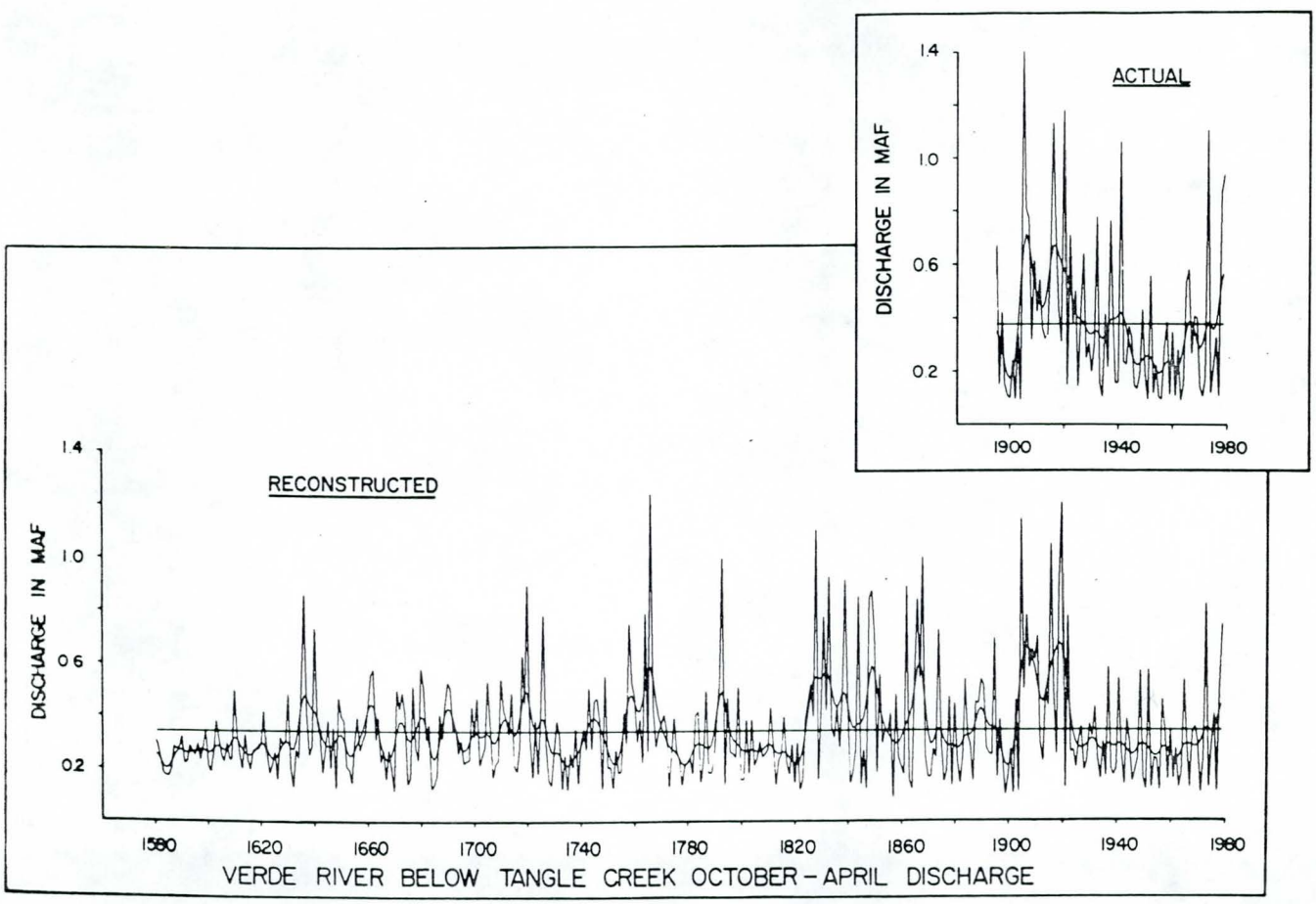

Figure 5. Actual and Reconstructed Stream Flow of the Verde River Below Tangle Creek (calibration period is from 1895-1979).

mean occurred in the mid-1800's. Low flows at the turn of this century resulted in the lowest two-year mean discharge in the entire reconstructed period. Longer periods of minimal discharge occurred at various times in the last 400 years, the most severe being from the mid-1770's through the mid-1780's. The period of sustained low flow from 1580-1620 was based on only one tree-ring series, and may not be reliable. In general, periods of low flow on the Verde River coincided with similar periods on the Salt. This was most likely due to the widespread nature of the Southwest Coast climatic regime, which dominates climate during most of the year (Mitchell, 1969).

TABLE 5. Results of Statistical Analyses of Reconstructed and Actual Discharge of the Verde River.

Season	Data	Period	Mean	Standard Deviation	Skewness	Kurtosis
October to April	Actual	1900-1979	385.9	294.0	1.44	4.82
	Recon.	1900-1979	360.7	246.3	1.48	5.17
		1820-1899	386.4	246.5	1.08	3.49
		1740-1819	327.3	185.6	2.40	11.30
		1660-1739	332.3	155.4	0.98	4.51
		1580-1659	291.7	115.9	2.35	11.60
		1580-1979	339.7	199.3	1.71	6.53

Notes: Mean and standard deviation in thousand acre-feet.

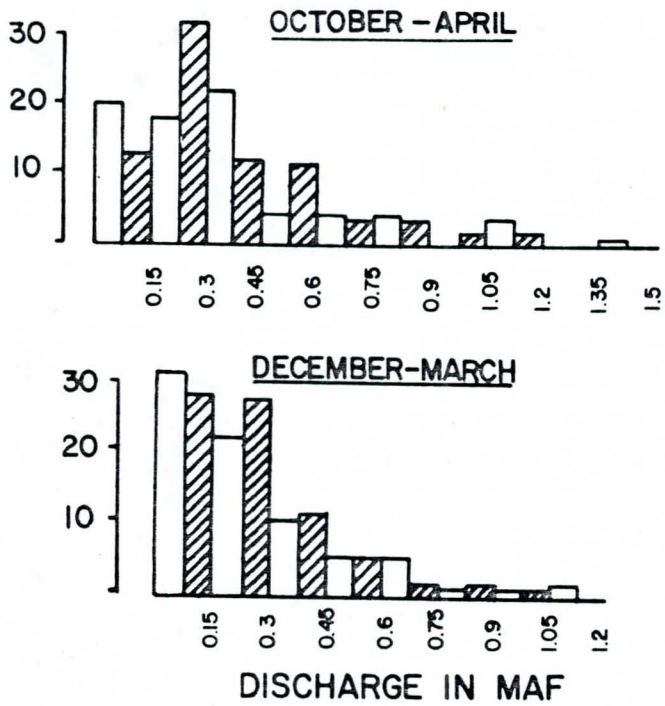

Figure 6. Frequency Distribution of Actual (open) and Reconstructed (hachured) Stream Flow for the Verde River Below Tangle Creek, 1895-1979.

The high flow characteristics of the Verde River were very similar to the Salt, with an above average number of high seasonal flows occurring during the period of gaged record. The 1979 seasonal discharge had essentially the same frequency of occurrence over the 400-year reconstruction as it did in the 1895-1979 period.

Spectral analysis of reconstructed discharge showed no significant periodicity. This most likely relates to the low flow character of the Verde, which is controlled by discharge of springs rather than climatic variations.

SUMMARY AND CONCLUSIONS

The reconstructions indicate that the available gaged records for each of these two rivers contain an above average number of high seasonal and annual flows, when compared to the entire 400-year period. Since high magnitude instantaneous peak flows tend to occur during years of high seasonal and annual runoff (Smith, 1981), the gaged records of peak flow may be biased in a similar manner. Therefore, any design based on the historical records of peak flow may be inherently conservative.

Recent flood flows on the Salt and Verde Rivers have caused significant management problems in the greater Phoenix area. The reconstructions indicate that the average frequency of occurrence of the annual and seasonal discharges associated with these peak flows has remained constant over the last 400 years.

Important implications for water supply planning are evident in the reconstructions. Although the mean annual flow of the Salt River near Roosevelt for the period of gaged record was not significantly different from the 400-year mean, it was significantly greater than the means for several periods of comparable length throughout the reconstruction. Therefore, the mean based on the period of gaged record may not be a reliable estimator of the dependable supply.

Several periods of sustained low annual discharge were reconstructed, many of which were more severe than any comparable period since 1890. The recurrence of such a period would result in severe water supply problems for all of the water users involved. The tendency of these sustained low flow periods to occur every 22 years must be incorporated in the assessment of the reliability of future water supplies.

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