Substrate and Dendrochronologic Streamflow Reconstruction

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Abstract

Two piñon (*Pinus edulis*) tree-ring chronologies developed on each of three substrates (sandstone, shale, and alluvial fan deposits) in southern Utah for the period 1702 to 1997 demonstrate that geologic substrate affects dendrochronologic streamflow reconstructions. Chronologies from alluvial fan deposits explain the most variance of winter streamflow reconstruction (October 1 to May 31) with an adjusted coefficient of determination (R_a^2) equal to 0.59. Chronologies from sandstone deposits account for 52 percent of the variance, while those on shale deposits account for 45 percent. Correlation coefficients among the three substrates are significantly different at the 95% confidence level.

The highest single-site annual discharge reconstruction (October 1 to September 30), $R_a^2 = 0.25$, is provided by chronologies from shale deposits. The highest substrate-pair annual discharge reconstruction, $R_a^2 = 0.27$, is provided by chronologies from alluvial fan deposits. The highest summer reconstruction (July 4 to September 3), $R_a^2 = 0.14$, is provided by chronologies from sandstone. Over 90 percent of the summer reconstructions are below $R_a^2 = 0.10$.

The different substrate response is attributed to varying amounts of clay in each substrate affecting infiltration and available water for tree growth. [5]

Keywords: streamflow reconstruction, substrate, dendrochronology

Introduction

Dendrochronological streamflow reconstructions are a valuable tool to assess the long-term discharge behavior of a river. The long-term behavior can provide insights into the management of discharge, and is useful for planning and restoration projects.

Dendrochronological streamflow reconstructions have been performed since the mid 1930s. Early 1900s streamflow studies (Hardman and Reil 1936, Hawley 1937, Schulman 1945, Schulman 1951) were not strict reconstructions as the term is used today. These early studies generally compared tree-ring records with streamflow, and made estimates for wet and dry periods for pre-gauged streamflow.

Tree-ring growth is directly related to precipitation (Fritts 1976, Loaiciga et al. 1993). Streamflow reconstructions represent precipitation less water lost to evapotranspiration and storage (Jones et al. 1984, Meko and Stockton 1984). Therefore, the climate and vegetation peculiar to a specific basin will directly influence the dendrochronologic streamflow reconstructions for that basin. Fritts (1976) reports that substrate and soil differences affect tree-ring width. The substrate controls infiltration, local drainage, and nutrient supply to the tree. A tree is therefore an integrator of the local environment, and the tree-ring record reflects not only precipitation but also the substrate on which the trees are growing.

The objective of this study is to address the effects of substrate on dendrochronological streamflow reconstructions. Geological substrate controls local hydrological systems. Drainage characteristics peculiar to different substrates are reflected in the tree-ring record, and trees on a particular substrate produce a chronology that provides improved streamflow reconstructions over trees on other substrates.

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The area chosen for this study is the Paria River basin in southern Utah and northern Arizona (Figure 1). The widespread presence of piñon and exposure of geologic strata provide an opportunity to address the effects of substrate on tree-ring chronologies and streamflow reconstructions.

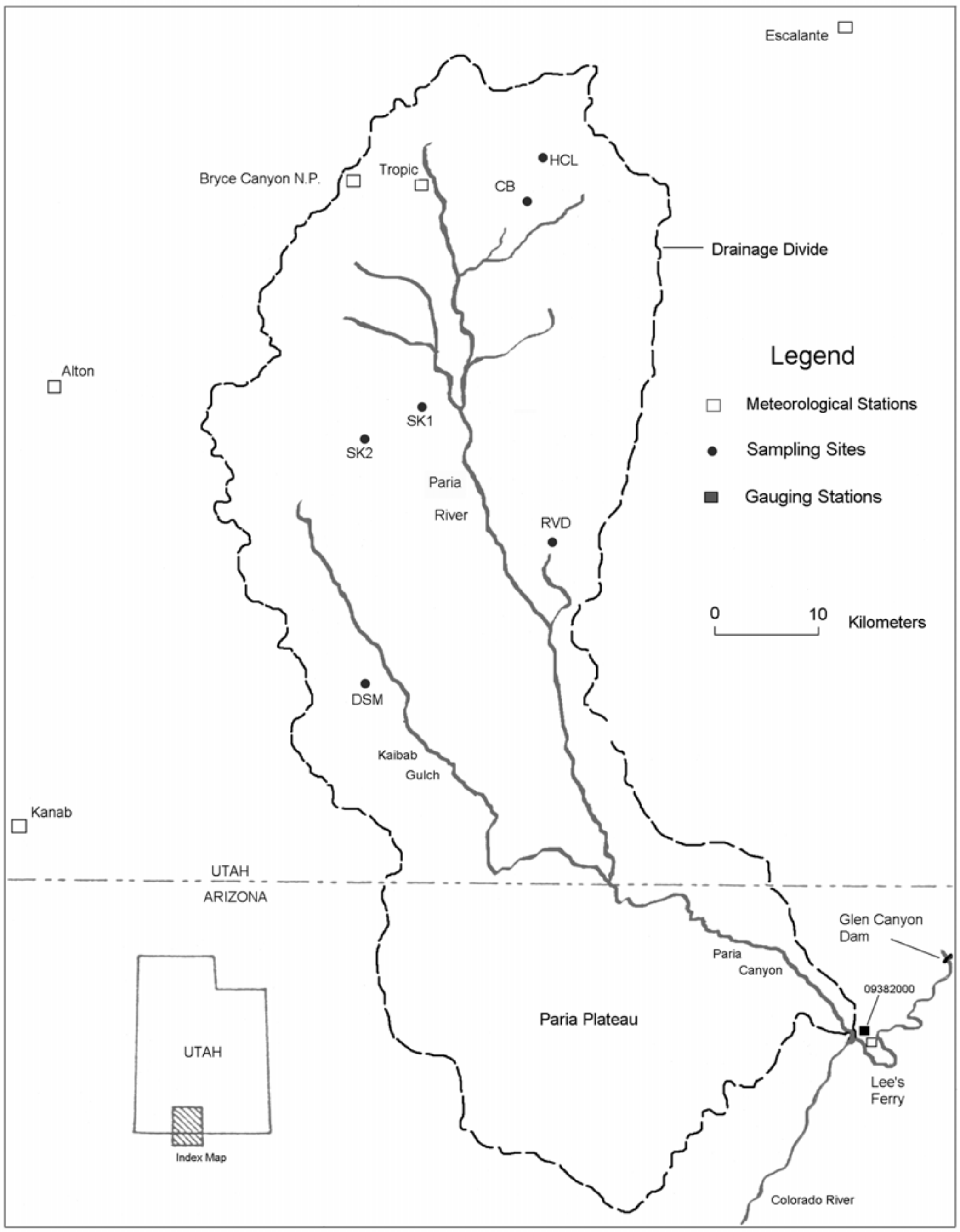


Figure 1. Paria River Basin in southern Utah showing locations of tree-ring sampling sites. Coal Bench (CB) and Henderson Canyon Lower (HCL) are located on alluvial fan deposits. Skutumpah Road site 1(SK1) and Skutumpah Road site 2 (SK2) are located on shale. Round Valley Draw (RVD) and Deer Springs Mesa (DSM) are located on sandstone.

Methods

Six tree-ring standard chronologies (indices) were developed for this analysis. A minimum of 10 trees, 2 cores per tree, was sampled at each site. Samples were prepared and mounted according to procedures described by Stokes and Smiley (1996). Cores were crossdated using skeleton plots, and crossdating was verified by Laboratory of Tree-Ring Research personnel. Ring widths were then measured to within +/- 0.01 mm. A standard chronology was created by removing differential growth trend among trees using a cubic smoothing spline. To obtain tree-ring indices of equal length for comparison, the six different chronologies were truncated so that each chronology spanned the period from 1700 to 1998.

Substrate characteristics

Soils throughout the basin are predominantly fine, sandy loams, very deep, and well drained (Swensen and Bayer 1990). The tree-ring sample sites are located on three different soil series (Table 1). Sites HCL and CB are located on the Hernandez-Clapper Series; DSM and RVD on the Podo Series; and SK1 and SK2 on the Cannonville Series. The Hernandez-Clapper series is formed in alluvium from sandstone and limestone. The Podo series is formed from sandstone residuum and alluvium. The Cannonville series is formed from shale residuum. The clay content of the soil series ranges from 5 to 50%, and permeability ranges from 0.15 to 15.24 centimeters per hour. These features affect the infiltration capacity, hydraulic conductivity, transmissivity, and available water capacity of the different substrates (Birkeland 1984, Ritter et al. 2002, Brooks et al. 2003). All samples were taken on relatively flat aspects of each substrate.

Table 1. Sampling site soil summary (Swenson and Bayer 1990).

Site	Clay Content (%)	Permeability (cm/hr)
CB	18-27	1.52 - 5.08
HCL	18-27	1.52 - 5.08
DSM	5-25	5.08 - 15.24
RVD	5-25	5.08 - 15.24
SK1	40-50	0.15 - 0.51
SK2	40-50	0.15 - 0.51

Streamflow discharge records for the period from 1924 to 1998 were obtained from U.S.G.S. gauging station 09382000 located at Lee's Ferry, Arizona. The total streamflow discharge for a year is based on the water year, October 1 through September 30. The water year was partitioned into three sub-periods: 1) October 1 through March 31 (Winter 1), 2) October 1 through May 31 (Winter 2), and 3) November 10 to April 17 (Winter 3). The annual and the Winter 2 partitions are the subject of this study.

Streamflow reconstructions

Multiple linear regression was used to estimate past streamflow. The chronologies were segregated by substrate: CB and HCL are on alluvial fan deposits, DSM and RVD on sandstone, and SK1 and SK2 on shale. Models of pre-gauged streamflow were developed by comparing the gauged discharge for each year with tree-ring indices for each year, with up to +/- 2 year lags.

The coefficients of determination were adjusted to account for the loss of degrees of freedom due to the addition of predictors (Weisberg 1985). The validity of each model was determined by examining the estimated model coefficients, the residuals from modeling, the root-mean-square-error (RMSE) of calibration and verification, and the reduction of error (RE) statistic of calibration and verification. Each model was verified using the PRESS statistic (Weisberg 1985).

Results and Discussion

The highest adjusted coefficients of determination (R_a^2) show that the Winter 2 partition provides the highest R_a^2 values, with the paired sites CB/HCL providing the highest discharge reconstruction ($R_a^2 = 0.59$). The differences in correlation coefficients are statistically significant at the 95% confidence level (□ = 0.05) (Table 2).

Table 2. Discharge reconstruction summary (R_a^2) for the annual (October 1 - September 30) and Winter 2 (October 1 - May 31).

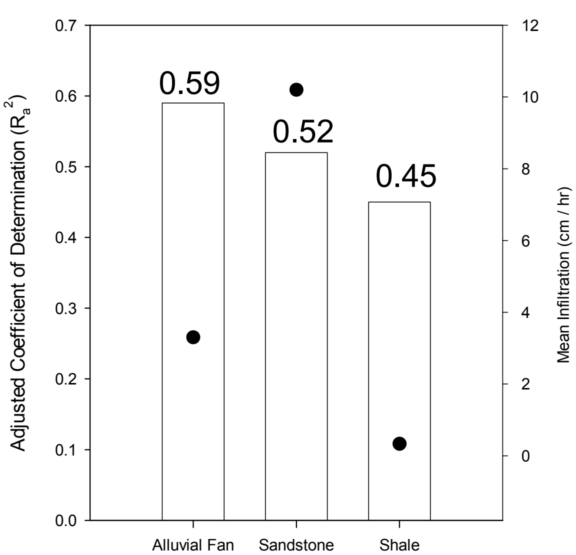
Site	Annual	Oct – May
CB	0.22	0.46
HCL	0.24	0.54
DSM	0.11	0.43
RVD	0.18	0.48
SK1	0.23	0.43
SK2	0.25	0.45
CB-HCL	0.27	0.59
DSM-RCD	0.18	0.52
SK1-SK2	0.25	0.45

Clay content and permeability are highest for sites SK1 and SK2, ranging from 40-50% clay content and 0.15 to 5.0 centimeters per hour permeability. Sites DSM and RVD are located on sandstone residuum.

Compared to alluvial fan and shale substrates, clay content is low, 5 - 25%, and permeability is high, 5.0 to 15.0 centimeters per hour. Sites CB and HCL are intermediate between the other two sites with clay content from 18-27%, and permeability from 1.5 to 5.0 centimeters per hour.

Substrate appears to play a major role in the streamflow reconstructions. The extremes of the infiltration rates of sandstone and shale, 5.08-15.24 cm/hr and 0.15-0.51 cm/hr, respectively, bracket the infiltration rate of 1.52-5.08 cm/hr for the alluvial fan deposits (Figure 2). The extremes represent end-points of water availability for tree growth. The lower infiltration capacity of the shale deposits may result in rapid surface runoff before the precipitation is recorded in the tree-ring record. The higher infiltration rates of the sandstone may result in water passing through the system vertically, again before being recorded in the tree-ring record. The alluvial fan deposits, being intermediate in infiltration, provide the substrate texture more conducive to water availability for tree growth, and is subsequently reflected in the tree-ring record.

Figure 2. Substrate versus the adjusted coefficient of determination (bars) for the Winter 2 discharge reconstruction with mean infiltration (circles).



Conclusions

Several factors influence tree growth and chronology development. This study has successfully compared geologic substrates with respect to tree-ring chronology development and streamflow reconstructions using multiple linear regression. The alluvial fan deposits generally provide the highest coefficient of determination values for streamflow reconstruction. These results suggest that substrate affects the available water for tree growth, and subsequently affects streamflow reconstructions. This information may prove useful to land managers for planning and restoration purposes.

This study provides a foundation to expand the substrate/species component of dendrochronological streamflow reconstructions. Future work on this topic should include more species and substrate comparisons.

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