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Concentrated Standing Tailwater: A Mechanism for Nutrient Delivery to Downstream Aquatic Ecosystems

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Abstract: Contribution of first flush runoff events from intense rainfall to downstream aquatic ecosystems are often reported in terms of sediment and nutrient delivery, with hardly any consideration to the contribution that standing, concentrated tailwater in primary aquatic systems makes to downstream nutrient loads. Two geographically distinct studies (Jonesboro Arkansas, and Stoneville Mississippi; 4 studies, n = 30) evaluated the effectiveness of drainage ditch systems to mitigate nutrient concentrations and loads. Within each independent study all experimental ditches had elevated background nutrient concentrations as a result of standing water, prior to the start of each simulated runoff experiment. These concentrations remained elevated 15-30 minutes post the start of each simulation as the concentrated, impounded water was pushed out through each system. In both these systems, it was hypothesized that water had accumulated in the respective drainage ditches and had been concentrated though evaporation and aquatic macrophyte transpiration. It is theorized that additional controlled drainage could decrease the potential of concentration toxicity downstream with improved dilution and hydraulic residence management.

Key words: Nutrient, ditches, wetlands.

1. Introduction

Contribution of excess agricultural fertilizers to the degradation of downstream aquatic ecosystem health is well documented [1-6]. Numerous studies have illustrated and reported the effect of first flush phenomenon on both surface [7-9] and subsurface [10, 11] runoff and its dominant contribution to nutrient loads leaving the agricultural landscape. Agricultural runoff is funneled via drainage ditches to secondary receiving waters and eventually into main stem rivers that lead to coastal ecosystems. Typically, these drainage ditches are ephemeral, flowing after storm and irrigation events, holding water at times of the year with precipitation, and running dry when evapotranspiration (ET) is greater than precipitation and runoff. Studies have shown that a few infrequent, large storm events (often post fertilization) will deliver 70%-90% of the annual nutrient export load for a particular system, with both surface and subsurface runoff cited as the major avenues for nutrient inputs (both concentrations and loads) to downstream aquatic ecosystems [12-14]. There may be, however, an undescribed mechanism concentrating nutrient delivery to receiving aquatic systems that has rarely been mentioned or quantified. Concentrated standing tailwater in a receiving system without controlled drainage structures, could function to elevate outflow concentrations and loads entering receiving aquatic systems during storm events.

Evapotranspiration is an important process in these ephemeral systems. Runoff water that remains in the

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drainage ditch is often high in nutrient concentrations; however, ET will further increase nutrient concentrations through a decrease in water volume. This paper highlights this phenomenon by documenting two geographically distinct and independent studies, in which four experiments evaluated drainage ditch capacity for nutrient reductions [15, 16]. Vegetated drainage ditches are being advocated as useful management practices for nutrient reductions in agricultural runoff [12, 13]. The ditches act as wetlands within the agricultural landscape, creating conducive conditions for biogeochemical processing of nitrogen and phosphorus. Moore et al. [15] documented nutrient reductions in two ditches in the Mississippi Delta. Results suggested no differences between vegetated and un-vegetated ditch systems for nutrient reductions in both concentration and load. However, improved nutrient reductions were suggested as possible by increasing hydraulic residence time within the system. Kröger et al. [16] evaluated the use of controlled drainage (weirs and riser pipes) in eight vegetated drainage ditches for nutrient reductions in Jonesboro, Arkansas. Results from that study support that controlled drainage provides effective nutrient reductions for agricultural runoff. However, in all experiments, background concentrations within each ditch at the beginning of the experiment were often significantly higher than groundwater additions to flow as well as amended simulated concentrations.

2. Experiment

These two independent studies occurred in the Lower Mississippi Alluvial Valley, in Mississippi and Arkansas. Ditches, both vegetated and non-vegetated at the Delta Conservation Demonstration Control (DCDC) facility in Stoneville, MS were evaluated for their capacity to mitigate nutrients in 2008 [15] (2 ditches × 7 sampling locations × 2 experiments). Similarly, eight constructed ditches with controlled drainage structures at the Agricultural Research Facility at Arkansas State University, Jonesboro, AR were evaluated for their capacity to mitigate nitrogen (N) and phosphorus (P) [16] (8 ditches × 1 sampling location × 2 experiments; n = 30). Further methodologies behind each experiment can be found in the respective articles [15, 16]. Both experiments took place in the middle of summer, where temperatures exceeded 32 °C consistently. Nutrient concentrations in the water samples were tested with standard methods [17] for nutrient analysis: nitrate-N (NO_3^-) – cadmium reduction; nitrite-N (NO_2^-) – diazotization; ammonia-n (NH_4^+) – phenate; reactive P (DIP) and total P (TIP) – filtered and unfiltered digested ascorbic acid [18] respectively. Nutrient concentrations were subjected to Shapiro Wilks W test through JMP 8.1 (SAS 2008) to test for normality. All concentrations were log-transformed to satisfy the assumption of normality for students *t*-test (two-tailed, unequal variances). If log-transformed data still failed to reject the H_o for Shapiro Wilks, data were compared using Wilcoxon-Mann-Whitney test for non-parametric data. Alpha values were set at 0.1, to support differences *in lieu* of unaccounted, and uncontrollable variability.

3. Results and Discussion

There were highly significant differences between standing or background concentrations for NO_3^- (*Wilcoxon* $z = 2.97$; $P \leq 0.001$), NH_4^+ ($t_{26} = 4.48$; $P \leq 0.001$), DIP ($z = 4.01$; $P \leq 0.001$), and total inorganic P (TIP) ($z = 4.4$; $P \leq 0.001$) and outflow samples 15 minutes post the beginning of the flow experiment for the replicated drainage systems at ASU (Fig. 1). Similarly, at DCDC, background concentrations of NH_4^+ ($z = 1.78$; $P = 0.08$), NO_3^- ($z = 1.89$; $P = 0.06$), NO_2^- ($z = 2.26$; $P = 0.02$), and DIP ($z = 3.31$; $P \leq 0.001$) were significantly higher than outflow samples taken 30 minutes post the beginning of the simulated storm event in a vegetated drainage ditch with the initial flushing of drainage ditch water (Fig. 2A). Interestingly, TIP levels were significantly higher (z =

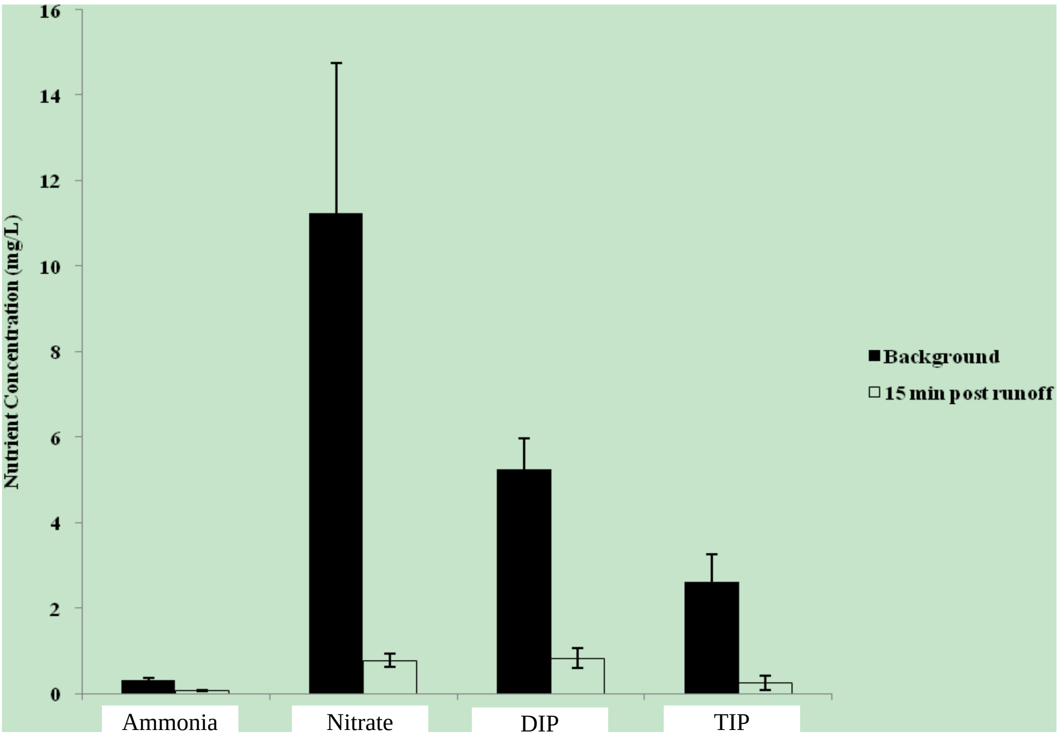


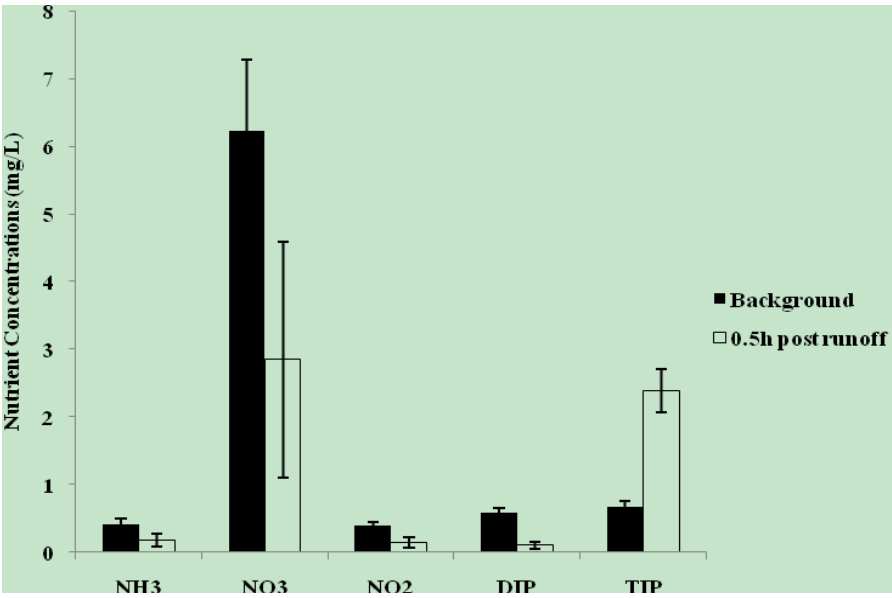
Fig. 1 Differences in nutrient concentrations between measured background concentrations and concentrations 15 minutes post runoff initiation at the ASU agricultural research facility.

-3.2; $P \leq 0.001$) at the 0.5 h sampling (2.4 ± 0.9 mg L^{-1}), than background (0.7 ± 0.2 mg L^{-1}) for both vegetated and non-vegetated ditches (Fig. 2B). When comparing the non-vegetated simulated storm event, where standing water was a result of rainfall occurring only 48 hrs prior to the simulated experiment, there were still differences between background and 0.5 h for NH_4^+ (z = -1.97; P = 0.04), NO_3^- (z = 2.39; P = 0.01), NO_2^- (t = -0.76; P = 0.46), and DIP (z = 2.68; P = 0.007). The magnitude of the differences, however, was significantly less. Increases in the vegetated and non-vegetated total inorganic P concentrations were attributable to increased flow and increased turbulence, resulting in elevated suspended particulate P levels in both vegetated and non-vegetated ditches.

Standing water, whether based for tailwater recovery or as a result of storage capacity in aquatic systems, will increase in concentration through time with a decrease in volume through evaporation and transpiration if plants are present. Certain management actions to reduce this impact, such as controlled drainage, might seem counter intuitive to reducing concentrations, as more water will be left standing in a particular system. The increased volume, however, can provide a dilution effect that reduces nutrient concentrations, but will not affect the load leaving the system. Load differences will be reduced through physical adsorption and assimilation with sediments, microbes and macrophytes within the system. In both experimental systems (DCDC, MS and Jonesboro, AR) previous storm events left standing water in the drainage systems. Evapotranspiration is hypothesized to have decreased standing water volume and increased nutrient concentrations within each drainage system resulting in elevated concentration leaving the system.

Water management structures such as low-grade weirs are drainage structures intended to increase hydraulic residence time and improve nutrient mitigation within the primary aquatic system. The ability to manipulate drainage ditches with controlled drainage structures will increase the amount of water

A



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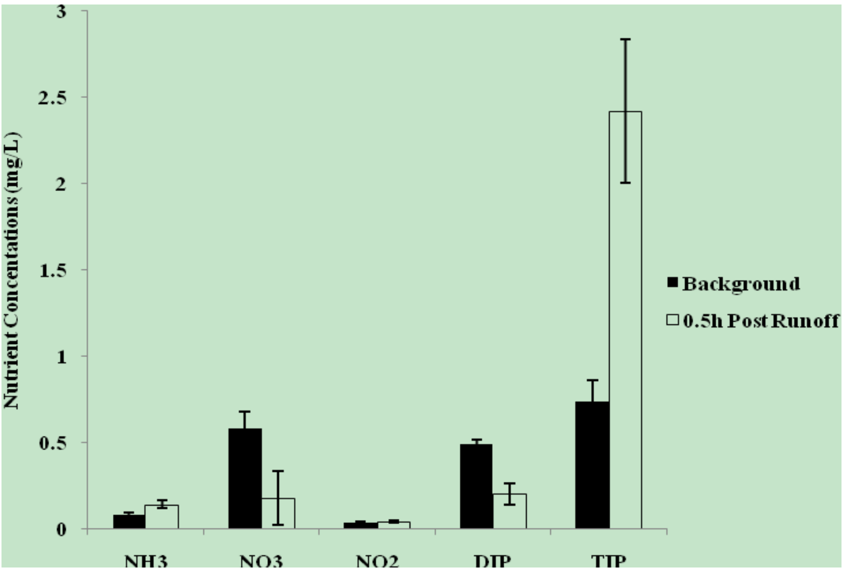

Fig. 2 Differences in nutrient concentration at delta center demonstration control between background and 30minutes post runoff for a vegetated (A) and non-vegetated drainage ditch (B).

remaining in the ditch post storm events. Weirs facilitate ecological and hydrological processes. Ecologically, weirs improve nutrient removal with multiple sites for drainage management and enhanced biogeochemical conditions. Hydrologically, incorporating weirs into the drainage ditch will result in more water being held at a single point in time, resulting in an improved dilution effect for nutrient reductions. This dilution effect will reduce nutrient concentrations in standing evaporated water within the system with the attenuation of storm flows throughout the year. Without drainage control structures, standing evaporated water with elevated nutrient concentrations within the drainage ditch will flush directly into receiving aquatic systems. As scientists, we need to be objective in our understanding of the role best management practices play in aquatic system nutrient dynamics.

4. Conclusion

Concentrated standing tailwater contributes to downstream nutrient loads and thus could result in eutrophication and aquatic system degradation. Low-grade weirs have the potential to facilitate nutrient reductions of agricultural runoff, storm events and standing tailwater prior to effluent reaching downstream receiving systems. The purpose of this study was not to highlight effectiveness of low-grade weirs to mitigate runoff, it was to show how standing accumulated water through volume reduction could enhance nutrient delivery to downstream systems. These retained pools of water through time could increase in concentration with a decrease in water volume and thus elevating concentrations in effluent with preceding precipitation events. With this understanding that concentrating tailwater elevates nutrient concentrations, research on management practices that increase hydraulic residence time, and promote mixing and dilution prior to runoff reaching downstream aquatic systems would be encouraged.

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