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Long-term streamflow relations with riparian gallery forest expansion into tallgrass prairie in the Southern Great Plains, USA

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ABSTRACT

Though the effects of forests on water yields have been studied since the early 20th century, considerable uncertainty remains regarding streamflow relations in landscapes where forestation of degraded grassland is accompanied by recovery of soil hydrological function. This uncertainty arises because trees may reduce subsurface flow by transpiring water inaccessible to shallow-rooted grasses, but forestation of degraded grassland may also improve soil infiltration capacity, thereby increasing soil water recharge, a prerequisite for baseflow. To determine how riparian gallery forest expansion affected streamflow, we classified a chronosequence of historical aerial photography covering a 78 km^2 watershed equipped with a streamflow gauge. Here we show that in the Council Creek watershed in north-central Oklahoma, the baseflow component of streamflow increased from 1938 to 1992 during which time tree cover increased from 5% to 18% of the watershed area. During this period there were significant increasing trends in precipitation and evapotranspiration, but no significant trends in total streamflow. Stepwise regression indicated that relative to increases in precipitation, increases in forest cover were a better predictor of the observed baseflow increase. Baseflow increases over time were not distributed uniformly throughout the year, but rather occurred only from October through May, during most of which time the primarily deciduous riparian gallery forest species and the herbaceous species that they replaced would have been dormant. Due to confounding factors including elevated precipitation from 1980 to 1992, changing precipitation characteristics, and changing land-use, it was impossible to determine to what extent riparian gallery forest expansion caused the associated baseflow increases. Nonetheless, the method used in the study—relating an historical aerial photography chronosequence to existing long-term stream gauge data—proved to be an inexpensive, efficient, and effective in disproving our hypothesis that riparian gallery forest expansion would reduce baseflows. Further research is needed to better predict how long-term changes in forest cover, the position of forest cover within a watershed, and associated changes in soil and floodplain hydrology will affect streamflow in large mixed land-use watersheds.

1. Introduction

Whereas forestation of both upland and riparian areas has transformed rangelands worldwide, research is needed to inform watershed managers as to the water yield implications of these changes (Tabacchi et al., 2000; Newman et al., 2006; Wilcox, 2007, 2010; Wilcox and Thurow, 2009). In the Great Plains of North America riparian gallery forest expansion is one such process that has transformed riparian corridors. Prior to European settlement, North American Indians used fire to convert large areas of forest to grassland (Pyne, 1983). Historically, these fires may have prevented the expansion of gallery forests into grasslands (Bragg et al., 1993; Abrams, 1996; Danner and Knapp, 2001, 2003). Since European settlement, fire intensity and frequency decreased, allowing expansion of riparian gallery forests (Abrams, 1986). For instance, at Konza Prairie (3487 ha) in the Flint Hills of Kansas, GIS analysis of historical aerial photographs uncovered an increase in riparian gallery forest from 157 ha in 1939 to 241 ha in 1985 (Knight et al., 1994). Eastern redcedar (*Juniperus virginiana*) encroachment into Great Plains rangelands (Linneman and Palmer, 2006; Coppedge et al., 2007; Crawford and Hoagland, 2009; Van Els et al., 2010; Wine et al., 2011) has been more widely documented than riparian gallery expansion. Similar to riparian gallery expansion, eastern redcedar encroachment is attributed to reduced fire frequency (Arend, 1950). Encroachment of this species can occur in both upland and riparian settings. Eastern redcedar encroachment is projected to affect over 3.5 million ha in Oklahoma alone by 2013 and is believed to reduce streamflow (Starks et al., 2011).

That forestation may reduce streamflow in areas where subsurface flow is an important streamflow generation process appears axiomatic from the literature (Hibbert, 1983; Wilcox, 2002, 2006; Huxman et al., 2005; Huang et al., 2006; Seyfried and Wilcox,

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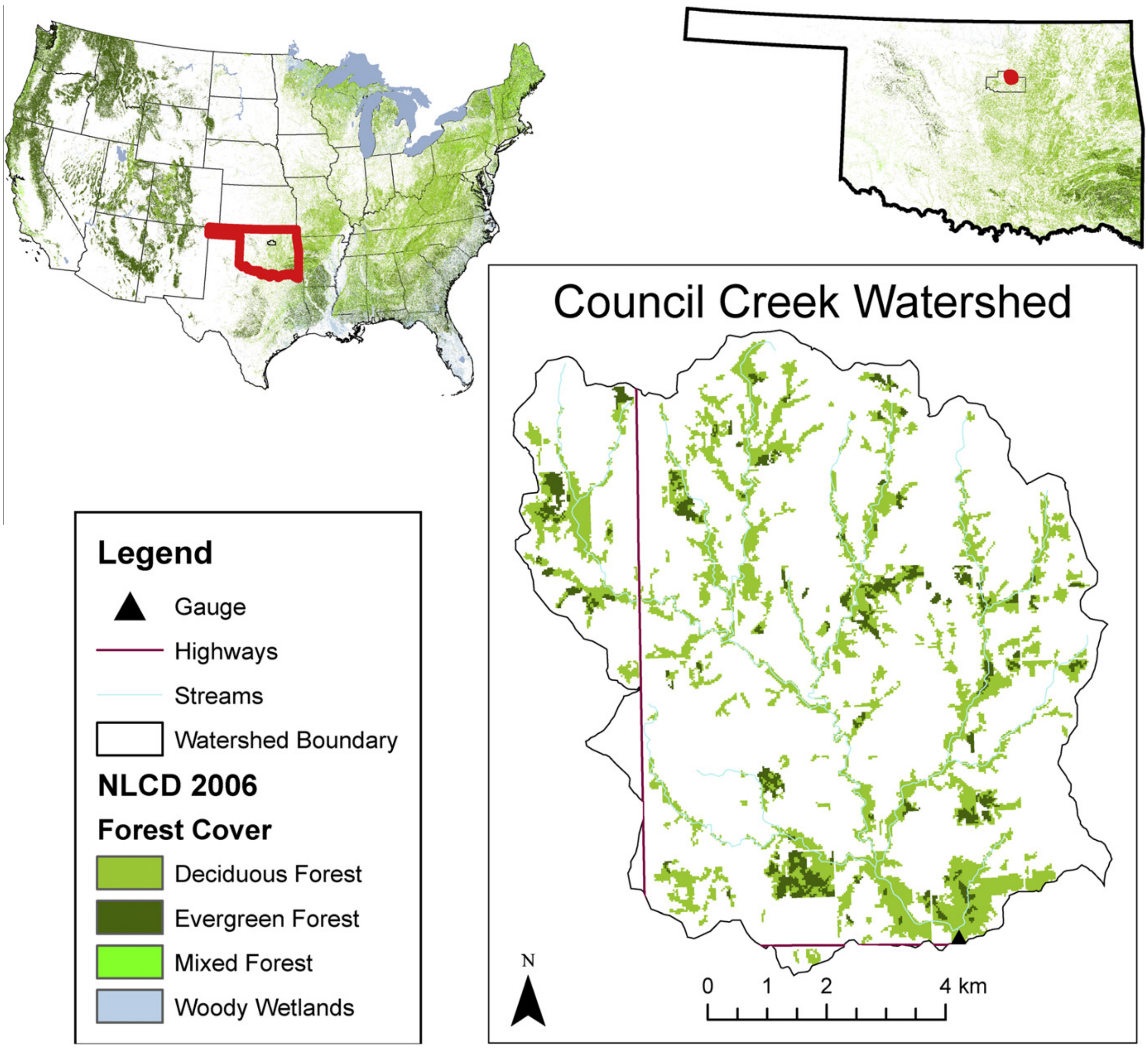

Fig. 1. Maps of the distribution and abundance of forest cover in the United States, Oklahoma, and the Council Creek watershed.

2006). Assuming other conditions remain the same, it seems logical that replacement of shallow-rooted grasses by deeply rooted trees could reduce streamflow if the latter were phreatophytic and transpired from aquifers or perched water tables inaccessible to shallow-rooted grasses. However, this line of reasoning disregards how forestation can transform the infiltration capacity of degraded rangeland soils. Forests or woodlands generally have considerably greater infiltration capacity than other land cover types such as grasslands (Wilcox et al., 2003; Bruijnzeel, 2004; Wilcox et al., 2008a; Neary et al., 2009). Thus, as degraded grassland converts to forest, subsurface flows should decrease due to the aforementioned axiom, but might be expected to increase as infiltration—a prerequisite for soil water recharge and subsurface flow—increases.

In central Texas watersheds, decreased stormflows and stable or slightly increasing baseflows were the net effects of deeper rooting depth and greater infiltration capacity of soils as degraded grasslands converted to woodlands (Wilcox et al., 2008b). In this study of three watersheds no decreases in total streamflow were observed, except in the watershed with the least karstic soil parent material. A similar study assessed long-term streamflow trends on the Edwards Plateau of Texas and uncovered a doubling of

Table 1
Mean, median, first quartile, third quartile, and *p*-values from Mann–Kendall trend tests for annual hydrologic variables from 1938 to 1992 in the Council Creek watershed, Payne County, Oklahoma.

Variable	Mean	Median (Q1–Q3)	*p*-Value
Precipitation (mm)	850	818 (711–950)	**0.021**
Potential evapotranspiration (mm)	1170	1160 (1109–1216)	−0.151
Streamflow (mm)	143	110 (49–212)	0.129
Stormflow (mm)	114	90 (38–151)	0.248
Baseflow (mm)	30	21 (10–42)	**0.012**
Evapotranspiration (mm)	706	718 (621–772)	**0.086**
Baseflow/streamflow (%)	20%	19 (15–24)	**0.001**
Streamflow/precipitation (%)	15%	14 (7–20)	0.173
Flow duration (days)	264	275 (220–330)	**0.008**

Bold values are statistically significant ($\alpha = 0.1$). Negative signs indicate decreasing trends and positive *p*-values correspond to positive trends.