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Research article

Nutrient exports from watersheds with varying septic system densities in the North Carolina Piedmont

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A B S T R A C T

Septic systems (SSs) have been shown to be a significant source of nitrogen and phosphorus to nutrient-sensitive coastal surface and groundwaters. However, few published studies have quantified the effects of SSs on nutrient inputs to water supply watersheds in the Piedmont region of the USA. This region consists of rolling hills at the surface underlain by clayey soils. There are nearly 1 million SSs in this region, which accounts for approximately 50% of all SSs in North Carolina. The goal of this study was to determine if significant differences in nutrient concentrations and exports exist between Piedmont watersheds with different densities of SSs. Water quality was assessed in watersheds with SSs ($n = 11$) and a sewer and a forested watershed, which were designated as controls. Stream flow and environmental readings were recorded and water samples were collected from the watersheds from January 2015–December 2016. Additional samples were collected from sand filter watersheds in April 2015–March 2016 to compare to septic and control watersheds. Samples were analyzed for total dissolved nitrogen (TDN) and orthophosphate (PO_4-P). Results indicated that watersheds served by a high-density (HD) of SSs (4.9 kg-N yr^{-1} ha^{-1}; 0.2 kg-P yr^{-1} ha^{-1}) exported more than double the median masses of TDN and PO_4-P, respectively, relative to low-density (1.0 kg-N yr^{-1} ha^{-1}; <0.1 kg-P yr^{-1} ha^{-1}) and control watersheds (1.4 kg-N yr^{-1} ha^{-1}; <0.1 kg-P yr^{-1} ha^{-1}) during baseflow. Isotopic analysis indicated that wastewater was the most likely source of nitrate-N in HD watersheds. In all other watersheds, isotopic results suggested non-wastewater sources as the dominant nitrate-N provider. These findings indicated that SS density was a significant factor in the delivery of septic-derived nutrients to these nutrient-sensitive, water supply watersheds of the North Carolina Piedmont.

1. Introduction

1.1. Nutrient impacts on water quality

Many surface waters are susceptible to substantial inputs of nutrients from various land activities. Waters that are deemed as nutrient-sensitive are at risk of eutrophication, which can degrade water quality. These water quality issues translate directly into economic losses. Dodds et al. (2008) estimated that the total annual costs of eutrophication in freshwater of the United States were approximately $2.2 billion. Nutrients occur naturally, but human interactions with ecosystems can substantially increase nutrient availability (Vitousek et al., 1997). One potential source of nutrients to water resources is from wastewater exports from residential septic systems (SSs). A review by Lusk et al. (2017) showed that both nitrogen and phosphorus can degrade water quality down-gradient from SSs. Previous studies have shown SSs to be significant contributors of nitrogen (Buetow, 2002; Harman et al., 1996; Hoghooghi et al., 2016; Iverson et al., 2015; Pradhan et al., 2007; Robertson et al., 1998; Valiela et al., 1997) and phosphorus (Harman et al., 1996; Humphrey et al., 2015; Robertson et al., 1998)

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to receiving groundwaters and surface waters in coastal plain settings. Several studies have quantified watershed nutrient exports from wastewater sources in coastal settings (Humphrey et al., 2015; Iverson et al., 2015; Valiela et al., 1997), but few published studies have addressed exports from Piedmont watersheds (Line, 2013; Pradhan et al., 2007). Soils in coastal regions are generally coarser grained relative to Piedmont soils, which have greater clay content. Greater nutrient attenuation was observed in clayey soils relative to sandy soils by studies in the US (Karathanasis et al., 2006; Humphrey et al., 2015; Iverson et al., 2015), Ireland (Gill et al., 2007), Australia (Carroll et al., 2006) and Canada (Robertson, 2003).

1.2. Septic system nutrient contributions

In the Southern U.S., land use change is occurring most rapidly in the Piedmont region (Terando et al., 2014) to accommodate population growth, which in turn generates more wastewater. More research is needed to determine the relationship between SS density and nutrient mass export from southern Piedmont watersheds. Prior studies have estimated nutrient exports (primarily nitrogen) from watersheds (Table 1), but contributions from SSs were approximated or ignored (Groffman et al., 2004; NC DENR, 2009; Shields et al., 2008). Recently, D'Amato et al. (2016) recommended subwatershed assessments in the Piedmont (and other settings) to further understand spatial and temporal variations in nutrient contributions from SSs to water resources. Due to the heavy reliance of southern Piedmont cities, such as Atlanta, Raleigh, and Charlotte, on nutrient-sensitive surface water reservoirs, there is a growing need to better quantify nutrient sources to these important water supplies.

The attenuation of nutrients from septic-derived wastewater can be highly variable due to differences in SS density, soil type, water use, depth to water table, distance to the creek, condition of buffer, and age and presence of a biomat (D'Amato et al., 2016). Watersheds with a high density (HD) of SSs (henceforth referred to as HD watersheds) may input significant nutrients to receiving waters. Hoghooghi et al. (2016) found that baseflow concentrations of nitrogen in Georgia Piedmont streams increased proportionally with SS density when densities exceeded 100 systems km^{-2} (1 system ha^{-1}). In addition to density, the technology used or design of a SS can also influence delivery of nutrients to surface waters.

The most common SS design is the conventional system, which includes a septic tank, drainfield trenches filled with porous media, and aerobic soil beneath the trenches (Fig. 1). Effluent from the septic tank is piped to the drainfield trenches for temporary

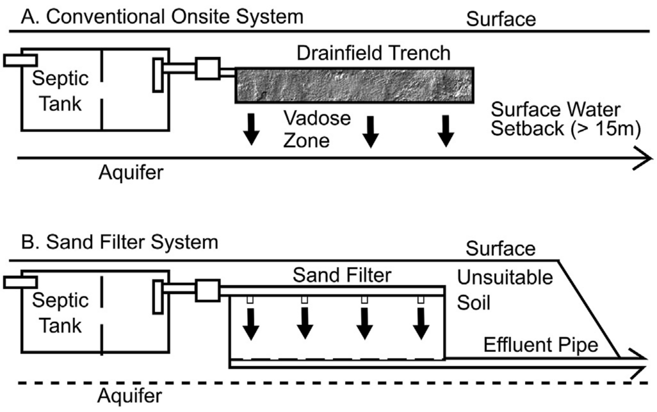

Fig. 1. Schematic design of a conventional onsite system (A), which uses gravity to infiltrate into native soils. The setback illustrated is based on a small residential system and a non-drinking water supply stream. B) shows a sand filter system which gravity drains effluent from the tank into a bed of sand with a pipe at the base of the filter to discharge treated effluent directly to an adjacent creek or conveyance ditch.

Table 1

Summary of findings by previous studies on total dissolved nitrogen and phosphate concentrations and exports from watersheds in the US and UK. Conc = concentration; Exp = export.

Reference	Study Region	Total Dissolved Nitrogen		Phosphate	
		Conc (mg L-1)	Exp (kg yr-1 ha-1)	Conc (mg L-1)	Exp (kg yr-1 ha-1)
Hoghooghi et al. (2016)	Georgia Piedmont				
Low-density septic		0.8–5.5	–	–	–
High-density septic		0.8–4.8	–	–	–
Iverson et al. (2015)	North Carolina Coastal Plain	0.8–2.8[a]	0.3–13	–	–
Humphrey et al. (2015)	North Carolina Coastal Plain	–	–	<0.00–0.07	<0.00–0.28
Ferrell and Grimes (2014)	North Carolina Piedmont	0.5–1.5	–	Below detection	–
Line (2013)	North Carolina Piedmont	0.1–13.9[a]	1.92–6.65[a]	<0.00–0.54	<0.00–0.14[b]
Lin and Li (2011)	North Carolina Piedmont	–	0.17–0.23	–	–
Withers et al. (2011)	Loddington, Leicestershire, UK				
Upstream of Septic		5.9 ± 4.1	14.07	0.04 ± 0.04	0.16
Downstream of Septic		6.7 ± 4.2	17.25	0.21 ± 0.34	0.26
NC DENR (2009)	North Carolina Piedmont	0.4–10	1.8–14.4	0.02–4.5[d]	0.2–1.3[d]
Shields et al. (2008)	Maryland Piedmont	–	6	–	–
Groffman et al. (2004)	Maryland Piedmont	–	4.5–7.2	–	–
Castro et al. (2003)	Various watersheds in USA[e]	–	11.7 (1.9–41.9)[f]	–	–
Oblinger et al. (2002)	North Carolina Piedmont				
Forested		<0.02–1.26	2.22	<0.01–0.12	0.08[c]
Mixed agricultural		<0.02–2.84	3.15–5.25	<0.01–0.12	0.16–0.52[c]
Mixed residential		<0.02–2.85	0.73–2.17	<0.01–0.76	0.27–0.81[c]
Nikolaidis et al. (1998)	Connecticut New England	2.91 ± 1.04	3.6 (nitrate)	0.03 ± 0.03[d]	–
Valiela et al. (1997)	Massachusetts Coastal Plain	–	2.20	–	–

[a] Reported as total nitrogen.

[b] Estimated based on data provided, Line (2013) did not report phosphate exports.

[c] Phosphate loads were not reported, estimated loads based on % PO_4 of total phosphorus.

[d] Reported as total dissolved phosphorus.

[e] Casco Bay, ME; Great Bay, NH; Merrimack River, MA; Massachusetts Bay, MA; Buzzards Bay, MA; Narragansett Bay, RI; Long Island Sound, CT; Hudson River-Raritan Bay, NY; Delaware Bay, DE; Charleston Harbor, SC; Terrebonne-Timbalier Bays, LA.

[f] Exports to estuaries from human sewage (septic + sewer) sources.