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Evaluating the impacts of crop rotations on groundwater storage and recharge in an agricultural watershed

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ABSTRACT

The Mississippi River Valley Alluvial Aquifer, which underlies the Big Sunflower River Watershed (BSRW), is the most heavily used aquifer in Mississippi. Because the aquifer is primarily used for irrigating crops such as corn, cotton, soybean, and rice, the water levels have been declining rapidly over the past few decades. The objectives of this study are to analyze the relationship and interactions between evapotranspiration and groundwater recharge rates in the BSRW, and model the effects of various crop rotation practices on groundwater storage and recharge.

The model performed well during the calibration period (R^2 = 0.53–0.68 and NSE = 0.49–0.66) and validation period (R^2 = 0.55–0.75 and NSE = 0.49–0.72) for daily streamflow, which was achieved by the SUFI-2 auto-calibration algorithm in the SWAT-CUP package. The model also performed well in simulating seasonal water table depth fluctuations during calibration (R^2 = 0.76 and NSE = 0.71) and validation (R^2 = 0.86 and NSE = 0.79). This study demonstrated a seasonal relationship between evapotranspiration and groundwater storage and recharge in the BSRW SWAT model. In general, groundwater storage decreased during the summer months while ET rates were high, and increased during the winter and spring months when ET rates were low. The crop rotation scenarios that include rice planting resulted in the lowest groundwater storage (down to −10.7%) compared to the baseline crop scenario, which is due to the high irrigation rates of the rice crop. However, the rice crop rotations resulted in the highest increases of groundwater recharge rates (up to +60.1%), likely because of the response to the deficiency of groundwater needed for irrigation as well as the limited water uptake by the rice crop. The crop rotations with corn and cotton resulted in the largest increases in groundwater storage (up to +27.2%), which is the result of the low irrigation rates as well as the short time period for irrigation applications. The results of this study are expected to aid farmers and watershed managers to conserve groundwater resources, but still maintain crop production.

1. Introduction

Research indicates that land use change is a prominent factor influencing the amount and movement of water in the hydrologic cycle, namely runoff, evapotranspiration, stream discharge, and groundwater flow (Batelis and Nalbantis, 2014; Khanal and Parajuli, 2013; Wang et al., 2013). These hydrological changes can result from alterations to surface roughness, soil characteristics, plant cover, and surface water storage (Parajuli et al., 2013; Thanapakpawin et al., 2006; Tuppad et al., 2010; Wild and Davis, 2009). While certain land use alteration strategies can alleviate the problems of surface water and groundwater scarcity, they can also cause adverse effects on the environment and exacerbate those problems (Foley et al., 2005; Lotze-Campen et al., 2008). Especially in agricultural areas, groundwater sources tend to be over extracted and exploited without any regard to employing any conservational or sustainable management practices (Fereres and Soriano, 2006). It is estimated that global groundwater reserves are being depleted very rapidly to meet the irrigation demand for crop production at a withdrawal rate of 545 km^3 per year, and this rate is expected to increase (Konikow, 2013; Siebert et al., 2010). Therefore, it becomes necessary to employ sustainable management practices to conserve groundwater in these areas while still maximizing crop production. Many field studies and modeling studies have attempted to quantify the effects of

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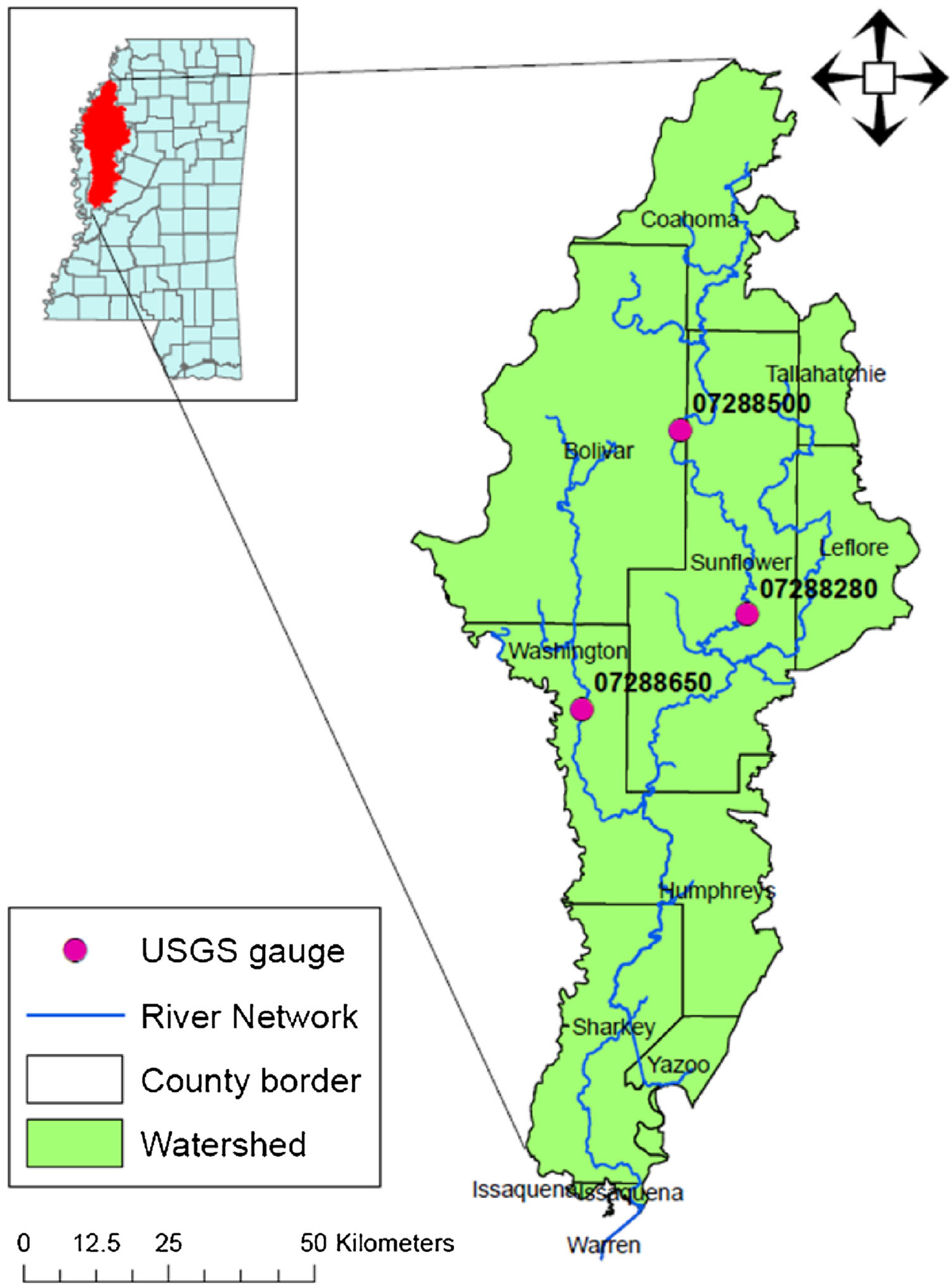

Fig. 1. Location of the Big Sunflower River Watershed (BSRW) in northwestern MS showing counties, river network, and USGS gauge stations.

changing land uses and soil characteristics on groundwater storage and flows. The results of a land use comparison study showed that groundwater recharge rates are much higher in an irrigated agricultural watershed (130–640 mm/yr) than in a non-irrigated agricultural watershed (9–32 mm/yr) (Scanlon et al., 2005). A study conducted in a watershed in Denmark found that converting grasslands to forests had a very small effect on groundwater recharge, while increased CO_2 caused considerable additional groundwater recharge within the watershed (Roosmalen et al., 2009). Huang et al. (2012) found that converting grassland to winter wheat over a 100-year period reduced groundwater recharge rates by up to 50%, which was attributed to the changes in evapotranspiration. A study that linked a vadose zone model and a saturated groundwater model for a watershed in south-western Australia found that recharge rates are higher in pasture land covers compared to areas with native vegetation (Dawes et al., 2012).

While the aforementioned studies evaluated the effects of land use change on groundwater flows, there are no studies specifically addressing the impacts of crop rotation practices on groundwater storage and recharge. This study will utilize the soil and water assessment tool (SWAT) to quantify the effects of crop rotations on groundwater storage and recharge.

In the past, SWAT has been used to calibrate and validate watershed models using groundwater table depths. However, it should be noted that the current version of SWAT does not print groundwater table depths, which makes verifying SWAT groundwater outputs somewhat challenging. For example, Vazquez-Amabile and Engel (2004) attempted to calibrate their watershed model with observed groundwater table depths using SWAT for three different soil types. They had to compute water table depths by using the soil input data and SWAT soil water output to predict fluctuations in the shallow aquifer, which is based on the DRAINMOD