Evaluation of an on-farm water storage system as a bmp for sediment and nutrient reduction, nutrient recycling, and irrigation in East Mississippi

By

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Evaluation of an On-Farm Water Storage (OFWS) system as a Best Management Practice (BMP) for nutrient and sediment loading control and irrigation in East Mississippi has shown that the system can effectively reduce sediment and nutrient loading as it was able to capture 46 tons of sediment and 558 kg of phosphorus over the monitoring period. The system was also able to decrease nitrogen loading as shown from the nitrogen concentration in the captured storm runoff events although an accurate estimate could not be made using AnnAGNPS because adequate model input data was not available. The system was able to provide about 63 million gallons of water for irrigation as a result of which increased corn and soybean yield was also obtained in irrigated fields when compared to non-irrigated fields. Water from the storage pond used for irrigation did not have adequate nutrient recycling to reduce commercial fertilizer application.

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CHAPTER I

INTRODUCTION

Nutrient loss from fertilizers applied to agricultural fields is a major source of nitrogen and phosphorus in downstream rivers and streams. Excess nutrient loads are often the major reason for declining water quality in surface waters. Nutrients are the second largest contributor to wetland impairment and a major cause of pollution to ground water and estuaries (EPA, 2000). Nutrients, sediment/siltation, and organic enrichment/low Dissolved Oxygen (DO) are the major causes of impairments of rivers and streams in Mississippi (MDEQ, 2014). Excess nitrogen and phosphorus in water can lead to algal blooms which can be toxic and also result in the development of hypoxic zones. These hypoxic areas have oxygen levels below 2 mg/L that are caused when the oxygen is used by bacteria during the decomposition of organic matter. Consequently, the hypoxic zone can result in the destruction of aquatic habitat and loss of many amenities including drinking and recreation.

Along with nutrient runoff, declining water for irrigation is another pressing problem in Mississippi. Water for irrigation is needed to maintain productivity and maximize yields. An increase in the number of irrigated acres (USDA, 2015), along with the problem of changing weather and more frequent periods of drought (Carter et al., 2014) have led to increasing water use for irrigation in Mississippi. As a result, there is stress on the water sources used for irrigation. The Mississippi River Valley Alluvial

(MRVA) aquifer, which is the major source of water for irrigation in the Mississippi Delta, is declining at an alarming rate. The MRVA is losing an average 0.37 km^3 per year, and the water level has dropped by more than 12.2 m in the worst affected areas of Central Delta (YMD, 2014). Farmers are also at risk of losing potential crop yield in regions like East Mississippi where there is no easy access to sources of water for irrigation.

An On-Farm Water Storage (OFWS) system is a best management practice (BMP) that works by collecting irrigation and storm runoff from agricultural fields in a storage pond, where it is held until later used for irrigation. By capturing runoff, the system also captures sediment and nutrients carried in the water and thus prevents these pollutants from going downstream. An OFWS system is a unique BMP that not only reduces nutrient and sediment loss from agricultural fields, but it also provides water needed for irrigation. These systems provide a valuable water source for irrigation in Northeast Mississippi, where there are no other feasible sources of water for irrigation. These systems are also used in the Mississippi Delta conjunctively with groundwater, which is declining at an alarming rate.

OFWS systems started appearing in the Mississippi Delta in 2010 when the Natural Resources Conservation Service (NRCS) along with its partners launched the Mississippi River Basin Healthy Watersheds Initiative (MRBI). The goal of the MRBI program is to promote the adoption of voluntary conservation practices among farmers and improve water quality by providing technical as well as financial assistance (USDA-NRCS, 2010). These OFWS systems are relatively new in East Mississippi and have been privately funded by farmers who established them for the primary purpose of irrigation.

As with all agricultural BMP’s that are currently being implemented, it is important to evaluate the effectiveness of these systems in meeting their intended goals. Funding assistance to implement OFWS storage systems in the Mississippi Delta has been provided by NRCS with the goal of reducing sediment and nutrient loading to achieve improvements in downstream water quality. Although OFWS systems have been implemented in the Mississippi Delta since 2010 as a part of MRBI studies, there is little peer–reviewed work evaluating the effectiveness of these systems for nutrient and sediment loading control. There is also little evidence on the performance of these systems to provide a reliable source of water for irrigation. Even less is known about the OFWS systems in East Mississippi, which are somewhat different in design and function than those systems in the Delta because of varying landscape and irrigation systems.

This study describes an OFWS system located in East Mississippi by monitoring and also by simulation of the agricultural site using Annualized Agricultural Non–Point Source Pollution Loading (AnnAGNPS) Model (Cronshey and Theurer, 1998) to evaluate the effectiveness of OFWS systems for nutrient and sediment loading reduction as well as a source of water for irrigation in East Mississippi.

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CHAPTER II

MONITORING OF AN ON-FARM WATER STORAGE (OFWS) SYSTEM FOR NUTRIENT AND SEDIMENT LOADING CONTROL, AND SUPPLEMENTAL IRRIGATION IN EAST MISSISSIPPI

Introduction

As a result of substantial nitrogen (N) and phosphorus (P) application to croplands (Sims et al., 1998; Smith, 2003), agricultural runoff rich in N and P is a major source of pollution to surface waters (Richards, 1998). According to the 2000 National Water Quality Inventory, agricultural nutrient runoff is the leading cause of declining water quality in many lakes and streams (EPA, 2000). Elevated levels of N and P in surface waters can lead to eutrophication (de Jonge et al., 2002) and is a major problem in many rivers, lakes, and oceans (Richards, 1998). Eutrophication is caused by the increase in organic content in a water body due to excess nutrients (Nixon, 1995). Decomposition of organic matter by bacteria requires oxygen and leads to the development of hypoxic zones, areas where the dissolved oxygen concentration falls below $2 mgl^{-1}$ (Rabalais et al., 2001). Hypoxic conditions caused by eutrophication can cause mass mortality of aquatic life (de Jonge et al., 2002; EPA, 2000). Eutrophication can also lead to turbid and foul smelling water, foaming, proliferation of macrophytes and loss of amenities that surface water provides, including drinking water and recreation (Dodds et al., 2008; Postel and

Carpenter, 1997). Almost 60% of the rivers and half of the lake area in the United States are impaired because of eutrophication (EPA, 1996).

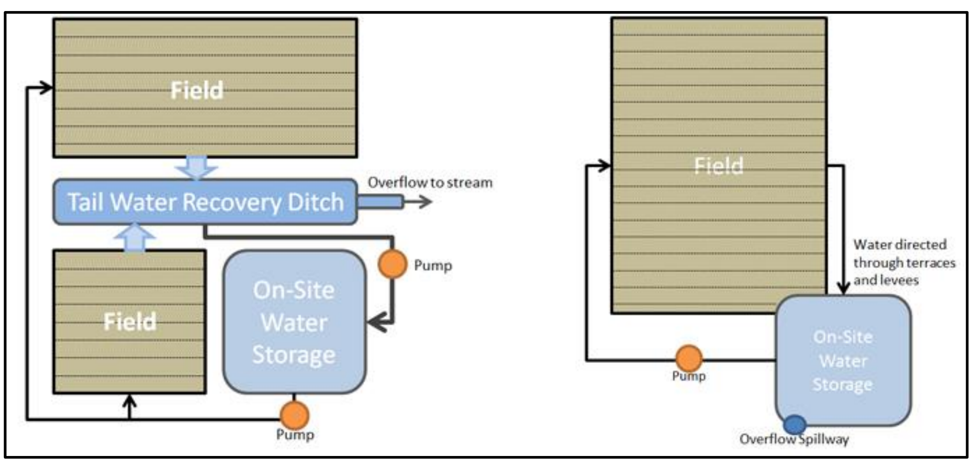
Crop production is a significant contributor to making agriculture the number one revenue–generating industry in the state of Mississippi (USGS, 2015), and like many states with intensive cropland, Mississippi is also facing problems from agricultural nutrients and sediments in runoff. The 2014 Mississippi Water Quality Assessment Report indicated that N and P are one of the major causes of impairment in Mississippi rivers and streams (MDEQ, 2014). Because N and P supply is highly associated with eutrophication of receiving waters, the management of nutrient runoff from agricultural fields is very important in improving downstream water quality.

Irrigation can help increase crop yields, decrease risk of yield loss, and provide an avenue for crop diversification. Although Mississippi receives an average 1,422 mm of rainfall annually, about 70% of it is received during the winter and spring months with periods of droughts normally occurring in late summer or early fall (Paulson et al., 1991). Having access to a water source that can be used for supplemental irrigation is critical in attaining maximum yield. However, most of East Mississippi is still in dryland production because of the lack of easy access to water for irrigation. The Black Warrior River aquifer underlies East Mississippi, but farmers must drill to a depth of more than 61 m to access the water (USGS, n.d.). In addition, there is no easily accessible surface water source for irrigation.

The Mississippi River Valley Alluvial (MRVA) aquifer is the primary source of water for irrigation in the Mississippi Delta, a very fertile and productive area in the northwest region of Mississippi with a total land area of about 16,188 km^2 (Snipes, 2005). However, the MRVA is under extreme stress as a result of excess withdrawals. The aquifer is losing water at a rate of roughly 0.37 km^3 per year (MAFES, 2014), and the water level has dropped by more than 12.2 m in the worst affected areas of the Central Delta (YMD, 2014). As a result, there is increasing interest in using surface water for irrigation both in East Mississippi and the Mississippi Delta.

An On-Farm Water Storage (OFWS) system is a constructed Best Management Practice (BMP) consisting of a tail water recovery ditch (TWR) and/or a storage pond with the primary goal of reducing downstream nutrient loading. These systems also conserve water by capturing precipitation and surface water runoff from irrigation and rainfall events. The design of these systems can vary according to topography. In regions like East Mississippi with a sloping landscape, the system consists of constructed terraces to direct water that is gravity–fed from the agricultural field directly to the storage pond (Figure 2.1). Because center pivots are the primary irrigation system used in East Mississippi, precision levelling is not common in this region, and the runoff captured by OFWS systems in this region is mostly limited to winter rainfall runoff. In the Mississippi Delta, which consists of flat plains, and in topography similar to it, OFWS systems consist of a TWR ditch and a storage pond. Fields are usually precision levelled and 'padded and piped' when these systems are implemented, and furrow irrigation is typically the preferred irrigation method that is applied once the systems are installed. The TWR ditch collects irrigation tailwater from furrow irrigation events and storm runoff from the fields, and the water is then pumped to a storage pond, where it is held for future use (Figure 2.1).

OFWS systems are a fairly new practice in East Mississippi and started appearing after implementation in the Mississippi Delta. These systems are privately funded by farmers due to the current lack of financial assistance programs and are primarily established for irrigation. OFWS systems began appearing in the Mississippi Delta when the United States Department of Agriculture–Natural Resources Conservation Service (USDA-NRCS) started a 12–state initiative in 2010, called the Mississippi River Basin Healthy Watersheds Initiative (MRBI). The MRBI now includes 13 states and, with help from its conservation partners, aims to improve water quality in priority watersheds by providing technical as well as financial assistance to producers and landowners who implement voluntary conservation practices (USDA-NRCS, 2010). In both regions of the state, however, farmers are interested in these systems primarily as a source of water for irrigation.



(a) (b)

Figure 2.1 General design of OFWS systems in the (a) Mississippi Delta and (b) East Mississippi.

Although these systems are presented as an agricultural BMP, there has been very little published in peer–reviewed literature about the effectiveness of OFWS systems as a BMP for nutrient and sediment loading control or as a water source of irrigation. Even less is known about the operation, management, and maintenance of OFWS systems that are found in East Mississippi. However, there are separate studies that have highlighted the importance of capturing excess rainfall for increasing agricultural productivity (Oweis et al., 1999; Zimmerman, 1966) and the importance of irrigation to increase productivity (Wesley et al., 1993).

The goal of this paper is to measure the value of OFWS systems as a BMP both for improving water quality and providing a source of water for irrigation. More specifically, this paper will 1) evaluate the ability of an OFWS system to reduce downstream nutrient and sediment loading from agricultural fields; 2) quantify surface water provided by the OFWS system for irrigation; and 3) determine if commercial fertilizer application can be reduced because of the nutrient load in the application of recycled surface water used for irrigation.

Methodology

Site description

The study area is about 35.4 km southeast of Starkville, MS in the Alabama and Mississippi Blackland Prairie–Major Land Resource Area (MLRA)–135A (USDA-NRCS, 2014) just outside of Brooksville, MS in Noxubee county. It is located in the Middle Tombigbee–Lubbub watershed (HUC 0316106) of the larger Tombigbee River Basin. The study area consists of Brooksville Silty clay, Vaiden Silty clay, and Catalpa Silty clay soils with slopes ranging from zero to five percent. Annual precipitation in the region is approximately 1371.6 mm, with most rainfall occurring during the winter and early spring months. The average air temperatures in the summer and winter are about 28.05° C and 7.2° C, respectively.

Corn and soybean are the primary crops grown in the study area. The study site was monitored from June 2014 to March 2016. Portions of three agricultural fields make up the two sub–watersheds that drain to the OFWS system storage pond (Figure 2.2). Management practice for the two agricultural fields (field A and B) that lie in the monitored sub–watershed (Figure 2.2) was obtained for this study. During the monitoring period, corn was grown for the 2014 and the 2015 season in field A (Figure 2.2) while soybean was grown in 2014 and corn was grown in 2015 in field B (Figure 2.2). Both fields were conventionally tilled after harvest, followed by subsoil tilling, disking, and bedding in both 2014 and 2015. In 2014 and 2015, respectively, 4485 kg and 3363 kg of poultry litter per hectare were applied after harvest and before tillage in both fields in preparation for the next growing season. Following the poultry litter application in the fall, starter fertilizer (7.2 kg ha^{-1} nitrogen, 24.2 kg ha^{-1} phosphorus), nitrogen sidedress (246.6 kg ha^{-1} nitrogen), and nitrogen at tassel (49 kg ha^{-1} nitrogen) were applied in corn for both the 2014 and 2015 growing seasons, while no fertilizer was applied on soybeans during the growing season.

On-Farm Water Storage (OFWS) System

An OFWS system with a storage pond of approximately 6.88 hectares surface area and 7.6 m in depth at its deepest point was constructed in the southeast corner of field A in 2012 (Figure 2.2). Constructed terraces and drainage ditches are used to direct the runoff from the agricultural fields to the storage pond. The total watershed area that drains to the storage pond is roughly 45 hectares and consists of two sub-watershed areas that drain to the storage pond (Figure 2.2). Only one sub-watershed was monitored for this study. The monitored sub-watershed covers approximately 30.3 hectares and lies in the northern portion of field A and southern portion of field B. The OFWS system provides irrigation water for three different center pivot systems which are located in fields adjacent to the OFWS system storage pond (Figure 2.2). There are two pumps routing water from the storage pond to the three center pivots to irrigate approximately 137.2 hectares.

Monitoring system

The monitoring system consisted of a portable automatic water sampler, a weather station, and three flowmeters. The locations of the weather station and autosampler within the study area are shown in Figure 2.2. The portable automatic water sampler (ISCO 6712[1]) was installed at the outlet of the monitored sub-watershed, which is also the inlet to the storage pond. The sampler captured storm runoff events based on a uniform time spacing, and the sampler was set to trigger when a water depth of 7.62 mm was measured in the drainage channel during storm events. The runoff depth and flow were monitored using the 750 Area Velocity Flow Module[2] attached to the ISCO sampler. When the sampler was triggered, 24 samples were collected on a uniform time spacing, but only the odd samples were analyzed. Hence, a total of 12 samples were analyzed for each storm event that was captured.

[1] Teledyne Isco. 4700 Superior Street, Lincoln, NE 68504.
[2] Teledyne Isco. 4700 Superior Street, Lincoln, NE 68504.

A Watchdog 2900ET[3] weather–station was installed to record precipitation along with wind speed, air temperature, relative humidity, and solar radiation at 15–minute intervals. An IM3000[4] magnetic flowmeter from Lindsay Growsmart was installed on each of the three center pivots fed by the storage pond to record the amount of irrigation water provided by the system.

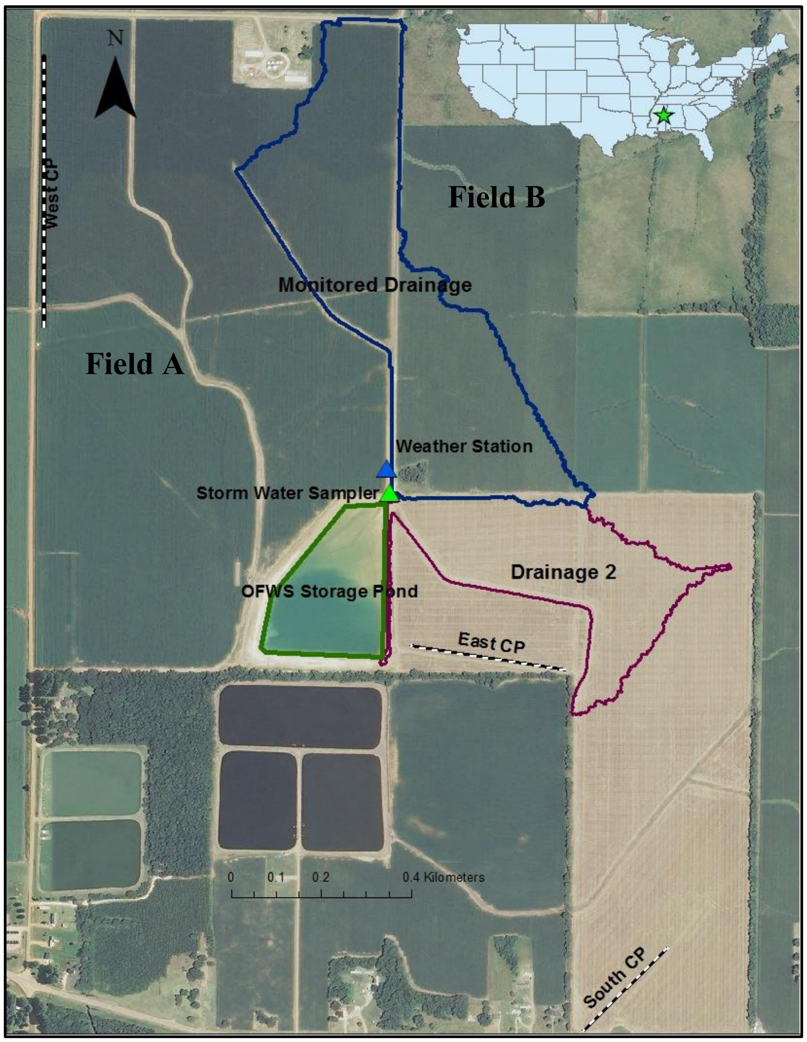


Figure 2.2 Location and layout of OFWS system in East Mississippi.

[3] Spectrum Technologies, Inc. 3600 Thayer Court, Aurora, IL 60504.
[4] Lindsay Corporation. 2222 North 111th Street, Omaha, NE 68164.

Grab samples were collected from the storage pond every 21 days during the study period, following the sampling protocol used by the Mississippi Department of Environmental Quality (MDEQ) as part of their Delta Water Monitoring Plan (MDEQ, 2009). In-situ measurements for temperature, dissolved oxygen, and conductivity were taken using the ORION STAR A329[5] portable multi-parameter probe. After collection, the samples were transferred to the lab on ice and stored at 4° C until being analyzed for soluble and particulate forms of N and P, and sediment. Storm runoff samples were also analyzed for the same constituents.

Grab samples were also collected from the west center pivot (Figure 2.2) during irrigation events to quantify the nutrient load being recycled by irrigating using water from the OFWS storage pond. The samples of irrigation water from the pivot were analyzed for nutrients and compared to the nutrient levels found in grab samples retrieved from the OFWS pond on the same day.

Water Quality Analyses

Reactive and total phosphorus were analyzed by the ascorbic acid method (HACH, 2007) using a DR-2800 spectrophotometer[6]. Samples were filtered through a phosphorus–free 0.45µm filter paper[7] before being analyzed for reactive phosphorus. Ammonia and nitrate were analyzed using the salicylate and dimethylphenol methods, respectively (HACH, 2007). Persulfate digestion was used for the analysis of total nitrogen (HACH, 2007), and the sulfuric acid digestion method was used to analyze samples for Total Kjeldahl Nitrogen (TKN) (Kopp and McKee, 1979). Samples were also

[5] Thermo Fisher Scientific Inc. 81 Wyman Street, Waltham, MA USA 02451.
[6] Hach Company. P.O.Box 389, Loveland, CO 80539-0389.
[7] Sterlitech Corporation. 22027 70th Avenue S, Kent, WA 98032-1911 USA.

analyzed for total suspended solids (TSS), following the EPA 160.2 gravimetric method. A Whatman GF/F microfiber filter[8] of 0.7µm pore size and 47 mm diameter was used for the analysis.

Soil Sampling

Soil sampling was conducted to analyze nitrate and phosphorus levels in the soil before and after irrigation events, to determine if there was a measurable change in nitrate or phosphorus levels resulting from the application of recycled water through irrigation. Phosphorus analysis was conducted using the Lancaster extraction procedure (Sikora and Moore, 2014), and nitrate concentrations were measured by using the Hanna HI 38050[9] nitrate test kit for soil and irrigation water.

Results and Discussion

Nutrient and TSS concentrations in surface runoff

The OFWS system was monitored for a period of 22 months from June 2014 to March 2016. During the study period, the total rainfall was 2132.8 mm with the highest rainfall event of 73.1 mm occurring on November 16, 2014. Storm runoff samples were captured and analyzed for nutrients to determine the nutrient concentrations being captured by the OFWS storage pond. Storm runoff events captured during the study period fell between October 2014–May 2015 (seven runoff events captured) and October 2015–February 2016 (four runoff events captured). Very little runoff was observed throughout the growing season (May through September) in both 2014 and 2015.

[8] Sterlitech Corporation. 22027 70th Avenue S, Kent, WA 98032-1911 USA.
[9] Hanna Instruments, Inc. 2081 Hutton Drive, Suite 111 Carrollton, TX 75006.

Nitrate, Total Kjeldahl Nitrogen (TKN), Ammonia, and Total Nitrogen (TN) concentrations in storm runoff events

It was evident from the monitored data that the highest nitrate concentrations for both 2014 and 2015 were recorded during the early fall (September–October) runoff events after harvest and subsequent fall application of poultry litter fertilizer (Figures 2.3 and 2.4). The lowest nitrate concentrations occurred in the late spring season for both 2015 and 2016. The highest measured nitrate concentration during the fall of 2014 was 84.6 mg/L on November 16, 2014 (73.1 mm rainfall), while the highest measured concentration during the fall of 2015 was 179 mg/L on October 31, 2015 (46.7 mm rainfall). The high nitrate concentrations that were observed during the fall of each year were most likely a result of the fall poultry litter application, which can contain an average 21.5 kg of N per ton of poultry litter (Dettmann, 2001). The farmer applied 4485 kg and 3363 kg of poultry litter per hectare after harvest and before fall tillage in 2014 and 2015, respectively.

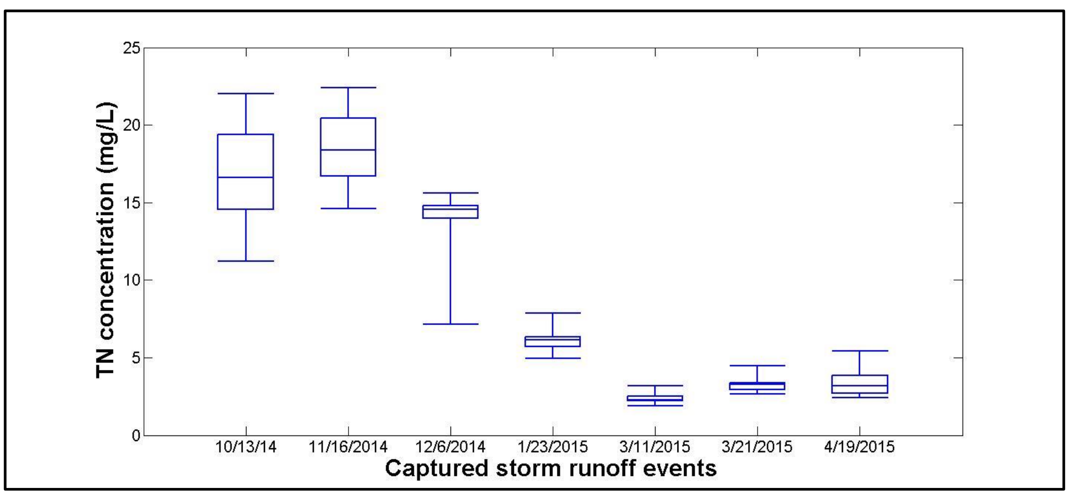


Figure 2.3 Nitrate concentration in individual storm runoff events captured from fall 2014–spring 2015.

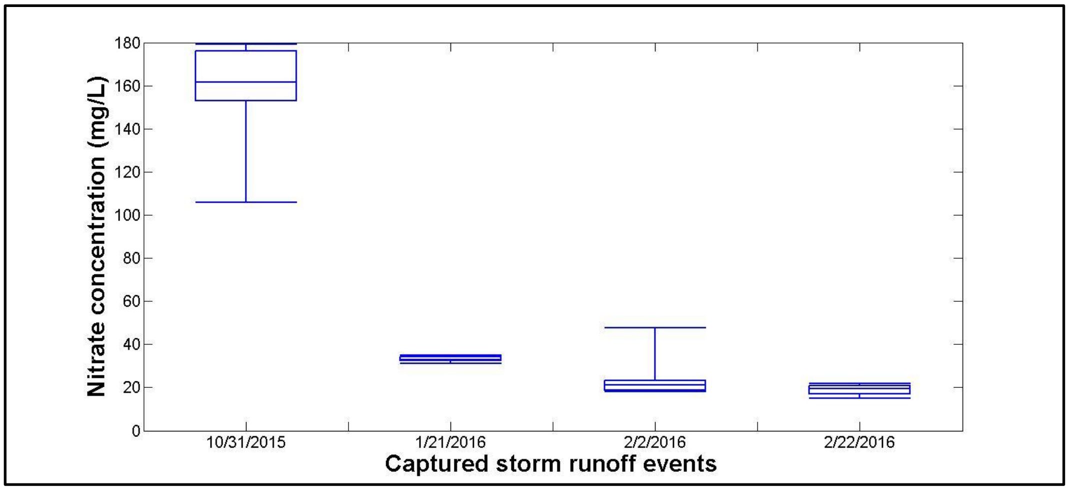


Figure 2.4 Nitrate concentration in individual storm runoff events captured from fall 2015–spring 2016.

A trend of decreasing nitrate concentrations in storm runoff samples was observed from fall to spring in both years of the study, with the fall nitrate concentrations being considerably higher than those occurring in the spring. These concentrations likely indicate a loss of fall–applied fertilizer during subsequent rainfall events. The data also showed that in fields receiving a fall fertilizer application, fall rainfall events are more critical to downstream water quality because runoff from these events have a higher nitrate concentration.

Total Kjeldahl Nitrogen concentration in the first runoff event (10/13/2014) during the fall of 2014 season was much higher than in the remaining storm events captured during the first year of the study (fall 2014–spring 2015) (Figure 2.5). The highest TKN concentration in the first runoff event was 11.73 mg/L (47.49 mm rainfall), while the maximum concentration in samples from subsequent storm events was only 3.9

mg/L (1/23/2015, 41.66 mm rainfall). Fall application of poultry litter could also be the reason for the high concentration of TKN in the first runoff event captured.

Ammonia concentrations in the same storm runoff events from fall 2014–spring 2015 ranged only from 0.015 to 0.729 mg/L (Figure 2.6). This showed that organic nitrogen was the major contributor to TKN rather than ammonia. There was no trend evident in the ammonia concentration in storm runoff events from fall to spring like for other nutrients. The highest ammonia concentration of 0.729 mg/L was recorded on December 6, 2014 (45.46 mm rainfall) and did not coincide with the date of the highest measured TKN concentration.

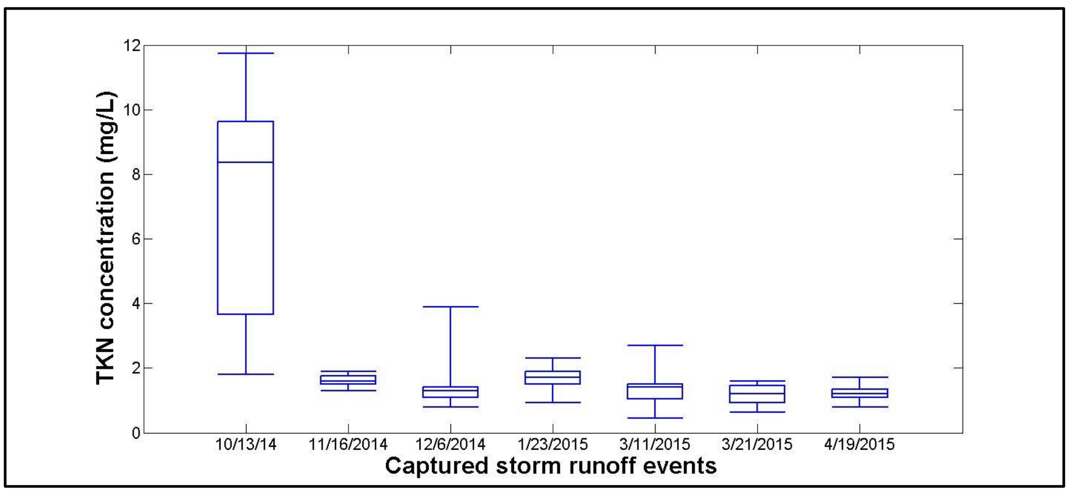


Figure 2.5 Total Kjeldahl Nitrogen concentration in individual storm runoff events captured from fall 2014–spring 2015.

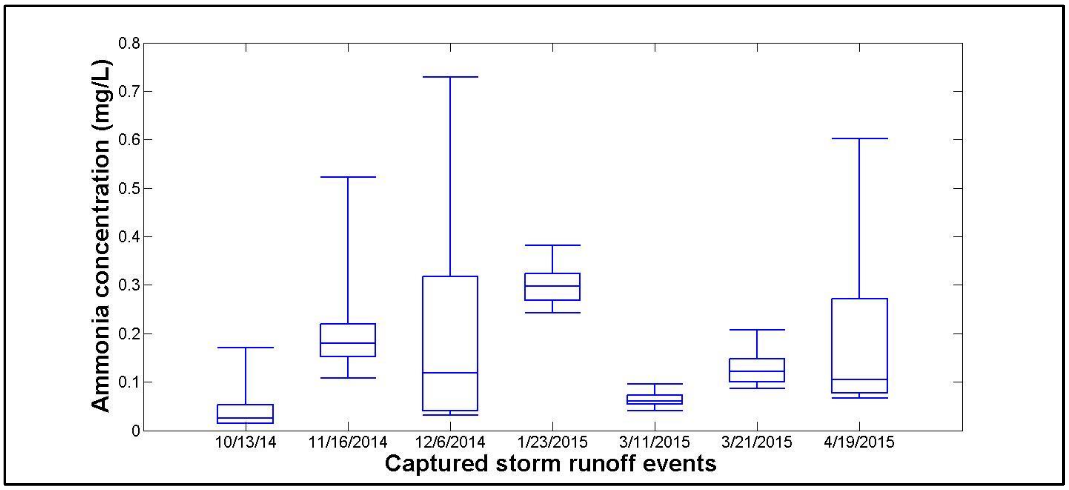


Figure 2.6 Ammonia concentration in individual storm runoff events captured from fall 2014–spring 2015.

The difference in TKN concentration between the first runoff event captured in the fall 2015 and the subsequent storm runoff events captured during the second year of the monitoring period (fall 2015–spring 2016) was not very high (Figure 2.7). This was in contrast to the trend seen during the first year of monitoring (fall 2014-spring 15). The highest measured TKN concentration was 6.7 mg/L in the during the February 2, 2016 (51.05 mm rainfall) storm event, but most TKN concentrations measured during 2015-16 storm events were around 2 mg/L.

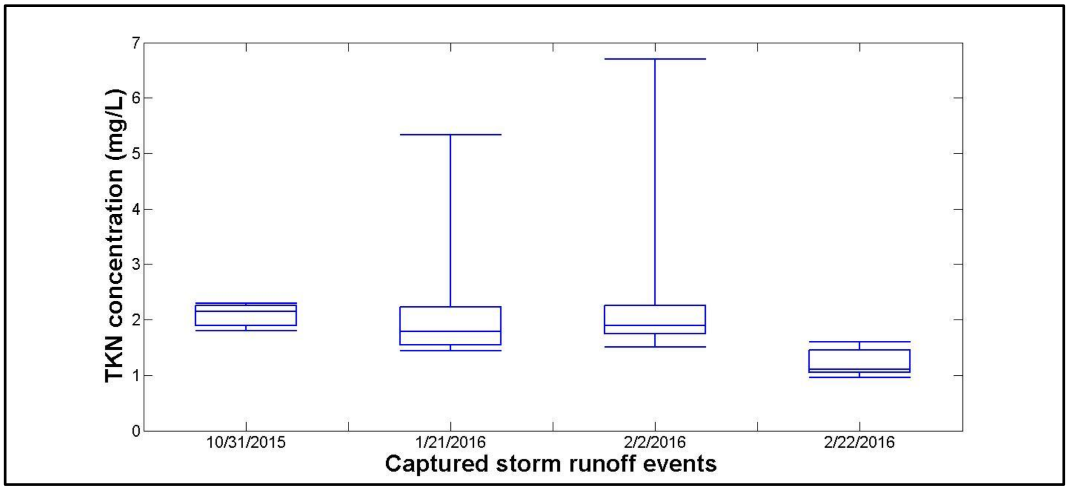


Figure 2.7 Total Kjeldahl Nitrogen concentration in individual storm runoff events captured from fall 2015–spring 2016.

Similar to the fall 2014–spring 2015 events, organic nitrogen constituted most of the measured TKN concentration. The highest measured ammonia concentration was 2.28 mg/L on February 2, 2016 (51.05 mm rainfall), but most measured ammonia concentrations for 2015-16 storm events were below 1 mg/L (Figure 2.8).

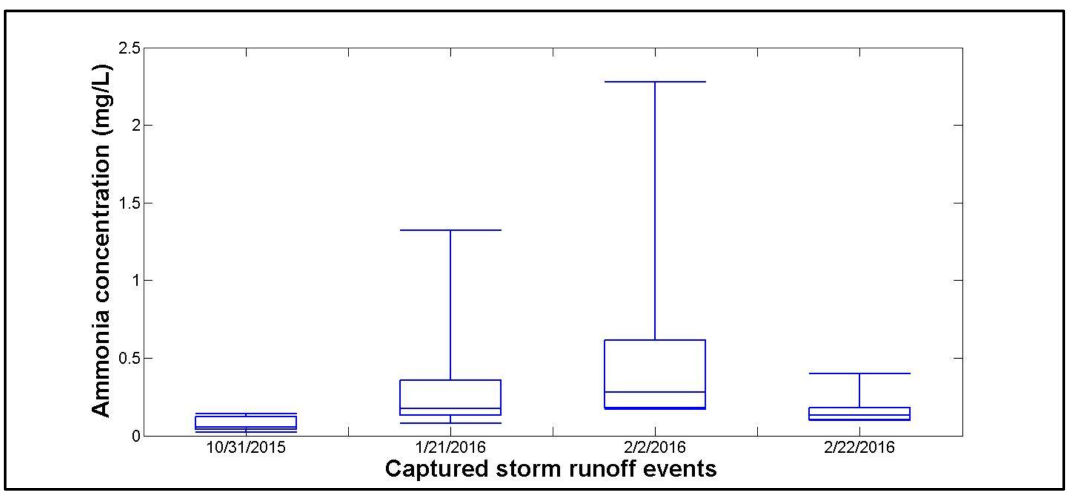


Figure 2.8 Ammonia concentration in individual storm runoff events captured from fall 2015–spring 2016.

TN concentrations in storm runoff events, as expected, followed a similar trend to nitrate concentrations. The highest measured concentrations were in the early runoff events during the fall of each year, and the lowest measured concentrations occurred with the spring runoff events. The highest measured TN concentration during the fall of 2014 was 22.4 mg/L on November 16, 2014 (Figure 2.9), and the highest measured TN during the fall of 2015 was 44.4 mg/L on October 31, 2015 (Figure 2.10).

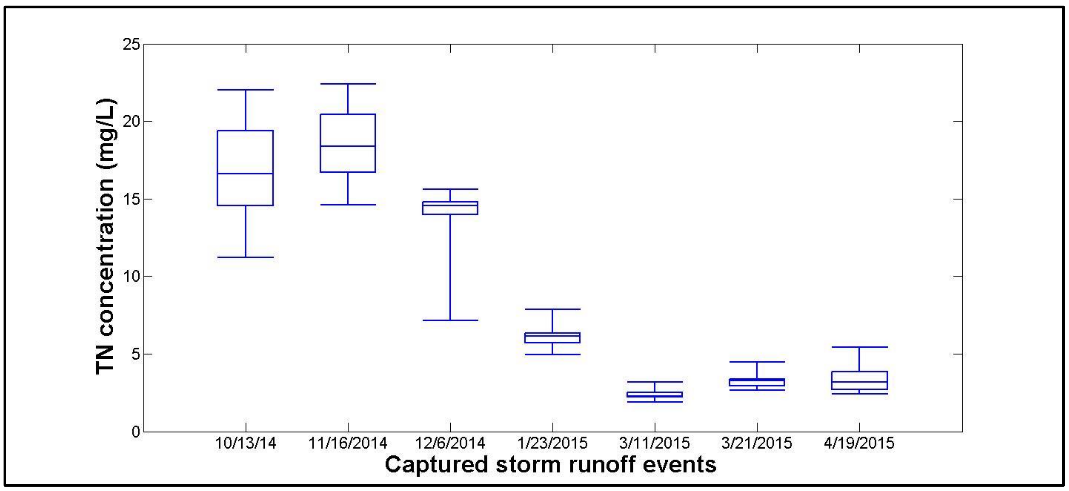


Figure 2.9 Total nitrogen concentration in individual storm runoff events captured from fall 2014–spring 2015.

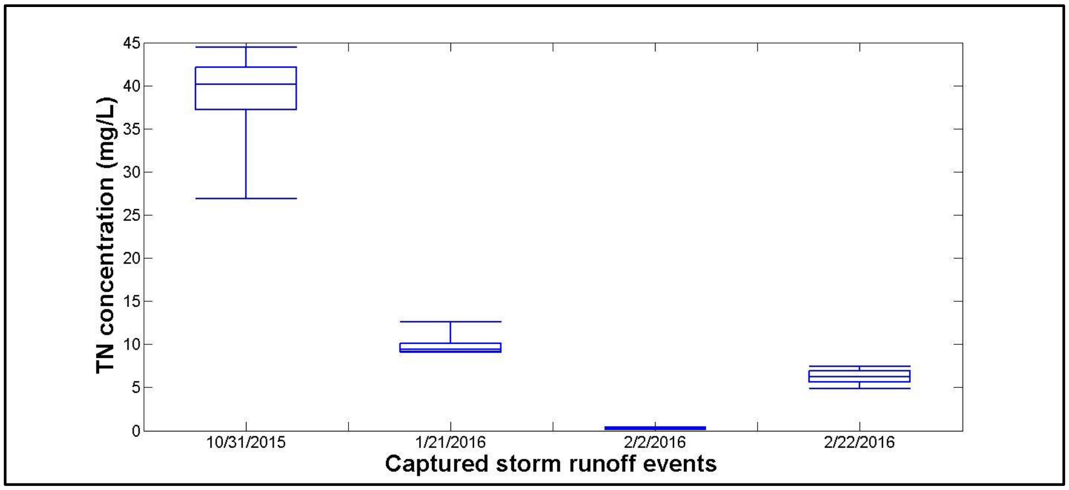


Figure 2.10 Total nitrogen concentration in individual storm runoff events captured from fall 2015–spring 2016.

Dissolved and total phosphorus concentration in storm runoff events

Similar to the nitrate and TN concentrations, the highest dissolved phosphorus (DP) concentrations were recorded in conjunction with the fall and winter runoff events of 2014 and 2015, while the lowest concentrations were measured during the spring seasons of 2015 and 2016 (Figures 2.11 and 2.12). However, unlike nitrate, there was not a significant difference between the highest concentrations measured during the fall runoff events and the lowest concentrations measured during the spring events. The highest DP concentration measured in fall 2014–spring 2015 was 0.541 mg/L on October 10, 2014 (47.4 mm of rainfall), while 0.69 mg/L was the highest DP concentration measured during the fall of 2015 on October 31 (46.7 mm rainfall). The high DP concentrations in the storm runoff events of early fall for both 2014 and 2015, again, is most likely a result of the fall poultry litter application after harvest and before tillage. Phosphorus in poultry litter averages 31.47 kg per ton of litter (Dettmann, 2001).

Unlike nitrate, TN, and DP, the highest total phosphorus (TP) concentrations were not recorded in the storm runoff events captured in early fall of 2014 and 2015. Also, there was no discernable trend in concentration from fall to spring as observed for nitrate, TN, and DP (Figures 2.13 and 2.14). TP concentrations measured during the fall of 2014 were only slightly higher than those observed during the spring of 2015 (Figure 2.13). During the 2015–16 monitoring period, median TP concentrations were fairly consistent for all runoff events, ranging from 0.4 to 0.8 mg/L (Figure 2.14); however, only four rainfall events were captured during this monitoring period. It is also important to note that the highest measured DP concentration did not coincide with the highest measured TP concentration for either year of the study. TP concentration is greatly affected by the TSS concentration in the storm events and could be the reason for highest measurements of TP and DP in different storm events for both years of study. The highest TP concentration of 1.48 mg/L measured during the fall of 2014 occurred on December 6, when 45.47 mm of rainfall occurred. The highest concentration measured during the fall 2015–spring 2016 monitoring period was 3.73 mg/L on February 2, 2016 (51.05 mm rainfall).

Because the highest nitrate, TN, and DP concentrations were recorded in the early fall runoff events for both years of the study, management of these runoff events is critical to maintaining downstream water quality. Early fall is also the time when the OFWS system storage pond is at its lowest depth level for the year from the use of stored water for irrigation during the growing season. Hence, the system is able to capture all of this critical runoff and prevent it from going downstream.

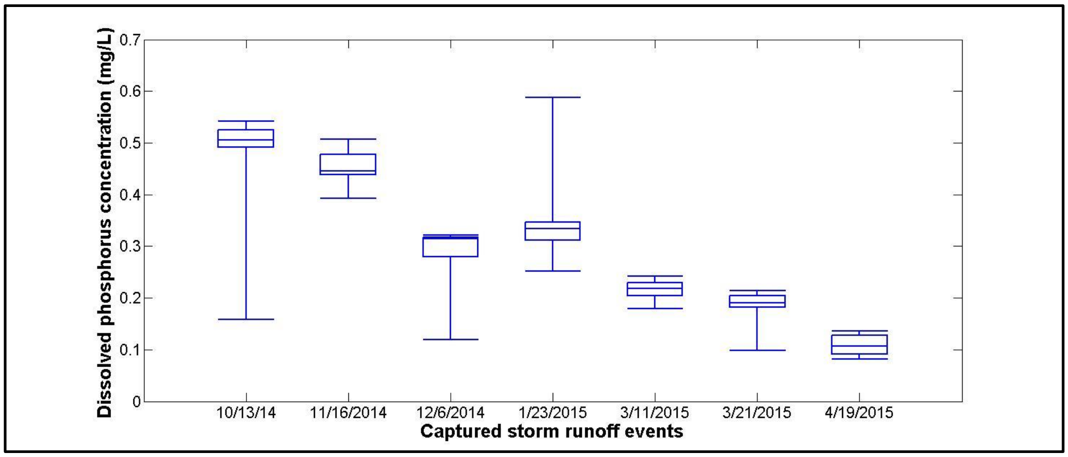


Figure 2.11 Dissolved phosphorus (DP) concentrations in storm runoff events captured from fall 2014–spring 2015.

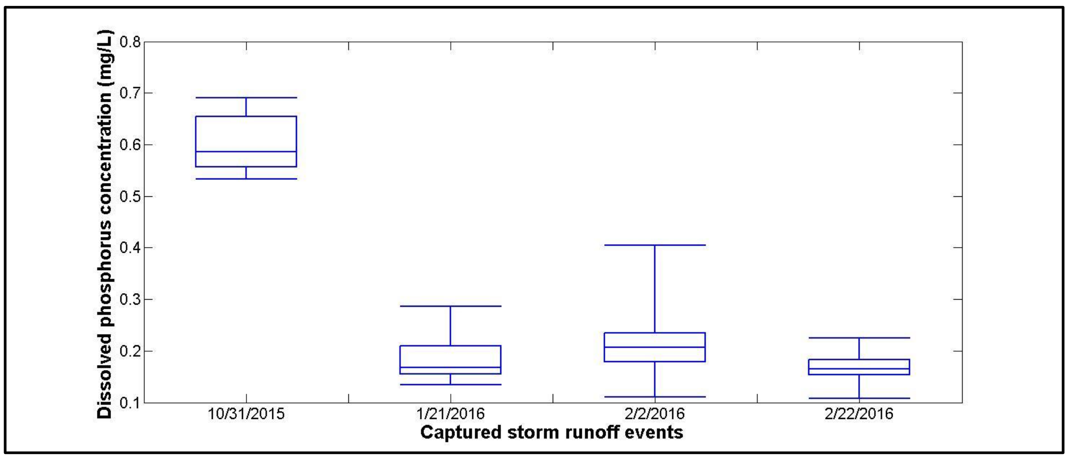


Figure 2.12 Dissolved phosphorus (DP) concentrations in storm runoff events captured from fall 2015–spring 2016.

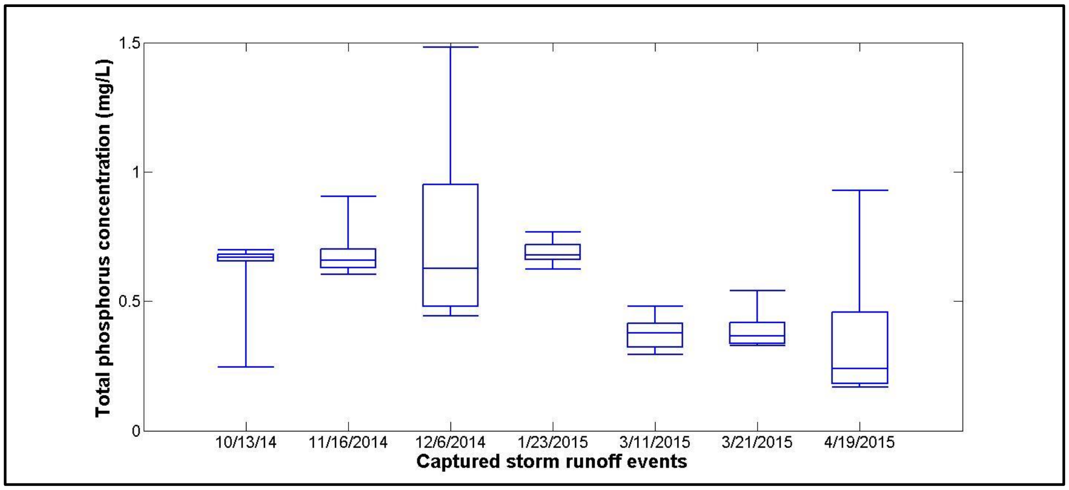


Figure 2.13 Total phosphorus (TP) concentrations in storm runoff events captured from fall 2014–spring 2015.

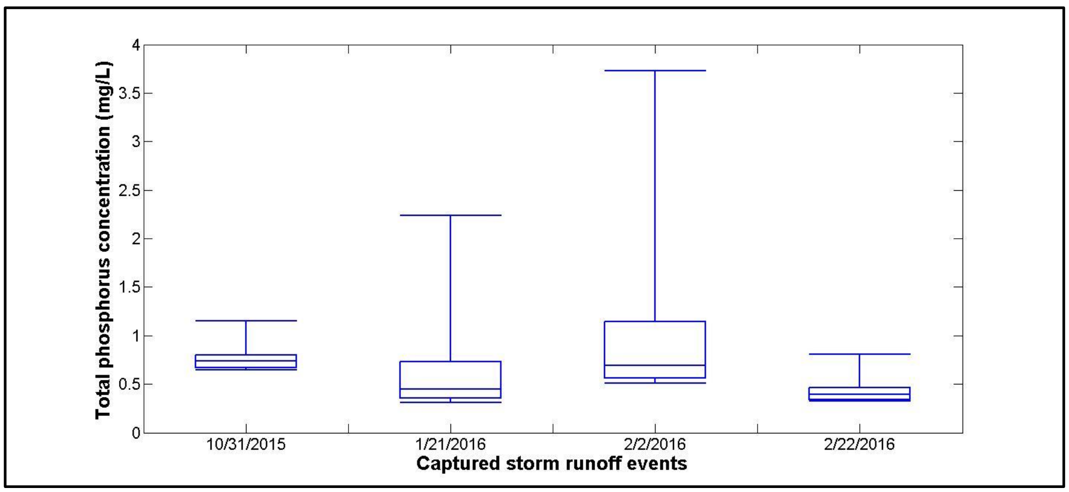


Figure 2.14 Total phosphorus (TP) concentrations in storm runoff events captured from fall 2015–spring 2016.

Total Suspended Sediment (TSS) concentration in storm runoff events

TSS analyses were conducted on samples collected during storm events that occurred from fall 2015 through spring 2016. Results showed that the highest TSS concentrations occurred during storm runoff events that produced the higher flow rates

(Figure 2.15). The single highest measured TSS concentration was 1,322 mg/L and occurred during the January 21, 2016 event that produced 38.86 mm rainfall and a maximum flow rate of 0.32 m^3/s. The second highest TSS concentration was 952 mg/L and was recorded during the February 2, 2016 event that produced 51.05 mm rainfall and a maximum flow rate of 0.68 m^3/s. The lowest measured TSS concentration of 99 mg/L was observed during the October 31, 2015 rainfall event, when 46.74 mm of precipitation was recorded but with only a maximum flow rate of 0.09 m^3/s. In addition, the storm runoff event with the highest TSS concentration that occurred on February 2, 2016 also had the highest measured TP concentration. A study conducted by Uusitalo et al. (2000) also found a correlation between TSS and TP.

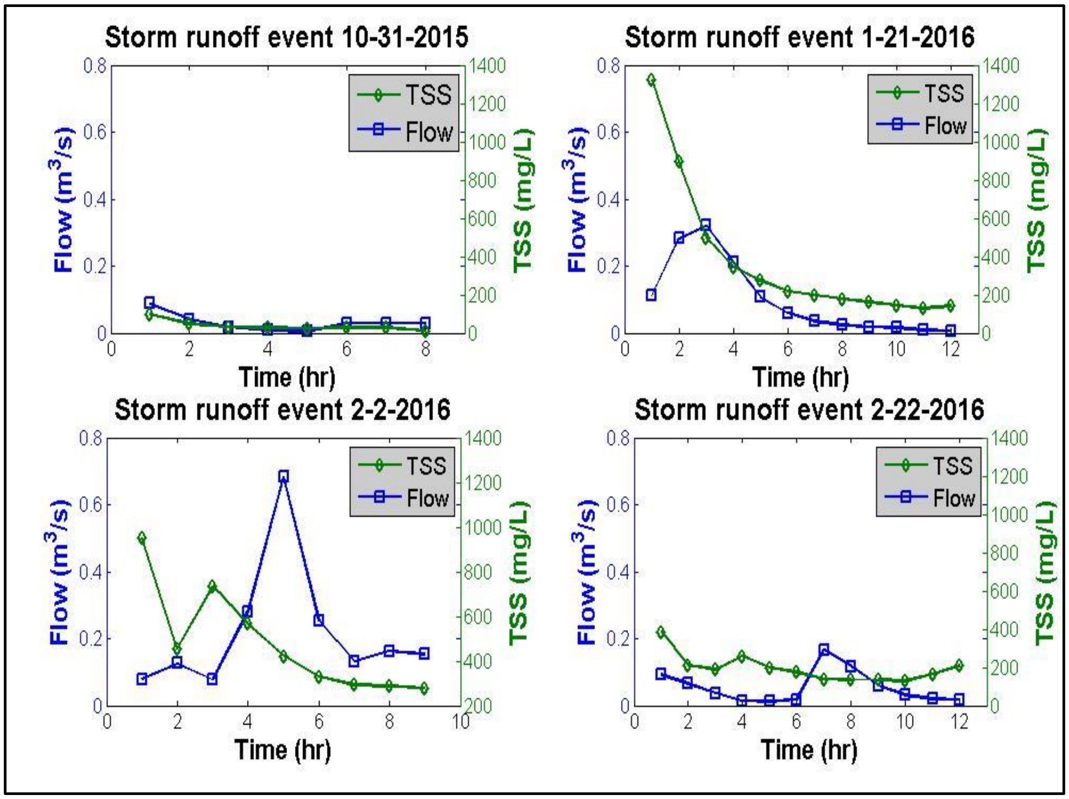


Figure 2.15 TSS concentrations for storm runoff events captured during fall 2015–spring 2016.

OFWS system storage pond

Nitrate, Total Kjeldahl Nitrogen (TKN), Ammonia, and Total Nitrogen (TN) concentrations in the OFWS system storage pond

The nitrate concentration in the OFWS system storage pond was measured at 1.86 mg/L when the first sample was collected on July 7, 2014. The concentrations in the grab samples collected from the pond continued to decrease until the storage pond began to capture runoff events in the fall of 2014. A similar trend was also observed in 2015 with low concentrations of nitrate at the end of the 2015 growing season and an increase in concentrations after fall rainfall–runoff events (Figure 2.16). It was evident over the two-year monitoring period that the nitrate concentration in the pond was lowest during the early fall (August – September) of each year, which also coincided with the driest period of the year. It was also during this period that the least amount of runoff occurred, and the water level in the storage pond was at its lowest depth after irrigation during the growing season. The nitrate concentration measured in the pond began to increase, in both 2014 and 2015, when runoff events were captured. Nitrate concentrations in the pond gradually increased over the winter, peaked around April and started to decrease again in the spring. The pattern coincides with the significant rainfall that occurred from early October through April and the sparse rainfall in late April through May as the growing season approached.

The highest nitrate concentration in grab samples collected from fall 2014 through spring 2015 was measured at 8.56 mg/L on March 29, 2015. The highest concentration during the fall 2015 through spring 2016 monitoring period was 5.77 mg/L, measured on February 25, 2016. The nitrate concentration in the storage pond spiked after runoff events and then started to decrease until another runoff event was captured by the system. The highest nitrate concentration measured in the pond during the study period was 11.3 mg/L and occurred on June 16, 2015, but the nitrate concentration that was measured in the preceding sample was very low (Figure 2.16). It is likely that rainfall between the two sampling events (140.46 mm) in combination with the application of starter fertilizer at planting could be the reason for the spike in nitrate concentration on June 16, 2015.

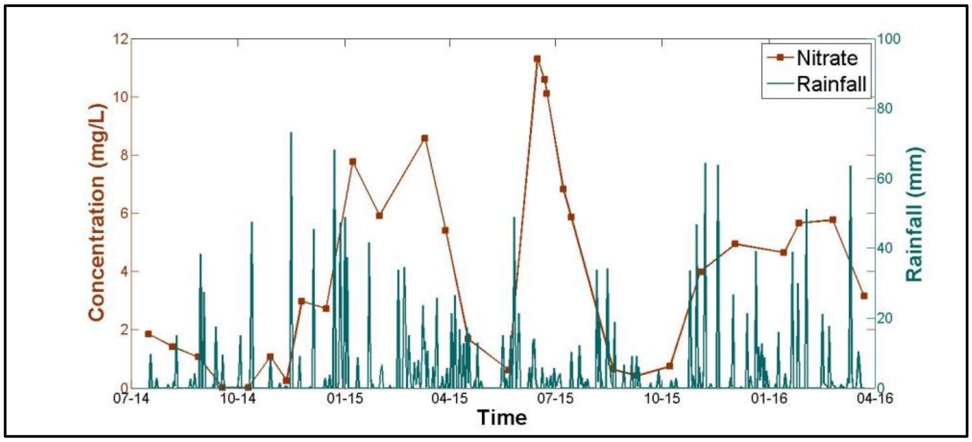


Figure 2.16 Nitrate concentration in the OFWS system storage pond.

Lower nitrate concentration in the storage pond compared to the storm runoff samples could be because of dilution and also denitrification in the pond. Several studies have documented the process of denitrification in reservoirs with elevated nitrate levels (Dettmann, 2001; Jensen et al., 1992). The nitrate concentrations in grab samples collected from the OFWS system storage pond remained higher than 10 mg/L for approximately a month in June of 2015 and were below 10 mg/L for the other samples collected during the study period (Figure 2.16). While the storage pond was able to capture most of the runoff from the drainage watershed, some runoff was lost from the storage pond through the spillway located opposite the inlet on the other side of the pond. Losses occurred only when the pond was at maximum capacity during March and April of each year. However, the nitrate concentration in any water that moved downstream was below 10 mg/L, as demonstrated by monitoring data from grab samples collected from the pond during this same time period.

The TKN concentration in the pond was 2.15 mg/L when monitoring began in. TKN concentrations ranged from about 2 to 5 mg/L in the pond samples collected from July to October of 2014 (Figure 2.17). The maximum measured TKN concentration of 5.31 mg/L occurred on October 29, 2014 and coincided with the period of runoff events captured in the fall of 2014 after poultry litter was applied. There was also a high TKN concentration in the first fall storm event on October 13, 2014 (Figure 2.5), explaining the higher TKN concentrations in the pond during October of 2014. TKN concentrations from November 2014 through the remainder of the monitoring period were lower than the initial few months of sampling, with most concentrations measuring around 1 mg/L.

Unlike the fall of 2014, the TKN concentration did not significantly increase after the runoff events during the fall of 2015, although a slight increase was noticed (Figure 2.17). Lower TKN concentration in the fall 2015 runoff events as compared to the fall 2014 events indicates lower TKN accumulation in the storage pond.

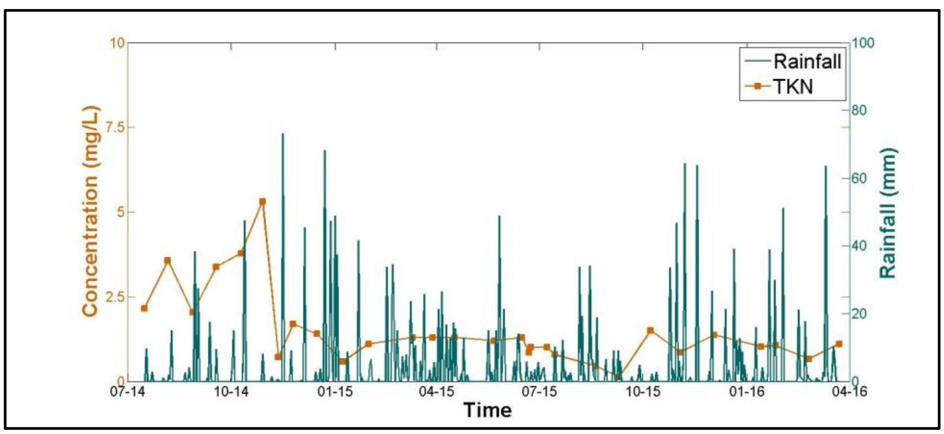


Figure 2.17 TKN concentration in the OFWS system storage pond.

Ammonia concentrations were less than 0.1 mg/L for most of the monitoring period except for the first few samples that were collected at the beginning of the monitoring period (Figure 2.18), which fluctuated from 2.3 mg/L (first sample in the monitoring period) to less than 0.015 mg/L (second sample), to 0.561 mg/L (third sample). Similar to the storm runoff events, lower concentrations of ammonia indicate that organic nitrogen makes up most of the TKN concentration in the storage pond as well.

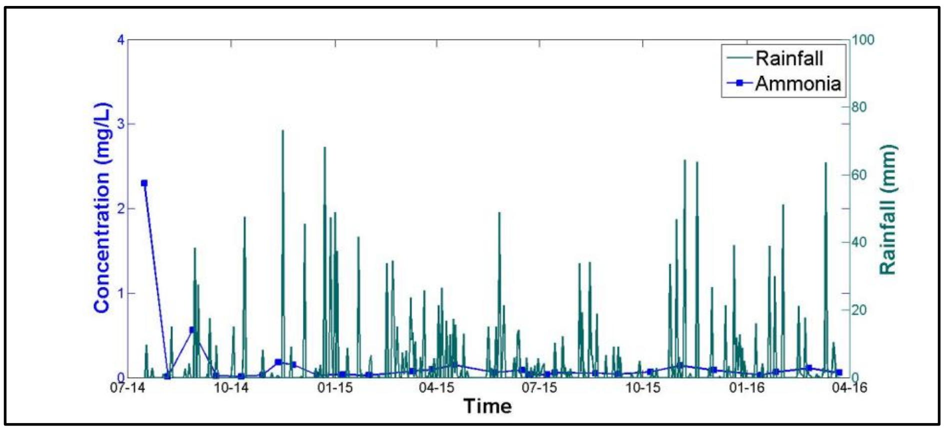


Figure 2.18 Ammonia concentration in the OFWS system storage pond.

TN concentrations followed a similar trend to that of nitrate concentrations in the OFWS system storage pond. The concentrations were lowest in the fall of 2015 and 2016 and increased throughout the winter when most runoff occurred and was captured by the pond (Figure 2.19). Consequently, TN concentrations decreased during the growing season when there were few runoff events. The highest TN concentration during the study period was measured at 7.02 mg/L in the sample collected on January 8, 2015.

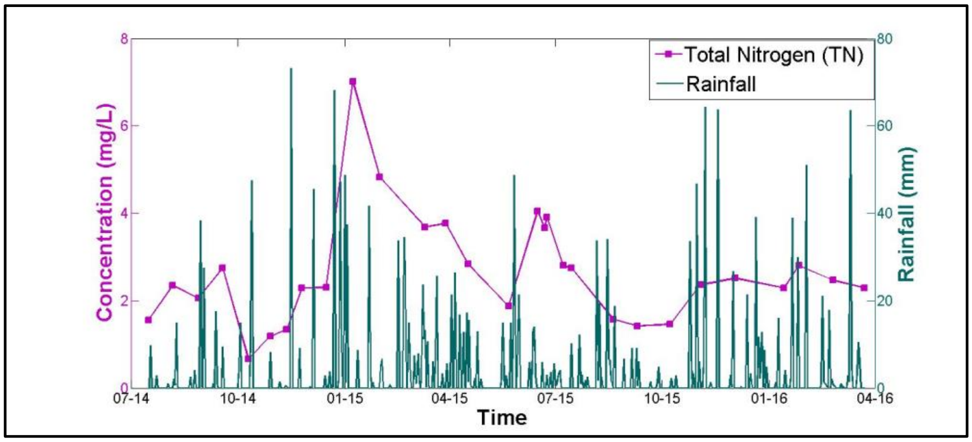


Figure 2.19 Total Nitrogen (TN) concentration in the OFWS system storage pond.

Dissolved and total phosphorus concentrations in the OFWS system storage pond

The DP concentrations in the storage pond were very low throughout the study period and were below the detection limit of 0.05 mg/L (HACH, 2007) in 24 of the 29 grab samples that were collected and analyzed. The highest DP concentration was measured at 0.09 mg/L in the sample collected on August 28, 2014, and was also the only sample above the detection limit in the 2014 growing season. Only one sample collected during the 2015 growing season had a concentration above the detection limit which was collected on June 22, 2015 and had a DP concentration of 0.07 mg/L. Three samples had concentrations above the detection limit during the non-growing season of 2014–15, while there were no samples collected during the non-growing season of 2015–16 with a measurable DP concentration above the detection limit.

The TP concentrations were above the method detection limit of 0.05 mg/L (HACH, 2007) in most of the grab samples collected from the pond during the non–growing season for both years of the study, and 0.425 mg/L was the highest TP concentration measured during the study period in the sample collected on January 31, 2015. The TP concentrations were below the detection limit for most grab samples collected from the pond during the growing season in both 2014 and 2015.

DP and TP concentrations in the OFWS storage pond were also lower than the concentrations recorded in the storm runoff samples. This reduction in concentration could again be attributed to dilution and settling of sediments. And similar to nitrate and TN, concentrations of DP and TP in water lost from the overflow pipe in the storage pond are much lower than if storm runoff events were deposited directly downstream.

Nutrient and TSS load captured by the OFWS system storage pond

Concentrations measured in the storm runoff events that were captured by the storage pond indicate that this OFWS system was able to capture nutrient loads moving off-site and, hence, can be very effective in reducing downstream nutrient loading. Similarly, these systems can also be effective in capturing sediment lost to erosion in runoff from agricultural fields; thereby, sediment is prevented from moving off-site to downstream waters.

Water use from the OFWS system storage pond

The OFWS system storage pond was able to provide 112,000 m^3 and 125,000 m^3 of water for irrigation during the 2014 and 2015 growing seasons, respectively (Figure 2.20). Irrigation was applied through three center pivot irrigation systems for 137.2 cultivated hectares. This shows that, if properly designed, an OFWS system can provide both downstream nutrient reduction benefits and sufficient water for irrigation in East Mississippi. These systems can also be a significant source of water for irrigation in the

Mississippi Delta, where the weather pattern is similar to that of East Mississippi–with most rainfall in winter and early spring and little rainfall during the growing season.

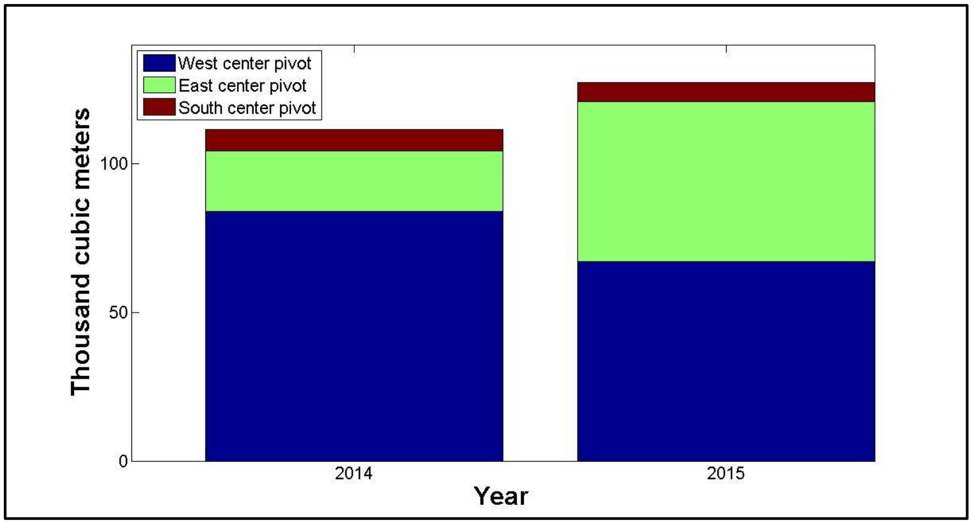


Figure 2.20 Water use from the OFWS system storage pond during the 2014 and 2015 growing seasons.

Yield variation between irrigated and non-irrigated acres

A comparison of yield between the portion of the field irrigated by the OFWS system and the portion of the field outside the reach of the center pivot during the monitoring period showed that irrigated corn yields were higher by an average of 1,532 kg ha^{-1} than for non-irrigated corn in 2014. In 2015, irrigated corn yield was higher by an average of 2,285 kg ha^{-1} (Figure 2.21). Soybean yield was higher by an average of 302 kg ha^{-1} for irrigated acres than for non-irrigated acres in 2014, and by 1,411 kg ha^{-1} on average in 2015. Although the field was not monitored for 2013, yield data obtained from the farmers showed that irrigated corn yield was higher by an average of 2,587 kg ha^{-1}, while irrigated soybean was higher by an average of 618 kg ha^{-1}.

Records obtained from the farmer on another field being irrigated with an OFWS system established in 2009 showed that irrigated corn yields were approximately 3,360 kg ha^{-1} higher than non-irrigated acres in both 2009 and 2010, and 6,719 kg ha^{-1} higher in 2011. The soybean yields were 739, 605, and 470 kg ha^{-1} higher, on average, for irrigated acres than for non-irrigated acres in 2009, 2010, and 2011, respectively.

This shows that even though East Mississippi receives roughly 1371.6 mm rainfall annually, irrigation is important in East Mississippi to enable crops to produce higher yields and allow farmers to maintain profitability.

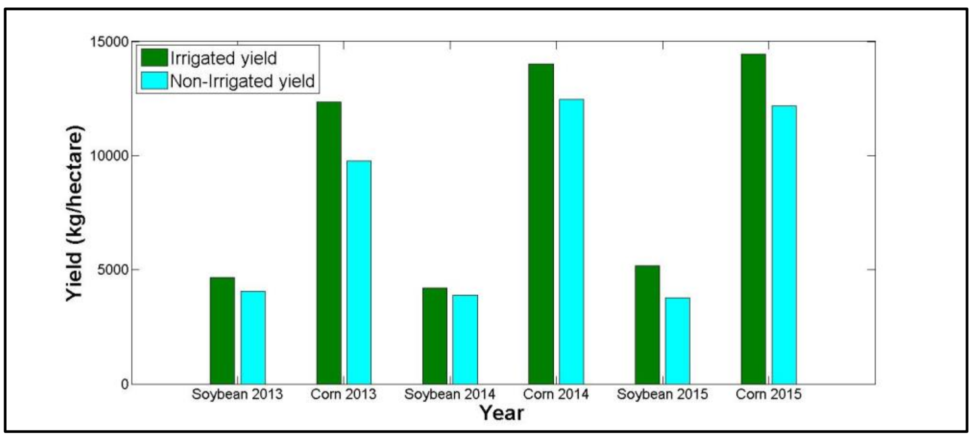


Figure 2.21 Irrigated vs non-irrigated yields for the study period.

Nutrient concentration in irrigation water

Since storm samples indicated high nutrient loads running off the field and grab samples collected from the OFWS system storage pond indicated the presence of nitrate, additional sampling was performed to determine if nutrient levels in the recycled water were high enough to reduce commercial fertilizer applications on the field. Grab samples were collected from the west center pivot during irrigation events and compared to the grab samples taken from the OFWS system pond on the same day. Grab samples collected from the OFWS system pond throughout the study period showed that the nitrate concentration in the pond was very variable (Figure 2.16). The nitrate concentration in the water from the center pivot was significantly lower than the water sampled from the OFWS system storage pond (Figure 2.22). The center pivot irrigation system was fed from an intake at the bottom of the pond. Anoxic conditions, presence of nitrate, and organic matter in the bottom layers of the pond make an ideal environment for the denitrification process (Seitzinger et al., 2006), contributing to the decreased nitrate concentrations in water from the center pivot. Nitrate concentrations in the samples from the center pivot and the difference in concentrations between the center pivot and the grab samples from the OFWS system storage pond also varied greatly in the two sets of samples taken.

It is also important to note that ammonia levels were much higher in the center pivot when compared to the grab samples from the storage pond. Decaying organic matter in the bottom of the pond could result in eutrophic conditions, and this along with high pH levels (above 9 for most of the monitoring period) could be the reason for higher ammonia concentrations in the irrigation water.

While some amount of nutrients are being recycled through the re-application of water captured by the OFWS system, fluctuation in the concentration of nitrate has shown that it is very difficult to accurately and consistently estimate the amount of nitrate that is recycled. A total of 266 kg of nitrogen was applied via the 125,000 m^3 of water used for irrigation over 137.2 hectares in 2015, if we assume that there was a nitrate concentration of 2.09 mg/L in all of the water that was applied. Therefore, the amount of nitrate-nitrogen being recycled is considerably lower than the recommended nitrogen application of 16.7 kg m^{-3} of corn (291 kg ha^{-1}nitrogen at 13438 kg ha^{-1} corn) (Larson and Oldham, 2008).

Although high ammonia concentrations indicate the presence of ammonium ions in the irrigation water, it is difficult to estimate the exact amount present. So, while some of the nitrate is being reapplied to the field, recycled nitrate levels are insufficient and inconsistent at this time to justify a reduction in commercial fertilizer application.

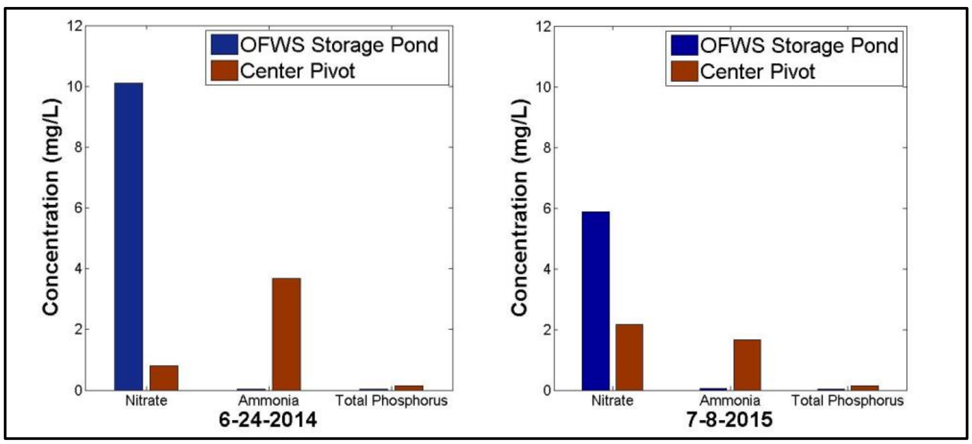


Figure 2.22 Nutrient comparison between west center pivot and OFWS system storage pond grab sample.

Soil Sampling

Soil nitrate testing using the Hanna HI 38050 nitrate test kit did not provide any conclusive indication of increased soil nitrate levels after irrigation using the OFWS pond water. It was difficult to get accurate readings, as the test kit used visual checker discs to determine concentrations, which was difficult to interpret and could be interpreted differently by different users.

There was also no indication of an increase in soil phosphorus levels after irrigation events, which was not surprising since there were low phosphorus concentrations in the OFWS system pond water used for irrigation.

Conclusions

The monitoring results from the study of the East Mississippi OFWS system show that these systems can be effective in controlling downstream nutrient and sediment loading by capturing nutrient-rich runoff and sediments from storm events. It was also evident that storm runoff events that occurred after fertilizer application were more critical to downstream nutrient loading reduction, as these runoff events had higher nutrient concentrations. Even though water could be lost downstream to runoff when the storage pond is at its maximum capacity, the nutrient concentration in the water lost was significantly lower than in the runoff events captured by the pond, demonstrating nutrient load reduction even when runoff is lost downstream. The rationale for fall fertilizer application in preparation for the next growing season, however, can be questioned as there was substantial loss of nutrients over the non-growing season, especially in storm runoff events following the fertilizer application.

The efficiency of OFWS systems in nutrient loading reduction could possibly be increased with better placement of the pond in relation to the agricultural field, even without increasing the maximum holding capacity. If more runoff from the agricultural field could be directed through the pond to increase the residence time of the runoff before flowing downstream, nutrient and sediment concentrations produced during these runoff events could be decreased, as some studies have demonstrated (Dettmann, 2001; Jensen et al., 1992).

Higher yields for irrigated corn and soybean when compared to the non-irrigated corn and soybean also demonstrated the importance of irrigation in East Mississippi for increasing yield. Thus, OFWS systems can potentially provide increased economic benefits from higher yields, in addition to the environmental benefits.

As the OFWS system was able to provide more than 237,000 m^3 of water over the 2014 and 2015 growing seasons, it can be concluded that these systems can be an effective water harvest system and a reliable source of water for irrigation in regions like East Mississippi where there is no other feasible water source for irrigation. As the weather in the Mississippi Delta is very similar to that of East Mississippi, these systems could also be used in the Delta to potentially decrease the dependency on ground water from the MRVA for irrigation.

Although some of the nutrient load, especially nitrate, is recycled back to the agricultural field from the use of OFWS system pond water for irrigation, consistent long-term monitoring is needed to better estimate nutrient concentrations in the recycled water. However, results to date indicate that nutrient concentrations in the recycled water are too low to allow a reduction in the rate of commercial fertilizer applied to the field.

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CHAPTER III

APPLICATION OF AnnAGNPS TO MODEL AN AGRICULTURAL WATERSHED IN EAST MISSISSIPPI FOR THE EVALUATION OF AN ON-FARM WATER STORAGE (OFWS) SYSTEM

Introduction

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

Many agricultural best management practices (BMPs) such as conservation tillage, crop nutrient management, buffer zones, and more have been implemented on farmlands to reduce the effects of sediment and nutrient non–point source (NPS) pollution from agricultural runoff 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. It is even more difficult to evaluate the impacts of these BMPs before implementation using a monitoring approach. 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 including Soil and Water Assessment Tool (SWAT) (Arnold et al., 2012), Areal Nonpoint Source Watershed Environmental Simulation (ANSWERS) (Beasley et al., 1980), Annualized Agricultural Non-Point Source Pollutant Loading Model (AnnAGNPS) (Cronshey and Theurer, 1998), and 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 a constructed BMP that first started appearing in the Mississippi Delta (northwest Mississippi) in 2010 when NRCS, along with its conservation partners, began a 12-state Mississippi River Basin Healthy Watersheds Initiative (MRBI). The objective of this initiative is to improve water quality in priority watersheds by providing technical and financial assistance to producers implementing voluntary conservation practices (USDA-NRCS, 2010).

OFWS systems work by capturing irrigation tail water and storm runoff from agricultural fields in a tail water recovery ditch and/or a storage pond, thereby preventing downstream nutrient and sediment loading and holding the stored water until it is needed for irrigation. These systems are fairly new in East Mississippi, funded privately by farmers because of the lack of governmental financial assistance and installed primarily for irrigation. Although these systems are believed to reduce downstream sediment and nutrient loading from agricultural fields, there is little published work on evaluating the effectiveness of these systems. Even less is known about these systems present in sloping landscapes like East Mississippi.

AnnAGNPS (Cronshey and Theurer, 1998) is a watershed-scale, continuous simulation, physical model that has been widely used to simulate hydrology and sediment transport successfully in different watersheds of varying sizes (Chahor et al., 2014; Sarangi et al., 2007; Shrestha et al., 2006; Yuan et al., 2011). The AnnAGNPS model has also been able to simulate nutrient transport with success (Baginska et al., 2003; Shamshad et al., 2008; Yuan et al., 2005). The AnnAGNPS model is an improvement to the older, single–event Agricultural NonPoint Source (AGNPS) model and can also be used to assess the impacts of alternative management practices for reducing runoff and sediment (Tian et al., 2010; Yuan et al., 2001).

It is important to calibrate and validate the model for local watersheds so that it can be used to evaluate BMPs and alternative management practices. Hence, the goal of this study was to assess the ability of AnnAGNPS for simulating runoff, sediment, and nutrients (total nitrogen and total phosphorus) for local conditions in Noxubee county of East Mississippi, so AnnAGNPS could then be used to evaluate the effectiveness of an OFWS system located in an agricultural watershed in this region. More specifically, the objectives of this paper are to: 1) evaluate AnnAGNPS for simulating runoff, sediments, and nutrients in an agricultural watershed in East Mississippi; 2) use AnnAGNPS to evaluate OFWS systems for reducing downstream nutrient and sediment loading; and 3) evaluate alternative management practices to reduce nutrient and sediment loading from the agricultural watershed.

Methodology

Watershed description

The watershed modeled for this study is about 35 hectares 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) in Brooksville in Noxubee county, Mississippi (33º14’46.62”N Latitude and 88º31’30.42” Longitude). The study watershed is a part of the Middle Tombigbee–Lubbub watershed (HUC 0316106) in the larger Tombigbee River Basin. The elevation of the watershed ranges from 75 m to 84 m and consists of slopes ranging from 0 to 5%; and corn and soybean are the main crops planted in the fields. The watershed consists of Brooksville Silty clay and Catalpa 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 about 1,371.6 mm, most 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.

The runoff from the monitored watershed drains to a 6.88 hectare storage pond that is 7.6 m deep at its deepest point and was constructed as a part of an OFWS system that was installed in 2012. The total watershed for the storage pond is about 45 hectares and consists of two sub-drainage areas. Only the bigger sub-drainage that covers an area of 30.3 hectares (Figure 3.1) was monitored for this study. Runoff from the monitored watershed is directed to the storage pond using constructed terraces and drainage ditches.

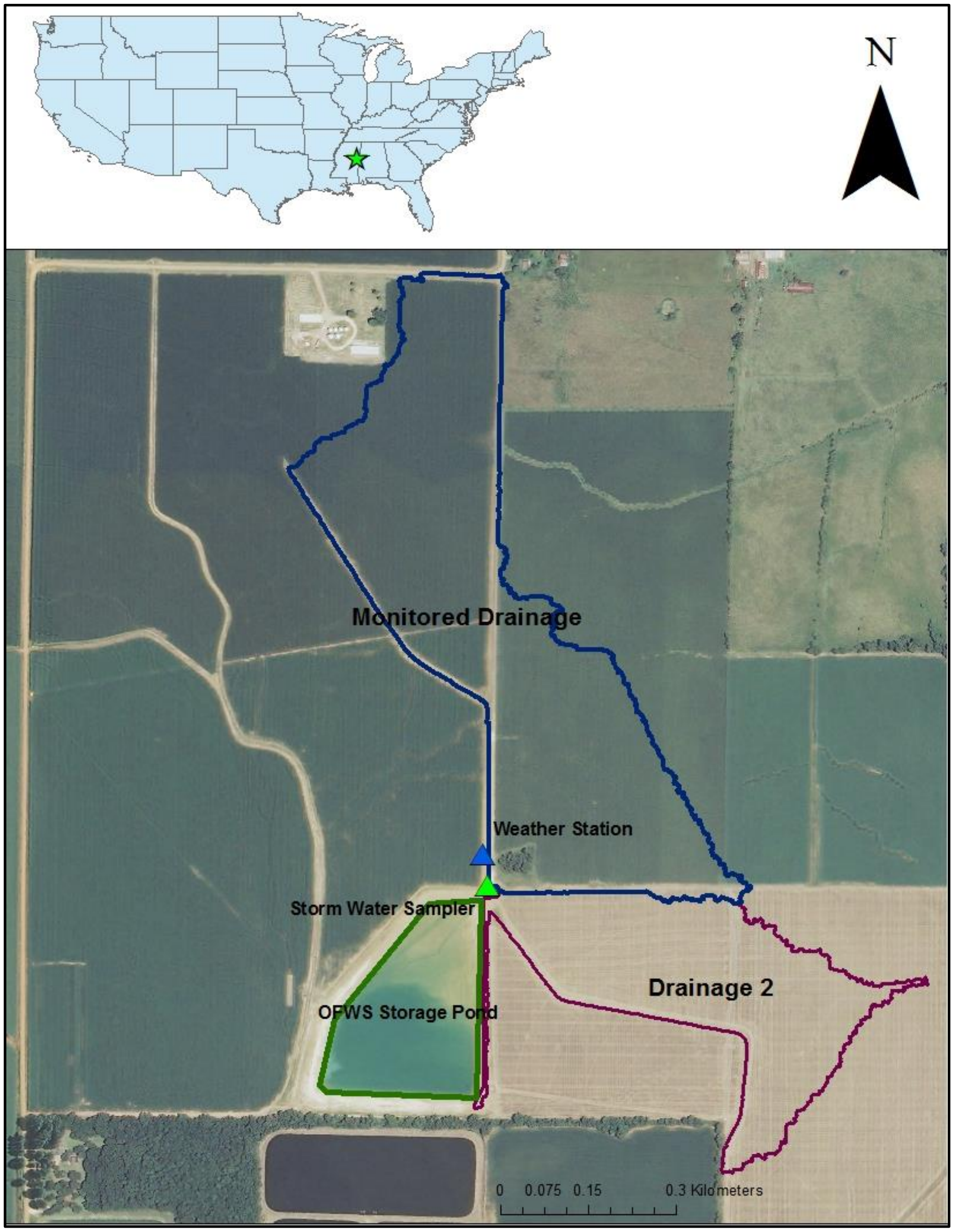

Figure 3.1 Study watershed, Brooksville, MS.

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 and Theurer, 2005). 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. The model is designed to model 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. 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 (DEM), soil data, etc., and these combined with land use data account for the spatial variation in the watershed, while climate 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). 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 yield from a watershed during storm events (Theurer and Clarke, 1991).

Input file preparation

Topography

Light Detection and Ranging (LIDAR) data for the watershed was downloaded from the Mississippi Automated Resource Information System (MARIS), a state–owned entity that provides mapping and geo–spatial data (MARIS, n.d.). The downloaded LIDAR data was transformed to a 1m x 1m DEM for model input. The latest and most detailed elevation dataset was used in this study to account for the recent changes in topography with the construction of terraces and drainage ditches to route runoff from the agricultural field to the OFWS system storage pond. TOPAGNPS used the DEM to divide the watershed into to 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 (Figure 3.2).

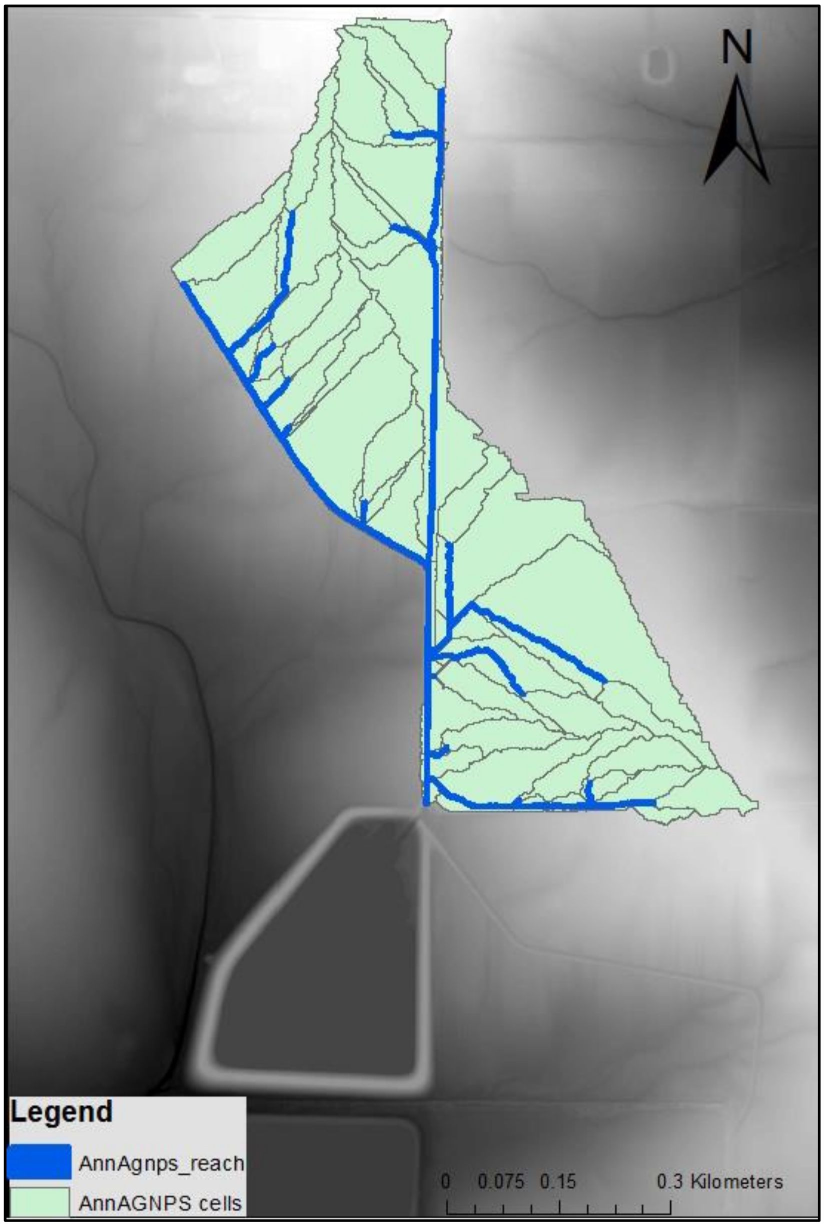

Figure 3.2 AnnAGNPS-determined cells and reaches for the study watershed.

Climate data

Daily maximum and minimum temperature, precipitation, dew point, solar radiation, and wind velocity are the minimum weather data inputs required for the model. All of the required climate data for this study were acquired from the WatchDog 2900 ET weather station that was installed in the watershed. Climate data collection began in September of 2014 and is ongoing. Along with the daily climate data, AnnAGNPS also required the two year 24-hr precipitation and the SCS rainfall distribution type. The two year 24-hr precipitation for the area was 101.6 mm (Hershfield, 1963), and the study area falls within the region with Type III rainfall distribution (Cronshey et al., 1985).

Land use and management information

The modeled watershed is all agricultural land use 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 watershed outlet. Agricultural fields cover about 98% of the watershed area. Detailed and accurate management information for the watershed is very important for the best possible estimate of sediment, nutrient, and water runoff. Management information for the agricultural fields within the watershed was obtained from the farmers. Corn and soybean are the major crops in the watershed (Figure 3.3). Poultry litter was applied each fall as fertilizer (Tables 3.1 and 3.2) in preparation for the next year’s growing season. 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.

Table 3.1 Management practice information for the corn field.

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	

Table 3.2 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	

Table 3.2 (continued)

Field	Date	Action	Fertilizer application rate
Corn – Soybean Rotation	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	

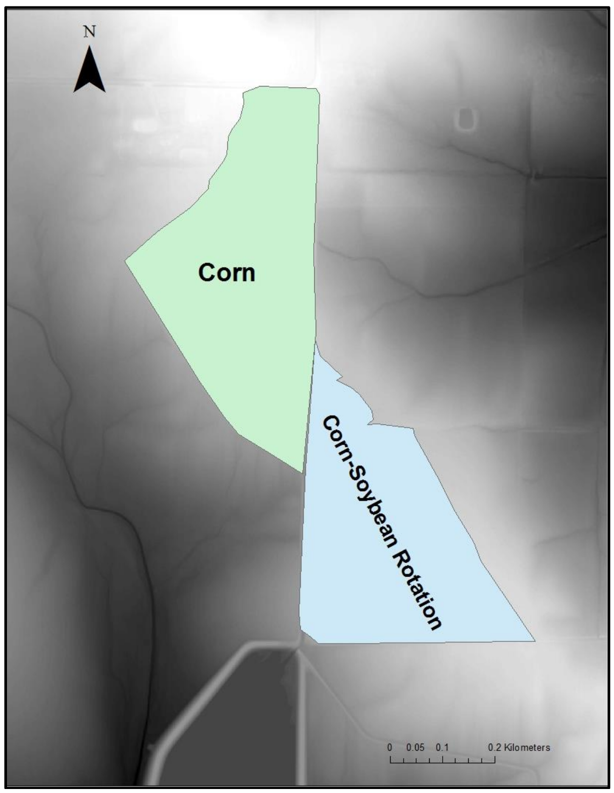

Figure 3.3 Corn and corn-soybean rotation fields in the monitored watershed.

Soils

The Soil Survey Geographic (SSURGO) soil map acquired from 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 (Figure 3.4). The 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 3.3 and 3.4) were directly populated in the model from the NRCS Soil Survey Center's National Soil Information System (NASIS) database (USDA-NRCS, n.d.-a). The rainfall-runoff erosivity factor (R) for the modeled watershed was 350 (Wischmeier and Smith, 1978b).

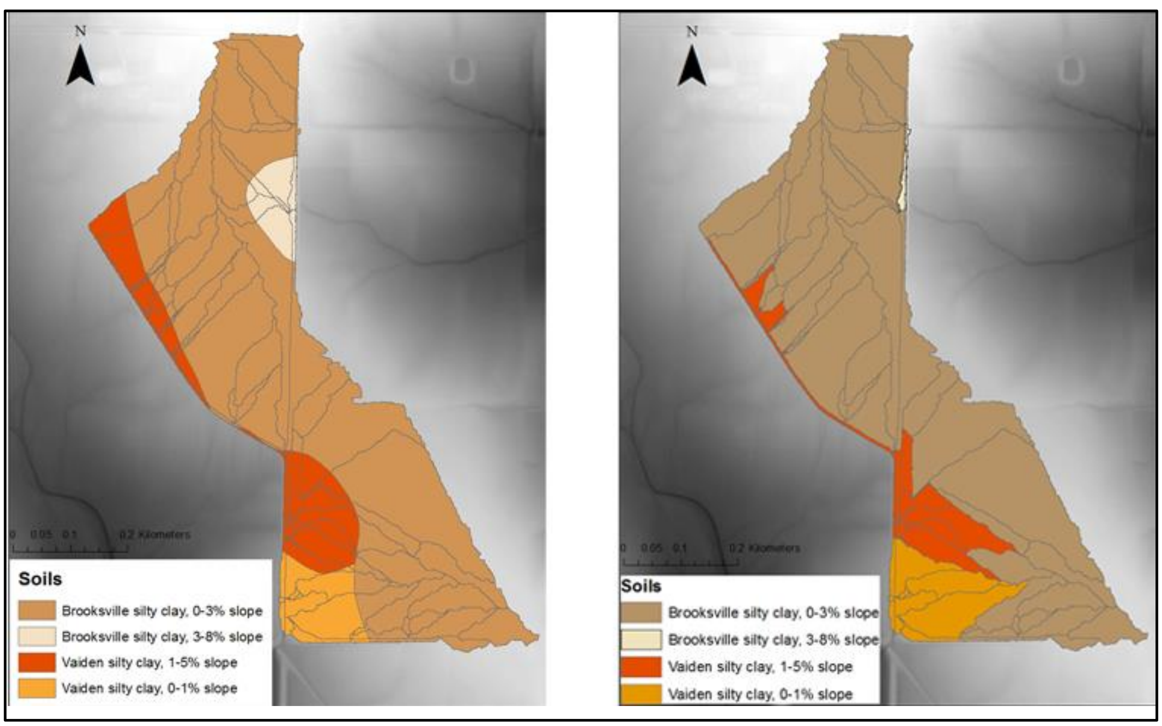

Figure 3.4 Major soil types in the watershed (left) and as assigned to each sub-watershed by AnnAGNPS (right).

Table 3.3 Characteristics of soils in the modeled watershed.

Soil	Soil texture	Clay ratio	Silt ratio	Sand ratio	Bulk density (gm/cm^3)
BrA	Silty clay	0.45	0.46	0.09	1.68
BrB	Silty clay	0.45	0.46	0.09	1.68
VaA	Silty clay	0.41	0.51	0.08	1.55
VaB2	Silty clay	0.41	0.51	0.08	1.55

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)

Table 3.4 Characteristics of soils in the modeled watershed (continued).

Soil	Saturated conductivity (mm/hr)	[a]Field capacity (%Vol)	[b]Wilting point (%Vol)	Organic matter	Hydrologic soil group
BrA	3.31	0.33	0.264	0.025	D
BrB	3.31	0.33	0.264	0.025	D
VaA	3.31	0.309	0.225	0.025	D
VaB2	3.31	0.309	0.225	0.025	D

[a] Field capacity, water content at 300 kPa, [b] Wilting point, water capacity at 1500 kPa

Hydrology, sediment, and nutrient data

A portable automatic water sampler (ISCO 6712) equipped with an Area Velocity Flow Module (model 750) was installed at the watershed outlet to monitor runoff from the watershed. The sampler was set to trigger and collect runoff samples at a uniform time spacing when a runoff depth of 7.62 mm was measured in the drainage channel. The collected samples were analyzed for total suspended sediments (TSS) and nutrients. TSS was analyzed following the EPA 160.2 gravimetric method, and samples were analyzed for nitrogen and phosphorus using a DR-2800 spectrophotometer (HACH, 2007). Samples collection in the watershed began in September 2014 to March 2016. Although runoff has been monitored for the entire study period, storm runoff events were captured and analyzed for nutrients between October 2014–May 2015 and October 2015–February

2016 because very little runoff was observed during the growing season of either year. Hence, the model was evaluated for nutrient and sediment runoff only during the time period for which monitoring data was available.

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. Peak discharge and sediment prediction were compared for each storm event, while nutrients were analyzed 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, 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 fits the predicted data in the 1:1 line. The E value ranges from - ∞ 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).

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 coefficient, root mass, rainfall height, and root mass 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 coefficient were used for sediment yield calibration, and canopy cover was excluded from calibration. The model was not calibrated but only evaluated for peak discharge and nutrient load estimation.

Ideally, the model should be calibrated and validated for separate time periods, so 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 yield 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 evaluated for estimating peak discharge from all storm runoff events from 9/2014 to 3/2016 and for predicting nutrient runoff from 10/2015 to 4/2015 and 10/2015 to 2/2016. The model was initialized for 6 years prior to performing the watershed simulation.

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 the agricultural field, alternative management practices were evaluated to determine its effects on runoff and sediment and nutrient loss from the monitored watershed. Three scenarios were evaluated: a) 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; b) soybean planted on all agricultural fields in the watershed; and c) corn planted on all agricultural fields in the watershed.

Results and discussion

Runoff

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. 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 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 prediction 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 to 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 condition was introduced for the modeled watershed for the spring months (February–May). The straight row crop curve number was then increased for the fall and decreased for spring and adjusted by running the model multiple times. Results were evaluated using both graphical (Figure 3.5) and statistical methods (Figure 3.6) until the best simulation results were obtained. Because the wooded area and drainage channel covered only about 2% of the total watershed, CN's for these two land-use types were not adjusted during the calibration phase.

Table 3.5 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			

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 (Figure 3.6), and an R^2 of 0.89 and E of 0.88 were obtained for monthly runoff (Figure 3.7). The model performed slightly better for monthly runoff estimation than for daily runoff estimation. Total runoff estimation by the model during the calibration phase differed from the observed runoff by only about 1% (Table 3.6). This showed that AnnAGNPS performed better when it was evaluated for a longer time period.

Table 3.6 Monthly observed rainfall and predicted and observed runoff.

Year	Month	Rainfall (mm)	Predicted runoff (m^3)	Observed runoff (m^3)
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
	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

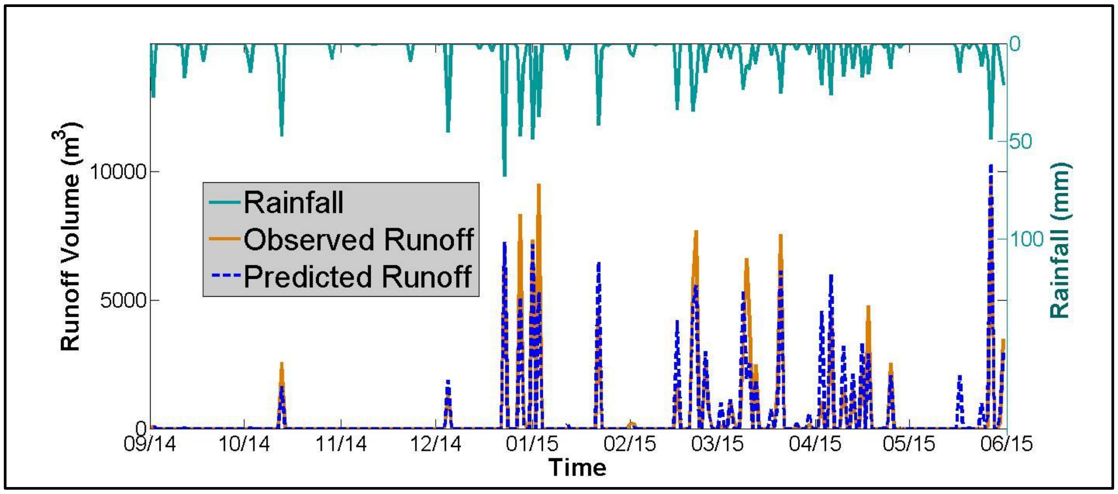

Figure 3.5 Graphical comparison between predicted and observed runoff after calibration.

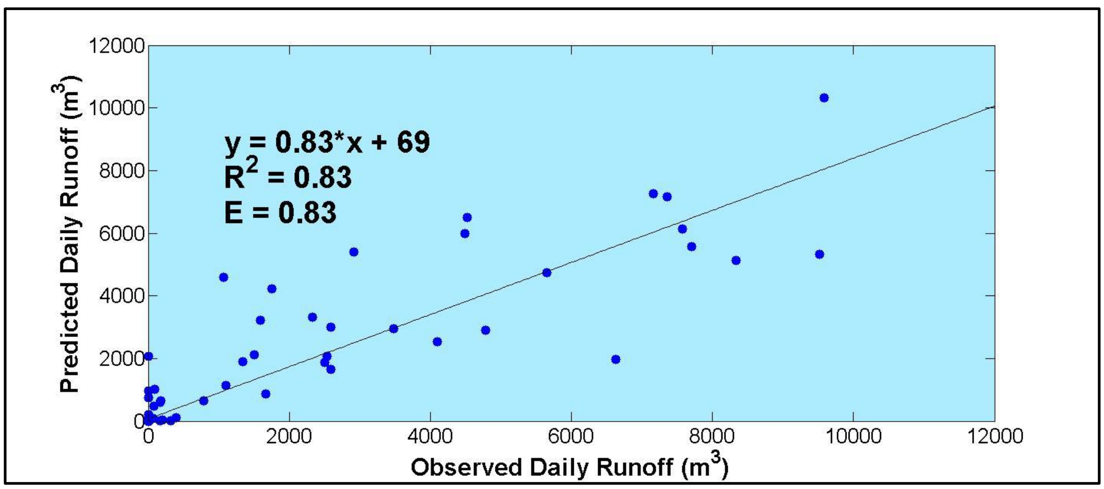

Figure 3.6 Comparison between daily observed and predicted runoff (calibration).

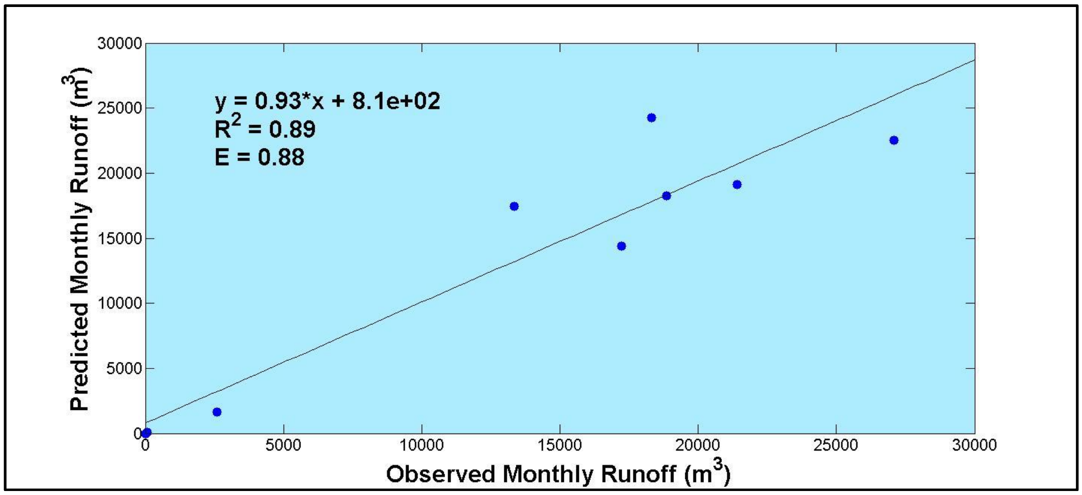

Figure 3.7 Comparison between monthly observed and predicted runoff (calibration).

Runoff Validation

The model was validated by running the model for a separate time period (from 06/2015 to 03/2016) than what was used for the calibration phase. All other model parameters after calibration were kept the same, and the simulated data was compared with the observed 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 (Figure 3.9), and comparisons of monthly runoff prediction showed an R^2 of 0.90 and E of 0.66 (Figure 3.10) 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 (Figure 3.8).

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

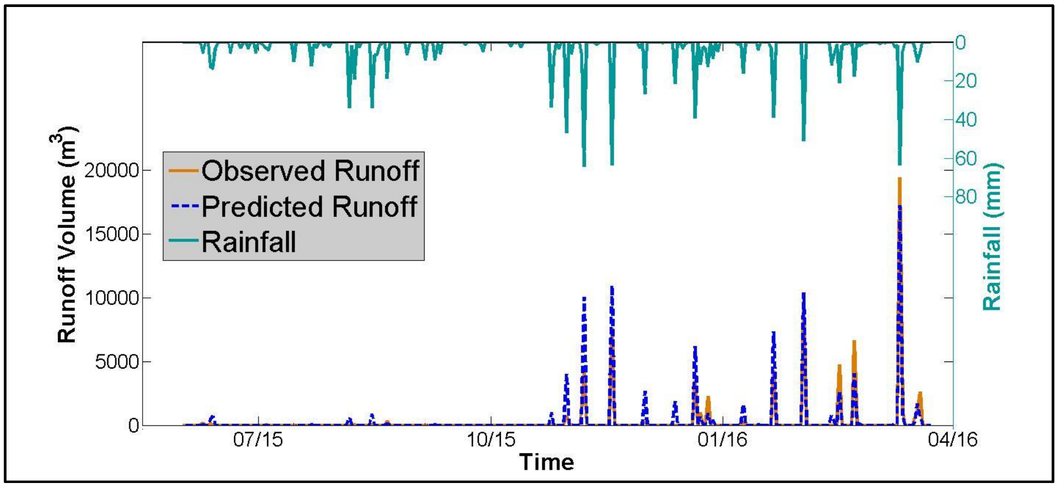

Figure 3.8 Graphical comparison between predicted and observed rainfall during model validation.

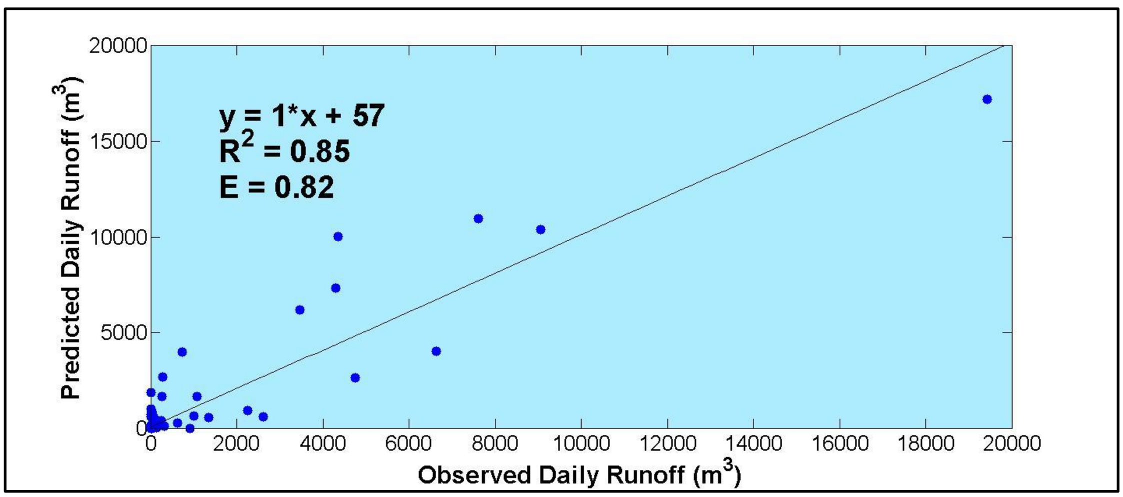

Figure 3.9 Comparison between daily observed and predicted runoff (validation).

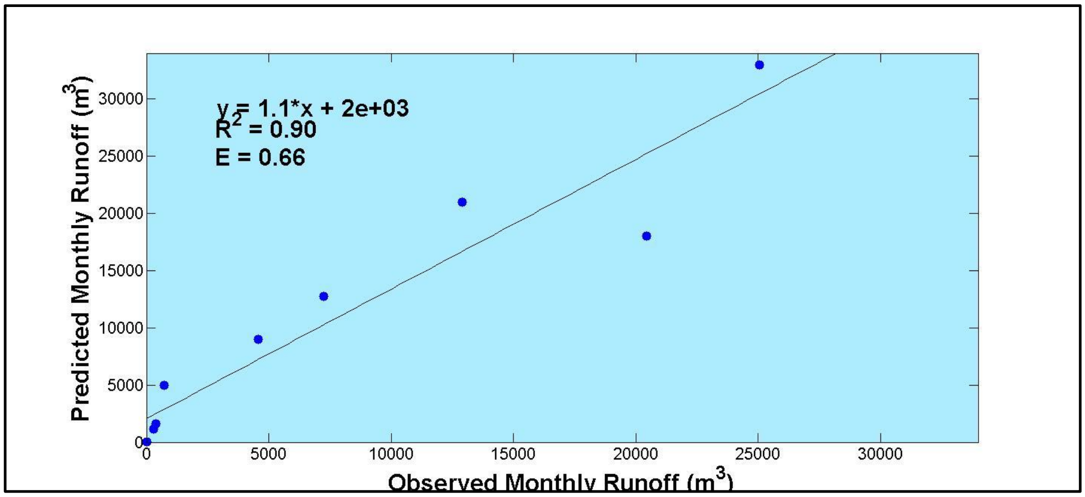

Figure 3.10 Comparison between monthly observed and predicted runoff (validation).

Peak discharge evaluation

After validating the model for daily and monthly runoff, the model was also evaluated for peak discharge for all storm events that occurred during the monitoring period. Peak discharge was evaluated because it affects sediment yield. The model under predicted peak discharge with an R^2 of 0.41 and E of 0.31 (Figure 3.11). Results from this study were in contrast to those obtained by Shrestha et al. (2006) and Babel et al. (2004), which found that AnnAGNPS overpredicted peak discharge.

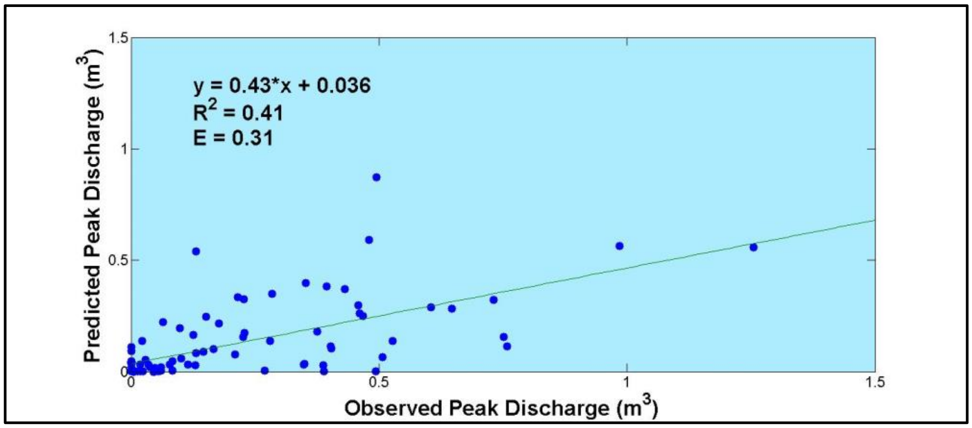

Figure 3.11 Comparison between observed and predicted event-based peak discharge (evaluation)..

Sediment yield

Sediment calibration

After the validation of the model for runoff, the model was run to evaluate sediment yield without calibration. Model performance assessment for daily sediment estimation without calibration showed that the model overestimated sediment by 93% with an R^2 of 0.74 but E of only 0.004.

An initial value of 0.5 was used for RUSLE–P based on P values for slopes of 3 to 5 percent (Wischmeier and Smith, 1978a). Manning's n was set to 0.40 for the wooded area and 0.15 for all the 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 sediment yield 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 sediment yield 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. An R^2 of 0.73 and E of 0.43 (Figure 3.12) were obtained for AnnAGNPS sediment prediction after calibration. However, the model still over predicted the sediment yield by roughly 50% (Table 3.7). These results could be due to the short period of time for which the model was evaluated (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 poor performance was reported when the model was evaluated for sediment yield at a smaller time scale by Shrestha et al. (2006). Below average performance of the model on peak discharge evaluation could also be the reason for the moderate performance on sediment estimation.

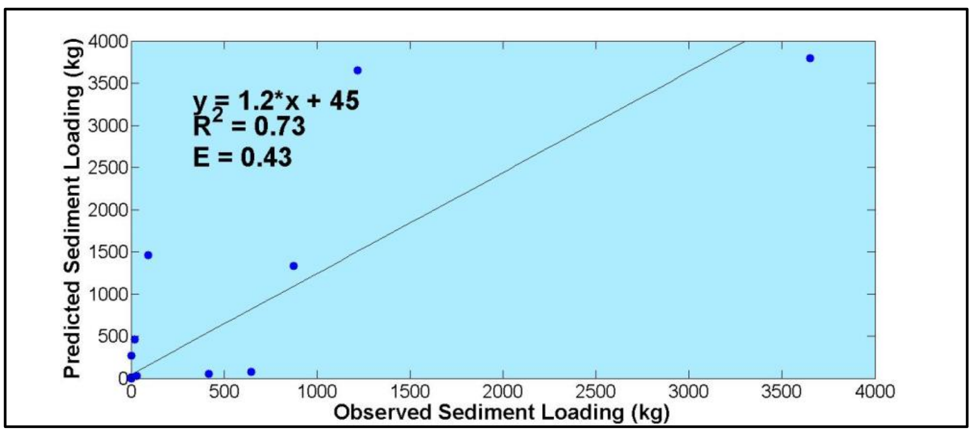

Figure 3.12 Comparison of observed and predicted event-based sediment yield (calibration).

Sediment validation

The model performed reasonably well and better than for calibration during the validation period (1/2016 to 2/2016) for predicting sediment yield, with an R^2 of 0.88 and

E of 0.67 (Figure 3.13). In contrast to the model results for sediment yield in the calibration phase, sediment yield was under predicted by the model during the validation phase (Table 3.7). However, it is important to note that if the model is evaluated for total sediment yield for the calibration and the validation phase combined, the model under predicted the sediment yield by only 1.8% (Table 3.7). 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 be used to predict sediment losses from agricultural watersheds in East Mississippi. The model can thus be used to estimate sediment that can be captured by an OFWS system by estimating the sediment load in the runoff captured by these systems.

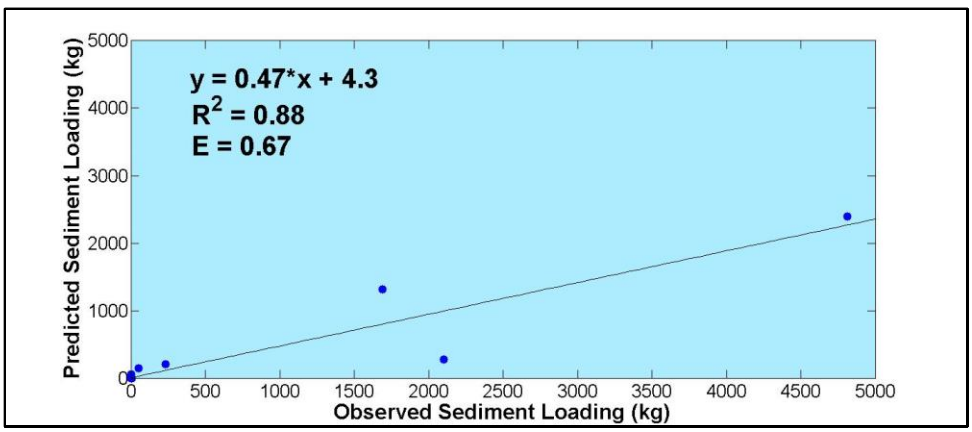

Figure 3.13 Comparison of observed and predicted event-based sediment yield (validation).

Table 3.7 Observed rainfall and predicted and observed sediment yield for storm runoff events.

Date	Rainfall (mm)	Predicted sediment yield (kg)	Observed sediment yield (kg)
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
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

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 (Figure 3.14). 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.

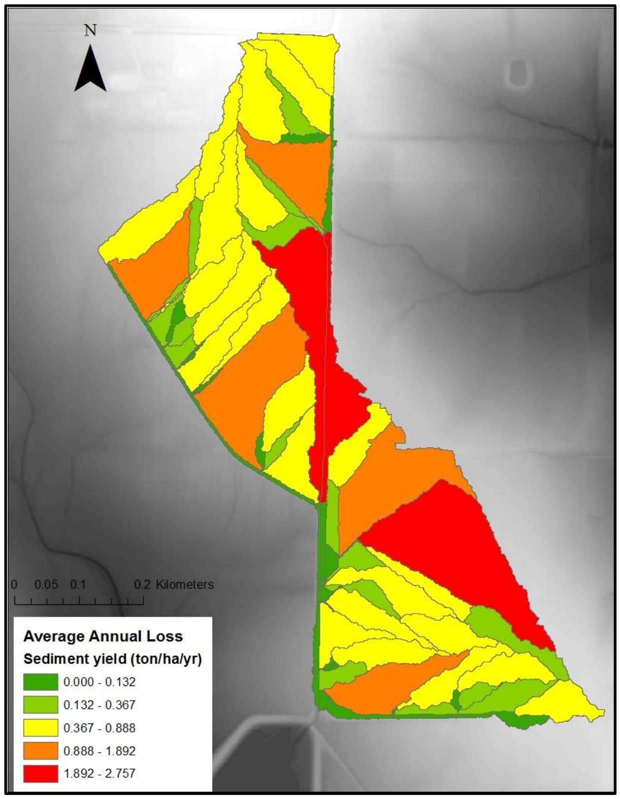

Figure 3.14 Average annual sediment loss from the modeled subwatershed cells.

Nutrient yield evaluation

The model was evaluated for total phosphorus and total nitrogen based on initial model input. The model was not calibrated for nutrient constituents. As soil nutrient information was not available in the SSURGO dataset that was used to populate the soil characteristics for this model, 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 also added to the model, with values taken from a review of the literature (Flannery, 1986) (Yuan et al., 2005) (Hermanson et al., 2000).

Evaluation of monthly phosphorus yields resulted in an R^2 of 0.74 and E of 0.54 (Figure 3.15). The model overpredicted phosphorus yields by 42.4% over the evaluation period. Phosphorus levels in the poultry fertilizer applied in the fall was based on a review of available of literature (Tabler et al., 2015). Similarly, soil initial phosphorus levels were also based on a review of literature. Therefore, a lack of site specific accurate nutrient data could be the reason for the model's low performance in comparison to measured water quality data. Better estimation of these parameters, which are critical to the model's predicted phosphorus load, can help the model better predict phosphorus yields. This evaluation shows that the model can satisfactorily estimate phosphorus losses from agricultural watersheds in East Mississippi if site specific and detailed management practices are made available.

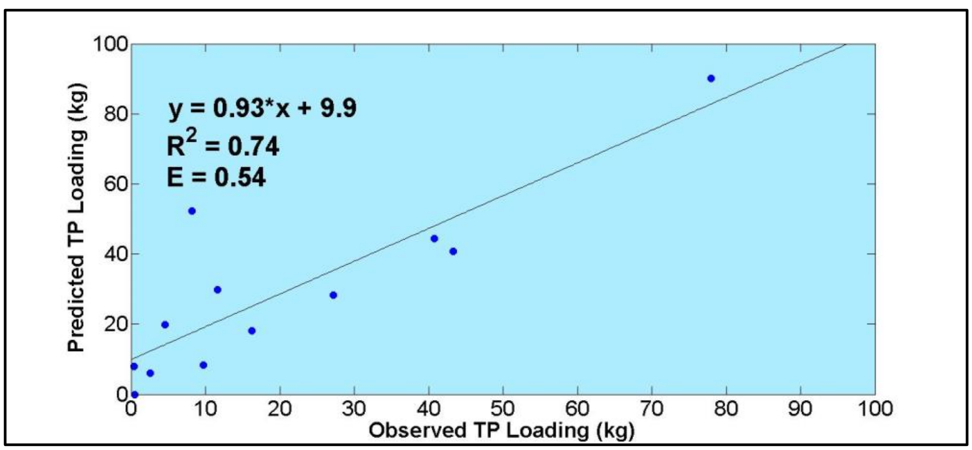

Figure 3.15 Evaluation of monthly TP loading estimation for AnnAGNPS.

Phosphorus yield was high from most sub-watersheds that also showed a high sediment loss (Figure 3.16). Low phosphorus yield was observed in the sub-watersheds near the outlet of the modeled watershed.

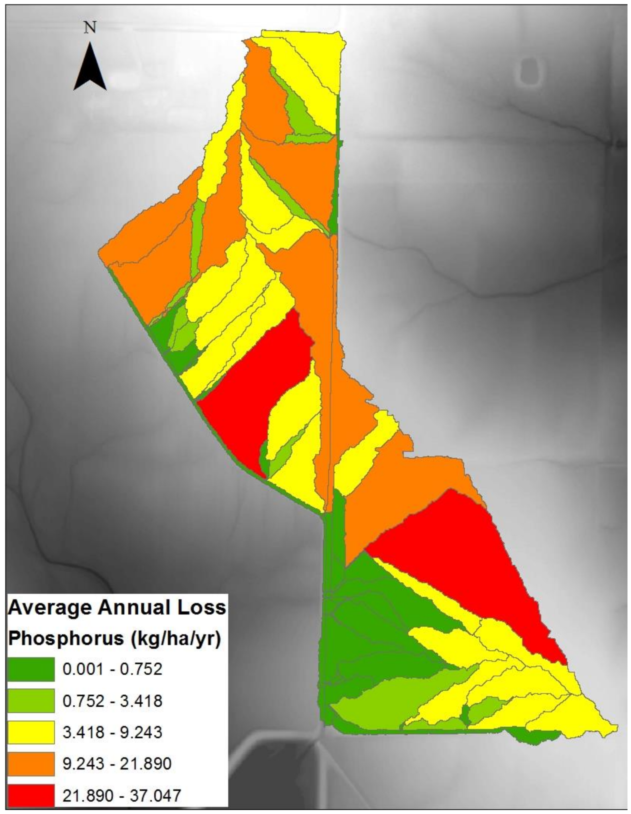

Figure 3.16 Average annual phosphorus loss from cells in the modeled watershed.

The model, however, did not have a satisfactory performance in the estimation of nitrogen loading from the watershed, with an R^2 of 0.15 and E of -0.107 (Figure 3.17). A study conducted to evaluate the short term prediction of nitrogen 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. A. 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. 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 model's poor performance in predicting nitrogen yields.

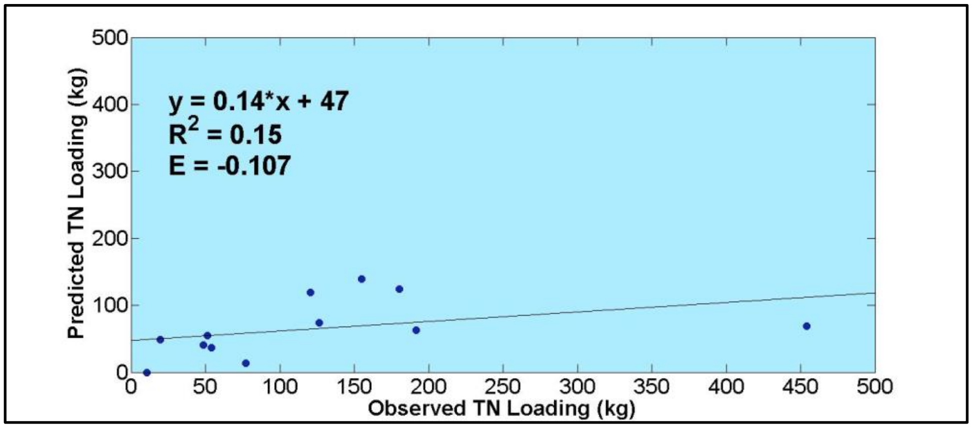

Figure 3.17 Evaluation of monthly TN loading estimation for AnnAGNPS.

Evaluation of OFWS system using AnnAGNPS

Evaluation of AnnAGNPS performance for the agricultural watershed in East Mississippi has shown that the model can be successfully used to evaluate an OFWS system. AnnAGNPS can be used to estimate potential runoff that can be available for the system from an agricultural field and the amount of sediment and phosphorus load that can be captured by the system in runoff. Use of the model for nitrogen loading reduction estimation will require further research.

AnnAGNPS estimates show that the OFWS system established in East Mississippi was able to capture 220,000 m^3 of water through the monitored watershed in the storage pond that can be used for irrigation. The storage pond also captured 46 tons of sediment and 558 kg of total phosphorus over the same period. The 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 significant amounts of sediment and phosphorus.

Runoff, sediment, and phosphorus yield response to alternative management practice

All tillage operations and application of poultry fertilizer in the spring rather than the fall and leaving the field no-till in the fall reduced phosphorus losses from the field by 7.49% and sediment losses by 3.18% (Figure 3.18). 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 availability of nutrients would presumably increase for crops with a spring application, while studies have shown a reduction in sediment loading with no tillage (Chichester and Richardson, 1992; Montgomery, 2007). The runoff, however, increased by 2.41%.

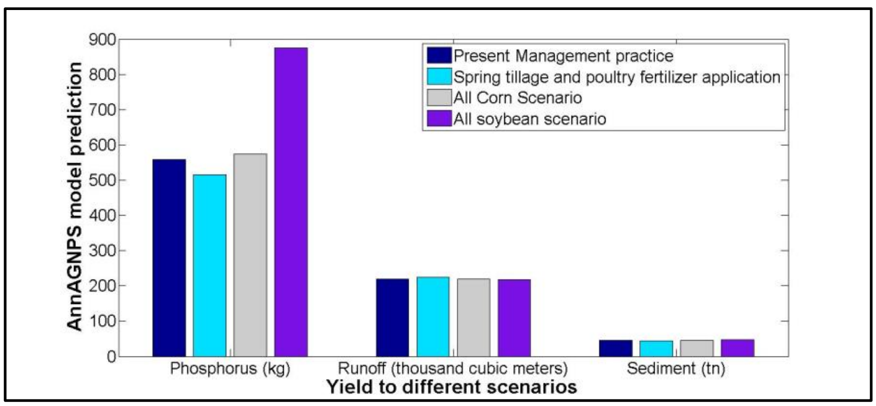

Figure 3.18 Phosphorus, runoff, and sediment yield for different management practice scenarios.

All corn or all soybean acreage had negligible effect on the total runoff yield from the field (Figure 3.18). Sediment yield also did not significantly change with either all corn or all soybean scenarios. However, total phosphorus yield from the agricultural field increased by 56.8% when soybean was planted in all agricultural fields. The result was as expected since soybean has a significantly lower P-uptake as compared to corn, and poultry fertilizer application in the fall is a significant source of P.

Evaluation of alternative scenarios has shown that spring application of poultry fertilizer and spring tillage operation has the best effect in reducing sediment and nutrient loading and increasing nutrient availability for plants. However, further evaluation is needed before the alternative management practices can be implemented, as the practice could postpone crop planting date during wet spring months in the study area and ultimately affect yield.

Conclusions

In conclusion, the model can adequately estimate runoff, peak discharge, sediment yield, and phosphorus loading from agricultural watersheds in East Mississippi as demonstrated in this study. These results also demonstrate that the model performs better with increased time scale, as better predictions were obtained over a larger time scale. Results also showed that the model was not able to estimate nitrogen loadings for the watersheds in East Mississippi. Lack of adequate and accurate model data input for nitrogen estimation could be the reason for the unsatisfactory prediction in the modeled watershed. Further research is required to determine if calibration of the important parameters of the model for nitrogen estimation after sensitivity analysis can improve model performance.

As the model was successfully evaluated for runoff, sediments, and phosphorus, the model can also be used to evaluate the effectiveness of OFWS systems already established in East Mississippi by helping estimate the amount of runoff the system is able to capture along with sediment and phosphorus loadings. The AnnAGNPS model can also help evaluate potential agricultural sites for the establishment of OFWS systems by estimating the amount of runoff. Design considerations for OFWS system storage ponds can also be aided, but further research on crop requirements will also need to be conducted.

Evaluation of the management practice 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, while no till in the fall after harvest and spring application of poultry fertilizer can decrease sediment and nutrient loss. AnnAGNPS can also be used to evaluate the effectiveness of alternative management practices for sediment and phosphorus loading reduction and also to conduct comparative studies between different management practices for watersheds in East Mississippi, with the goal of optimizing management practices to decrease nutrient and sediment loss before actual implementation.

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CHAPTER IV

CONCLUSIONS

The major objectives of this study were to: 1) Evaluate the effectiveness of an On–Farm Water Storage (OFWS) system to reduce downstream sediment and nutrient loading from an agricultural watershed in East Mississippi; 2) Quantify surface water provided by the OFWS system for irrigation; and, 3) Determine if commercial fertilizer application could be reduced because of the nutrient load in the recycled surface water that is reapplied through irrigation.

Monitoring of the OFWS system was detailed in Chapter Two, and results showed that storm runoff events captured by the OFWS system storage pond had nitrate concentrations measuring up to 179 mg/L, total phosphorus up to 3.73 mg/L, and sediment concentrations up to 1322 mg/L. In Chapter Three, watershed modeling of the study area was performed using the Annualized Agricultural Non–Point Source Pollution Loading Model (AnnAGNPS). When compared to the monitoring data described in Chapter Two, the modeling results showed that AnnAGNPS was able to successfully estimate runoff, sediments, and phosphorus from agricultural watersheds in East Mississippi. Utilizing the model, it was estimated that the OFWS system monitored in East Mississippi was able to capture 220,000 m^3 of runoff from the watershed between September 2014 and March 2016 that could be later used for irrigation. The OFWS system also captured approximately 46 tons of sediment and 558 kg of phosphorus, protecting downstream water quality. However, further evaluation of the model is required to determine if the model can be used for nitrogen loading estimation for the area. Although the model was not able to estimate nitrogen load reduction, the high concentrations of nitrogen that were measured in storm runoff samples captured by the OFWS pond indicate that downstream nitrogen loading is also reduced by these systems.

During both years of the study, early fall and winter runoff events after harvest had the highest nutrient concentrations. Fall application of poultry litter fertilizer following harvest, in preparation for the next year's growing season, was the most critical management practice in the study area that led to high nutrient concentrations in early fall runoff events. AnnAGNPS was used to evaluate a change in the timing of the poultry litter fertilizer application and tillage operation, and model predictions showed that the phosphorus loading decreased by 7.49% and sediment by 3.18% when these operations were moved to the spring before planting. However, many considerations including potential yield loss due to delayed planting as a result of fertilizer application and tillage in the spring will have to be considered before this alternative management practice can be implemented.

Monitoring the nutrient concentrations in the storage pond revealed that the nitrate concentration in the pond was lower than 10 mg/L Maximum Contaminant Level (MCL) in all but one of the 22 months the pond was monitored, while the dissolved phosphorus was below the detection limit of 0.05 mg/L for much of the monitoring period. Hence, even if water was lost downstream from the storage pond spillway when the pond was at its maximum capacity during April–May in both years of study, the nutrient load in the overflow water was considerably lower than in the storm runoff events captured by the pond.

The OFWS system was able to provide a total of about 237,000 m^3 of water for irrigation over the 2014 and 2015 growing seasons which showed that the system can be an effective source of irrigation in East Mississippi. Modeling of the study area showed that the monitored sub–watershed, one of the two that drains to the storage pond, produced a runoff volume of 220,000 m^3 that was captured by the OFWS system.

Yield comparison between irrigated acreage and non-irrigated acreage for corn and soybeans showed higher yields when irrigated for both crops. Even though East Mississippi receives an average 1371.6 mm rainfall annually, it is evident that irrigation is important to attain higher yields. Increased yield as a result of irrigation from the OFWS storage pond also demonstrated the economic benefits of the OFWS system along with the environmental benefits.

Grab samples collected from the center pivot system during irrigation events showed lower nitrate concentrations than those in the grab samples collected from the OFWS pond on the same day. Phosphorus concentrations were negligible in the center pivot samples and in the OFWS pond samples. In addition, the nitrate concentrations in the center pivot sample were not consistent. So although there is some nitrate recycling, it was not present at levels which could allow a reduced commercial fertilizer application.

As AnnAGNPS was successful in estimating runoff, sediment, and phosphorus for watersheds in East Mississippi, the model can be used to evaluate potential sites for establishing OFWS systems by predicting potential runoff and drainage lines for the construction of storage ponds. AnnAGNPS can also be used to estimate potential sediment and phosphorus reduction downstream by estimating the loads in the runoff which will be captured by the storage pond.

This study has demonstrated that OFWS systems can greatly aid in reducing downstream nutrient and sediment loading from agricultural watersheds. These systems can also provide water for irrigation, which can aid in increased yield for the farmer. However, cost of establishment can be a major impediment to increased implementation of these systems in the agricultural watersheds of East MS. The price of constructing a storage pond and installing irrigation systems can be very high and a major drawback for some farmers. The technical and financial assistance provided to farmers in the Mississippi Delta through the NRCS–Mississippi River Basin Healthy Watersheds Initiative (MRBI) and other groups has been instrumental in implementing these systems there. Similar technical and financial assistance in East Mississippi Counties could be very important in helping farmers in this region implement these systems.