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**Water Resources Management**

An International Journal - Published  
for the European Water Resources  
Association (EWRA)

ISSN 0920-4741

Water Resour Manage  
DOI 10.1007/s11269-020-02526-3



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# Assessing Agriculture Conservation Practice Impacts on Groundwater Levels at Watershed Scale

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Received: 11 October 2019 / Accepted: 8 March 2020 / Published online: 14 March 2020  
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## Abstract

Over the last several decades, increased groundwater usage by agriculture with a consequence of groundwater resource depletion has motivated the discussion of sustainability of groundwater resource. In this study, to investigate the impacts of agricultural best management practices (BMPs) on groundwater level, two kinds of conservation practices and five scenarios of tail water recovery pond and crop rotation were simulated by various groundwater recharge and pumping plans in Soil and Water Assessment Tool (SWAT) and MODFLOW models in an agriculture watershed in Mississippi, U.S.. The calibrated and validated ground water model indicated coefficient of determination ( $R^2$ ) of 0.81 and Nash–Sutcliffe model efficiency coefficient (NSE) of 0.79 respectively. The results from this study showed that the groundwater recharge changed with irrigation plans and surface hydrological impact of management practices. In addition, it determined that tail water recovery pond could help mitigate groundwater depletion. The groundwater recharge due to continuous corn crop scenario was 7% higher in average than that of the continuous soybean. Non-growing season groundwater recharge may be critical for groundwater recovery. The average groundwater level was increased continuous corn scenario by 15%, continuous soybean by 13%, and corn-soybean by 14% as compare to the baseline scenario with rice planted. Results of this study can be helpful for planning on how various BMPs impact on groundwater.

**Keywords** BMPs · Groundwater · MODFLOW · SWAT · Tail water recovery pond

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s11269-020-02526-3>) contains supplementary material, which is available to authorized users.

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## 1 Introduction

Human activity impacts on groundwater resource have been widely discussed over last several decades (Kim and Jackson 2012; Luo et al. 2019; Lyu et al. 2019; Siebert et al. 2010). In United States (U.S.), groundwater resource provides approximately 40% of nation's water supply (Alley et al. 1999) and over 40% of total irrigation water of croplands (Maupin et al. 2014). Compared to other water resources like precipitation and surface water, groundwater continuous supports irrigation both temporally and spatially. However, progressively growing of groundwater usage for irrigation has caused groundwater depletion in many places in U.S., which motivates the discussion of sustainability of groundwater resources in agriculture region focusing on agricultural management plans (Logan 1990; Wada et al. 2010).

Agricultural management practices alter temporal or spatial water use and consequently affect groundwater recharge (Dakhlalla et al. 2016; Klocke et al. 1999; Zhang and Schilling 2006). For example, crop rotation as a widely applied best management practice (BMP) in U.S. results in different water use efficiency due to evapotranspiration amount and irrigation plans varying by vegetation species planed every year, which has potential impacts on groundwater recharge (Kim and Jackson 2012; White et al. 2002; Zhang and Schilling 2006). However, Klocke et al. (1999) monitored drainage volume from continuous corn and corn-soybean rotation fields in Nebraska, U.S. and found there was no significant difference between two crop rotation plans. Similarly, Dakhlalla et al. (2016) simulated groundwater recharge under different rotation scenario. They found that the different crop rotation plans did affect groundwater recharge amount at various levels. Rotations involving rice generally have more groundwater recharge amount compared to others, while scenario with corn and soybean rotation provided similar groundwater recharge with continuous corn and soybean.

Given various groundwater recharge and withdrawal of BMPs, surface water and groundwater balance changes leading to different responds of groundwater level (Barlow and Clark 2011; Yang et al. 2015, 2002). Yang et al. (2002) analyzed groundwater level from 1974 to 1998 in Gaocheng, China and indicated that decrease of groundwater recharge contributed to groundwater decline in that area. For Mississippi River Valley alluvial aquifer, Barlow and Clark (2011) evaluated several groundwater conservation plans with reducing groundwater pumping by 5% and 25%. Their results showed reducing agricultural consumption brought an increase of groundwater storage from 2% to 31.7% while the recharge rate assumed to be same. Among BMPs in terms of groundwater consumption reduction, tail water recovery pond is a relative new application in recent decades and has the potential to affect temporal groundwater usage by storing and then reusing the excess runoff (USDA 2011) However, the evaluation of its quantitative impact on groundwater level has not been discussed. Thus, with BMPs continued to be implemented to improve surface water and groundwater use efficiency, evaluating their groundwater impacts is necessary.

Simulating the BMP impacts on groundwater involves both surface and groundwater hydrological model. For an agricultural watershed, spatial variation of groundwater recharge and withdrawal due to various land covers is critical for estimating the BMP hydrological impacts (Anuraga et al. 2006; Cheema et al. 2014; Lyu et al. 2019). Therefore, distributed surface hydrological models accounting land cover variation were usually applied to simulate groundwater recharge (Arnold et al. 1993; Sharma 1986). Evaluating the impacts of BMPs on groundwater recharge requires the modeling tools with factors representing both surface hydrology and agricultural activity such as irrigation schedule. Compared to other watershed modeling tools, the Soil and Water Assessment Tool (SWAT) has been developed comprehensively for agriculture watershed and widely applied on BMP simulation (Arabi et al. 2008;

Jayakody et al. 2014; Parajuli et al. 2016). The ability of simulating irrigation source and schedule using SWAT was successfully indicated by several studies (Dechmi and Skhiri 2013; Gosain et al. 2005; Rosenthal et al. 1995). Thus, SWAT has the potential to obtain the different recharge among various BMPs regarding distributed land cover. In addition to surface water model, groundwater model is needed to simulate water movement in aquifer to obtain the groundwater response to the change of groundwater recharge and withdrawal (Arnold et al. 1993; Kollet and Maxwell 2008; Sulis et al. 2010). Modular Three-Dimensional Finite-Difference Groundwater Flow Model (MODFLOW) (Harbaugh et al. 2000) has been used to investigate the impacts of changing groundwater consumption on groundwater resource (Barlow and Clark 2011; Karamouz et al. 2004; Scanlon et al. 2012). In addition, studies indicated that the MODFLOW and SWAT could be combined to simulate groundwater movement in agricultural watershed (Guzman et al. 2013; Kim et al. 2008). From above, the combining SWAT and MODFLOW is an efficient method to evaluate the groundwater impacts of BMPs.

Here, the main objective of this study was to evaluate the impacts of tail water recovery ponds and crop rotations on groundwater resource, which has not been established before. In addition, this study can be helpful to policy makers or watershed managers for watershed planning and understanding how various crop rotations or tail water recovery pond BMPs impact on groundwater. The specific tasks included: (i) obtain the groundwater recharge from various BMPs using the SWAT model and (ii) evaluate the impacts of BMPs on groundwater level by various groundwater recharge and withdrawal plans.

## 2 Material and Method

### 2.1 Study Area

The study area was in the Big Sunflower River Watershed (BSRW) (Fig. 1) located in the west part of the state of Mississippi, U. S, which is a major watershed within Yazoo River Basin. Around 76% of the area covered by cropland including corn, soybean, cotton, and rice (USDA/NASS 2009), which contributes to approximately 80% total water use in the area (YMD 2006). Due to the intensive crop production, to enhance agricultural water management, BMPs including crop rotation and tail water pond were implemented in the study area.

Although the state of Mississippi was ranked as the third wettest state in U.S. with annual precipitation around 1400 mm, the average monthly precipitation of irrigation months (generally from May to September) was 30% less compared to other months of the year (Osborn 2010a, b). Because of the difficulty to continuously use precipitation for irrigation, irrigation caused large groundwater consumption. Since early 1990s, the Yazoo Mississippi Delta Joint Water Management District (YMD) has monitored the groundwater level in the Mississippi Delta region through irrigation wells and has observed steady 0.23 m/a decline of groundwater in some of the central Delta region in Mississippi River Valley alluvial aquifer (Hart et al. 2008; YMD 2006). The aquifer is with a relatively thin thickness around 40 m, but the most used aquifer among the aquifers in Mississippi embayment and potentially providing 0.02–0.13 m<sup>3</sup>/s yield as the irrigation water (Clark and Hart 2009). The aquifer sand content ranges from 20 to 100% (Clark and Hart 2009) and with varied layers in different region (Brown 1947). In the study region near the Sunflower county of Mississippi, the aquifer contains an approximately 11 m clay layer and followed by sand and gravel (Brown 1947).

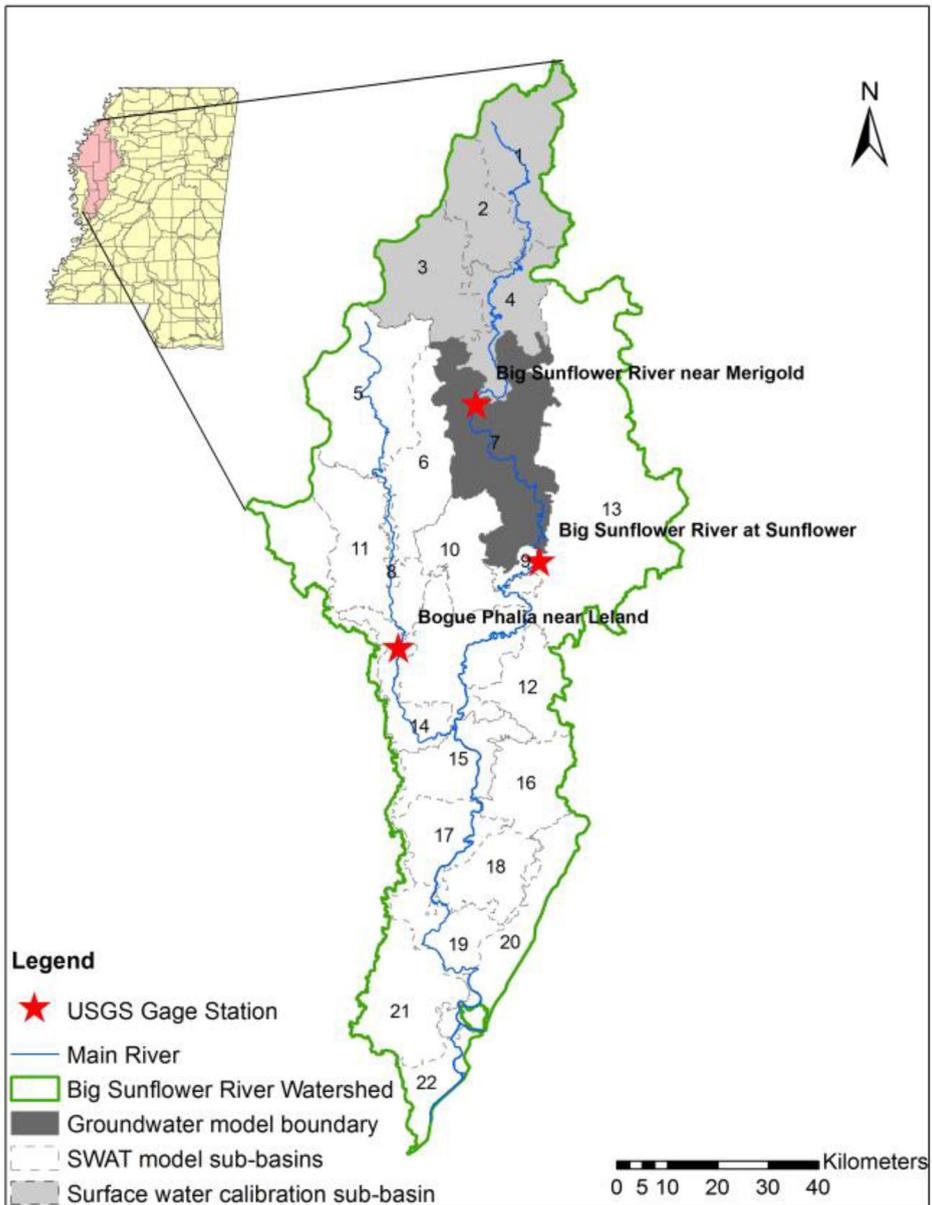


Fig. 1 Boundaries of surface and groundwater models

## 2.2 SWAT Model

A calibrated SWAT model of BSRW (Fig. 1) conducted by Ni and Parajuli (2018) was used to simulate BMPs including crop rotation and tail water recovery ponds. The tail water recovery ponds estimated by satellite images were synthesized and simulated as reservoir in each sub-basin. The crop rotation scenarios were presented by various management schedules in SWAT

model and shown in Table 1 (MAFES 2002-2014; Parajuli et al. 2013; YMD 2002-2010b). The model was evaluated by coefficient of determination ( $R^2$ ) and Nash–Sutcliffe model efficiency coefficient (NSE). More detailed data description (Table S1), model parameters (Table S2), scenario setting, and model performance of the SWAT model could be found in Ni and Parajuli (2018).

### 2.3 MODFLOW Model

The modeling area of groundwater model was the sub-basin 7 in the BSRW SWAT model with the area of approximately 690 km<sup>2</sup> (Fig. 1). This area was with two surface water gaging stations and under severe groundwater declination situation (Barlow and Clark 2011; Dakhllala et al. 2016). The no-flow boundary condition was applied in modeling area with cell dimension of 90 m\*90 m. The modeling stress periods in this study contain 1 steady state indicating average condition before modeling period and 108 transient states with daily time steps from January 2002 to December 2010. The inputs of MODFLOW included aquifer dimension; and sources and sinks in relation to groundwater recharge, river, and well-pumping.

#### 2.3.1 Aquifer Dimension

Figure 2 shows the conceptual groundwater model with two layers according to Brown (1947) and the “Status of Delta water supplies” presentation (Bryd 2014). The two layers included a surficial clay layer simulated as unconfined aquifer with thickness of 11 m, and an unconfined aquifer with thickness of 50 m. Layer 1 was interacted with streams, while layer 2 was the source of groundwater pumping. DEM with resolution of 30 m was considered as the top of the aquifer with elevation of approximately 40 m above the sea level. According to over 20 years groundwater level monitoring data, the groundwater level in study area was approximately 27 m.

**Table 1** Crop rotation irrigation schedule in SWAT model

Crop type	Applied scenarios	Irrigation date	Total irrigation amount	Pond irrigation	GW <sup>i</sup> irrigation
			Baseline	Tail water pond scenario	
Corn	Repeat every year or in year 1 during corn/soybean rotation	15-May	51 mm	17 mm	34 mm
		24-Jun	122 mm	17 mm	105 mm
		15-Jul	68 mm	17 mm	51 mm
		15-Aug	17 mm	17 mm	0
Soybean	Repeat every year or in year 2 during corn/soybean rotation	24-Jun	57 mm	17 mm	40 mm
		15-Jul	78 mm	17 mm	61 mm
		7-Aug	83 mm	17 mm	66 mm
		2-Sep	8 mm	8 mm	0
Cotton	Baseline	14-Jun	24 mm	24 mm	0
		15-Jul	82 mm	30 mm	52 mm
		15-Aug	45 mm	30 mm	15 mm
Rice	Baseline	15-May	137 mm	17 mm	120 mm
		15-Jun	296 mm	17 mm	279 mm
		15-Jul	323 mm	17 mm	306 mm
		15-Aug	153 mm	17 mm	136 mm

<sup>i</sup> groundwater

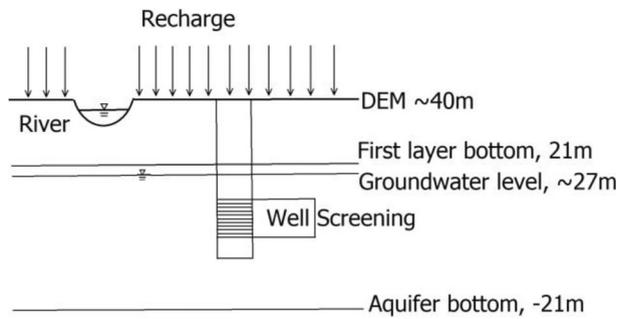


Fig. 2 Conceptual ground water model with two layers

### 2.3.2 Sources and Sinks

For the source of the groundwater, HRU-based monthly recharge calculated in the SWAT model was inputted for each stress period in MODFLOW. The spatial variation of the recharge depended on the scenarios.

River could be both source and sink in the model. Two USGS gage stations in the groundwater modeling boundary shown in Fig. 1 were used to interpolate river stages in each river cell in MODFLOW.

The agricultural pumpage for crop irrigation was considered as the sink in MODFLOW. The irrigation rate of each well was estimated by multiplying the base irrigation rate by the site-specific coefficient. The base irrigation rate of a well depended on its irrigated crop and was decided by adjacent land cover. The monthly base irrigation rate of different crop species was estimated by the average crop use from YMD groundwater use annual reports (Powers 2007; YMD 2002–2010b). There were total 32 wells simulated across the study area. 26 of them were located adjacent to cropland including 4 cornfields, 2 rice fields, and 20 soybean fields. The total monthly water usage volume of different crops summarized from YMD (2002–2010a) from May to September is shown in Fig. 3. In addition, to ensure the simulated total water use equivalent to reality, a site-specific coefficient describing the ratio of the number of irrigation wells and monitoring wells was needed to avoid underestimating water usage. This coefficient was decided by the calibration performance. For non-irrigation season, a constant pumping rate was applied to represent the average water usage, which was indicated by Clark et al. (2011).

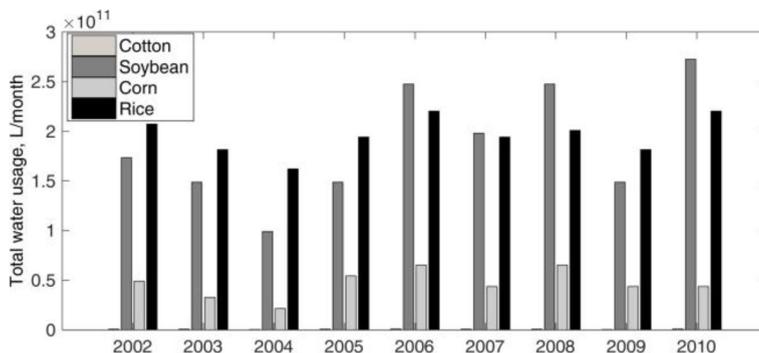


Fig. 3 Total monthly water usage of main crops in the watershed

## 2.4 Scenarios

Connecting the surface agricultural activities to the groundwater was the main challenges also the novelty of this study. BMPs were represented by different HRU-based monthly recharge calculated from SWAT model and specific pumping plans converted from irrigation schedules. The overall modeling process is shown in Fig. 4. The parameters altered for different BMP scenarios setting are described in the following paragraphs.

Baseline scenario used groundwater recharge calculated from the calibrated SWAT model and irrigation plan for original land use. The irrigation source considered in the SWAT model was the shallow aquifer.

In the SWAT crop rotation scenarios, the irrigation amount and schedules varied by crops shown in Table 1 (MAFES 2002-2014; Parajuli et al. 2013; YMD 2002-2010b). Three crop rotation scenarios were evaluated in this study, including continuous corn (CC), continuous soybean (SS), and corn-soybean (CS) rotation to investigate the impacts of crop rotation on groundwater level. All croplands were converted to continuous corn, continuous soybean, and corn-soybean rotation, respectively, in corresponding scenarios. Afterwards, in MODFLOW, the calculated monthly groundwater recharge from above SWAT scenarios was applied to the groundwater model to represent different crop rotation scenarios from 2002 to 2010. In addition to groundwater recharge, the irrigation plans in groundwater model were modified to corn water use, soybean water use, and corn and soybean water use in sequence, respectively, to represent the different irrigation schedules in crop rotation scenarios in groundwater model.

To evaluate tail water recovery pond, surface water model with updated land use with tail water recovery pond and corresponding irrigation farm was developed with same parameters as in the baseline SWAT model. The pond irrigation rate depended on the estimated pond sizes

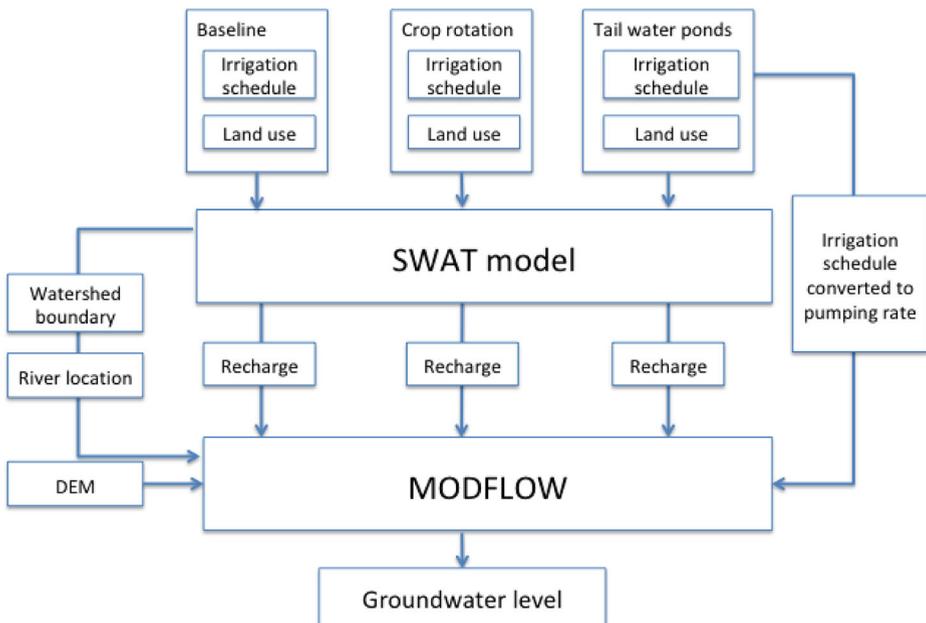


Fig. 4 Surface-ground water modeling process used in this study

and was calculated based on (USDA (2011)) (Table 1). In case of that the irrigation amount of water from tail water recovery pond may less than the total crop needs, the shallow aquifer in the SWAT model was another source of irrigation to ensure the total irrigation rates in the SWAT model compatible with the well pumping rates in MODFLOW. For irrigation plans in MODFLOW, irrigation rate was reduced to 96% of that in the baseline scenario based on the ratio of the area of irrigated farm by that of total croplands. From above, the calculated groundwater recharge and altered pumping rate were compatible and could represent the tail water recovery pond scenario in the groundwater model.

## 2.5 Calibration and Validation

The SWAT model was calibrated and validated at three gaging stations (Fig. 1) in Ni and Parajuli (2018) with  $R^2$  and NSE up to 0.61 and 0.56 at Merigold and Sunflower gaging stations. For groundwater model, monitoring groundwater level measured by YMD from 2002 to 2010 was applied to calibrate and validate the groundwater model (YMD 2002–2010a). The monitoring groundwater level was conducted on April and October, twice a year. Calibration time period was from April 2002 to April 2006, while validation period was from October 2006 to October 2010. The calibrated parameters include hydraulic conductivity, specific yield, and the site-specific coefficient of irrigation rate.

## 3 Results

### 3.1 Groundwater Model

Calibrated hydraulic conductivity was considered as homogeneous through the modeling area with value of 50 m/d and 120 m/d for layer 1 and layer 2, respectively. Clark et al. (2013) indicated the hydraulic conductivities were ranged from 45 to 183 m/d in the study area. Storage was 0.0002 /m, while Clark et al. (2013) suggested that the specific storage was less than 0.015 /m in the study area. Specific yield was set as 7% and 20% for two layers. Brown (1947) indicated the top layer material was clay with typical specific yield of 5% (Johnson 1967), and Mississippi alluvial was sand and gravel aquifer with typical specific yield of 20 to 35% (Johnson 1967). In addition, the site-specific irrigation rate coefficient was as 8, which indicated that each monitoring well represented 8 surrounding irrigation wells during irrigation season.

Figure 5 shows the calibration and validation results. The groundwater model was evaluated by  $R^2$  and root mean squared error (RMSE). The values of  $R^2$  were 0.81 and 0.79, and those of RMSE were 0.94 and 1.04 m for calibration and validation, respectively. The model shows acceptable performance as compared to literature using MODFLOW (Scanlon et al. 2003; Xu et al. 2011).

### 3.2 Groundwater Recharge in the SWAT Model

Figure 6 shows the average monthly groundwater recharge comparison among scenarios. The high groundwater recharge rate occurred from October to May, while there was few during irrigation season. The groundwater recharge of the continuous corn scenario was 7% higher in average than that of the continuous soybean. The simulated groundwater recharge of tail water recovery pond and baseline scenarios was same.

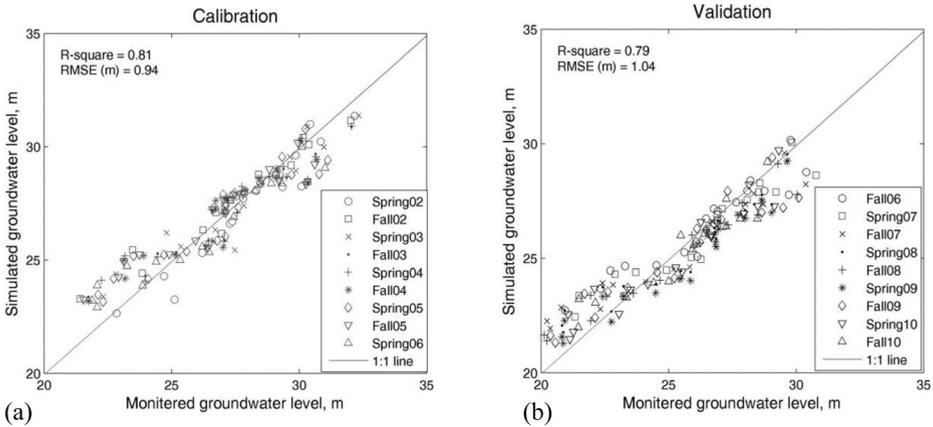


Fig. 5 Monitored vs simulated groundwater levels during model (a) calibration, and (b) validation

### 3.3 Scenario Analysis

Figure 7 shows the area of different classes of groundwater level of all the simulated scenarios. Bryd (2014) indicated that the potential pumping level was approximately 23 m below land surface. The maximum surface elevation in study area was 47 m (USGS 1999). Thus, the area with groundwater level less than 24 m was the main concern in this study. Figure 7(a) indicate the area with groundwater level less than 24 m was 43% smaller in the tail water pond scenario (72 km<sup>2</sup>) compared to that in the baseline scenario (127 km<sup>2</sup>). The average groundwater level in baseline scenario was 26.8 m, while that in CC, SS, and CS scenarios were 31, 30.4, and 30.6 m, respectively.

Area with simulated groundwater level less than 28 m in CC, SS, and CS scenarios were 123, 183, and 179 km<sup>2</sup>, respectively (Fig. 7b). The moderate groundwater recharge and pumping rate in CS scenario resulted in the area with groundwater less than 28 m was between that in CC and SS scenarios. From above, the groundwater level in CC scenario increased the most compared to that in SS and CS scenarios.

Figure 8 shows the groundwater level change during the modeling time period in various scenarios. In baseline scenario, the groundwater level had been declined up to 5 m. The area with groundwater level decline larger than 3 m was 24% less in tail water recovery pond

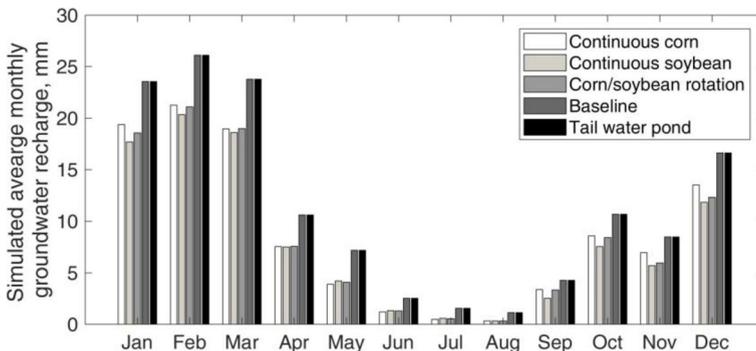
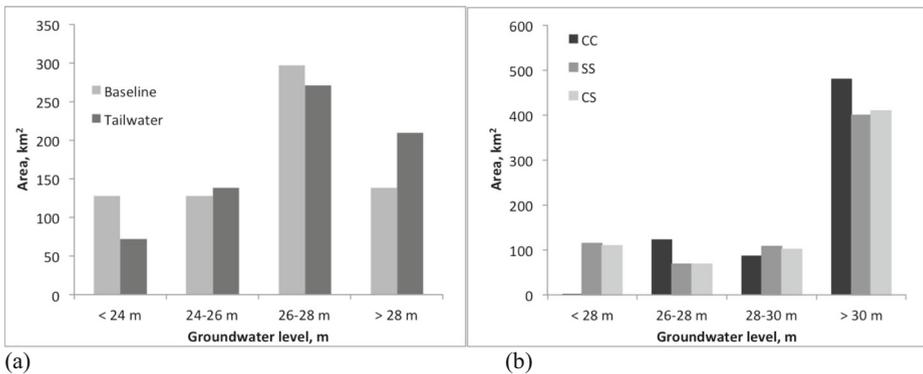


Fig. 6 Average monthly recharge from the SWAT model simulation in the study area



**Note:** CC = continuous corn scenario, SS = continuous soybean scenario, CS = corn and soybean rotation scenario

**Fig. 7** Groundwater level classes vs Area among baseline and BMP scenarios

scenario (Fig. 8b) compared to that in baseline scenario (Fig. 8a). This indicated that the tail water recovery pond scenario could slow groundwater depletion. In addition, groundwater level increase larger than 4 m in CC, SS, and CS scenarios (red area in Fig. 8c-e) were 22, 5.9, and 6.6 km<sup>2</sup>, respectively. This indicated that the fluctuation of groundwater level in modeling time period was the highest in CC scenario compared to that of in SS and CS scenarios.

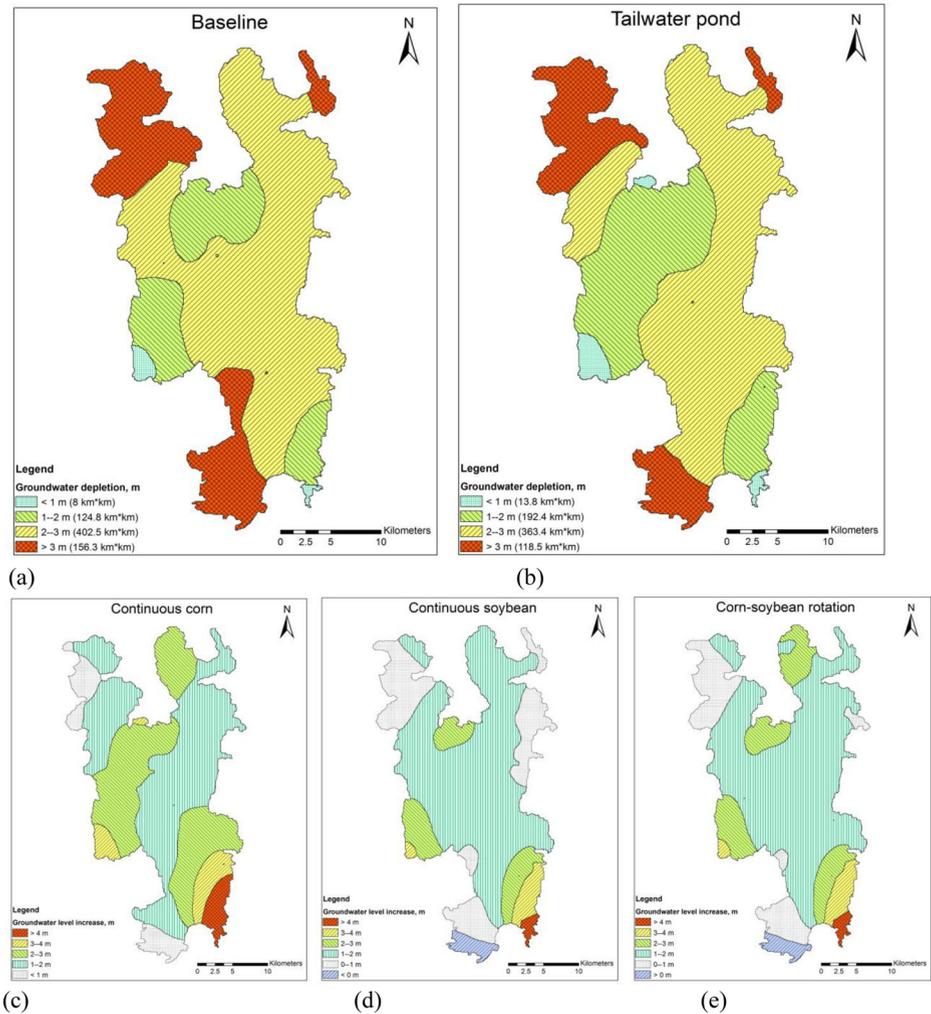
## 4 Discussion

### 4.1 Groundwater Recharge in the SWAT Model

The results showed the groundwater recharge was around 10% larger in CC scenario than that in SS and CS scenarios. The minor differences between corn and soybean scenarios were also indicated in previous studies (Dakhlalla et al. 2016; Klocke et al. 1999), although they pointed out that the differences among these common crop rotation plans are not significant. In our study, there was no enough analysis to draw this conclusion. Meantime, the reason of this difference was dominantly from the hydrological impact of the crop residues. The defaulted curve number was slightly lower for corn than that for soybean during the non-planting season in the SWAT model because of the larger amount of crop residue of corn left on the ground compared to that of soybean (Dickey et al. 1986). The groundwater recharge from the crop rotation scenarios was less than the baseline and tail water recovery pond scenarios. This was because of that the crop rotation scenarios considered in this study only involved corn and soybean. Figure 3 indicated that rice was another high water-consuming crop in the study area other than soybean, which simulated in the baseline and tail water recovery pond scenarios. This results matched the results of previous study by Dakhlalla et al. (2016) indicating that the irrigation amount is the dominate factor affect groundwater recharge calculating by SWAT model.

### 4.2 Scenario Analysis

The baseline and tail water recovery pond scenario analysis indicated that the area of groundwater critical region in tail water recovery pond scenario was less than that in the



**Fig. 8** Groundwater level changes during model simulation period with scenarios: **a** baseline scenario, **b** tail water recovery pond, **c** continuous corn, **d** continuous soybean, **e** corn-soybean

baseline scenario. The main difference between baseline scenario and tail water recovery pond scenario was the reduced pumping rate in tail water recovery pond scenario. Thus, reducing pumping in study area could help reduce the area with the critical situation, as indicated in Barlow and Clark (2011).

The simulated groundwater level was lower in the crop rotation scenarios than that in the baseline and tail water recovery pond scenario. Figure 6 shows that the groundwater recharge was less in crop rotation scenarios. Moreover, the pumping rates were converted to corn irrigation rate, soybean irrigation rate, and corn-soybean irrigation rate in sequence in CC, SS, and CS scenarios, respectively. Figure 3 indicated the corn and soybean irrigation rates were both lower than rice irrigation rate. In this case, less groundwater recharge may not result in lower groundwater level. The groundwater recharge and pumping rate were averagely 7% and

29% more in the CC scenario compared to those in the SS scenario. The larger groundwater recharge was mainly from non-planting season (Fig. 6) according to the SWAT model simulation. In this case, increasing recharge in non-planting season could help recover groundwater storage even with the increase of groundwater consumption in irrigation season. On the contrary, Anuraga et al. (2006) indicated that the groundwater level depended on groundwater consumption more than recharge rate since the groundwater consumption could be controlled by human activities other than groundwater recharge. Although agreeing this statement, groundwater recharge played an important roll in non-planting season. This could indicated that winter crop may need to be planted with more cautions, which is also agreed by Yang et al. (2015).

## 5 Conclusion

This paper combined various simulations of BMPs in relation to irrigation plans and groundwater to evaluate the impacts of surface agricultural activities on groundwater level. The model performance was determined acceptable compared to literatures with  $R^2$  of 0.81 and RMSE of 0.94 for calibration time period. Thus, within the modeling period, the model could represent the groundwater level response to the change of irrigation plans.

The results of BMPs scenario analysis indicated that tail water recovery pond scenario could help improve groundwater critical situation (groundwater level < 24 m). It also could mitigate the groundwater depletion due to reduced groundwater use. From above, from an environmental perspective, tail water recovery ponds could be considered as an efficient BMP in relation to groundwater resource improvement. In crop rotation scenario analysis, continuous corn has the smallest area with groundwater level less than 28 m compared to continuous soybean and corn-soybean rotation scenario. The groundwater level in continuous corn scenario increased the most as compared to that in continuous soybean and corn-soybean rotation scenarios. Given that groundwater consumption of continuous corn is larger than others, this study indicated that non-planting season recharge could be critical for groundwater restoration.

**Acknowledgements** We would like to acknowledge the partial financial support of AFRI competitive grant award # 2013-67020-21407, and 2017-67020-26375, from the USDA/NIFA for this project. We would like to acknowledge the support of Yazoo Mississippi Delta Joint Water Management District; USGS; and all our collaborators.

## Compliance with Ethical Standards

**Conflict of Interest** None

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