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Effects of dynamic land use inputs on improvement of SWAT model performance and uncertainty analysis of outputs

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ABSTRACT

The objective of this study was to evaluate the impacts of static and dynamic land use input conditions on the performance of non-point source (NPS) model and find out whether dynamic land use input can improve the model accuracy. Soil and Water Assessment Tool (SWAT) model was selected as the evaluation model and seven different land use input conditions were set by setting the land use update file in SWAT. The results showed that the land use pattern in the study area changed from 2000 to 2015 due to climate change and human activities, leading to inconsistencies between different land use patterns. The calibrated results indicated that dynamic land use input conditions could apparently improve the simulation accuracy of total nitrogen (TN) and total phosphorus (TP). CE5Y condition had the best calibrated result with R^2 and NSE larger than 0.7 and 0.6, respectively. However, for flow simulation, the land use input conditions had no apparent effect on the model calibration and validation results. The deviation analysis of the model outputs indicated that monthly outputs were more affected by the land use input conditions than annual outputs and that deviations in wet seasons were larger than those in normal and dry seasons. The highest MAD occurred in June and August with a value of 82.87 t and 1.56 t for TN and TP, respectively. This study revealed the importance to consider the land use change when simulating the NPS pollution, and could provide support for land use input settings of NPS pollution models.

1. Introduction

Non-point source (NPS) pollution has been widely studied in recent years because it contains many uncertainties and is harder to control than point source pollution (Shen et al., 2015; Chen et al., 2017). Many studies have shown that NPS pollution has become the primary source of water contamination, rather than point source pollution (Wang et al., 2004; Mi et al., 2015). The simulation of NPS pollution should be carried out to provide information for its management. The mechanism models have been widely used to simulate NPS pollution with the development of computer science and the better understanding of the migration and transformation mechanism of pollutants in the real world (Moges et al., 2017; Yang et al., 2017a). The Soil and Water Assessment Tool (SWAT), the Annualized Agricultural Non-Point Source (AnnAGNPS) and the Hydrological Simulation Program – Fortran (HSPF) models have been used for the majority of NPS pollution simulations (Ahn and Kim, 2016; Karki et al., 2017; Teshager et al., 2017). Compared to the previously used export coefficient method and empirical models, the mechanism models have a higher simulation accuracy and universality (Liu et al., 2017b).

To appropriately control NPS pollution, the spatial and temporal characteristics of NPS pollution first need to be analyzed using models. The processes of NPS pollution generation and discharge are affected by many factors, such as land use type, topography, soil characteristics and meteorological conditions (Yang et al., 2017c; Lin et al., 2018; Zhi et al., 2018). These factors are also the basic input data for most NPS pollution models. Thus, the simulation results will be significantly affected by the spatial distribution and temporal changes in these input data (Bajracharya et al., 2018; Goyal et al., 2018). The spatial distribution data of these factors were used in most of the NPS models, considering the impacts of spatial variation of input data on the NPS pollution simulation (Du et al., 2016; Ouyang et al., 2016). In addition, the impacts of the spatial resolution of these input data on model outputs have also been analyzed by many studies (Kumar et al., 2017; Sun et al., 2017). However, for the temporal variations in NPS, only the time series of meteorological conditions were considered in most NPS models, while the other input data, such as land use type, topography and soil characteristics, were set as invariable during the simulation periods (Chen et al., 2013; Liu et al., 2013, 2014).

Analyzing the temporal characteristics of NPS pollution is conducive to the management of NPS contamination. Thus, the simulation periods of NPS pollution were usually long, from several years to several

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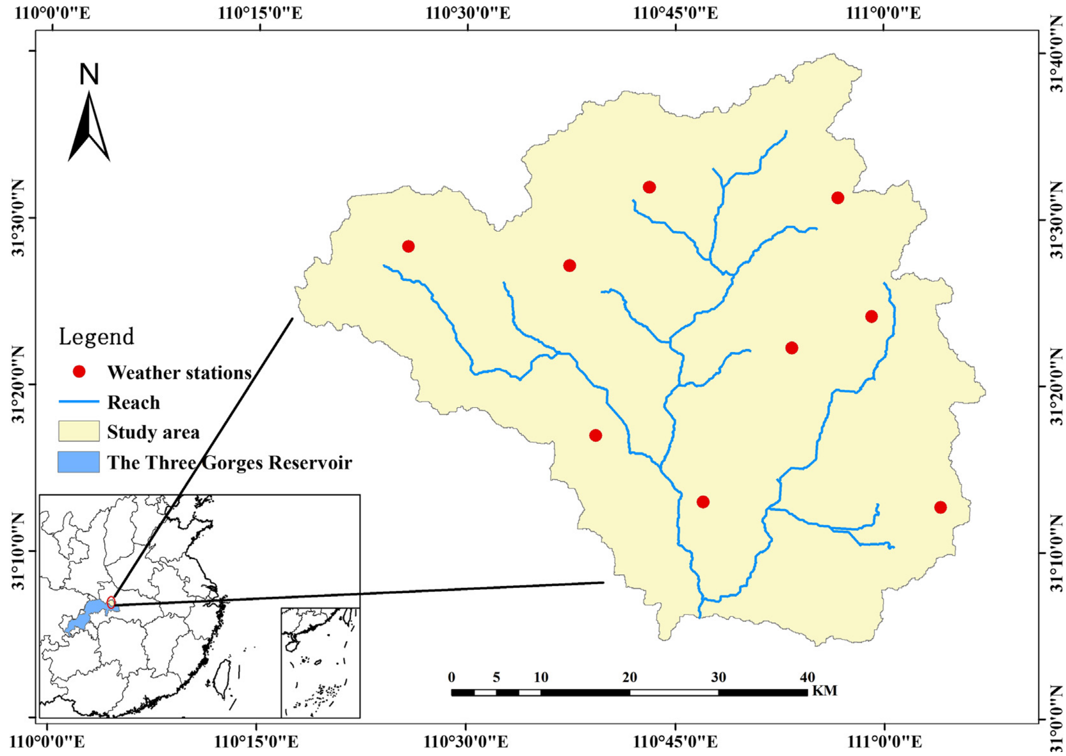

Fig. 1. Location of the Xiangxi River watershed.

decades, and simulation periods longer than 10 years were the most common (Ouyang et al., 2014; Zhai et al., 2014; Liu et al., 2017b). The temporal change of NPS pollution represents its response to changes in input data. Meteorological conditions experience the most change and have the greatest effects on the NPS pollution discharge within one year, but land use patterns will also change when the simulation periods are longer than several years. Many studies have found that land use will change significantly in 5 years (Sewnet and Abebe, 2017; Gashaw et al., 2018; Minta et al., 2018). When the time scale is large, in addition to meteorological conditions, the influence of land use change on the simulation of NPS pollution cannot be ignored.

The impacts of land use change on NPS pollution generation and discharge have received much focus in recent years (Chu et al., 2010; Zhang et al., 2013). In these studies, land use in different periods were used as input data to analyze the variations in model outputs resulting from land use change. However, land use in different periods was only set as different scenarios in these studies. In each simulation process, just one period of land use was used (Worku et al., 2017). These studies mainly focused on the influence of the spatial variations in land use patterns in different periods on NPS pollution, without taking temporal changes in land use into consideration. More recently, Wagner considered the land use dynamic change during SWAT simulation periods and found that different land use input scenarios during the period of simulation had great impacts on the SWAT model outputs (Wagner et al., 2017). This discovery embodied the temporal characteristics of land use change, but the analysis was only based on the predicted land use. The impacts of land use in different period on the temporal characteristics of NPS pollution need to be analyzed further.

In this study, the impacts of different land use input conditions on the model simulations were studied based on the SWAT model in Xiangxi river watershed. The main goals of this study were to (1) study the impacts of different land use input conditions on the model performance based on the calibration and validation results; (2) discuss whether dynamic land use input conditions can improve model performance; and (3) analyze the impacts of the land use input conditions on model outputs.

2. Materials and methods

2.1. Study area

The Xiangxi River is approximately 94 km long and is located between 110.47° to 111.13° E and 30.96° to 31.67° N in the Three Gorges Reservoir. It flows through three counties and its drainage area covers approximately 3099 km^2 (Fig. 1). The altitude in the area ranges from 110 m to 3088 m. A humid subtropical monsoon climate is the main climate in the watershed. The annual average precipitation is 1213.3 mm and the average annual temperature is 17.8 °C. June, July and August represent the wet season; April, May, September and October were the normal season; and January, February, March, November and December represent the dry season. Forest area dominates the total area of the watershed, with a proportion more than 80%. However, due to excessive fertilizer application and livestock breeding, the watershed still faces serious NPS pollution (Liu et al., 2016).

2.2. SWAT model and calibration

SWAT is a basin-scale, continuous-time model that was developed by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) (Arnold et al., 1998). The SWAT model is designed to simulate the impact of management on the hydrological processes and water quality (Kang et al., 2006). The SWAT model has been developed over 30 years. It is a descendant of the Simulator for Water Resources in Rural Basins (SWRRB) model (Arnold and Williams, 1987). To overcome the limitation that SWRRB can only simulate 10 subbasins at a time, the Routing Outputs to Outlet (ROTO) model was merged with SWRRB into the SWAT model (Arnold et al., 1995). The SWAT model simulates the hydrological process based on the water balance equation (Eq. (1)):

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

where SW_t is the final moisture content of soil, SW_0 is the initial