The use of farm ponds with modified outlet structures to decrease peak flow and erosion in the West Fork of the White River

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Introduction

The use of farm ponds to control erosion is well documented. For example, the large expansion of farm ponds in Central Texas during from 1950-1970s decreased the sedimentation rates significantly (Berg et al. 2016). However, these farm pond systems tend to only have emergency outlets, that typically overflow during heavy rains resulting in increased peak flow and sedimentation rates downstream. In urban settings, the use of stormwater management ponds are a common practice to decrease peak flows caused by increased impervious landcover. Water is slowly released from stormwater management ponds through the outlet that can have different designs ranging from overflow, perforated or bottom draw (REF). Thus, adding these outlet designs to farm ponds can be beneficial to decrease peak flows and retain sediment.

Beaver Lake uses include recreation, flood storage, and provides drinking water for approximately 300,000 consumers in North West Arkansas (Miller and Daniels 2002). Given the importance of this reservoir, monitoring and managing the watershed will help to maintain and/or improve water quality. The three major tributaries of Beaver lake are Richland Creek, War Eagle Creek, and White River. The West Fork of the White River is on the 303(d) list, classified as impaired caused by high levels of turbidity that can cause decreases in dissolved oxygen (USEPA, 2017). One best management practice to control erosion is to create stormwater ponds that decreases the peak flow of rain events and captures sediment and nutrients. As the percent of pasture landcover increases so does the risk of soil erosion. Through adding farm ponds in these locations can decrease the peak flow by 17-20% depending on the dryness of the soil (Scott and Haggard, 2015) resulting in less erosion downstream and improving water quality.

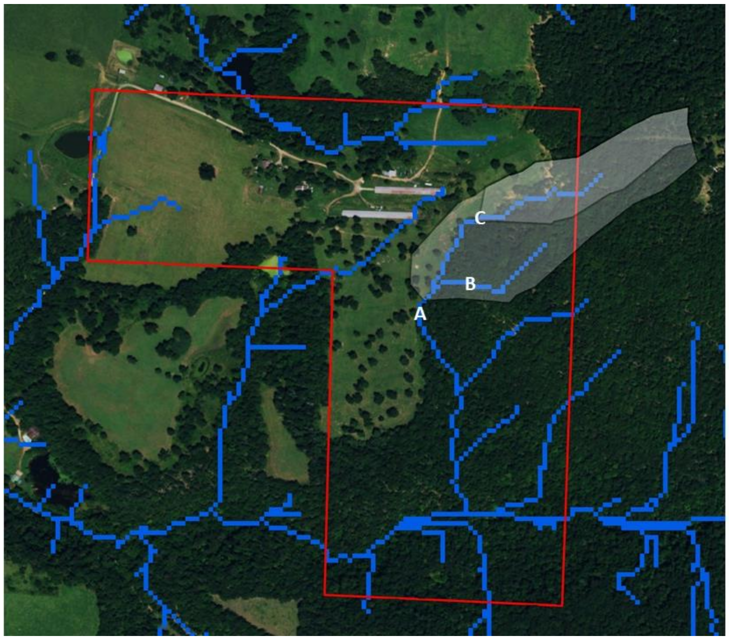

Figure 1: Watershed and site location of three sites. A is the lower site, B is the upper forest site, and C is the upper field site.

Here we investigated the use of a farm pond with a perforated outlet to decrease peak flow and retain sediments and nutrients in a second order stream in North West Arkansas that leads to the West Fork of the White River. To investigate performance of the pond we monitored the hydrology for 16 months prior to constructing a pond with a perforated outlet and then continued monitoring for an additional 12 months (at time of writing this report). In addition to the hydrological data, we also collected water samples both before and after pond construction and measured the total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP).

Methods:

Site Description

To test whether farm ponds can decrease peak flow and improve water quality, we chose intermittent streams located at 35º57’30N and 94º07’41W near West Fork, Arkansas. We selected two first order streams to monitor hydrology located above the pond and classified as the upper field site (Fig 1, C), and the upper forest site (Fig 1, B). The upper field site drains mainly pasture land use, while the upper forest site drains forested areas. Additionally, we monitored a lower site that is located downstream of the two upper sites and is also downstream of the pond (Fig 1, A). To monitor hydrology, we installed flumes at each site that allowed us to calculate the discharge of water for each site and each rain event (Fig. 2). After installation, we added a pressure sensor in each flume that recorded the pressure every 5 minutes starting on March 11, 2018 for all sites.

Figure 2: Top: Lower site flume looking down stream. Bottom: Lower site flume looking up stream

As the flume fills with water it causes the pressure to increase that was corrected to the atmospheric pressure. We subtracted atmospheric pressure recorded at the same time located in the barn of the landowner’s property from the pressure in the flume. This pressure data (kPa) was converted into water depth in meters using the conservation factor 0.102. The depth of water (m) in each flume was then converted into discharge (Q) using the following equation provided by the manufacture

$$Q = -0.01019406 - (0.10384217 * (m\hat{}0.4) + (160.46136 * (m\hat{}1.5) + (891.4730165 * (m\hat{}2.5)$$

where, Q is discharge in L s^{-1}, and m is depth of water in the flume.

For each rain event, we calculated the total volume of water, duration of rain and peak flow for each site (i.e., upper field, upper forest and lower site). For the upper field site and upper forest site the rain event started when the depth of water in the flume was above 1cm and continued until depth was lower than 1 cm for 30 min. However, for the lower site a rain event occurred when the depth of water was greater than 3 cm in the flume. To determine total water per rain event we assumed the discharge between each data point was constant. Therefore, each discharge measurement was multiplied by 300 seconds to obtain the volume of water (L) during a 5 min interval. We then summed the volume of water for each 5 min interval that had water in the flume. Finally, we obtained the total upper volume by adding the volume of water from the upper field and upper forest sites. The duration of each rain event was calculated by the amount of time water was above 1 cm in the upper sites and 3 cm in the lower sites. As the duration of each rain event differed between the upper field and upper forest site, we used the maximum duration from either the upper field or upper forest site. The peak flow was determined by selecting the highest discharge for each rain event. For the upper field and upper forest sites we used the maximum peak flow. These data were used to generate relationships between the upper sites (i.e. upper field and upper forest site) and the lower site for the pre pond rain events.

Aside from the high frequency hydrology data, we sampled 20 rain events from each flume before the pond was constructed and 10 rain events after the pond was constructed until May 2020. From these water samples we measured, TSS, TN and TP. Briefly, TSS was determined by filtering a known volume of water on to a preweighed precombusted glass fiber filter (GF/F Whatman). Filters were dried for a minimum of 24 h at 60 ºC and reweighed on a microbalance to the nearest µg. The difference between the pre and post filtering weighed was converted into mg L^{-1}. Total N and TP were digested using persulfate and measured on a Lachet following APHA (1992) standard protocols. All data for hydrology and TSS and total nutrients collected before July 16, 2019 were classified as pre-pond and all data after September 30, 2019 were classified as post-pond. Rain events between July 16, 2019 and September 30, 2019 were ignored in calculating differences between pre and post pond as the perforated outlet was not completed, and no water was released over the emergency spillway.

Figure 3: Perforated outlet

Pond details

Construction of the pond began on July 16, 2019 and was completed on July 30, 2019. The perforated outlet was completed on September 30, 2019. By adding the perforated outlet, it separated the pond into two pools, the conservation pool that is a permanent pool and the flood pool that is slowly released from the perforated outlet. In addition to the perforated outlet, there is also another outlet that is controlled by a value that can drain both the flood pool and conservation pool for the landowner to use.

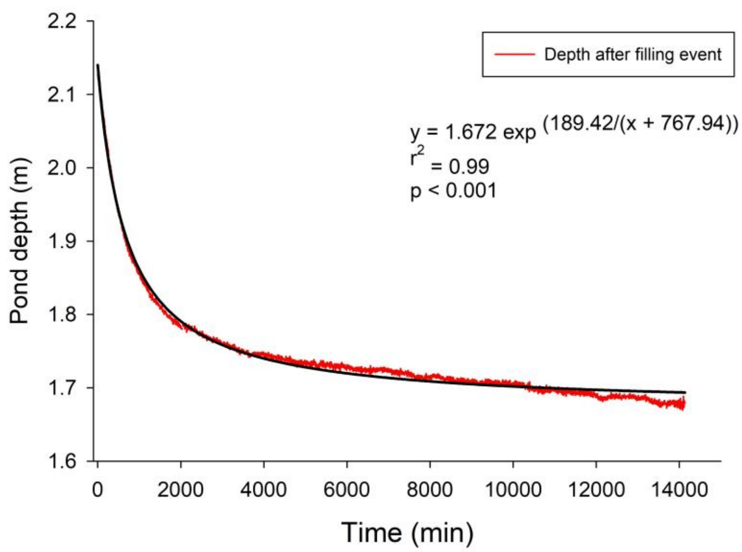

Figure 4: Change in pond depth after rain event that caused pond to reach top of the flood pool and drained the flood pool completely. Time took 9.7 days (14000 min) to drain flood pool.

To estimate the volume of pond, we assumed the pond is half of an egg shape using the following equation

$$v = \frac{\frac{4}{3}abc}{2}$$

where the volume (v) is equal to 4/3 pi multiplied by the radius of the length, width and depth of the pond divided by 2. The maximum length, width and depth of the pond is 47.5 m, 68.6 m, and 2.3 m giving a total volume of 1983 m^3 (1,983,000 L) or 1.6 acre-feet. We created perforated outlet by drilling 2.54 cm (1") holes from the top of the emergency spillway down 46 cm (18") at 2.54 cm intervals, thus 4 x 2.54 cm holes are at each level for a total of 72 holes in the outlet (Fig. 3). The outlet resulted in a conservation pool of 1027 m^3 (1, 027, 000 L) or 0.83 acre-feet, and a flood storage of 956 m^3 (956, 000 L) or 0.77 acre-feet. If the pond fills from the conservation pool to the emergency spillway it will take approximately 10 days to research the conservation level again (Fig. 4).

Hydrology

In general, 2018 was a drier year than 2019 during the pre-pond stage. For all rain events in the pre-pond hydrology, the lower site had the highest discharge, often doubling the highest discharge in the upper field or upper forest sites (Figure 5). However, after the pond was constructed, the lower site often had less discharge or equivalent to the upper field site (Figure 5). So far 2020, appears to have numerous rain events with rain continuing into mid-summer.

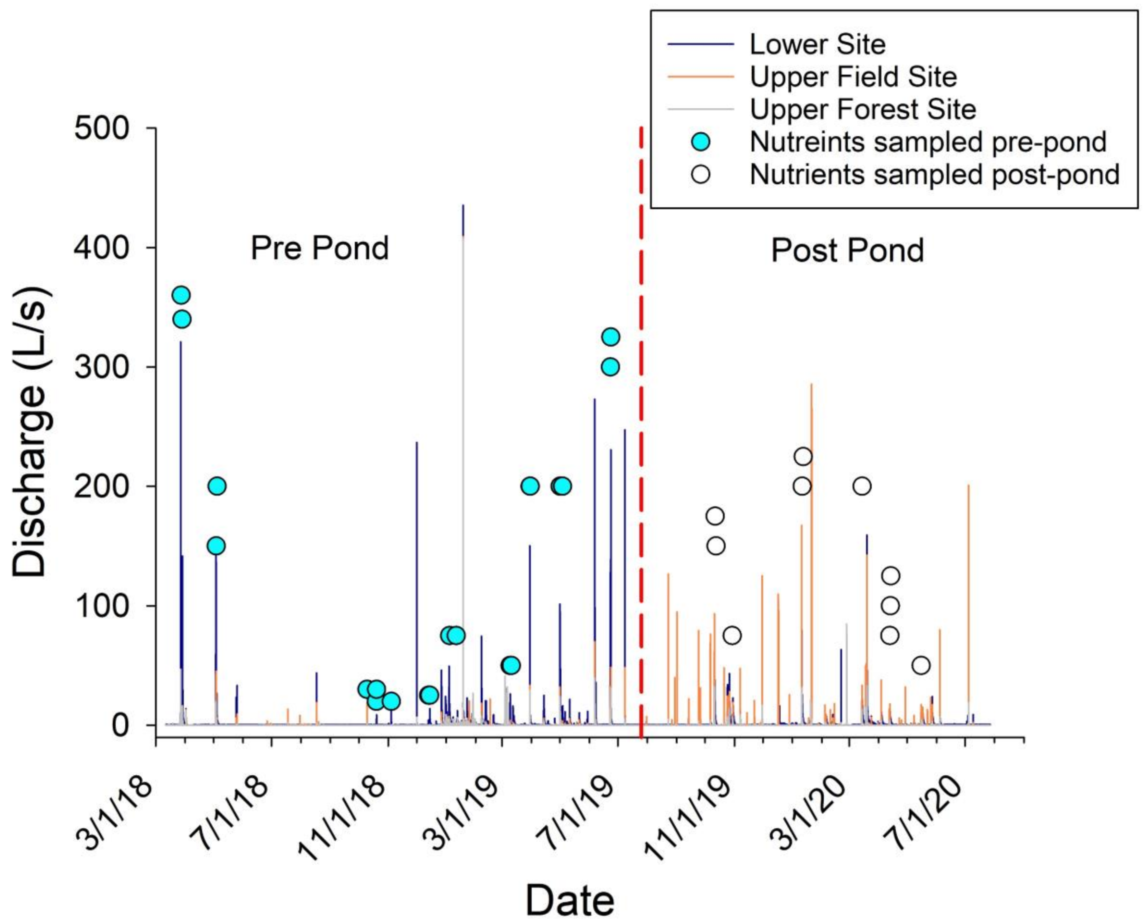

Figure 5: Discharge in L/s from the lower site (blue) upper field site (orange), and upper forest site (grey). Nutrients sampled pre-pond are in cyan circles and post-pond in white circles. Red dashed line indicates when construction of the pond was completed.

Hydrology pre and post pond

We examined the relationships between the upper sites and lower site during the pre-pond period for the total volume, duration of flow, and peak flow for each rain event as described in the methods. We then used this relationship to predict the total volume, duration of flow, and peak flow during the post pond rain events. If the post pond data appeared around the predicted line (black lines in figure 6), then the relationship is likely similar between pre and post pond hydrology. However, if the post data falls above the predicted relationship, then the pond caused increased the response compared to the pre-pond hydrology. Finally, if the post-post data falls below the predicted relationship, then the response was decreased compared to the pre-pond hydrology. We also tested for significant differences between the pre and post pond relationships between the lower and upper sites using the SMATR program (REF) that tests for differences in slope and intercept.

There was no statistical difference in total volume of each rain event pre and post pond ($t_1 = 1.55$, $p = 0.26$; Fig. 6A). In smaller rain events the data is scattered around the black line indicating a high variation between the upper sites and lower site as the pond was constructed. However, for larger rain events the majority of the data falls just below the black line indicating some water is being retained within the pond than what would be predicted without the pond present.

After the pond was constructed the duration of each rain event defined by the amount of time the lower site had flowing water through the flume increased, with almost all the data points being above the black predicted line ($t_1 = 12.18$, $p < 0.001$; Fig. 6B). On average the duration of each rain event lasted 25 h longer and ranged between 3 hours shorter and 100 h longer with the pond than before the pond was constructed.

Peak flow in the lower site was significantly decreased after the pond was built ($t_1 = 96.50$, $p < 0.001$; Fig. 6C). All but one rain event after the pond was built resulted in a lower peak flow compared to the before the pond. On average peak flow decreased 103 L/s and ranged between 4 and 514 L/s.

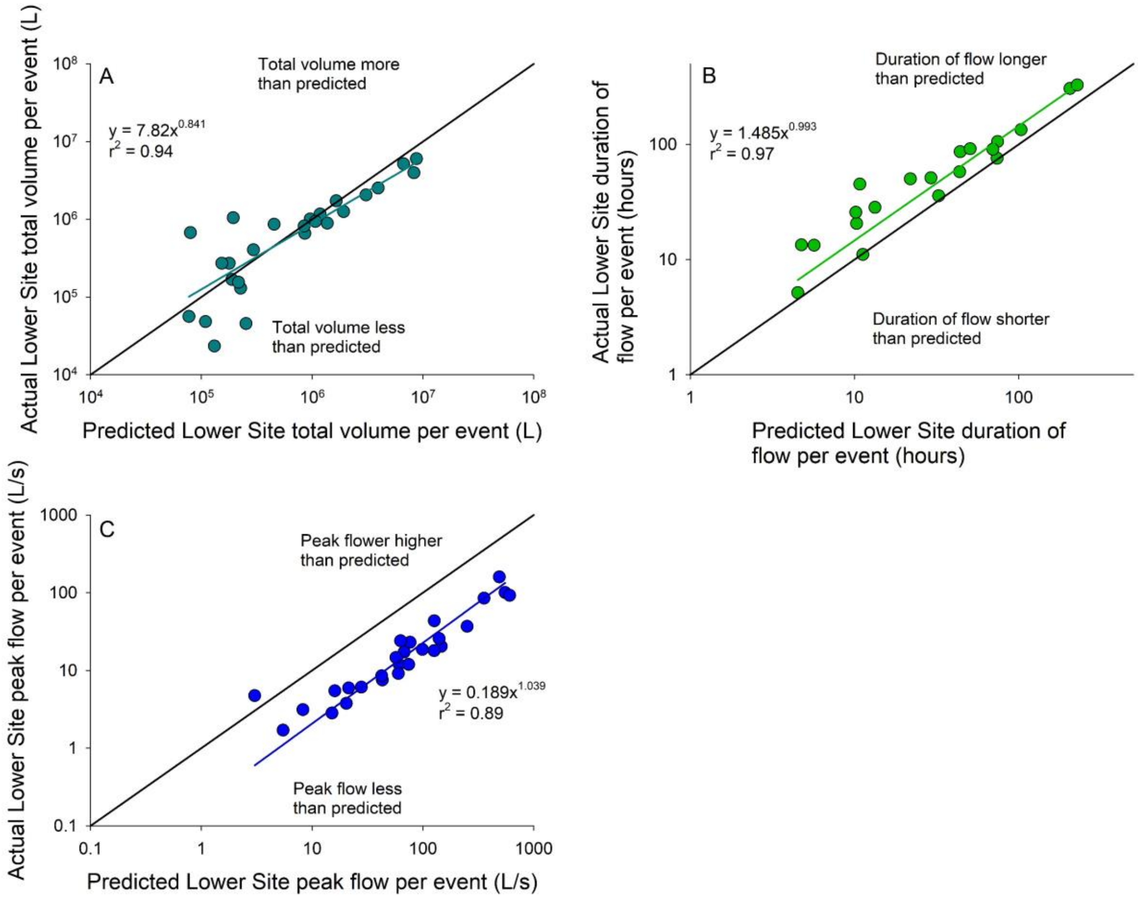

Figure 6: Hydrology differences between pre and post pond for A) Total volume of rain per event, B) Duration of rain event, C) Peak flow of rain event. Solid black line is the relationship between the upper sites (upper forest site and upper field site) and the lower site pre-pond. Colored circles are the actual data and relationship between the upper sites and lower site post pond.

Sediment and nutrients pre and post pond

We compared the flow corrected TSS, TN and TP loads by examining the slopes and the intercept of the relationship in the lower site pre and post pond. The TSS, TN, and TP flow corrected loads resulted in similar slopes and intercepts both pre and post pond (TSS, $t_1 = 3.5$, $p = 0.06$; TN, $t_1 = 2.18$, $p = 0.14$; TP, $t_1 = 0.09$, $p = 0.76$; Fig. 7), indicating the pond did not alter suspended sediments or nutrients.

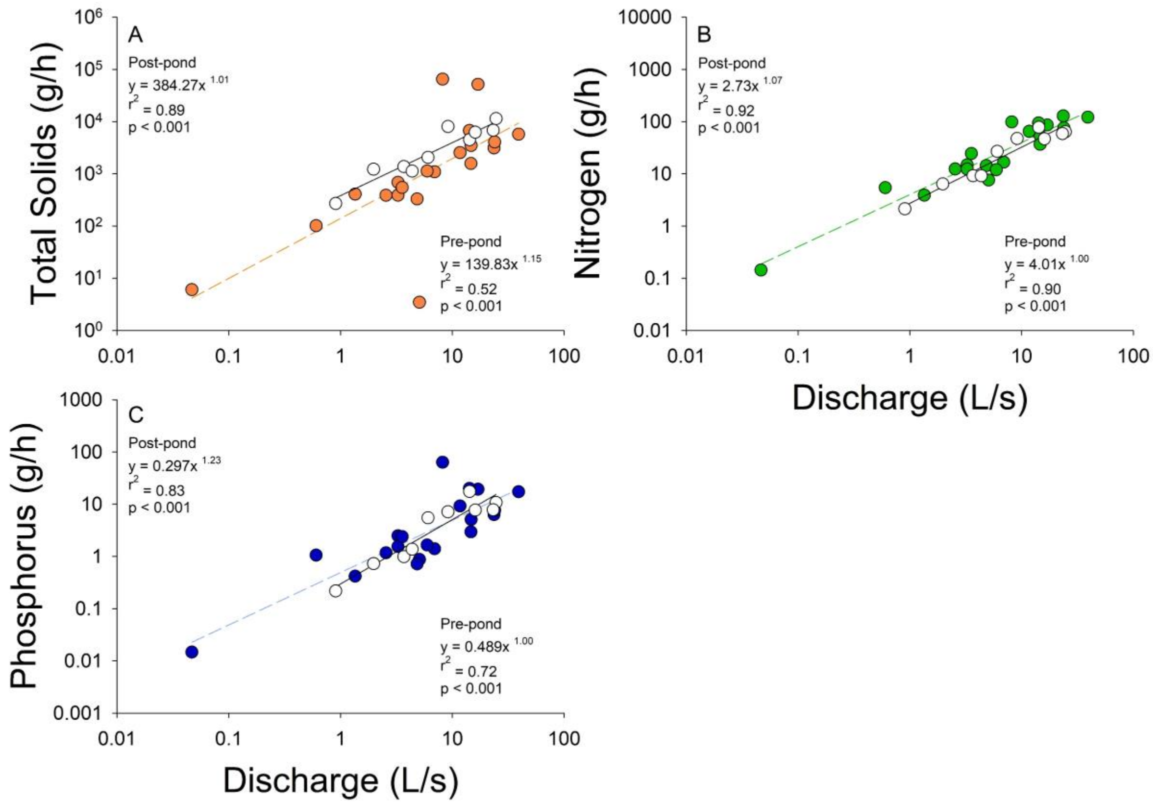

Figure 7: Suspended solids and nutrient loads in pre-pond (colored circles) and post pond (open circles) in the lower site for A) total suspended solids (g/h), B) Total nitrogen (g/h), C) total phosphorus (g/h).

Discussion

Overall, the farm pond with a perforated outlet altered hydrology by increasing the duration of each rain event and decreasing the peak flow. However, these changes in hydrology did not affect TSS, TN or TP loads for each rain event.

The TSS, TN, TP did not change after pond construction was likely caused by other hydrological changes that occurred right after pond construction. Two old ponds upstream of the upper field site had the dams removed right after the pond construction was completed. It was noticed when the pressure sensors data was collected the upper field site flume often contained a lot more sediment than prior to the pond construction. Additionally, the altered landscape needed to construct the pond caused the removal of trees and grass that would have further led to increased sedimentation after construction. We are hopeful that the landscape around the pond has become less disturbed the TSS and nutrient loads will decrease within the next year.

Even with no change in TSS and nutrient loading after pond construction, the decreased peak flow should promote sediment retention downstream by preventing erosion during high flow events. Erosion is controlled by the soil type, slope of the stream and the intensity of the rainfall (Sunburg and Rapp 1986).

Overall, after one year post-pond construction, we have significantly improved hydrology by increasing the duration of each rain event and decreasing the peak flow. We will continue to monitor TSS and nutrients in hopes that the loads decrease as the landscape around the pond becomes more stable.