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Storm flow dynamics and loads of fecal bacteria associated with ponds in southern piedmont and coastal plain watersheds with animal agriculture

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ABSTRACT

Storm events that increase flow rates can disturb sediments and produce overland runoff in watersheds with animal agriculture, and, thus, can increase surface water concentrations of fecal bacteria and risk to public health. We tested the hypothesis that strategically designed and placed ponds in watersheds with animal agriculture would attenuate downstream fluxes of fecal bacteria. We measured concentrations and fluxes of fecal indicator bacteria (commensal *Escherichia coli* and fecal enterococci) and manure pathogens (*Salmonella* and *E. coli* 0157:H7) in in- and outflows of Bishop Pond in the Southern Piedmont of Georgia during three storm events and in- and outflow concentrations and fluxes of fecal indicator bacteria at Ponds A and C in the Coastal Plain of Georgia during two storm events. Mean concentrations and fluxes of fecal indicator bacteria associated with pond in- and outflow during hydrograph rise, peak, fall, and 5-days after peak flow at Bishop Pond were significantly greater than their mean base flow concentrations and fluxes. In storm flow Bishop Pond significantly reduced the outflow concentrations and fluxes of fecal indicator bacteria compared with corresponding inflow measurements. Unlike fecal indicator bacteria, Bishop Pond appeared not to reduce outflow concentrations and fluxes of *Salmonella* or *E. coli* 0157:H7. At Ponds A and C in the Coastal Plain mean in- and outflow concentrations and fluxes of the fecal indicator bacteria associated with the hydrograph rise and peak flows of the storms were not different. Bishop Pond, with a length to width ratio of 3.3, attenuated downstream fluxes of fecal bacteria. In contrast, Ponds A and C were not effective at reducing downstream fluxes of fecal bacteria under storm flow conditions. The ineffectiveness of Ponds A and C may be attributed to their having length to width ratios of 1.2 and 2.5, respectively, both of which are below the minimum for effective pond performance. Our results indicated that in the humid Southeast an appropriately placed and configured pond in watersheds with animal agriculture can reduce storm flow loads of fecal indicator bacteria but not necessarily pathogenic *E. coli* 0157:H7.

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1. Introduction

Small and large ponds are ubiquitous across agricultural landscapes in the United States. In Georgia, an estimated 100,000 constructed ponds exist scattered across the state (CAES, 1998). Traditionally ponds have proven to be a reliable and economic source of water for livestock and irrigation as well as fishing. Demand on and competition for water has increased the need for ponds since 1980. An estimated 2.6 million small, constructed ponds are in agricultural areas of the mid-west and eastern United States (Smith et al., 2002).

As awareness of environmental issues has increased, so has the use of ponds for water conservation, wildlife habitat, recreation, landscape improvement, and pollution control from agricultural runoff and storm water. Such awareness and practice has brought

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to light shortcomings in the efficiency of the hydraulic performance of some constructed ponds in pollution control. Van Buren et al. (1996) studied the literature and surmised that the performance of ponds varied and was dependent on factors such as climate, the nature of runoff and storm flow, pond size, and design. Persson and Wittgren (2003) pointed out that poor design of many ponds in terms of their hydraulic performance limits their efficiency in pollutant control. Thackston et al. (1987) developed a model (Eq. (1)) to estimate hydraulic efficiency of basins and ponds as an aid in optimal design for pollutant control purposes:

$$\frac{T_M}{T} = 0.84\left[1 - e^{-0.59(L/W)}\right] \quad (1)$$

where T is the theoretical volumetric residence time computed as V/Q, where V is the pond volume and Q is flow rate; T_M is mean volumetric residence time; L is length and W is width. In the current study T can be expressed in days, V in cubic meters, Q in cubic meters per day and L and W in meters. Thackston et al. (1987) referred to the parameter T_M/T as "hydraulic efficiency", which is an indicator of the degree of reduction of resident time from the optimal theoretical residence time, which ultimately reduces the pollution reduction potential of a pond. Thackston et al. (1987) showed the strong dependence of this parameter on the length-to-width ratio of ponds per equation 1, and recommended the use of this equation in setting the geometry of ponds for a desired hydraulic efficiency level. Thus, ponds constructed across perennial streams may take advantage of topography that leads to a narrow but long pond a configuration that results in increased hydraulic efficiency.

The manure-borne pathogens *Salmonella* and *Escherichia coli* 0157:H7 each have low infective doses of 100 cells (Bitten, 1984) and 10 cells (Jones, 1999), respectively. Thus, apparent insignificant surface water loads of these two zoonotic pathogens can become a risk to public health. Watersheds with dairies, beef cattle, swine, and poultry operations together with wildlife and cropped and hayed fields receiving manure as soil amendments are potential non-point sources of zoonotic pathogens (Ferguson et al., 2003). Management practices to reduce or eliminate surface water contamination with fecal indicator bacteria and zoonotic pathogens such as *Salmonella* spp., *E. coli* 0157:H7, and *Cryptosporidium* spp. have been tested and developed. Riparian filter strips, for example, have been implemented and tested as a means to reduce and eliminate manure-borne pathogens in overland runoff (Coyne et al., 1995; Entry et al., 2000). Recently, Jenkins et al. (2014) demonstrated that applications of flue gas desulfurization gypsum, a byproduct of coal-fired power plants, can significantly reduce the poultry litter loads of the fecal indicator bacterium *E. coli* in overland runoff. In a three year study in Texas Harmel et al. (2013) concluded that poultry litter applications under hot, dry conditions reduced the load of *E. coli* in runoff. However, even under base flow conditions pathogen contamination can occur in agricultural watersheds when concentrations of fecal indicator bacteria, commensal *E. coli* and fecal enterococci, are below impairment criteria (Jenkins et al., 2008, 2009). Under base flow conditions, pond retention times can be extensive, ranging between two and three months (Jenkins et al., 2012), allowing exposure to solar UV-irradiation and protozoan predation to reduce the downstream fecal bacterial load (Davies et al., 1995; Schultz-Fademrecht et al., 2008; Jenkins et al., 2011). Jenkins et al. (2012) reported on a multi-month study that focused on the prophylactic effect of ponds on downstream loads of manure-borne fecal indicator bacteria and zoonotic pathogens *Salmonella* and *E. coli* 0157:H7 under base flow conditions. They demonstrated that a hydraulically efficient pond (Bishop Pond) with continuous in- and outflow reduced downstream fluxes of fecal indicator bacteria, but was not as effective at reducing loads of *E. coli* 0157:H7. By comparison, two ponds in the Coastal Plain of Georgia (Ponds A and C), not connected to perennial streams and characterized by ephemeral base (simultaneous in- and out-) flows, were not as effective at reducing outflow concentrations of fecal bacteria.

In contrast to base flow loading of fecal bacteria in agricultural watersheds, storm flow events have the potential to increase loads of fecal bacteria (Crabill et al., 1999; Dorner et al., 2006; McKergow and Davies-Colley, 2010; Stumpf et al., 2010; Hogan et al., 2012). With increased flow rates, increased concentrations and fluxes of fecal bacteria have been attributed to sediment agitation (Crabill et al., 1999; Dorner et al., 2006) and overland runoff (McKergow and Davies-Colley, 2010; Stumpf et al., 2010). Under storm flow conditions, pond retention times decrease, thus decreasing exposure of the fecal bacterial load to solar irradiation and predation.

After three years of drought and several months of base flow measurements, three storm events occurred at Bishop Pond in the Southern Piedmont, and two storm events occurred at two impoundments, Ponds A and C, in the Coastal Plain of Georgia (Jenkins et al., 2008, 2009, 2012). These storm events were monitored to characterize storm flow effects on transport and loads of fecal indicator bacteria, *Salmonella* and *E. coli* 0157:H7, and, as McKergow and Davies-Colley (2010) suggested, contrasted these storm events against base flow results. We tested the hypothesis that the influx of manure-borne bacteria into ponds under storm flow conditions would be attenuated resulting in a decreased flux of fecal bacteria in the pond's outflow.

2. Materials and methods

2.1. Study sites

Bishop Pond (Fig. 1) is located in the Southern Piedmont of Georgia, and has been described in detail (Jenkins et al., 2008). Briefly, it is approximately 1.6 ha. It is located in a 100 ha first-order watershed consisting of rotational grazing of around 200 head of pure bread Angus cattle (cows and calves) during each year in pastures W1 and W2 and other pastures east and west of the riparian zone, a cropped field, P1, that was amended with around 2100 kg ha^{-1} poultry litter in December of 2006 and 2007, and 2008, and a wooded riparian zone with wildlife from which cattle were excluded. A perennial first-order stream fed by a series of springs flows into and out of Bishop Pond which captures base and storm flow from approximately 60% of the 100-ha watershed. It has an approximate mean length of 235 m and mean width of 70.5 m. This is a ~3.3 length to width ratio that Van Buren et al. (1996) recommended as a minimum ratio for effective pond performance. In this case pond performance relates to how well the pond reduces agricultural pollutants; thus, a pond design of higher hydraulic efficiency (per Eq. (1)) is expected to perform better than one with less. The deepest part is about 4-m from permanent pool level and occupies an approximately 35 × 80 m area close to the outlet. The bed level then gradually rises toward the edges where it is about 0.4 m from permanent pool level. The pond holds approximately 24 ML at pool level.

Ponds A and C (Fig. 2) are located in the Coastal Plain of Georgia. They are in a sub-watershed of the Little River known as the University of Georgia Animal and Dairy Science Farm watershed (ADS watershed). Livestock in the 240 ha ADS watershed can include 100 head of beef cows and calves, which are pastured in the watershed year round. There is a 250-cow free stall dairy and dairy heifer and dry cow feeding and grazing area. Pond A is approximately 0.67 ha in area with length and width of approximately 90 and 75 m, respectively, giving it a 1.2 length to width ratio which is below the minimum ratio that Van Buren et al. (1996) recommended for effective pond performance. Approximately half the pond area centered near the downstream end is 1.0 to 1.3 m deep. The bottom