Agricultural Water Management 185 (2017) 93–104

Contents lists available at ScienceDirect

Agricultural Water Management

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

Human factors were dominant drivers of record low streamflow to a surface water irrigation district in the US southern Great Plains

Erik S. Krueger[a,*], Yohannes Tadesse Yimam[b], Tyson E. Ochsner[a]

[a] Dep. of Plant and Soil Sciences, Oklahoma State Univ., Stillwater, OK 74078, United States
[b] Dep. of Soil and Crop Sciences, Texas A&M Univ., College Station, TX 77843-2474, United States

ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form 5 December 2016
Accepted 31 January 2017
Available online 20 February 2017

Keywords:
Groundwater
Drought
Climate
Conjunctive water management
Climate elasticity

ABSTRACT

Irrigated agriculture in the North Fork of the Red River watershed in western Oklahoma and the Texas Panhandle depends on groundwater upstream of Lake Altus-Lugert and surface water from the lake, but like much of the world, the region is prone to water scarcity. During a severe drought from 2010 to 2015, streamflow into the lake reached record lows, and the lake was depleted until no water remained for the surface water irrigation district. Area residents were left wondering whether drought or human factors were primarily responsible for the reduced streamflow and the four years of crop failures that resulted. We aimed to clarify climate and human influences on streamflow in the North Fork of the Red River watershed by (1) quantifying changes in annual streamflow, climate, groundwater use, and land use upstream from Lake Altus-Lugert from 1970 to 2014, (2) determining the relative contributions of climate and human factors to changes in streamflow, and (3) developing statistical models describing the relationships of climate and human variables with streamflow. We found a counteracting increase (around 1986) and decrease (around 2001) in streamflow, with human factors being responsible for slightly more than half (51–56%) of each change. There were no long-term trends in precipitation and reference evapotranspiration (ET_0), but low streamflow from 2002 to 2014 coincided with a period of low precipitation, high ET_0, and a 75% increase in groundwater withdrawal for irrigation in the Oklahoma portion of the watershed. A multiple regression model containing only precipitation and groundwater withdrawal for irrigation explained 81% of annual streamflow variability. These statistical relationships suggest that upstream groundwater use was an important driver of streamflow changes. Our results indicate that sustained agricultural productivity near Lake Altus-Lugert may require the adoption of conjunctive water management strategies, and our methods offer a framework for similar assessments in other water-scarce regions.

1. Introduction

Approximately two thirds of the people in the world live in regions facing severe water scarcity at least one month out of the year (Mekonnen and Hoekstra, 2016), which causes a wide array of harmful effects including lost crop production, decreased food security, degraded ecosystem health, and increased infant mortality (Ejaz Qureshi et al., 2013; Ibáñez and Caiola, 2013; Meng et al., 2016; Rocha and Soares, 2015). Water scarcity is essentially a spatial or temporal mismatch between the availability and demand for freshwater and thus can result from transient climate factors, such as drought, or from potentially longer time-scale human factors, such as demand growth (Martin-Carrasco et al., 2013). Recurring drought is part of the climate of many water-scarce regions, and its impacts on water availability and demand are somewhat inescapable. Human factors such as groundwater withdrawal and changes in land use, on the other hand, can potentially be managed to mitigate water scarcity, but the individual effects of climate and human factors on water availability are often difficult to discern. To alleviate or prevent water scarcity, there is a need to differentiate the relative influences of climate and humans on water availability (Renner et al., 2014); a challenging task because human activities can mimic, exacerbate, counteract, or mask climate effects (Jones et al., 2012).

In this study, we seek to clarify the influences of climate and human factors on water availability (in the form of streamflow) within the context of irrigated agriculture in the southern Great Plains of the United States, a region noted for high levels of water

* Corresponding author.
E-mail address: erik.krueger@okstate.edu (E.S. Krueger).

http://dx.doi.org/10.1016/j.agwat.2017.01.018

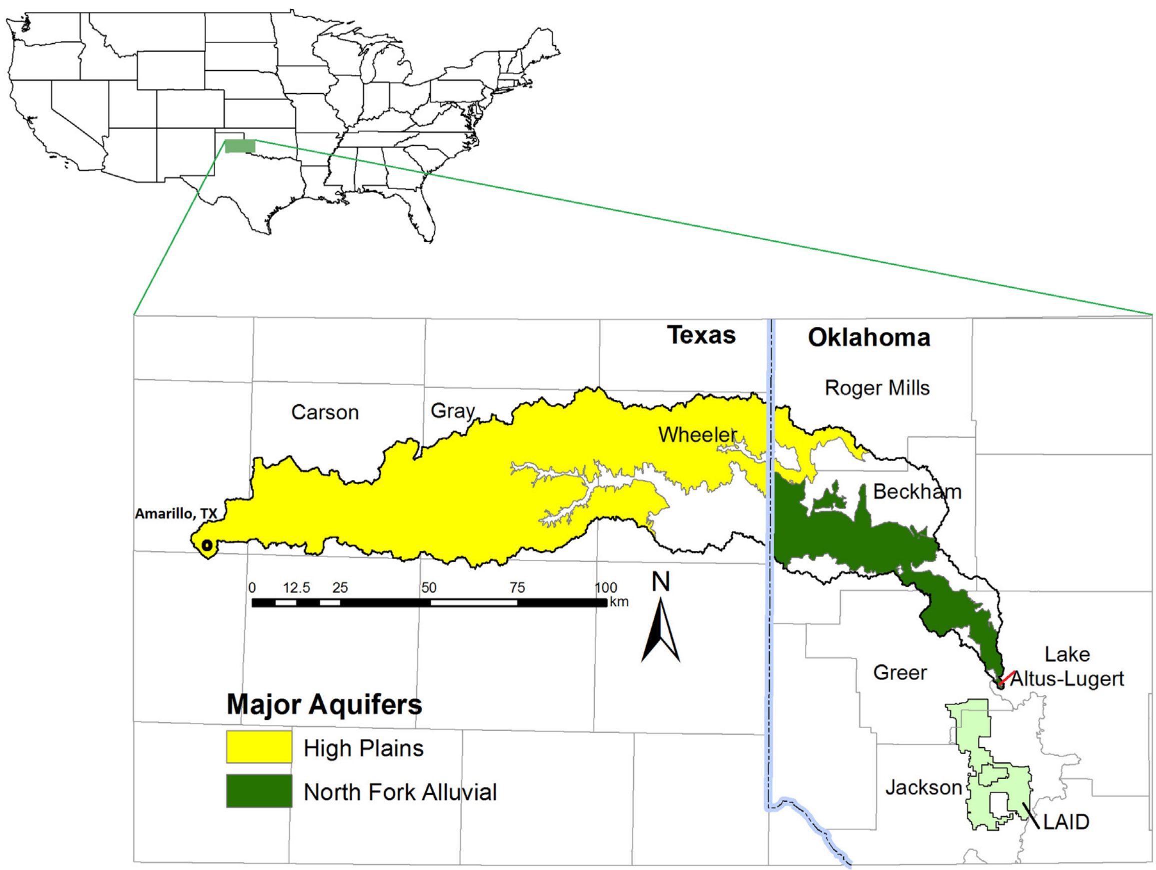

Fig. 1. The North Fork watershed and underlying portions of the High Plains and North Fork Alluvial aquifers upstream from Lake Altus-Lugert stretch from the central Texas Panhandle to southwest Oklahoma, covering 7335 km^2. The Lugert-Altus Irrigation District (LAID) is downstream (south) of Lake Altus-Lugert.

scarcity (Mekonnnen and Hoekstra, 2016). From late 2010 through early 2015, a particularly severe instance of reduced streamflow affected the North Fork of the Red River (North Fork hereafter) in Texas and Oklahoma, a river that supports one of the few surface water irrigation districts in the southern Great Plains (Fig. 1). The surface water irrigation district, called the Lugert-Altus Irrigation District (LAID), draws water from Lake Altus-Lugert, which was formed by the impoundment of the North Fork in 1945 (Kent, 1980; Smith and Wahl, 2003). In 2010, water release from the lake to the irrigation district was 89 million m^3 (USDOI-BOR, 2015), making the district the largest surface water irrigation user in Oklahoma (Tortorelli, 2009). That water was primarily used to irrigate cotton, and the county in which the district is located produced ~36,600 Mg (168,000 bales) of cotton worth ~$83 million USD that year (USDA-NASS, 2015a). But in October 2010, Oklahoma and Texas entered a period of unprecedented drought (Hoerling et al., 2012), with annual precipitation in 2011 that was the lowest on record near the North Fork in the Texas Panhandle (<250 mm) (TWDB, 2016c) and the lowest since 1970 in west central Oklahoma (<450 mm) (OCS, 2015). During the summer of 2011, streamflow into the lake was <0.1 mm (2% of long-term summer average), and for the first time in the history of Lake Altus-Lugert, irrigation release was terminated (USDOI-BOR, 2015). Water for irrigation did not become available again until mid-2015.

Without irrigation, cotton crops failed, and cotton production in the county from 2011 to 2014 averaged less than 10% of the production in 2010 (USDA-NASS, 2015a). As a result of these four successive crop failues, agricultural producers in the county received crop insurance payments totaling over $223 million USD (USDA-RMA, 2016), a fact that gives some idea of the magnitude of the economic impact of the drought. By early 2015, the lake had almost disappeared, falling below 10% of its normal capacity, before heavy spring rains in 2015 finally produced adequate streamflow to refill the lake. This experience of water scarcity had severe local economic and ecological impacts, and the lake and a portion of its watershed are classified as a water resources "hot spot" because of expected future water shortages (OWRB, 2012).

The question facing the citizens and agricultural producers in the area is unmistakable: was reduced streamflow due solely to the drought, or did upstream factors such as increased groundwater use for irrigation or land-use changes contribute to the lake's demise? The answer is not obvious because the links between streamflow, climate, and human factors are complex. For example, elevated streamflow in seven Oklahoma watersheds was attributed to increased precipitation when human factors were absent (Garbrecht et al., 2004). But streamflow has also been found unchanged when precipitation increased in a prior study on the North Fork, suggesting human factors can mitigate the impact of precipitation changes (Smith and Wahl, 2003). When streamflow decreased without a change in precipitation, groundwater withdrawal was implicated for streamflow declines in the Beaver-North Canadian River in northwest Oklahoma (Wahl and Tortorelli, 1997). The impact of groundwater withdrawal and other human factors can be large, contributing nearly 50% of the variability in annual streamflow (Dale et al., 2015). In extreme cases, decreased streamflow caused by groundwater withdrawals and climate change can result in unsustainable reservoir storage, or in the Oklahoma Panhandle, complete reservoir failure (Brikowski, 2008).

Land use change can also alter streamflow characteristics, with decreased cropland and increased grassland in north central Okla-