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Application of AnnAGNPS to model an agricultural watershed in East-Central Mississippi for the evaluation of an on-farm water storage (OFWS) system

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ABSTRACT

Annualized Agricultural Non-Point Source Pollutant Model (AnnAGNPS) is a watershed-scale, continuous simulation, physical model that has been widely used to simulate runoff, nutrients, sediment, and pesticides in different watersheds. This study applied AnnAGNPS to simulate runoff, nutrients (total Nitrogen and total Phosphorus), and sediment from an agricultural watershed of 30.3 ha in East-Central Mississippi. AnnAGNPS was then used to evaluate an On-Farm Water Storage (OFWS) system as a Best Management Practice (BMP) for nutrient and sediment loading control from agricultural fields within this watershed and as a source of water for irrigation. An R^2 of 0.85 and E of 0.82 in daily runoff estimation showed that the model can adequately simulate runoff from watersheds in East-Central Mississippi. In addition, an R^2 of 0.88 and E of 0.67 for event-based sediment estimation and an R^2 of 0.74 and E of 0.54 for monthly phosphorus estimation also showed that the model can satisfactorily simulate sediment and phosphorus. However, the model was not able to simulate nitrogen at a monthly scale, with an R^2 of only 0.15 and E of −0.107, because of the lack of site specific and accurate input data. After AnnAGNPS successfully simulated runoff, sediment, and phosphorus, an evaluation of the OFWS system showed that the system was able to capture 220,000 m^3 of runoff from the monitored watershed that can be stored and used for irrigation. AnnAGNPS estimated that the OFWS system also captured 46 tons of sediment and 558 kg of phosphorus during the monitoring period, preventing downstream nutrient and sediment pollution.

1. Introduction

Agricultural nutrient runoff is a result of substantial nitrogen and phosphorus application to croplands (Sims et al., 1998) and is the leading cause of declining water quality in many lakes and streams of the United States (EPA, 2000). According to the USDA Natural Resources Conservation Service (NRCS), sediment and nutrients from agricultural watersheds are the major causes of surface water quality degradation (USDA-NRCS, n.d.-c). Of the assessed rivers and streams in Mississippi, nutrients, sediment/siltation, and organic enrichment are the major causes of impairments (MDEQ, 2014). Excessive nitrogen and phosphorus loading from agricultural fields can cause algal blooms, which can lead to the development of hypoxic zones and result in loss of aquatic life. Increased sediment concentrations can also harm the aquatic ecosystem by causing loss of habitat.

Many agricultural best management practices (BMPs) such as conservation tillage, crop nutrient management, and buffer zones have been implemented on farmlands to reduce sediment and nutrient non-point source (NPS) pollution from agricultural areas and protect downstream water quality. However, the cost of evaluating the benefits of these practices is very high because of the complex field monitoring systems and water quality analyses that are required. As a result, hydrologic watershed models are considered a viable and cost-effective method of evaluating the effectiveness of these BMPs before implementation. Throughout the years, many watershed models have been developed to simulate hydrology, sediment transport, and pollutant loadings from agricultural watersheds as well as evaluate alternative management practices. Examples of models include the Soil and Water Assessment Tool (SWAT) (Arnold et al., 2012), the Areal Nonpoint Source Watershed Environmental Simulation (ANSWERS) model (Beasley et al., 1980), the Annualized Agricultural Non-Point

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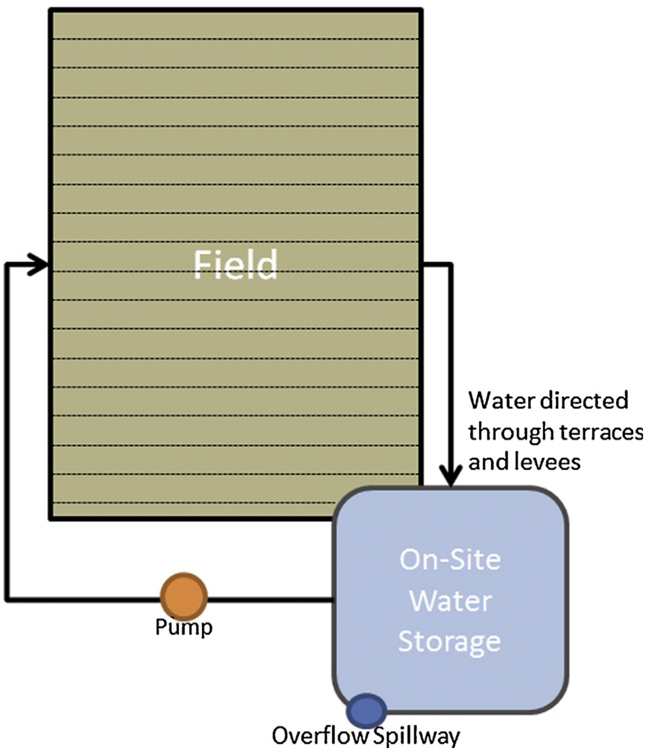

Fig. 1. General design of on-farm water storage (OFWS) systems in the sloping landscape of East-Central Mississippi.

Source Pollutant Model (AnnAGNPS) (Bingner et al., 2015), and the Dynamic Watershed Simulation Model (DWSM) (Borah et al., 2002). Borah and Bera (2003) provide a detailed review of 11 hydrologic and non-point source pollution models.

An On-Farm Water Storage (OFWS) system is an agricultural BMP that started appearing in Mississippi when NRCS, along with its conservation partners, began implementing the now 13-state Mississippi River Basin Healthy Watersheds Initiative (MRBI) in northwest Mississippi (part of the Mississippi Delta) in 2010. The objective of this initiative is to improve water quality in priority watersheds of the Mississippi River Basin by providing technical and financial assistance to producers implementing voluntary conservation practices (USDA-NRCS, 2010). OFWS systems work by collecting nutrient- and sediment-rich irrigation tail water and/or storm runoff from agricultural fields in a tail water recovery ditch and/or a storage pond (Fig. 1). The system also holds the stored water until it is needed for irrigation. These systems are fairly new in East-Central Mississippi, funded privately by farmers because of the lack of government-based financial assistance programs in this area of the state. Although OFWS systems are installed primarily for irrigation in East-Central Mississippi, these systems are thought to reduce downstream sediment and nutrient loading from agricultural fields. However, there is little published work on evaluating the effectiveness of these systems.

AnnAGNPS is a watershed-scale, continuous simulation, physical model that has been widely used to simulate hydrology, sediment, and nutrient transport successfully in different watersheds of varying sizes (Baginska et al., 2003; Chahor et al., 2014; Sarangi et al., 2007; Shamshad et al., 2008; Shrestha et al., 2006; Yuan et al., 2005, 2011). AnnAGNPS has also been used to assess the impacts of alternative management practices for reducing runoff and sediment (Tian et al., 2010; Yuan et al., 2001). The model is an improvement to the older, single-event Agricultural Non-Point Source (AGNPS) model (Young et al., 1989).

Estimating runoff, sediment, and nutrients draining into the storage pond of an OFWS system from the agricultural watershed is important to understanding, evaluating, and designing these systems. This study evaluates the OFWS system established in East-Central Mississippi by modeling runoff, sediment, and nutrients that drain from the watershed to the OFWS system storage pond. It is important to calibrate and validate the model for local watershed conditions before evaluation. Hence, the goal of this study was to assess the ability of AnnAGNPS to simulate runoff, sediment, and nutrients (total nitrogen and total phosphorus) for local conditions in Noxubee county of East-Central Mississippi and use the model to evaluate the effectiveness of an OFWS system located in an agricultural watershed in the region. More specifically, the objectives of this paper are to (1) evaluate AnnAGNPS for simulating runoff, sediment, and nutrients in an agricultural watershed located in the Blackland Prairie of East-Central Mississippi; (2) use AnnAGNPS to evaluate the effectiveness of OFWS systems for reducing downstream nutrient and sediment loading; and (3) use AnnAGNPS to estimate total runoff and nutrient loading under different cropping practices to determine if nutrient loading from the agricultural watershed can be further reduced.

2. Methodology

2.1. Watershed description

The watershed modeled for this study is about 30.3 ha and consists mainly of agricultural fields. The watershed is located in the Alabama and Mississippi Blackland Prairie-Major Land Resource Area (MLRA)-135A (USDA-NRCS, 2014) near the town of Brooksville in Noxubee county, Mississippi (33°14′46.62″N Latitude and 88°31′30.42″ Longitude). The study watershed is a part of the Middle Tombigbee-Lubbub watershed (HUC 0316106) located in the larger Tombigbee River Basin. The elevation of the watershed ranges from 72 m to 84 m and consists of slopes ranging from 0 to 5%. Corn and soybean are the main crops planted in the fields. The watershed consists of Brooksville silty clay and Vaiden silty clay soils, with Brooksville silty clay as the dominant soil series covering more than 78% of the watershed. The watershed has a warm and mostly humid climate typical of Mississippi. The average annual rainfall is approximately 1372 mm, about 70% of which occurs during the winter and the spring months. The summer average air temperature is 28.1 °C, and the winter average air temperature is 7.2 °C.

An OFWS system with a storage pond having 6.88 ha surface area and 7.6 m deep at its deepest point was constructed in the watershed in 2012. Constructed terraces and drainage ditches are used to route runoff from the agricultural fields to the storage pond. The total area of the watershed that drains into the storage pond is about 45 ha and consists of two sub-watersheds (Fig. 2). Only the bigger of the two sub-watersheds that has an area of roughly 30.3 ha was monitored and evaluated for this study because of separate flow paths of the two sub-watersheds into the inlet of the storage pond.

2.2. AnnAGNPS model description

AnnAGNPS is a batch-process, continuous-simulation, daily time step, watershed-scale, pollutant loading model developed by the USDA-Agricultural Research Service (ARS) and the NRCS (Bingner et al., 2015). It is a continuous version of the single event AGNPS model (Young et al., 1989) and is designed to simulate runoff, sediment of five different particle sizes (clay, silt, sand, small aggregates, and large aggregates), nutrients (nitrogen, phosphorus, and organic carbon), and pesticide transport.