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Streamflow responses to vegetation manipulations along a gradient of precipitation in the Colorado River Basin

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ABSTRACT

The Colorado River Basin has been, and continues to be, the focus of a wide diversity of research efforts to learn more about the effects of natural and human-induced disturbances on the processes and functioning of the basin's upland watersheds. These watersheds are situated at the headwaters of streams and rivers that supply much of the water to downstream users in the western United States. Responses of streamflow to vegetation manipulations have been, and are, one of the research foci in this water-deficient part of the country. The watershed-scale research, led by the U.S. Forest Service and its cooperators, has spanned nearly a century and included an array of vegetation types along a wide range of precipitation gradients. Results from this research have shown that vegetation can be managed to enhance annual water yields while still providing the other natural resource benefits. Analyses of the research results suggest that the effect of vegetation manipulation on streamflow is associated with precipitation–elevational gradient and, therefore, vegetation type. An annual water yield increase between 25 and 100 mm could be achieved by implementing vegetation manipulations in the high elevation subalpine and mixed conifer forests, the ponderosa pine forests (in the Lower Basin), and portions of the low elevation chaparral shrublands. Negligible effects or small increases in water yield were observed for treating sagebrush, pinyon-juniper woodland and desert scrubs. Results from this research have improved our understanding of the basin's hydrology and provided much needed insights to manage forest to mitigate global climate change induced hydrologic impact and meet the increased needs of people living in the basin.

1. Introduction

Impact of vegetation manipulation on streamflow generation was one of the important components in the early experimental watershed research in forest hydrology (Bates and Henry, 1928; Kittredge, 1948; Coleman, 1953). During the past century, studies of different scales, at various locations, and under different climatic conditions demonstrated the tight coupling between vegetation and streamflow production and other hydrological processes (Ice and Stednick, 2004; Sun et al., 2005). However, the direction and magnitude of streamflow change associated with vegetation reduction has long been an issue of debate (Robinson et al., 2003; Wilcox et al., 2005). Both increases and decreases in streamflow production of varying magnitudes were reported when vegetation manipulations were implemented. These different results have been attributed to an array of factors including the vegetation manipulation techniques and the recovering phase, precipitation regime and intensity, evapotranspiration changes, and interactions among all of these factors (Lane and Mackay, 2001; Swank et al., 2001; Brooks et al., 2003; Komatsu et al., 2008). From the manager's viewpoint, it was vital to understand the individual and combined responses to planned vegetation manipulations encompassing the precipitation–elevation gradients to holistically manage the vegetation and water supplies for downstream users.

The Colorado River drains approximately 650,000 km^2 (65 million ha) of virtually all of Arizona and portions of New Mexico, Colorado, Wyoming, Utah, Nevada, and California before it enters the Gulf of California in Mexico. This drainage area is arbitrarily separated into the Upper and Lower Basins at Lee's Ferry, about 16 km south of the Utah–Arizona border (Fig. 1). The Upper Basin of the Colorado River contains 28.3 million ha and the Lower Basin 36.4 million ha in area. Vegetation types in the basin are closely related to precipitation gradients that (in turn) are associated to elevational gradients. In descending order of precipitation–elevation gradients montane forests are at the "high end" of these gradients, followed by woodlands and shrub communities in the "middle range" of the gradients, and, finally, desert ecosystems at

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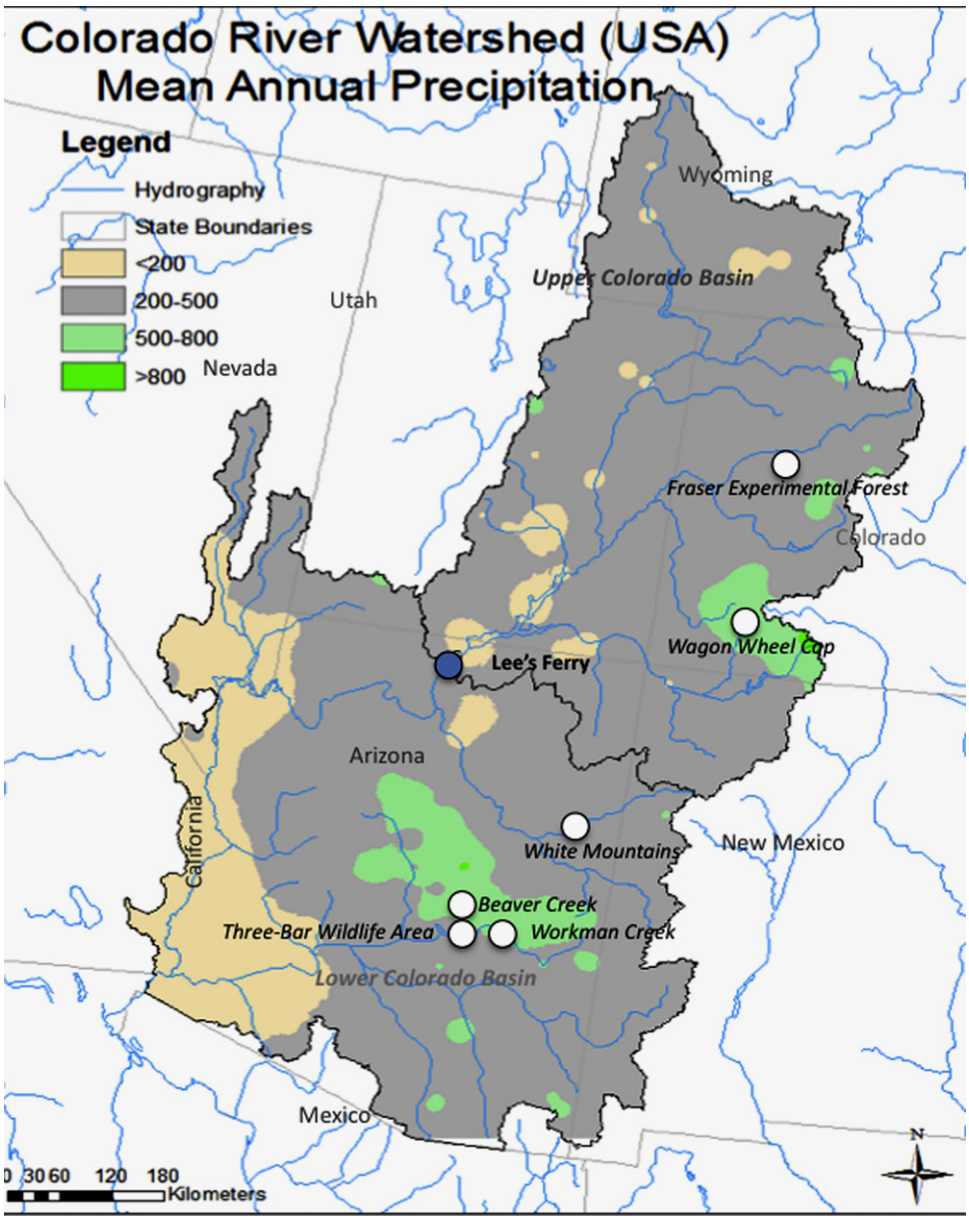

Fig. 1. Mean annual precipitation of the Colorado River Basin. The boundaries of the watershed were determined using the USGS national hydrography dataset. Precipitation was interpolated using Inverse Distance Weighting of Unifed Climate Access Network Cooperative Climate Stations with 1971–2000 Precipitation Normals for the United States. The analysis was conducted using Albers Equal Area Conic Projection NAD 1983. State boundaries were from the USGS.

the "lowest end" of the gradients (Fig. 1). The magnitudes of streamflow responses to vegetation manipulations also follow along these gradients as discussed below.

1.1. Upper Basin

Annual precipitation in the Upper Basin averages 400 mm, most of which is concentrated on the mountain landscapes. The proportion of this precipitation that is converted into streamflow basin-wide is about 65 mm, or 16%. However, precipitation and the resulting streamflow vary greatly from year to year. Annual streamflow amounts between the Upper and Lower Basins at Lee's Ferry have ranged from about 35% to nearly 165% of the estimated long-term mean streamflow volumes of 1.8 million ha-m. Much of this flow is concentrated in a few spring months when snow melts at the higher elevations (Baker and Ffolliott, 2000). About 4.6 million people are served by the water flows that are available in the Upper Basin, with two-thirds of this water used in the agricultural sector.

Subalpine forests of spruce, fir, Douglas-fir, and lodgepole pine occupy 2.8 million ha at elevations of 2100–3500 m. These forests are situated in a cool, moist climate immediately below the high-mountain alpine zone and receive 500–1400 mm of annual precipitation, two-thirds of which is snow. Ponderosa pine forests are found on 0.6 million ha at lower elevations between 1850 and 2750 m. These forests attain their "best development" on sites that are warmer and drier than those in subalpine forests. Annual precipitation averages 380–635 mm, with about one-half being snowfall. Mountain brush lands dominated by the shrub-form of Gambel oak are located on 1.3 million ha at elevations from 1500 to 3000 m. Sometimes classified as chaparral shrublands, mountain brush ecosystems are comprised of woody plants that are deciduous rather than evergreen. Annual precipitation ranges from 400 to 600 mm less than one-half of it is snow. Big sagebrush