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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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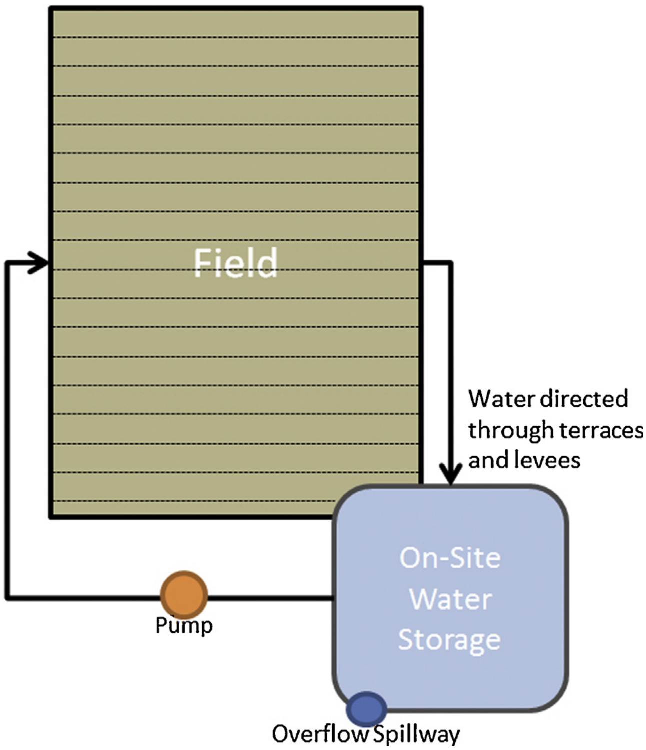

Fig. 1. General design of on-farm water storage (OFWS) systems in the sloping landscape of East-Central Mississippi.

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.

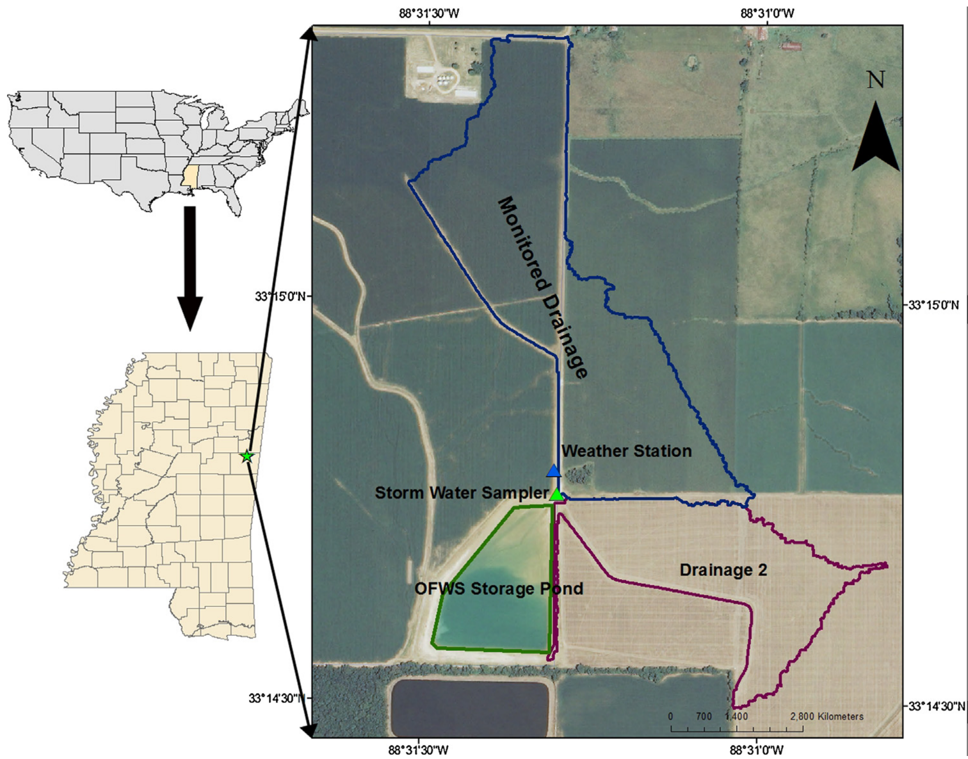

Fig. 2. Study agricultural watershed, Brooksville, MS.

The model is designed for agricultural watersheds and used predominantly for this purpose. There are as many as 33 different input datasets such as watershed data, gully data, point source data, impoundment data, fertilizer application, pesticide application and others that can be used with the model depending on the components simulated. However, the required model input parameters include watershed physical characteristics, land-use and management operations data, and daily climate information. The watershed's physical characteristics are defined by data from Digital Elevation Models (DEMs), soil data, etc., and these combined with land use data account for the spatial variation in the watershed, while climate and some management data accounts for the temporal variation in the watershed.

TOPAGNPS, a Geographic Information System (GIS)-based landscape analysis component of AnnAGNPS, uses DEM data to determine the spatial characteristics of the watershed. It divides the watershed into homogeneous sub-watersheds called 'cells' and routes flow through reaches, which are a required model input for simulation (Bingner, 2014). The model uses the Soil Conservation Service (SCS) Curve Number (CN) method to estimate surface runoff from the simulated watershed (USDA, 1972). The CN can be adjusted in the model to account for changes in land use throughout the watershed. Sheet and rill erosion are estimated in the model using the Revised Universal Soil Loss Equation (RUSLE) method (Renard et al., 1991). As RUSLE is used only for predicting erosion but not deposition, the Hydro-geomorphic Universal Soil Loss Equation (HUSLE) is used within the model to predict sediment load from a watershed during storm events (Theurer and Clarke, 1991).

2.3. Input file preparation

2.3.1. Topography

Light Detection and Ranging (LIDAR) data for the watershed was acquired from the Mississippi Automated Resource Information System (MARIS), a state government entity that provides mapping and geospatial data for the state of Mississippi. The downloaded LIDAR data was transformed to a 1 m × 1 m DEM for model input. The LIDAR data was acquired from a NRCS/USGS 2012 project (MARIS, 2012) which accounted for the latest change in topography with the construction of terraces and drainage ditches to route runoff from the agricultural fields to the OFWS system storage pond. TOPAGNPS used the DEM to divide the watershed into sub-watersheds, or cells, route flow through channel reaches, and determine cell parameters such as area, slope, and average elevation.

A user-selected watershed outlet location is required for TOPAGNPS to generate the required model input files from the DEM dataset. In addition, Critical Source Area (CSA) and Minimum Source Channel Length (MSCL) are the important user-defined values for determining the stream network and AnnAGNPS cells. The CSA value defines the minimum area below which a permanent channel can be defined, so this value determines the size, or area, of the subwatershed cells. The MSCL value defines the acceptable length for the source channel. Different combinations of CSA and MSCL values were tested until an accurate representation of the stream network was acquired, as compared to field observations. A CSA of 0.5 ha and a MSCL of 5 m was used for the modeled watershed, which divided the area into 84 cells with 34 reaches (Fig. 3).

2.3.2. Climate data

Daily maximum and minimum temperature, precipitation, dew point temperature, sky cover (cloud cover), and wind speed are the minimum weather data inputs required for the model. All of the required climate data for this study except for sky cover were acquired from the WatchDog 2900ET weather station that was installed in the watershed. Sky cover data was generated by the model using the solar radiation data that was acquired from the weather station. Climate data was collected from September 2014 to March 2016 for the study. Along with the daily climate data, AnnAGNPS also required the two year 24-h precipitation and the SCS rainfall distribution type. The two year 24-h precipitation for the area was 101.6 mm (Hershfield, 1963), and the study area falls

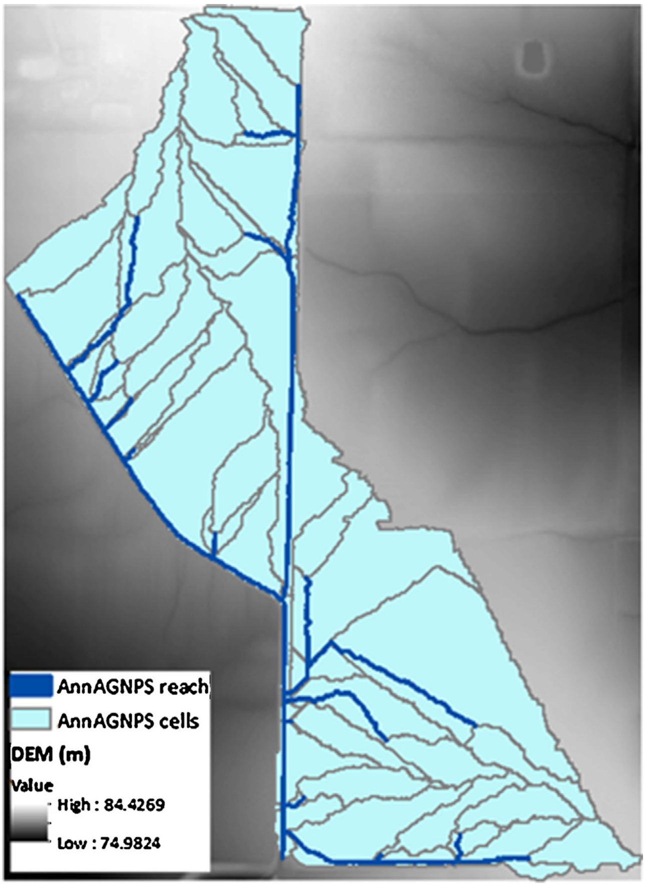

Fig. 3. AnnAGNPS-determined cells and reaches for the study watershed.

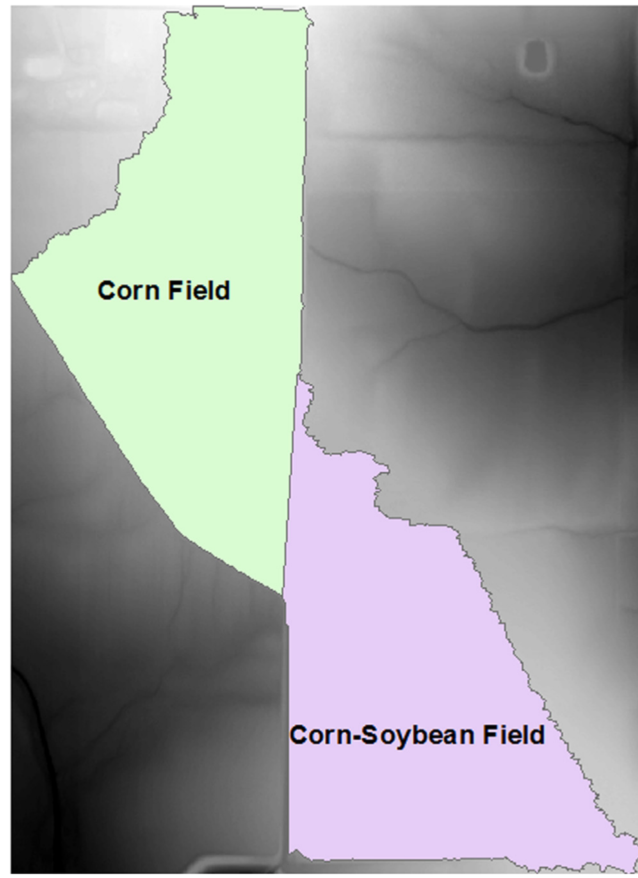

Fig. 4. Corn and corn-soybean fields in the modeled watershed.

within the region with Type III rainfall distribution (Cronshey et al., 1985).

2.3.3. Land use and management information

The modeled watershed is mostly agricultural land with fields planted in row crops, except for the terraces and drainage ditches used to route the runoff and a small wooded area near the monitored watershed outlet. Two agricultural fields cover about 98% of the watershed area. Corn was grown in one field during the two years of monitoring while corn and soybean were rotated in the other field (Fig. 4). Detailed and accurate management information for the watershed is important for the best possible estimate of sediment, nutrient, and water runoff. Management information for both agricultural fields within the watershed was obtained from the farmers (Tables 1 and 2). Poultry litter was applied each fall as fertilizer (Tables 1 and 2) in preparation for the next year's growing season in both fields. The fields were conventionally tilled after harvest each year, and no cover or winter crops were grown. Because the modeled watershed was small, a land use map was not created, but rather land use for each cell in the watershed was manually assigned.

2.3.4. Soils

The Soil Survey Geographic (SSURGO) soil map acquired from the NRCS (USDA-NRCS, n.d.-b) was overlaid onto the delineated watershed using the GIS tool in AnnAGNPS, and the dominant soil type for each subwatershed cell was determined. Brooksville silty clay is the major soil type in the watershed (Fig. 5), and it consists of 14 soil layers with a top-layer depth of 14.9 cm and a total soil depth of 202.9 cm. Vaiden silty clay contains three layers with the top-layer depth of 14.9 cm and a total soil depth of 151.9 cm. The

Table 1
Management practice information for the corn field.

	Date	Action	Fertilizer application rate
Corn	4/23/2014	Corn planting	
	4/25/2014	Starter fertilizer	46.7 L ha^{-1} (11–37-0)
	5/25/2014	Sidedress fertilizer	246.6 kg N ha^{-1}
	6/28/2014	Fertilizer tassel	49 kg N ha^{-1}
	9/3/2014	Harvest	
	9/16/2014	Poultry fertilizer	4485 kg ha^{-1} (5.5% N, 3.8% P)
	9/21/2014	Disking	
	9/25/2014	Chisel	
	9/28/2014	Bedder	
	5/5/2015	Corn planting	
	5/7/2015	Starter fertilizer	46.7 L ha^{-1} (11–37-0)
	6/5/2015	Sidedress fertilizer	246.6 kg N ha^{-1}
	7/8/2015	Fertilizer tassel	49 kg N ha^{-1}
	9/15/2015	Harvest	
	9/25/2015	Poultry fertilizer	3363 kg ha^{-1} (5.5% N, 3.8% P)
	10/1/2015	Disking	
	10/4/2015	Chisel	
	10/8/2015	Bedder	

soils are deep and poorly drained with low permeability and are formed of clay with a calcareous sub layer. Detailed properties for each soil type including bulk density, saturated conductivity, field capacity and others (Table 3) were directly populated in the model from the NRCS Soil Survey Center's National Soil Information System (NASIS) database (USDA-NRCS, n.d.-a). As soil initial nutrient concentration was not available from the NASIS database, soil initial nitrogen and phosphorus concentrations were set in the model based on soil sampling results and a review of literature (Table 4). Inorganic phosphorus concentration was set to 43 mg kg^{-1} for the top layer and 22 mg kg^{-1} for the subsequent layers, while the initial organic phosphorus concentration was set to 50 mg kg^{-1} for the

Table 2
Management practice information for the corn-soybean rotation field.

Field	Date	Action	Fertilizer application rate
Corn–Soybean Rotation	5/1/2014	Sprayer – pre-emergence	
	5/5/2014	Soybean planting	
	6/15/2014	Cultivator	
	10/5/2014	Harvest	
	10/15/2014	Poultry fertilizer	4485 kg ha^{-1} (5.5% N, 3.8% P)
	10/17/2014	Disking	
	10/18/2014	Chisel	
	10/20/2014	Bedder	
	5/3/2015	Corn Planting	
	5/5/2015	Starter fertilizer	46.7 L ha^{-1} (11–37-0)
	6/8/2015	Fertilizer sidedress	246.6 kg N ha^{-1}
	7/10/2015	Fertilizer tassel	49 kg N ha^{-1}
	9/21/2015	Harvest	
	9/28/2015	Poultry Fertilizer	3363 kg ha^{-1} (5.5% N, 3.8% P)
	10/05/2015	Disking	
	10/09/2015	Chisel	
	10/13/2015	Bedder	

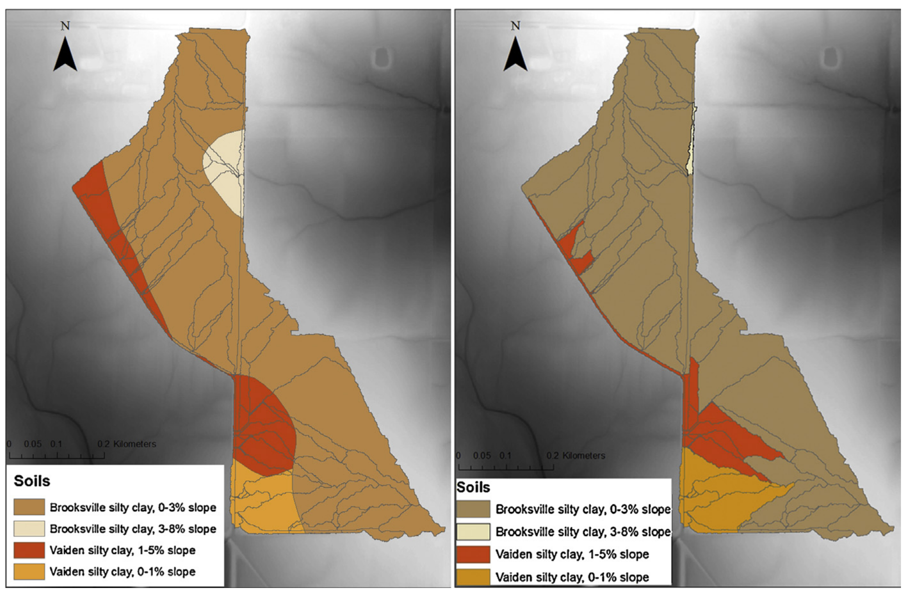

Fig. 5. Major soil types in the watershed (left) and as assigned to each sub-watershed by AnnAGNPS (right).

Table 3
Characteristics of the top soil layer for the soils in the watershed.

Soil	Soil texture	Clay ratio	Silt ratio	Sand ratio	Bulk density (g/cm^3)	Saturated conductivity (mm/h)	[a]Field capacity (%Vol)	[b]Wilting point (%Vol)	Organic matter	Hydrologic soil group
BrA	Silty clay	0.45	0.46	0.09	1.68	3.31	0.33	0.264	0.025	D
BrB	Silty clay	0.45	0.46	0.09	1.68	3.31	0.33	0.264	0.025	D
VaA	Silty clay	0.41	0.51	0.08	1.55	3.31	0.309	0.225	0.025	D
VaB2	Silty clay	0.41	0.51	0.08	1.55	3.31	0.309	0.225	0.025	D

BrA – Brooksville silty clay (0–3% slope), BrB – Brooksville silty clay (3–8% slope), VaA – Vaiden silty clay (0–1% slope), VaB2–Vaiden silty clay (1–5% slope).
[a] Field capacity, water content at 300 kPa.
[b] Wilting point, water capacity at 1500 kP.

Table 4
Soil initial nitrogen and phosphorus concentrations set up in the model.

Input Parameter	Organic	Inorganic
Soil P content in the top soil layer (mg kg^{-1})	50	43
Soil P content in the subsequent soil layers (mg kg^{-1})	25	22
Soil N content in the top soil layer (mg kg^{-1})	75	50
Soil N content in the subsequent soil layers (mg kg^{-1})	15	15

top layer and 25 mg kg^{-1} for the subsequent layers. Similarly, soil organic nitrogen concentration was set to 75 mg kg^{-1} for the top layer and 15 mg kg-1 for the subsequent layers.

Crop information for the model including nutrient uptake, crop residue, and growth was acquired from the RUSLE crop data. However, crop nutrient uptake was not available in the database and hence, was obtained from available literature. Soybean N uptake was set at 0.092 and P uptake at 0.0095 (Flannery, 1986a). Corn N uptake was set at 0.015 (Hermanson et al., 2000) and P uptake at 0.0031 (Flannery, 1986b).

2.4. Hydrology, sediment, and nutrient data

A portable automatic water sampler (ISCO 6712) equipped with an ISCO Area Velocity Flow Module (model 750) was installed at the monitored watershed outlet to monitor runoff and capture storm runoff events draining to the OFWS system storage pond. The sampler was set to trigger and collect runoff samples at a uniform time spacing of 60 min when a runoff depth of 7.62 mm was measured in the drainage channel. The collected samples were analyzed for total suspended solids (TSS) and nutrients. TSS was measured following the EPA 160.2 gravimetric method, and samples were analyzed for total nitrogen and total phosphorus using a DR-2800 spectrophotometer (HACH, 2007). Runoff from the watershed to the storage pond was monitored from September 2014 to March 2016. Although the goal was to capture samples from all storm runoff events that flowed into the storage pond during the monitoring period, some events were not captured because of various issues including equipment malfunction and scheduling problems. Therefore, the model was evaluated for nutrients and sediment for only the time period during which monitoring data was available.

2.5. Model assessment

Model evaluation was performed by comparing observed and AnnAGNPS-predicted data at the watershed outlet where the autosampler was located. The model was assessed for runoff on a daily and monthly time scale. Sediment prediction was compared for storm events, while nutrient data were compared on a monthly time scale. Assessment of model performance for runoff, sediment, and nutrients included both qualitative and quantitative methods. Qualitative methods included comparing graphs of observed and predicted data, while coefficient of determination (R^2) and Nash Sutcliffe Efficiency (E) were the statistical methods used for quantitative evaluations.

R^2 represents the variation in measured data explained by the model (Moriasi et al., 2007). Values can range from 0 to 1, with 1 indicating that all variation in the measured data is explained by the model. Values greater than 0.5 are normally considered acceptable (Moriasi et al., 2007).

E is a normalized statistic that determines the relative magnitude of the residual variance ('noise') when compared to the variance in the measured data ('information') (Nash and Sutcliffe, 1970). The statistic denotes how well the observed data fit the predicted data in the 1:1 line. The E value ranges from $-\infty$ to 1 with 1 representing a perfect fit. Values between 0 and 1 are considered an acceptable performance level for the model (Moriasi et al., 2007).

2.6. Model calibration and validation

The SCS curve number is the most important parameter in the model for predicting runoff, and it is the parameter utilized in many studies to calibrate runoff (Chahor et al., 2014; Shamshad et al., 2008; Shrestha et al., 2006). Therefore, the SCS curve number was also used to calibrate runoff in this study.

Sediment load sensitivity analysis conducted by Chahor et al. (2014) showed that RUSLE-P and canopy cover were highly sensitive parameters while crop residue, Manning's sheet and reach coefficients, root mass, and rainfall height were medium sensitive parameters. As most runoff events for the study site occurred in the winter months, RUSLE-P, crop residue, and Manning's sheet and reach coefficients were used for sediment load calibration, and canopy cover and root mass were excluded from calibration.

The model was calibrated and validated for runoff and sediment for separate time periods based on data availability. The model was calibrated for runoff from 9/2014 to 5/2015 (1062.48 mm rainfall) and validated from 06/2015 to 03/2016 (925.32 mm rainfall). Sediment load was calibrated from 10/2015 to 12/2015 (328.42 mm rainfall) and validated from 1/2016 to 2/2016 (144.27 mm rainfall). The model was also evaluated for predicting nutrient load from 10/2014 to 4/2015 and 10/2015 to 2/2016. The model was initialized for two years prior to performing the watershed simulation.

2.7. Evaluation of alternative management practices

Although an OFWS system has already been established as a BMP to capture runoff and associated sediment and nutrients from agricultural fields, alternative management practices were evaluated to determine how changing management practices may affect runoff volume and nutrient loading from the watershed. It is important to know if the runoff amount may change under different cropping practices, because this could affect the total water availability for irrigation. It was also helpful to determine if nutrient loss from the monitored watershed could be decreased, leaving more nutrients available for plant uptake. The goals were to evaluate the change in nutrient loss from the watershed with the spring application of poultry fertilizer and tillage rather than fall and also the change in runoff amount under different crops. Thus, three alternative management scenarios were evaluated: Scenario (1) apply poultry fertilizer in the spring (rather than the fall) and conduct all tillage operations in the spring, leaving the field no-till after harvest; Scenario (2) only soybean planted on all agricultural fields in the watershed; and Scenario (3) only corn planted on all agricultural fields in the watershed.

3. Results and discussion

3.1. Runoff

3.1.1. Runoff calibration

Initial SCS CNs for the different land use types were selected based on the National Engineering Handbook (Cronshey et al., 1985). The CN for a straight row crop with good hydrological conditions was used for corn and soybean during the growing season, while the CN for a fallow field with crop residue and good hydrological conditions was used after harvest during the non-growing season. The CN for brush was used for the small wooded area in the watershed, and the CN for open space with good condition was used for the drainage channel (Table 5). The initial run of the model, without calibration, resulted in an R^2 of 0.73 and E of 0.74 for daily runoff prediction and an R^2 of 0.66 and E of 0.65 for monthly runoff prediction. These results demonstrate that AnnAGNPS can simulate runoff satisfactorily even without calibration in watersheds in East Mississippi. However, the model was calibrated for runoff to aid in better predictions for sediment and nutrient runoff.

Graphical comparisons of observed and predicted runoff showed that the model was under-predicting runoff in the late fall and winter (September-January) and over-predicting in the spring (February–May) for the calibration phase (9/2014–5/2015). Initial model runs used the same CN for the winter and spring months, so a new CN was added for the spring to improve runoff estimates. The CN for a fallow field with crop residue and poor hydrological conditions was introduced for the modeled watershed for the spring months (February–May). The straight row crop CN was then increased for the fall and decreased for spring and adjusted by running the model multiple times. Results were evaluated using both graphical (Fig. 6) and statistical methods (Fig. 7) until the best simulation results were obtained. Because the wooded area and drainage channel covered only about 2% of the total watershed, CNs for these two land-use types were not adjusted during the calibration phase.

The model performance improved for both daily and monthly runoff predictions after calibration. An R^2 of 0.83 and E of 0.83 were obtained for daily runoff comparisons, and an R^2 of 0.89 and E of 0.88 were obtained for monthly runoff comparisons (Fig. 7). Total runoff estimation by the model during the calibration phase dif-

Table 5
Curve Numbers (CN) used for model calibration.

Cover description	Curve number for hydrological soil groups							
	Initial Values				Values after calibration			
	A	B	C	D	A	B	C	D
Row crop (SR + Good)	67	78	85	89	60.5	70.4	76.8	80.43
Fallow (CR + Good)	74	83	88	90	70.3	78.9	83.6	85.5
Fallow (CR + Poor)	76	85	90	93	78.3	87.5	92.7	95.81
Brush (Fair)	35	56	70	77	Not Changed			
Open Space (Good)	39	61	74	80	Not Changed			

SR – Straight row, CR – Crop residue cover.

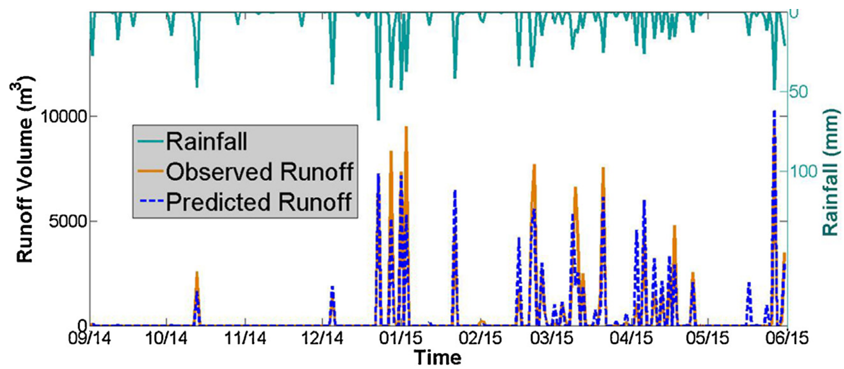

Fig. 6. Graphical comparison between predicted and observed runoff after calibration for the calibration phase.

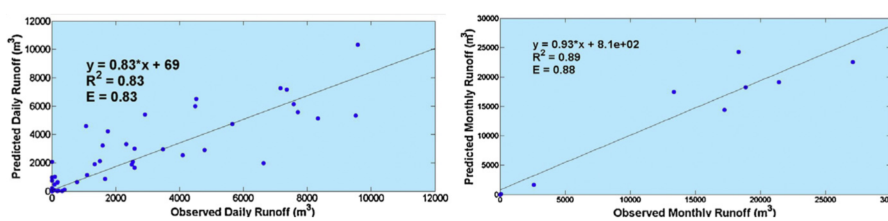

Fig. 7. Comparison between daily (left) and monthly (right) observed and predicted runoff during calibration.

Table 6
Monthly observed rainfall and predicted and observed runoff.

Year	Month	Rainfall (mm)	Predicted runoff (m^3)	Observed runoff (m^3)
Calibration				
2014	September	56.39	98.68	75.6
	October	86.36	1652.59	2585.7
	November	11.43	0	0
	December	181.1	14391.01	17235.9
2015	January	142.24	19131.27	21402.9
	February	125.48	18253.04	18867.6
	March	128.52	22519.64	27072.9
	April	131.32	24240.35	18320.4
	May	126.49	17478.41	13331.7
Validation				
	June	54.36	1185.37	289.8
	July	41.15	0.63	1.8
	August	132.59	1628.19	373.5
	September	32.51	0.03	0
	October	97.02	4990.66	730.8
	November	145.79	20985.20	12902.4
	December	135.89	12742.87	7235.1
2016	January	63.24	8983.43	4559.4
	February	116.58	17998.94	20433.6
	March	147.82	33010.39	25076.7

fered from the observed runoff by only about 1% (Table 6). This showed that AnnAGNPS performed better when it was evaluated for a longer time period.

3.1.2. Runoff validation

The model was validated for runoff by running the model for a separate time period (06/2015–03/2016) than what was used

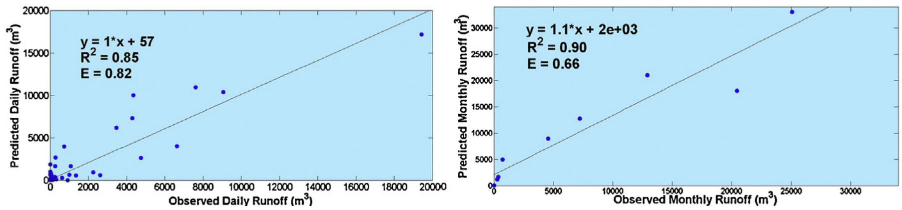

Fig. 8. Comparison between daily (left) and monthly (right) observed and predicted runoff during validation.

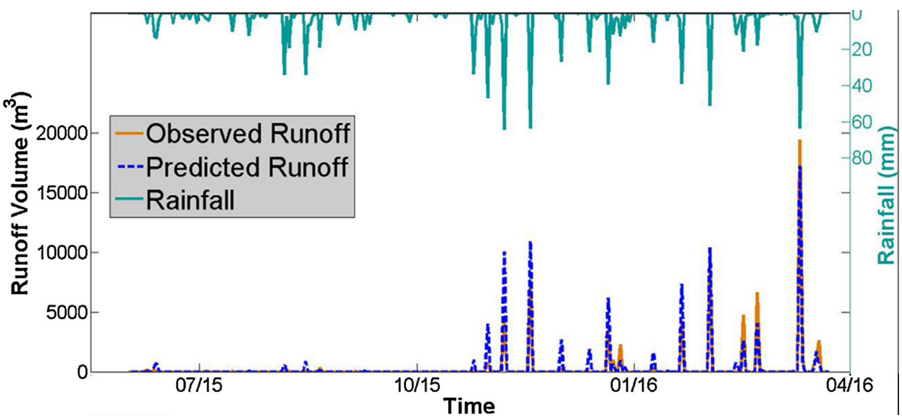

Fig. 9. Graphical comparison between predicted and observed runoff during model validation.

for the calibration phase. All other model parameters after calibration were kept the same, and the simulated data was compared with the observed runoff data. The runoff was validated for both a daily and monthly time scale. An R^2 of 0.85 and E of 0.82 were obtained for daily runoff prediction, and comparisons of monthly runoff prediction showed an R^2 of 0.90 and E of 0.66 (Fig. 8) during the validation phase. The model slightly over predicted during the late fall and winter and under predicted during the spring of the validation phase (Fig. 9).

These results show that AnnAGNPS can be successfully used to model runoff from agricultural watersheds in East Mississippi. And, as a result, the model can be used to predict potential runoff amounts and associated drainage area to aid in planning and implementing OFWS systems including the optimal location of an OFWS system storage pond for increased effectiveness.

3.2. Sediment load

3.2.1. Sediment calibration

After validating the model for runoff, AnnAGNPS was run to evaluate sediment load without calibration. Model performance assessment for daily sediment estimation without calibration showed that the model overestimated sediment by 267% with an R^2 of 0.73 but E of −5.15.

An initial value of 1 was used for RUSLE-P based on P values for gentle slopes of 3–5%, with no presence of gullies and rills, and farming up and down the slope (Wischmeier and Smith, 1978). Manning's n was set to 0.40 for the wooded area and 0.15 for all remaining sub-watersheds (Te Chow, 1959). Multiple simulations were run by adjusting these parameters along with the crop residue value, one at a time, until the best simulation result for event-based sediment load was obtained during calibration (using data from 10/2015 to 12/2015). The RUSLE-P value was decreased while the Manning's n and crop residue values were increased to reduce overprediction of sediment by the AnnAGNPS model. The best model prediction for event-based sediment load was obtained after calibration with the following parameters: RUSLE-P of 0.4, cell Manning's n of 0.175, reach Manning's n of 0.2, and a 10% increase in crop residue (Table 7). An R^2 of 0.73 and E of 0.43 (Fig. 10) were obtained for AnnAGNPS event-based sediment prediction after calibration. However, the model still over predicted the sediment load by roughly 50% (Table 8). These results could be due to the short period of time for which the model was calibrated (due to limited observed data) and evaluation of data on a daily scale. RUSLE is designed to predict long-term annual soil loss values (Renard et al., 1991). Similar less than ideal performance was reported when the model was evaluated for sediment load at a smaller time scale by Shrestha et al. (2006).

Table 7
Model parameters used for sediment calibration.

Model Parameters	Initial Values	Values after calibration
RUSLE-P	1	0.4
Manning's sheet n	0.15	0.175
Manning's reach n	0.15	0.2
Crop residue	Default	10% increase

3.2.2. Sediment validation

The model performed reasonably well and better during the validation period (1/2016 to 2/2016) than during calibration for predicting event-based sediment load, with an R^2 of 0.88 and E of 0.67 (Fig. 10). In contrast to the model results for sediment load in the calibration phase, sediment load was under predicted by the model during the validation phase (Table 8). Storm events during the validation phase had much lower rainfall amounts than during the calibration period, which could be the reason for the model's under prediction of event-based sediment load during the validation period. However, it is important to note that if the model is evaluated for total sediment load for the calibration and the validation phase combined, the model under predicted the sediment load by only 1.8% (Table 8). Therefore, as with runoff, the model performed better when estimation was made for a longer period of time. These results showed that the AnnAGNPS model can predict sediment loss from an agricultural watershed in East-Central Mississippi reasonably well with limited observed data. However,

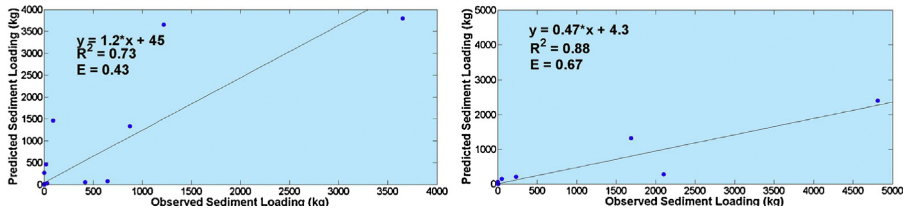

Fig. 10. Comparison of observed and predicted event-based sediment load during calibration (left) and validation (right).

Table 8
Observed rainfall and predicted and observed sediment load for storm runoff events.

Date	Rainfall (mm)	Predicted sediment load (kg)	Observed sediment load (kg)
Calibration			
10/31/2015	46.74	1463.28	91.83
11/2/2015	6.1	0	1.16
11/7/2015	64.26	3649.60	1219.88
11/18/2015	63.75	3792.03	3649.05
12/1/2015	26.67	459.03	19.49
12/13/2015	21.34	271.24	0
12/21/2015	39.12	1334.46	874.43
12/23/2015	11.68	55.33	418.05
12/25/2015	3.81	0.22	0
12/26/2015	12.7	76.20	645.89
12/28/2015	8.64	25.40	30.57
12/30/2015	4.83	9.97	0
Validation			
1/9/2016	16.0	149.68	52.72
1/15/2016	4.06	4.53	0
1/21/2016	38.86	1315.42	1690.81
2/2/2016	51.05	2394.97	4812.75
2/13/2016	11.94	57.15	0
2/14/2016	6.6	13.61	0
2/16/2016	21.08	271.25	2099.98
2/18/2016	1.02	0	6.99
2/22/2016	17.78	205.93	234.53

calibrating the model for a longer time period with more monitoring data, particularly so that all seasons are captured within the calibration period, would likely improve the model performance for sediment load estimation. The AnnAGNPS model can be used to predict sediment losses from agricultural watersheds in East-Central Mississippi, although future applications of the model in this region may benefit from a longer calibration period. The model can thus be a useful tool in estimating the amount of sediment that can be captured by an OFWS system by estimating the sediment load in the runoff captured by these systems.

Average annual sediment loss in the sub-watersheds showed that sediment loss was not concentrated in one area but occurred throughout the watershed. However, there were some sub-watersheds along a main flow route near the inlet which had higher sediment losses (Fig. 11). The cells with high sediment loss had agricultural land use and higher average land slope which could be the reason for the higher sediment loads.

3.3. Nutrient load evaluation

The model was evaluated for total phosphorus and total nitrogen after calibration and validation of runoff and sediment estimation. The model was not calibrated for nutrient constituents because of the lack of long term monitoring data. Soil nutrient information was not available in the SSURGO dataset that was used to populate the soil characteristics for this model, so the soil initial condition for phosphorus and nitrogen was updated in the model based on available literature (Yuan et al., 2005) and soil sampling results. Nutrient uptake for corn and soybean was added to the model, with values also taken from a review of the literature (Flannery, 1986b; Yuan et al., 2005; Hermanson et al., 2000). Evaluation of monthly phosphorus loadings resulted in an R^2 of 0.74 and E of 0.54 (Fig. 12). The model overpredicted phosphorus load by 42.4% over the evaluation period. The phosphorus level in the poultry fertilizer applied in the fall was based on a review of available literature (Tabler et al., 2015). Because several important nutrient inputs in AnnAGNPS were populated with estimates from the literature, a lack of site specific accurate nutrient data could be the reason for the model's overprediction in comparison to measured water quality data. Better estimation of these parameters, which is critical to the model's predicted phosphorus load, can help improve the model's predicted phosphorus loads. This evaluation shows that the model can estimate phosphorus losses from an agricultural watershed in East-Central Mississippi reasonably well with limited measured water quality data. The overprediction of phosphorous loads by the model highlight the importance of access to site specific and detailed management information for the modeled watershed.

High phosphorus loads were estimated from sub-watersheds that showed high sediment loss (Fig. 13). A study conducted by Wall et al. (1996) also showed a correlation of higher phosphorus loss with increased suspended sediment loss. Low phosphorus loading was observed in the sub-watersheds near the outlet of the modeled watershed.

The model did not, however, have a satisfactory performance in the estimation of total nitrogen loading from the watershed at a monthly scale, with an R^2 of 0.15 and E of −0.107 (Fig. 14). Lack of tile drainage in the agricultural fields and the drainage network to the storage pond makes it difficult to account for all the nitrogen lost from the watershed as some nitrogen could have been also lost through sub-surface runoff, which was difficult to collect using the established surface runoff monitoring system. This may have

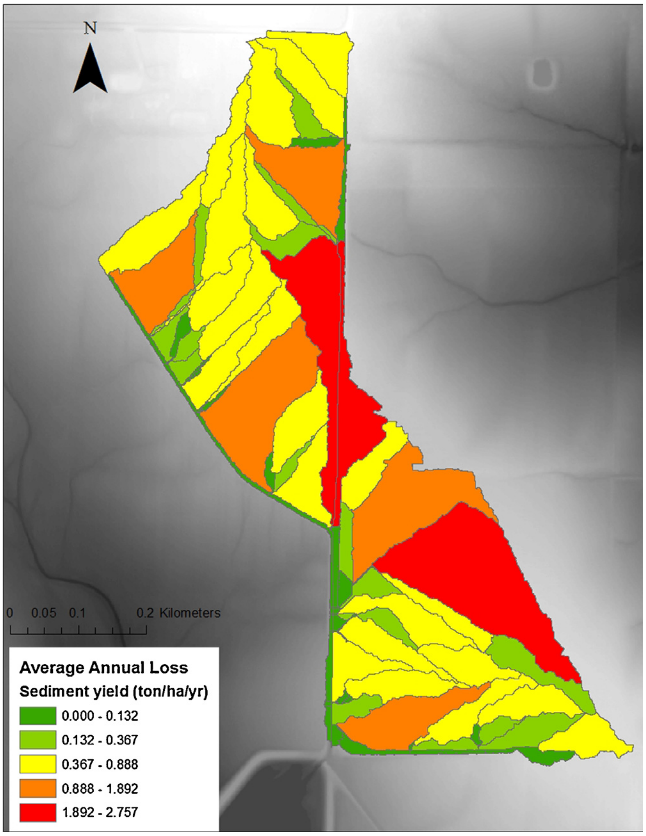

Fig. 11. Average annual sediment loss from cells in the modeled watershed.

contributed to the discrepancy between the nitrogen monitoring data and the AnnAGNPS model predictions for nitrogen loading.

A previous study that was conducted to evaluate the short-term prediction of nitrogen loading using AnnAGNPS showed similar results (Yuan et al., 2003) with poor model performance. The paper also indicated that the simplification of nitrate loading processes could be a reason for the low performance of the model. Shamshad et al. (2008) mentioned that an R^2 of 1 for nutrient loading is largely impossible, as the nutrient mass is not transferred from one day to the next in the AnnAGNPS model. These reasons along with the lack of site specific data for soil initial nitrogen concentration, crop nitrogen uptake, and nitrogen concentrations in poultry litter applied to the farm could be the reasons for the model's poor performance in predicting nitrogen loads.

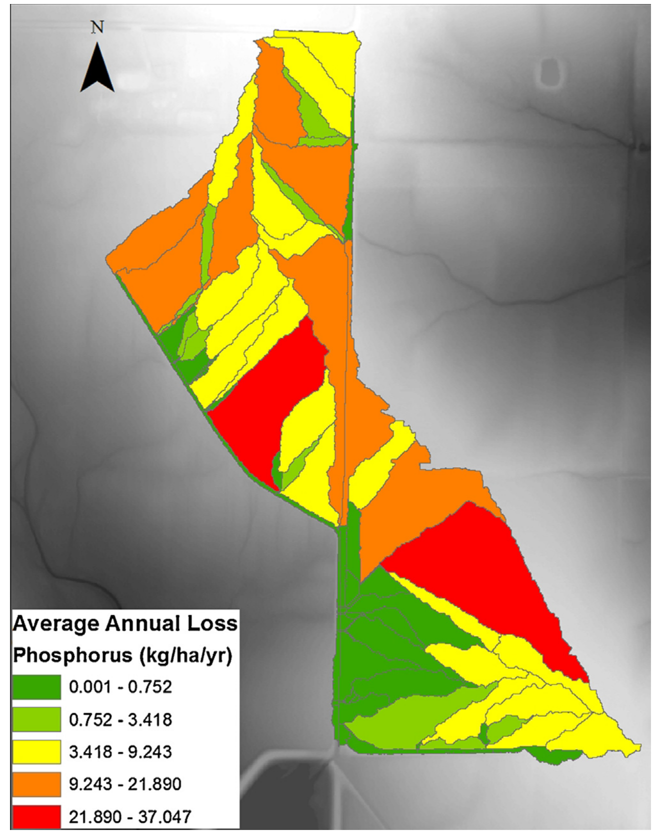

Fig. 13. Average annual phosphorus loss from cells in the modeled watershed.

3.4. Runoff and phosphorus load response to alternative management practices

The agricultural watershed was simulated using each alternative management practice from September 2014 to March 2016. Fig. 15 shows the phosphorus loss and total runoff from the watershed for the current management practice and the three alternate management scenarios that were evaluated. By moving all tillage operations and application of poultry fertilizer from the fall to the spring before planting and leaving the field no-till in the fall (Scenario 1), phosphorus losses from the field were reduced by 7.49% (Fig. 15). This result could be expected as no additional nutrients that would have been available with a fall fertilizer application, were available in the soil during the fall runoff events. The avail-

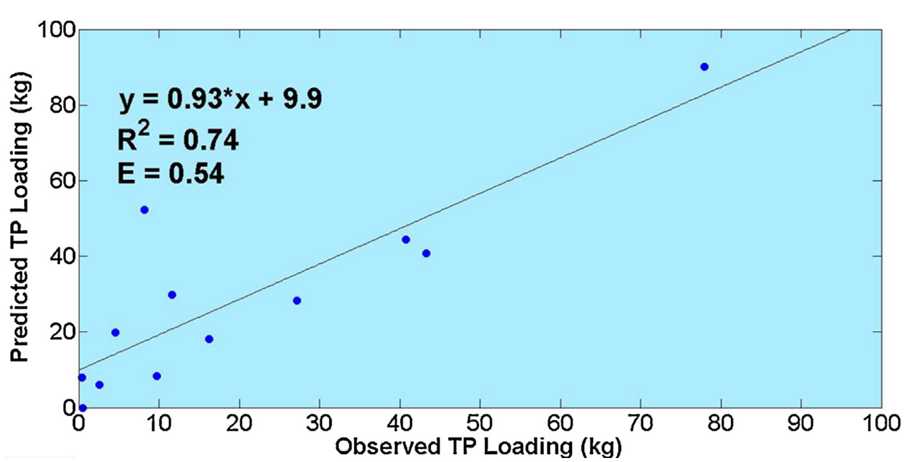

Fig. 12. Comparison between AnnAGNPS-predicted and observed monthly TP loading.

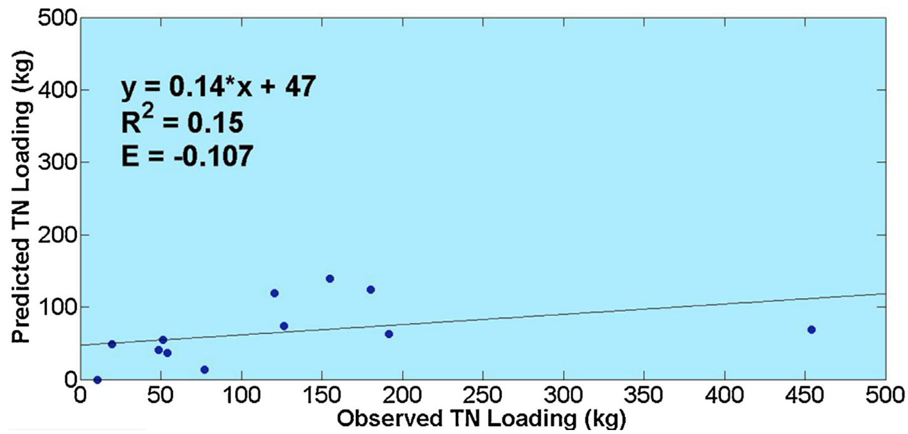

Fig. 14. Comparison between AnnAGNPS-predicted and observed monthly TN loading.

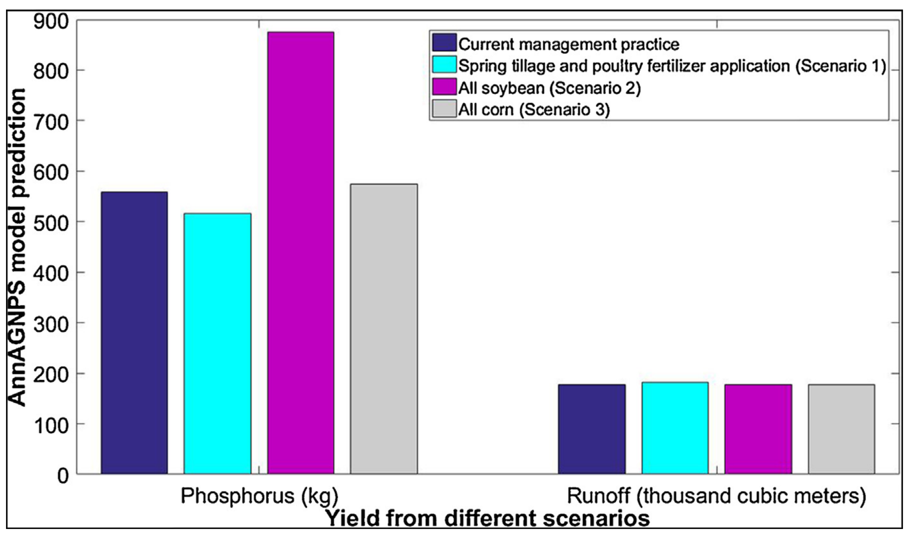

Fig. 15. Phosphorus loading and total runoff for different management scenarios simulated from September 2014 to March 2016.

ability of nutrients would also presumably increase for crops with a spring application. The runoff increased slightly by 2.41% with scenario 1.

All soybean (Scenario 2) or all corn (Scenario 3) acreage had negligible effect on the total runoff from the field (Fig. 15). However, total phosphorus load from the agricultural field increased by 56.8% when soybean was planted on all agricultural fields. The result was as expected since soybean has a lower P-uptake as compared to corn, and a post-harvest poultry fertilizer application in the fall is a source of P.

Evaluation of alternative scenarios has shown that a spring application of poultry fertilizer and spring tillage operation has the best effect on reducing phosphorus losses in runoff from the fields and possibly increasing nutrient availability for plants. However, it is important to note that although the model evaluation of alternative scenarios for phosphorus loss provides us with a loss estimation with the different scenarios, the results should be handled with caution since the model was only evaluated and not calibrated or validated for phosphorus loading. Further evaluation is also needed before the alternative management practices can be implemented, as the practice could postpone crop planting dates during wet spring months in the study area and ultimately affect yields. The scenario analysis also showed that planting the entire watershed in either corn or soybean will not affect the water availability for irrigation for the next growing season.

4. Conclusions

In conclusion, AnnAGNPS effectively estimated runoff but performed only reasonably well in predicting sediment and phosphorus loads from an agricultural watershed in East-Central Mississippi. AnnAGNPS estimates show that, over the monitoring period (September 2014–March 2016), the OFWS system established in East-Central Mississippi was able to capture 220,000 m^3 of water that drained from the modeled watershed into the storage pond, to be used for irrigation. The storage pond also captured an estimated 46 t of sediment and 558 kg of total phosphorus over the same period. The results showed that AnnAGNPS performed better for runoff and sediment estimation when evaluated for a longer time scale. While AnnAGNPS performed better when predicting runoff than for estimating sediment and phosphorus loads, future applications of the model may be used to more accurately quantify the benefits of OFWS systems if more measured data is available for calibration. The AnnAGNPS model was not able to accurately estimate nitrogen loadings from the watershed. The lack of adequate and accurate model input data for nitrogen is most likely the reason for the unsatisfactory prediction of nitrogen in the modeled watershed. As the study showed, sufficient monitoring data and detailed and site-specific management information are required to increase model performance and better estimate sediment and nutrient loads that can be captured by the system.

Because AnnAGNPS was successfully evaluated for runoff, the model can aid in designing new OFWS systems by estimating the runoff per area per year along with the associated runoff flow paths that can help identify the ideal location for the storage pond. AnnAGNPS can also help estimate the size of the storage pond as well as the total drainage area required for irrigating crops based on the water needs and acreage of the crop(s) to be irrigated. In addition, the model can be used to evaluate the water supply benefits of OFWS systems already established in similar regions. The OFWS system was able to provide water for irrigation through captured runoff in a region where there is no other source of water for irrigation, and by doing so, also helped protect downstream water quality by capturing considerable amounts of sediment and phosphorus.

AnnAGNPS can also help predict the runoff and sediment that can be captured by the OFWS system storage pond under a variety of different management scenarios. Evaluation of current and alternative management practices showed that fall application of poultry litter fertilizer in preparation for the next growing season can cause increased downstream nutrient loss from an agricultural field in an East-Central Mississippi watershed. Additionally, leaving the field no till in the fall after harvest and moving to a spring application of poultry litter fertilizer can decrease nutrient losses from the agricultural fields and allow more nutrients to be available at planting. AnnAGNPS can also be used to evaluate the effectiveness of alternative management practices for phosphorus loading reduction, although additional measured data for model calibration and better site-specific management information would improve comparative studies of different management practices for watersheds in East-Central Mississippi. If adequately calibrated, the AnnAGNPS model can help optimize management practices to decrease nutrient and sediment loss before actual implementation of BMPs, including OFWS systems.

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