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Hydrologic impacts of drought-adaptive agricultural water management in a semi-arid river basin: Case of Rincon Valley, New Mexico

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ABSTRACT

This paper examines the coupled effects of weather condition, crop coverage change, and regional water management (i.e., releases from Caballo Reservoir) on hydrologic characteristics of Rincon Valley (2466 km^2), a semi-arid agricultural area in New Mexico, U.S.A., using Soil and Water Assessment Tool (SWAT). The model simulates the vertical water budget and horizontal water transfers during the period 1994–2013, incorporating irrigation of fourteen crops in normal (2008) and dry (2011) years to evaluate the hydrologic impacts of cropping change as a drought-adaptive water management strategy. It was calibrated (2000–2002) and validated (2003–2005) using daily-observed streamflow data. Furthermore, evapotranspiration, diversion and irrigation water volume were verified for the period of 2000–2005 using monthly crop irrigation requirement data and canal discharge data. Results demonstrate the significant role of surface water infiltration, providing approximately 18% of the average annual groundwater recharge during the irrigation season. Watershed scale evapotranspiration (ET) and return flows for the irrigation season were estimated to be 23% and 1% higher than those for the non-irrigation season, respectively. For irrigation units, the ratio of ET to combined precipitation and irrigation water for the dry year was 5% higher than the normal year whereas surface runoff, soil water storage, and groundwater recharge were 7%, 17%, and 39% lower than the normal year, respectively. High groundwater recharge occurs in the hydrologic response units (HRU) where corn and cotton are planted on silty clay loam soil. The Alfalfa acreage (i.e., the largest water user) was reduced by 15% while the cotton acreage was increased by 13% in order to adapt to lower water availability during the dry year. Quantitative understanding of the hydrologic fluxes in the Rincon Valley's irrigated agricultural area illuminates adaptive land and water management to buffer the adverse impacts of prolonged droughts.

1. Introduction

Global changes in temperature and precipitation patterns are expected to alter regional climates and hydrological systems (Changnon et al., 1998; Zektser and Loaiciga, 1993; Scibek et al., 2007). Numerous studies have documented that the hydrological cycle is already being impacted by climate change (Dragoni, 1998; Labat et al., 2004; Huntington, 2006; IPCC, 2007; Seager et al., 2007; Fagre et al., 2009; Sheng, 2013; Ahn et al., 2016; Ahn and Kim, 2016) and human activities, such as irrigated agriculture and urban development, especially in arid and semi-arid regions (Zektser et al., 2004; Ma et al., 2005; Barnett et al., 2008; Kim et al., 2017). These changes are particularly evident in the southwestern U.S. where climatic variations are affecting water availability through changing the watershed scale hydrologic budget and water balance (e.g., Garfin et al., 2013).

A number of recent studies have assessed water availability for effective watershed management in arid regions through hydrologic modeling. McDonald et al. (2013) assessed the river stages and groundwater flow paths and predicted hydrologic responses to changes in the timing and magnitude of streamflow of dryland river systems in the Pecos River, Texas. Awan et al. (2013) examined the impacts of improved irrigation efficiency on the rate of groundwater recharge by combining hydrological modeling and GIS approaches in the Khorezm district of Uzbekistan, Central Asia. Herrera-Pantoja and Hiscock (2015) discussed the impact of future climate on water availability and water management using a daily water balance in a semi-arid region in Queretaro River Basin, Mexico. Guo and Shen (2016) estimated water availability and agricultural water demand and proposed effective

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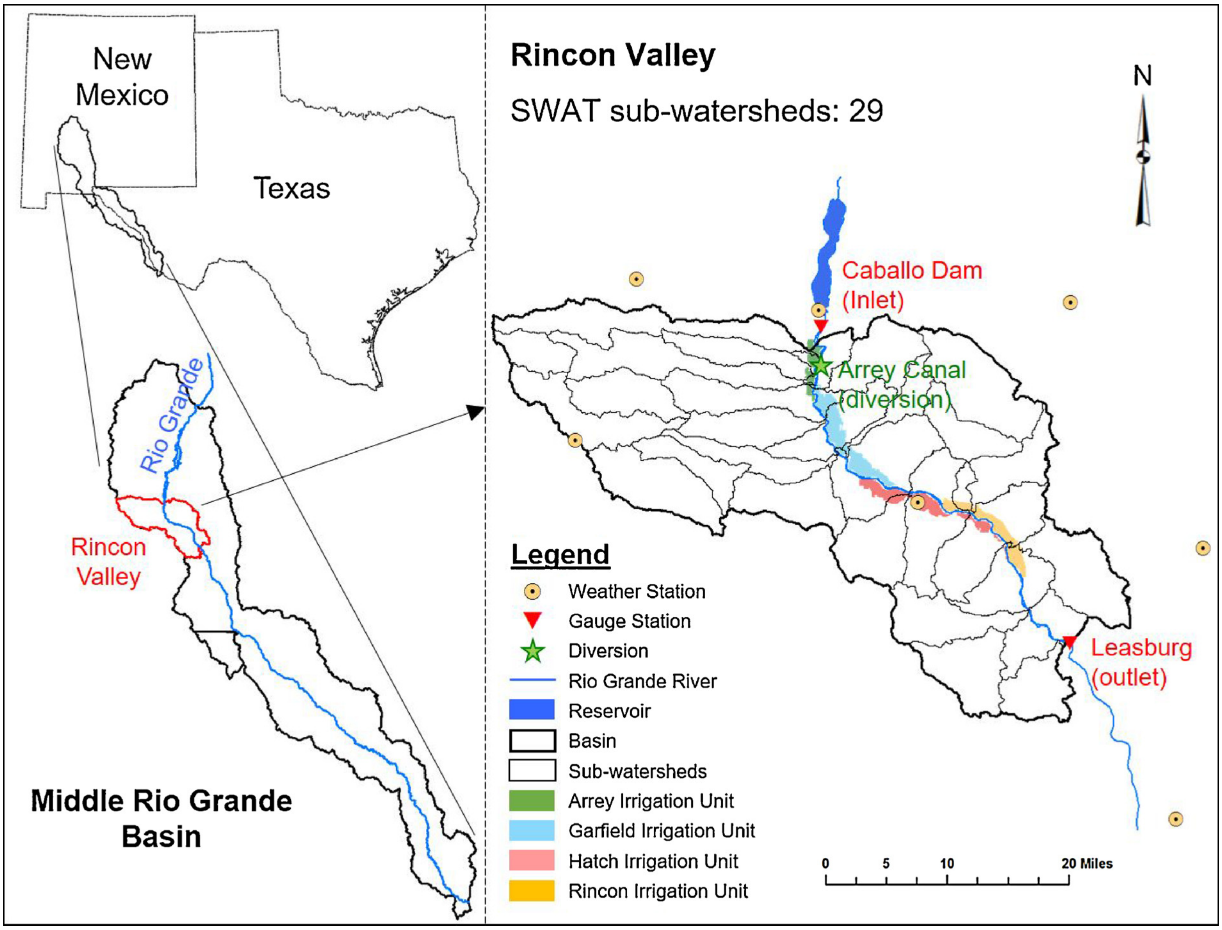

Fig. 1. Locations of the Rincon Valley, gauging stations and the sub-watersheds for the hydrological (SWAT) modeling, and irrigation units.

adaptation strategies to cope with severe water shortages under possible climate change trends in the arid region of northwestern China.

The Upper Rio Grande basin is an arid/semi-arid river basin relying on the conjunctive use of surface water and groundwater to sustain irrigated agriculture. With increasing uncertainty of surface water availability and consequent increase in groundwater extraction under variable climates, there has been growing interest in better understanding how these resources can be managed to meet urban, agricultural, and environmental water demands. Due to increasingly frequent, extended periods of severe drought, the Rio Grande River alone no longer meets regional water needs. Thus, it is critical to account for interactions of surface water with groundwater in the assessment of water availability in this region (Liu and Sheng, 2011).

Unlike river basins in humid regions, arid/semi-arid river basins typically exhibit reduced flow in the downstream direction as a result of transmission losses, which include seepage of streamflow into the underlying aquifer, open water evaporation, and riparian plants transpiration. Moreover, reduced precipitation in dry regions could trigger disproportionately large drops in groundwater levels as a result of groundwater mining for irrigation (Dragoni and Sukhija, 2008). Therefore, much remains to be learned about the exchange between surface water and groundwater in these landscapes through long-term hydrologic modeling analyses, especially in terms of spatial and temporal water variability (Nanson et al., 2002; McDonald et al., 2013).

The regional water balance and hydrologic budget can be assessed through systematic modeling using the Soil and Water Assessment Tool (SWAT; Arnold et al., 1998) because of the model's robust approach based on the soil water balance at the watershed scale. SWAT has been successfully used to study the temporal and spatial effects of hydrological changes in a number of river basins (Sun and Cornish, 2005; Awan et al., 2013; Ahn et al., 2016; Karlsson et al., 2016; Sellami et al., 2016; Chung et al., 2017; Molina-Navarro et al., 2016), including irrigated agricultural watersheds around the world (Kannan et al., 2011; Xie and Cui, 2011; Dechmi et al., 2012; Perrin et al., 2012; Awan and Ismaeel, 2014; Chen et al., 2017; Jang et al., 2017; Özcan et al., 2017).

This study aims to narrow the knowledge gap about surface water-groundwater exchange in a semi-arid irrigated agricultural region by investigating the hydrologic behavior of Rincon Valley in the Upper Rio Grande basin. To this end, we applied a watershed-scale SWAT model under different weather conditions and cropping patterns. The calibrated SWAT model was used to analyze the water balance by vertical water budget (infiltration, evapotranspiration, percolation, soil water storage, re-evaporation, and groundwater recharge) and horizontal water transfer (surface runoff, lateral flow, and return flow) for irrigation and non-irrigation seasons of the period 1984–2013. Then, the impacts of surface water and groundwater exchange on the water balance and groundwater recharge were evaluated. The spatial crop coverages including normal and dry years were one of the important inputs for the SWAT model. Furthermore, the effects of different weather conditions and crop coverage change on hydrologic components were simulated at different hydrologic response units (HRUs) within the irrigation district. The results provide detailed information on hydrologic components over time and space, offering insights about surface water-groundwater exchange in climatically similar areas where water and land management to sustain irrigated agriculture is a primary goal. The study has important implications for regulating irrigation water use and enabling agricultural water users to devise adaptation plans taking into account plausible impacts of increasing aridity on the hydrologic components.