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Integrated constructed wetlands for treatment of dairy operation runoff in Eastern Tennessee during first year establishment

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ABSTRACT

Integrated constructed wetlands (ICWs) were implemented to reduce nutrient and sediment transport from a confined-animal dairy operation in East Tennessee. The objectives of this study were to (1) characterize first flush concentrations of potential pollutants from a typical confined animal dairy operation, and (2) determine if two ICWs have acted as hydrologic and physicochemical buffers in agricultural drainages during the establishment phase (first year after construction). Nine events between the two ICWs were sampled within the first year of construction and flow rates were continuously measured at the inlets and outlets. First flush sampling showed that phosphorus concentrations exceeded critical levels in six of the eight sampled events and nitrogen concentrations exceeded critical levels in half of the sampled events. Suspended solids, organic carbon, and phosphate were the most commonly detected pollutants of concern carried by runoff leaving the dairy operation. The documented performance of ICWs indicated that the practices generally reduced sediment and nutrient concentrations in runoff flowing to receiving waterways during wet weather conditions during the first year following construction and acted to buffer hydrologic pulses by reducing peak flow rates. In four sampled storm events spanning the time of late summer through winter, a total of over 2200 kg of suspended solids and 0.22 kg of nitrogen were retained in one ICW. Organic carbon was exported from the ICW practices during most events. Overall, the practice removed significant amounts of suspended solids and nitrogen, and event-based phosphorus.

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1. Introduction

Agricultural best management practices are used to protect water quality from potential degradation in many agricultural systems. Constructed wetlands have been used to treat concentrated waste streams globally for decades. However, they have only begun widespread implementation as a stormwater treatment practice in North America to protect stream water quality at a watershed scale (Mitsch et al., 2001; Zedler, 2003). Integrated constructed wetlands (ICWs) are free water surface emergent wetlands that are designed to treat animal-agricultural runoff for potential pollutants while being integrated into the traditional farm landscape to minimize operational costs and provide wildlife habitat and other additional ecological services (Scholz et al., 2007). Dairy operations may be a source of excess nutrients, because a dairy cow excretes approximately 88% of daily-consumed phosphorus (Morse et al., 1992). Cow manure is often used as a fertilizer, which provides a means for nutrients to be transported to receiving waters via runoff during storm events. In general, the distributions of nutrients in the landscape is disrupted from it's natural balance, resulting in nutrient surpluses in aquatic systems (Hooda et al., 2000). ICWs are ideal BMPs for applications in wet weather conveyances to intersect runoff before it enters into receiving waters. Wetland systems have been shown to successfully attenuate high nutrient loads in stormwater runoff on the time scale of natural storm events (Casey and Klaine, 2001).

In undisturbed systems, wetlands normally occur with a regular frequency in association with riparian areas and act as buffers by helping retain floodwater and subsequently provide a means of biogeochemical processing of nutrients. This buffering capacity may be mimicked through the application of ICWs to minimize shifts in physicochemical changes in surface waterways by moderating the transport of nutrients, organic materials, or other pollutants and the hydraulic pulses of agricultural runoff (Cronk, 1996; Dunne et al., 2005; Knight et al., 2000). In this study, we evaluate whether

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or not ICWs in wet weather conveyances act as buffers to mitigate the impacts of dairy operation runoff on surface water quality in the first year after wetland establishment.

Pollutant attenuation efficiency and processing of other allochthonous loads in constructed wetlands is a function of many physical and biogeochemical processes and interactions. Gradients in reduction and oxidation potentials as well as pH properties at the soil–water interface mediate transformations that are critical to pollutant removal (Reddy and D'Angelo, 1997). Physical design of wetland topography defines hydraulic properties, such as loading rate, water depth, and mixing patterns, which combine to affect hydraulic retention time distributions and efficiency (Holland et al., 2004; Persson et al., 1999). Phosphorus retention has show to increase with increased hydraulic loading (Braskerud, 2002; Knight et al., 2000).

The objectives of this study were to (1) characterize first flush concentrations of potential pollutants from a typical confined animal dairy operation, and (2) determine if the ICWs have acted as hydrologic and physicochemical buffers in agricultural drainages during the establishment phase (first year after construction). Long-term research goals include the characterization of event-based nutrient attenuation and seasonal variation associated with farm activities. We will examine the buffer capacity of two ICWs in agricultural drainages on a dairy operation regarding peak flowrate and/or decrease overall load to receiving waters during runoff events. We expect these management practices to minimize peak flow rates, completely attenuate small events, lower peak pollutant concentrations, and attenuate pollutant loads on an event-basis.

Treatment potential in constructed wetland systems is a function of storage volume displacement; as runoff enters the wetland, it mixes with and pushes out the existing storage water that is contained in the wetland (a mixture of previously occurred runoff, ground water, and precipitation) (Hey, 1982). Through volume displacement, runoff is treated through a variety of biological, chemical, and physical processes, and this can be modeled as a series of continuously stirred tank reactions (Werner and Kadlec, 1996). The degree of mixing and volume replacement is described as hydraulic efficiency, which is intricately related to residence time. Hydraulic efficiency has shown to be improved with the use of internal topographic features, such as deep pools, variable depth marshes, and islands (Walker, 1998). Free water surface emergent wetlands were selected for implementation over other constructed wetland alternative (such as vertical flow and horizontal subsurface flow) due to the relatively high capacity to treat sediment, pathogen, and nutrient pollution while keeping costs low (Kadlec and Wallace, 2009). Through the ICW concept implementation, the practices were designed and implemented under space constraints, as to minimize impacts on the dairy operation, and integrated into the existing site topography.

While there are no numeric criteria for pollutants leaving animal feeding operations during wet weather in Tennessee, there are numeric nutrient criteria for surface waters in other states in the southeast United States. The United States Environmental Protection Agency (USEPA) and Florida Department of Environmental Protection (DEP) published numerical nutrient criteria for inland flowing waters of south Florida. These criteria were statistically determined using an ecological endpoint of nuisance algae (represented by >30 μg/L chl-a). These criteria are 2 mg/L TN and 0.052 mg/L TP to not be exceeded more than 10% annually (USEPA, 2012). While the data collected in this study represent concentrations during storm flow, which occurs less frequently than 10% annually, and while these criteria are for waters of the state (as opposed to wet weather conveyances such as that of the ICW inflow), these criteria provide context to interpret the potential impact of dairy dirty water runoff on receiving waterways.

2. Materials and methods

2.1. Dairy site and operation

The dairy operation is located in the Little River Watershed in Eastern Tennessee and is bounded by the Little River running along its northern and western perimeter and Ellejoy Creek to the north and east. Ellejoy Creek is listed on the state's impaired streams list due to inputs of bacteria, sediment, and nitrates from discharges into the Little River directly north of the dairy operation. The Little River originates in the Great Smoky Mountains National Park (GSMNP) and runs north toward the Knoxville Metropolitan Area, where it discharges into the Upper Tennessee River. The segments of the Little River in the GSMNP and are identified as a sensitive aquatic habitat. As the Little River flows from the GSMNP down into the Tennessee River Valley, the drainage basin becomes increasingly urbanized and lower gradient.

The dairy operation maintained a herd size of 75 cows during the period of study. On the 550-ac operation, land use and management activities included dry cow pasture, heifer grazing pasture, and silage production crop land that included hay and corn in rotation. Crop fields and under-producing pastures are normally amended with liquid and solid dairy manure in the spring and fall every year. Management buffers were implemented within 35 feet of a perennial stream or wet weather conveyance. In this zone, no pesticides or herbicides are sprayed, but and hay was harvested. ICWs were integrated into the existing lay of the land in areas that were not utilized for silage production or pasture (because they were seasonally wet).

2.2. Integrated constructed wetland design

The crop field ICW is approximately 0.28 ha in surface area and captures drainage from approximately 17 ha of cropland and pasture. The wetland surface area can be classified as consisting of three zones, approximately 15% in deep pools (depth >1 m), 55% in fringe high marsh (0–0.2 m depth), and 30% low marsh channels (0.2–0.5 m depth) (Fig. 1). The deep pools were installed just below the inlet pipe outfalls to act as sediment-trapping forebays. The low marsh channels wind through the high marsh to spread out the water and provide growing conditions for a variety of wetland plants (both obligate and facultative species). A detailed topographic survey showed the inlets (38-cm and 61-cm culverts) are at elevations 0.23 m and 0.61 m above the outlet structure, respectively. Overall wetland slope is nearly 0.06% (Fig. 2). The pasture ICW is approximately 0.34 ha in surface area and captures runoff from approximately 10 ha of a combination of grass pasture, cattle travel lanes, and several operational buildings. Similar macrotopographic features were implemented (Fig. 1). A detailed topographic survey was not completed here, but the flowpath is approximately 220 m with a change of elevation between inlet and outlet of approximately 0.7 m. Both ICWs hold water in storage throughout the year and are connected with the water table. During dry periods, the water surface of the crop field ICW is suspected to be a perched water table on a dense clay lens. This is based observations of a water table at more than 2 m below the soil surface at a location approximately 75 m down gradient from the outlet structure. All the wetland vegetation was transplanted from other areas of the dairy and consists predominately of obligate wetland grasses and leafy emergent species.