Journal of Hydrology 529 (2015) 524–534

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

A millennium-length reconstruction of Bear River stream flow, Utah

R.J. DeRose [a,*], M.F. Bekker [b], S.-Y. Wang [c], B.M. Buckley [d], R.K. Kjelgren [c], T. Bardsley [e], T.M. Rittenour [f], E.B. Allen [g]

[a] USDA, Forest Service, Forest Inventory and Analysis, Rocky Mountain Research Station, 507 25th Street, Ogden, UT 84401, United States
[b] Department of Geography, 690 SWKT, Brigham Young University, Provo, UT 84602, United States
[c] Plant, Soil, and Climate Department, 4820 Old Main Hill, Utah State University, Logan, UT 84322-4820, United States
[d] Tree Ring Lab, Room 108, Lamont-Doherty Earth Observatory, Columbia University, 61 Route 9W, Palisades, NY 10964, United States
[e] Western Water Assessment, 2242 West North Temple, Salt Lake City, UT 84116, United States
[f] Department of Geology, 4505 Old Main Hill, Utah State University, Logan, UT 84322-4505, United States
[g] United States Geological Survey, 4200 New Haven Road, Columbia, MO 65201, United States

ARTICLE INFO

Article history:
Available online 17 January 2015

Keywords:
Dendrohydrology
Drought
Medieval Warm Period
Mega-droughts
Pacific Ocean teleconnection
Water management

SUMMARY

The Bear River contributes more water to the eastern Great Basin than any other river system. It is also the most significant source of water for the burgeoning Wasatch Front metropolitan area in northern Utah. Despite its importance for water resources for the region's agricultural, urban, and wildlife needs, our understanding of the variability of Bear River's stream flow derives entirely from the short instrumental record (1943–2010). Here we present a 1200-year calibrated and verified tree-ring reconstruction of stream flow for the Bear River that explains 67% of the variance of the instrumental record over the period from 1943 to 2010. Furthermore, we developed this reconstruction from a species that is not typically used for dendroclimatology, Utah juniper (*Juniperus osteosperma*). We identify highly significant periodicity in our reconstruction at quasi-decadal (7–8 year), multi-decadal (30 year), and centennial (>50 years) scales. The latter half of the 20th century was found to be the 2nd wettest (~40-year) period of the past 1200 years, while the first half of the 20th century marked the 4th driest period. The most severe period of reduced stream flow occurred during the Medieval Warm Period (ca. mid-1200s CE) and persisted for ~70 years. Upper-level circulation anomalies suggest that atmospheric teleconnections originating in the western tropical Pacific are responsible for the delivery of precipitation to the Bear River watershed during the October–December (OND) season of the previous year. The Bear River flow was compared to recent reconstructions of the other tributaries to the Great Salt Lake (GSL) and the GSL level. Implications for water management could be drawn from the observation that the latter half of the 20th century was the 2nd wettest in 1200 years, and that management for future water supply should take into account the stream flow variability over the past millennium.

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1. Introduction

The Bear River is located in the heart of the Intermountain U.S., and is one of the largest sources of underdeveloped surface water in three states, Idaho, Utah, and Wyoming (DWR, 2004). Originating in the western Uinta Mountains of Utah, the Bear River follows a tortuous path, meandering across the Utah–Wyoming border several times, before entering the same valley as Bear Lake, then looping back through southeastern Idaho before becoming the largest inflow to the Great Salt Lake. The Bear River is the single largest river in the eastern Great Basin, and demand for its water is high. It is used for rural, urban, and wildlife purposes (e.g., the Bear River Migratory Refuge). Moreover, flow is diverted through Bear Lake for water storage and to act as a buffer against regional drought (Endter-Wada et al., 2009; Welsh et al., 2013), and is the cornerstone for supplying water for the future growth of the Wasatch Front metropolitan region (DWR, 2004). However, water management on the Bear River is complex and despite its political, social, and geographic importance few studies have sought to quantify the variability of the Bear River's natural flow regime. In this paper we use tree rings to develop a 1200-year statistically calibrated and verified reconstruction of mean annual flow (MAF) from one of the Bear River headwater gages located near the Utah–Wyoming border. We then compare this reconstruction to other recent reconstructions of important tributaries to the Great Salt Lake, in order to provide the larger context of long-term hydrologic variability to this rapidly growing region.

* Corresponding author. Tel.: +1 801 625 5795.
E-mail address: rjderose@fs.fed.us (R.J. DeRose).

http://dx.doi.org/10.1016/j.jhydrol.2015.01.014
0022-1694/Published by Elsevier B.V.

Regional tree-ring data provide a proven source of proxy information for stream flow that can be utilized for understanding long-term flow variability beyond the limits of historical records (Axelson et al., 2009; Strachan et al., 2011; Wise, 2010; Woodhouse et al., 2006). Although there is no direct physical relationship between ring width and stream flow, they both are reflective of common hydroclimatic variables such as precipitation, snowpack, and soil moisture, such that trees growing in the vicinity of arid region river systems often exhibit a strong relationship with both stream flow and precipitation (see, for example, Stockton and Jacoby, 1976). In particular, in the Four Corners region of the Colorado Plateau where the vast majority of precipitation is delivered in the cool season, roughly centered in the water year (WY, October–September), tree rings have been found to be excellent proxies of MAF.

Tree-ring reconstructions in the vicinity of Bear River have been lacking, but recent stream flow reconstructions of several water bodies on the Wasatch Front have improved our understanding of Bear River's hydroclimate: the Weber River (Bekker et al., 2014) – another tributary of the Great Salt Lake that originates near Bear River headwaters in the Western Uinta Mountains; the Logan River – the largest tributary to the Bear River (Allen et al., 2013); and Great Salt Lake level (DeRose et al., 2014). These studies have indicated incongruities in species-specific tree-ring responses to climate across the region. They also indicate that variation in reconstructed flow might represent differences (both spatially and temporally) in precipitation delivery to the Wasatch Front, primarily during the winter, that are important for water management. Decadal-scale climate oscillations originating in the tropical and North Pacific as recorded by the GSL elevation, for example, have been shown by various studies to dominate the hydrology of the Wasatch Front (Gillies et al., 2011; Wang et al., 2010, 2012).

For regional water managers tasked with planning for future demand, reconstructions of magnitude, intensity, and periodicity of stream flow variability at different temporal scales provide a solid basis to augment planning (Woodhouse and Lukas, 2006). Longer-term reconstructions spanning over a millennium can not only illuminate possible hydrologic extremes, but also reveal low-frequency variability that potentially affects the region with long-term, severe dry and wet periods (Cook et al., 2011). Finally, the annual resolution of tree-ring reconstructions provides a characterization of stream flow variability at a scale that may be more readily interpretable by water managers who can make comparisons with historical events (Woodhouse and Lukas, 2006).

Unlike other regions in western North America, e.g., in the Four-Corners region of the Colorado Plateau, that have been explored using tree-ring data (Cook et al., 2007), the Bear River Watershed lacks an extensive network of tree-ring chronologies. Furthermore, three of the four most useful hydroclimate-sensitive species in the west, ponderosa pine (*Pinus ponderosa*), common pinyon (*Pinus edulis*), and singleleaf pinyon (*Pinus monophylla*) – are entirely lacking from the region. The fourth such species, interior Douglas-fir (*Pseudotsuga menziesii*), is present in the Bear River watershed, but has not been particularly useful. Older Douglas-fir individuals are rare due to extensive resource extraction by Mormon settlers since their arrival in the mid 1800s (Bekker and Heath, 2007), and the few extant old stands typically occur at higher elevation where their ring-width is less sensitive to precipitation (e.g. Hidalgo et al., 2001). This paucity of moisture-sensitive species for the Bear River watershed is a predicament we have resolved by focusing on species that are not commonly used for dendroclimatology, Rocky Mountain juniper (*Juniperus scopulorum*) (Allen et al., 2013), see also (Spond et al., 2014), and especially Utah juniper (*Juniperus osteosperma*). These species are usually found at sites characterized by limited available water—low elevations, southerly exposures, and limited soil development—and as a result often have a strong relationship between ring-width and hydroclimate, and yet they have long been considered too difficult to use for dendrochronology purportedly owing to false ring formation and extreme stem lobing (Fritts et al., 1965).

In this study we focus on living and dead Utah juniper trees that extend more than 1200 years into the past, and we use the data to reconstruct Bear River MAF from a near-natural headwater gage record located at the Utah–Wyoming border. We characterize wet and dry periods at annual- and decadal-scales as deviations from the mean condition with a particular focus on the period ~800–1500, as we provide the first long-term hydroclimatic information for the region that covers this time period. For the period of 1500 to the present we compare and contrast with other regional tree-ring based hydroclimate reconstructions that cover this same period from the Logan River (Allen et al., 2013), the Weber River (Bekker et al., 2014), and the Great Salt Lake (DeRose et al., 2014), but that used different species (Douglas-fir, common pinyon, Rocky mountain juniper, and limber pine (*Pinus flexilis*)). Finally, we examine circulation anomalies associated with precipitation in the region to elucidate climatic drivers of stream flow. Combining the new Bear River reconstruction with these other regional reconstructions and the potential climatological drivers results in a more comprehensive characterization of past hydroclimatology for northern Utah, and provides the fullest picture to-date of regional stream flow variability for a rapidly growing metropolitan region of the Intermountain West.

2. Methods

2.1. Regional climate

The climate of the greater Bear River region exhibits a stark contrast between cold and warm seasons. The vast majority of annual precipitation comes in the form of winter snowpack from storms that originate in the Pacific Ocean, while summers are typically and predictably dry (i.e., the summer monsoon system that brings rains to the US Southwest does not typically extend into northern Utah, Mock, 1996). Stream discharge in this region is strongly related to the quantity of snowpack, spring precipitation, antecedent soil moisture conditions, and temperature during the transition between the cool season and the growing season. Furthermore, northern Utah exhibits a strong 'seasonal drought' during the summer, characterized as sparse precipitation from July through September. Therefore, water-year characterization of stream discharge integrates the primary conditions thought to also influence tree-ring increment, winter snowpack and spring moisture. Influence by the North American Monsoon on the hydroclimate of this region is possible but rare (MacDonald and Tingstad, 2007; Mock, 1996). Any direct effect on plant growth this far north is likely due not to precipitation, but rather to increased humidity, which lowers vapor deficit and allows greater late growing season photosynthesis (Woodruff et al., 2010).

2.2. Study area

We collected core samples and cross-sections from Utah juniper living and dead trees, respectively, from the South Fork of Chalk Creek (SFC), a tributary to the Weber River that is directly adjacent to the Bear River watershed (Fig. 1, 2160 m asl). The site was selected from aerial imagery based on the presence of Utah juniper and was characterized by minimal soil development, little herbaceous cover, steep, south-facing slopes, and trees that were widely spaced. These are the basic conditions that are sought by dendroclimatologists because they minimize the availability of soil