Dendrohydrology Literature Review

by Charles W. Stockton
Laboratory of Tree-Ring Research
University of Arizona, Tucson

December 31, 1966

The relation between plant growth and hydraulic technology is quite old, probably as old as the science of hydraulics itself. Since ancient times, use has been made of living plants for protection of dams and embarkments. Use of plants with high water requirements in connection with drainage and reclamation projects is also generally known. However, more recently, a quantitative approach using dendrochronology as the basic tool has received limited attention. Most interest along these lines has been directed toward climatic interpretation which of course can not be divorced from hydrology (See for example Douglass, 1919, 1928, 1936). But generally, in the early 1900's, hydrologic interpretations from tree-rings was of secondary importance to most investigations. Perhaps the first major concentrated use of dendrochronology to a hydrology problem can be attributed to Hardman and Reil (1936). In their attempt to extend hydrologic records for the Truckee River in Nevada-California, they initiated an extensive investigation of surface runoff and tree ring indices. They were able to show that (a substantial) correlation existed. In fact, higher degrees of correlation were obtained when ring widths were compared with runoff than with precipitation records. The values obtained are shown in Table I.

Table I, after Hardman and Reil (1936)

Stream		Length of record (years)	Coefficient of correlation*	Probable error
1	Truckee	26	.8883	±.028
2	Feather	25	.8874	.029
3	American	22	.8906	.030
4	Modelumne	22	.8218	.047
5	Tuolumne	31	.7309	.056
6	Yuba	24	.7943	.051
7	Bear	22	.5380	.102
8	Feather	55	.6704	.078

*data smoothed by 5 year moving mean.

Smoothing of the data is justified by the authors: "On the fact that the soil acts as a conserving agency for moisture, causing the water which is fed into the soil to become effective over long periods of time. It is estimated that moisture falling on the mountains has an effect upon stream flow for at least three and at times as much as five years afterward. This retarding effect of soil upon moisture is also operative with the use of the moisture by the trees, though the effect may not be as strong with the trees as with the stream flow. Smoothing tends to equalize, and for this reason aids in bringing the trends in stream runoff and tree growth into greater harmony and in showing their relationship more clearly."

From their study of 46 trees (ponderosa pine), Hardman and Reil concluded:

1) In the last four hundred years, from 1530 to 1930, stream flow in the Truckee River varied between rather wide limits. There were relatively long periods from ten to even thirty or forty years when the flow was close to the average for the entire period. There were other similar periods when it was far below or above this average.

2) Periods of unusually great stream flow in the Truckee and of high water in Lakes Tahoe and Pyramid were followed by periods of reduced flow and of low water in these lakes.

3) The forty years between 1875 and 1915 formed the largest period in which the flow of the Truckee River was above the average in nearly three centuries between 1630 and 1930.

4) Only twice before in this long period was the flow of the Truckee almost equal to that in the twenty years between 1890 and 1910.

5) In earlier centuries such periods of drought as that experienced since 1915 were of frequent occurrence. For example, there appears to have been a similar dry period from 1840 to 1870 and another one from 1755 to 1785.

6) Nothing in the tree ring record shows at all clearly that future dry periods will be followed by wet ones with sufficient regularity to be predictable. The variations in stream flow appear to have been irregular in both duration and interval.

7) While the tree ring studies make it seem probable that the recent dry period will be followed by one of more abundant water supply, they do not show how soon the change will come or how long it will last, or how long the period of deficient supply will exist.

Keen (1937) studied the relationship between the annual growth of 340 ponderosa pine and the climate of eastern Oregon. Included in his work is a brief correlation of ring widths with Columbia River runoff. He found a correlation coefficient of .56 for unsmoothed data when ring width was compared to runoff at The Dalles, Oregon.

Antevs (1938), on the other hand, attempted to use dendrochronology to supplement and verify data on paleoclimatology and paleohydrology in the Great Basin. He used dendrochronology in conjunction with historical accounts, fluctuations of lake levels (i.e. the Great Salt Lake), lake terraces and other similar evidences. In correlation of tree-rings with precipitation records at Susanville, California and Lakeview, Oregon, he found the tree-rings gave inconclusive evidence of precipitation about 50% of the time. Therefore, he concluded: "when tree ring curves are taken alone, only general and somewhat conditional conclusions concerning past rainfall fluctuations can be made, but they (tree-ring curves) take on greater significance when supported by other types of evidence." He did not, however, attempt direct correlation with runoff.

Schulman (1945a, 1945b, 1947, 1951) has shown that the fluctuating widths of the successive growth rings of trees provide a significant index to the past history surface runoff.

In his first publication, Schulman (1945a), points out the relationship of tree-rings to surface runoff along the Pacific Coast. Although the development is not strong, the possibilities are definitely shown.

In the Colorado River basin, Schulman (1945b), points out, with rigorous proof, that dendrochronology can be a solution to extension of hydrologic records. In this case, the regional index which was ultimately correlated with runoff at Lee's Ferry, Arizona, was developed in a weighted manner, such that variance in the chronologies from tributary basins was taken into consideration. It was found that the weighted sum of the tree-ring indices developed separately for six individual tributary basins, give the best correlation with river flow at Lee's Ferry.

From this analysis, he was able to make valuable use of the relationship, but definite quantitative long range forecasting was not possible. In general a correlation coefficient of +.88 was obtained with smoothed tree-ring curves when correlated with runoff at Lee's Ferry. A value of +.66 was obtained for unsmoothed data.

A similar investigation for the Southern California area (Schulman, 1947) revealed correlation coefficients between bigcone-spruce growth and seasonal rainfall for the last forty-nine years of record are +.71 (unsmoothed data) and +.86 (three-year moving means). Between growth and San Gabriel River runoff the corresponding coefficients were +.61 and +.87; between growth and Kings River runoff, +.52 and +.64. No significant relation to seasonal temperature was found.

In a summary of work completed up to the year 1951, Schulman points out the relationship of the Mesa Verde growth index with the October-June rainfall at Durango, Colorado, and the water year runoff of the Animas River. Also, he points out the limitations of comparison of tree-ring chronologies to runoff in areas subject to flash floods as opposed to those basins where the largest portion of the runoff is derived from snow melt. Again the effects of smoothing of data are shown to produce the best correlation coefficients. Table II below is a summary of results of investigations in dendrohydrology up to 1951.

Table II

Tree Index	Correlated with	Period	Interval yrs.	unsmoothed	smoothed*
Colo. River Basin	Colo. River Runoff	Oct-Sept	49	+0.66	+0.8
Eastern Oregon	Eastern Oregon Run.	Sept-Aug	66	+0.50	---
Eastern Oregon	Columbia River Run.	Jan-Dec	57	+0.54	---
So. California	Coastal Rain	July-June	94	+0.65	+0.7
So. California	Coastal Rain	July-June	49	+0.71	+0.8
So. California	Kings' River Run.	Oct-Sept	49	+0.52	+0.6
So. California	San Gabriel River Run.	Oct-Sept	49	+0.61	+0.8

*by formula $b = \frac{a + 2b + c}{4}$

The most recent use of dendrochronology in hydrologic studies, (to the writer's knowledge), was conducted by Gatewood et al, 1964. In this study, tree-ring correlation with runoff was used to determine if the 50 year base-period (1904-53) used by the authors was a representative sample of runoff for the southwest at least for the last 150 years. Tree ring studies in the southwest did indicate that mean runoff during the base period 1904-53 was closely representative of mean runoff for the 154 year period 1800-1953 and also for periods of 450 years of more. In this study, the data previously published by Schulman was used and an attempt to improve the direct relationship between dendrochronology and surface runoff was not undertaken.

References Cited

Anteve, Ernst, 1938, Rainfall and Tree Growth in the Great Basin: Am. Geograp. Soc. Sp. Pulb. No. 21, 97 p.

Hardman, G., and Reil, O. E., 1936, Relationship between Tree Growth and Stream Runoff in the Truckee River Basin, California-Nevada: Bull. Nev. Agric. Exp. Sta. No. 141, pp. 1-38.

Gatewood, J. S., Wilson, Alfanso, Thomas, H. E., and Kister, L. R., 1964, General Effects of Drought on Water Resources of the Southwest: U. S. Geol. Surv. Prof. Paper 372-B, pp. 31-36.

Keen, F. P., 1937, Climatic Cycles in Eastern Oregon as Indicated by Tree-Rings: Mon. Wea. Rev. Wash. Vol. 65, No. 5, pp. 175-188.

Schulman, Edmund, 1945a, Runoff Histories in Tree Rings of the Pacific Slope: The Geographic Review, Vol. 35, No. 1, pp. 59-73.

Schulman, Edmund, 1945b, Tree-Ring Hydrology of the Colorado River Basin: Univ. of Arizona Bull., Lab. of Tree-Ring Research Bull. No. 2, 51 p.

Schulman, Edmund, 1947, Tree-Ring Hydrology in Southern California: Univ. of Arizona Bull., Lab. of Tree-Ring Research Bull. No. 4, 36 p.

Schulman, Edmund, 1951, Tree-Ring Indices of Rainfall, Temperature, and River Flow: In Compendium of Meteorology, Am. Meteorological Society, Boston, Mass., pp. 1024-1029.