Nitrogen treatment efficiency of five onsite wastewater systems in the Falls Lake Watershed, North Carolina

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Abstract

Onsite wastewater treatment systems (OWTSs) are commonly used in rural areas for treatment and dispersal of residential wastewater. Nitrogen from OWTSs not reduced in the drainfield can leach into the groundwater and/or be discharged to surface waters posing environmental and public health concerns. The goal of this study was to evaluate nitrogen reduction in conventional-style and alternative (e.g., bed and single-pass sand filter) OWTSs. Five, volunteered sites with OWTSs in the Falls Lake Watershed, North Carolina, were identified for evaluation. Piezometers were installed near (< 1 m) the drainfields of 4 sites, and 2 sites had additional piezometers installed downgradient (> 6 m) from OWTSs. One site used a single-pass sand filter system where samples were collected from the tank and effluent discharge pipe. Samples were collected at least once each season and 5 to 6 times for each site. Samples were analyzed for total dissolved nitrogen (TDN), chloride (Cl), and physicochemical parameters. TDN/Cl ratios were used to estimate mass reductions. Wastewater contained the highest concentrations of TDN with a median of 75.15 mg L^{-1}. Median concentrations of TDN decreased by an order of magnitude within groundwater beneath drainfields (6.33 mg L^{-1}) and downgradient of the systems (3.68 mg L^{-1}), respectively. Concentration and mass reductions between tanks and groundwater beneath drainfields ranged from 63.8% - 94.7% and 18.1% - 92.2%, respectively. Concentration and mass reductions between tanks and groundwater downgradient from OWTSs ranged from 79.6 – 97.3% and 53.4 – 74.4%, respectively. Findings from this study may assist in policy development for management strategies of nitrogen in the Falls Lake Watershed.

Introduction

Why should we study septic-derived nutrients in Falls Lake?

- Falls Lake is listed as impaired on the North Carolina 303(d) list for exceeding chlorophyll a standards because of elevated nutrient inputs
- Septic systems can be a significant source of nutrients to surface and ground waters (Humphrey et al. 2010; O'Driscoll et al. 2014; Withers et al., 2014; Iverson et al., 2015; D'Amato et al. 2016; Lusk et al. 2017)
- There are approximately 50,000 septic systems in the Falls Lake Watershed and more information is needed on nitrogen attenuation at the system and landscape scale to better understanding of septic-derived nutrient transport to Falls Lake

The goal of this study was to evaluate nitrogen reduction in conventional-style and alternative (e.g., bed and single-pass sand filter) septic systems.

Materials and Methods

Site Selection and Instrumentation

- 5 volunteer sites within Triassic Basin of Falls Lake Watershed (Fig. 1)
- 4 sites served by conventional septic and 1 served by a sand filter
- Piezometers installed within 1 m of drainfield for conventional septic sites
- Sites 100 and 200 have downgradient piezometers *ca.* 24 m and 7 m, respectively

Sampling Protocols and Laboratory Analysis

- Depth to water was measured using a *Solinst* temperature, level, conductivity meter and piezometers were purged 2 bailer full volumes before sampling.
- Water samples were collected 5 times at least 1 sample per season from septic tanks (wastewater), piezometers (groundwater), and the sand filter's effluent pipe
- Physicochemical parameters (pH, temperature, specific conductance, dissolved oxygen, and oxidation-reduction potential) was measured in-field with a *Hanna Instruments 9289* multiprobe meter.
- Samples were transported on ice back to ECU's Environmental Research Laboratory for nitrogen analysis
- A *Shimadzu* TOC-TN analyzer was used for total dissolved nitrogen (TDN) enumeration and a *SmartChem* 170/200 discrete autoanalyzer was used for chloride

Statistical Analysis

- Treatment efficiency was calculated via percent reduction equation
- TDN/Cl ratios were used to estimate mass reductions
- Statistical analysis and figure develop was conducted in the R statistical framework

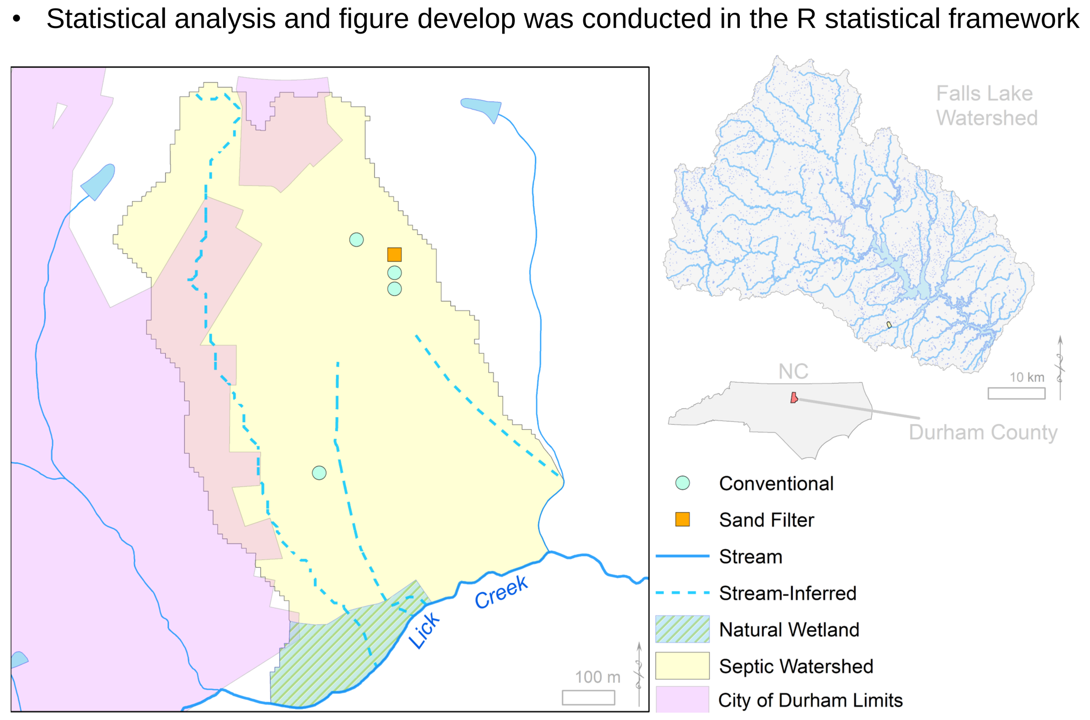

Figure 1. A) Watershed boundary map and location of in-stream bioreactor (IBR). B) Woodchip media; C) *Stalite* media.

Results & Discussion

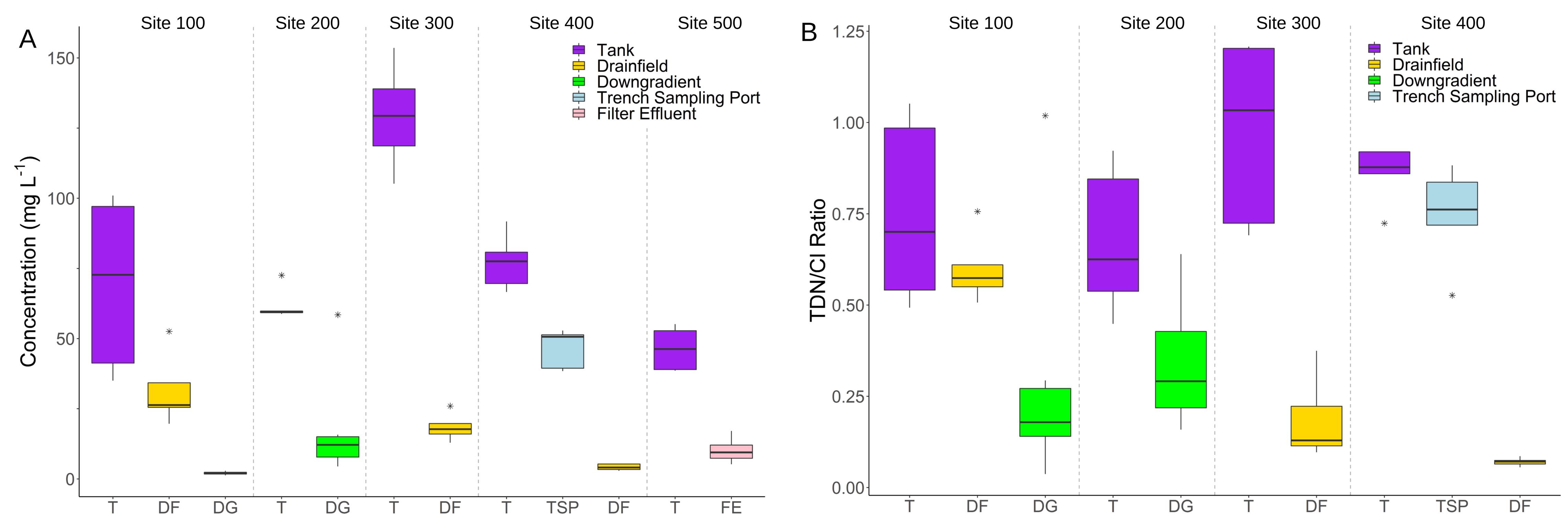

Figure 2. Boxplot of total dissolved nitrogen concentrations (TDN) (A) and the TDN-to-chloride (Cl) ratios (B) for samples collected from septic tanks (T), drainfield (DF) piezometers, downgradient (DG) piezometers, DF trench sampling port (TSP), and sand filter effluent (FE).

Figure 3. Photos of the site instrumentation process depicting augering boreholes, constructing piezometers, characterizing soil profiles, and collecting physicochemical parameters and water samples.

Table 1. Mean (standard deviation) of physicochemical parameters from all sampling locations. DTW= depth to water; Temp= temperature; SC= specific conductance; DO= dissolved oxygen; ORP= oxidational-reduction potential; Cl= chloride; T= tank; TSP= trench sampling port; FE= filter effluent; SF= sand filter.

Site	Identifier	DTW (ft)	Temp (°C)	SC (µS cm^{-1})	DO (mg L^{-1})	pH	ORP (mv)	Cl (mg L^{-1})
100-T	Wastewater		16.0 (8.9)	1604.4 (1064.1)	1.87 (1.47)	6.94 (1.33)	-119.7 (117.9)	86.3 (13.0)
101	Drainfield	5.50 (1.68)	16.9 (6.3)	851.8 (481.7)	4.00 (0.51)	5.92 (0.99)	211.3 (191.0)	49.9 (12.5)
103	Downgradient	0.24 (0.35)	16.6 (5.3)	167.0 (82.4)	2.26 (1.06)	5.59 (0.44)	63.0 (148.6)	15.9 (22.2)
104	Downgradient	0.48 (2.00)	16.1 (8.6)	250.0 (162.2)	3.12 (1.45)	5.19 (0.30)	129.1 (167.4)	10.6 (2.6)
200-T	Wastewater		17.0 (4.76)	1916.0 (429.0)	1.68 (0.85)	7.01 (0.20)	-196.0 (99.0)	97.7 (30.7)
201	Drainfield	2.18 (0.14)	16.6 (4.89)	604.4 (137.8)	2.45 (1.06)	6.26 (0.21)	4.5 (99.3)	11.5 (2.2)
202	Drainfield	1.81 (0.23)	16.0 (5.28)	550.6 (179.4)	3.16 (0.82)	6.15 (0.10)	45.5 (85.7)	32.6 (7.9)
203	Downgradient	1.91 (0.62)	14.8 (4.98)	718.0 (328.7)	3.30 (1.02)	6.07 (0.36)	71.1 (85.7)	50.4 (24.2)
204	Downgradient	2.49 (0.40)	14.8 (4.54)	401.0 (168.3)	3.26 (1.35)	5.61 (0.24)	96.3 (97.5)	27.0 (5.1)
300-T	Wastewater		18.2 (2.07)	2591.8 (570.0)	1.49 (1.07)	6.81 (0.15)	-200.3 (51.6)	137.3 (37.7)
301	Drainfield	2.95 (0.59)	16.2 (4.13)	1100.4 (305.2)	3.18 (0.67)	3.82 (0.67)	164.2 (67.8)	112.9 (45.3)
400-T	Wastewater		15.3 (3.99)	1872.2 (419.2)	1.40 (0.42)	7.28 (0.11)	-219.8 (55.3)	86.5 (18.0)
400-TSP	Wastewater in Trench	2.02 (0.11)	15.1 (4.35)	1340.0 (412.6)	1.92 (0.95)	6.58 (0.23)	-121.2 (58.0)	62.2 (7.4)
401	Drainfield	4.03 (0.68)	15.3 (3.62)	344.6 (118.0)	3.36 (2.12)	4.20 (0.25)	111.2 (101.3)	48.3 (10.3)
500-T	Wastewater		19.1 (3.12)	1025.8 (250.1)	1.60 (0.82)	6.43 (0.32)	-178.2 (61.6)	34.8 (7.6)
500-FE	SF Effluent		15.2 (5.04)	364.8 (142.8)	3.40 (1.84)	6.08 (0.37)	6.2 (97.9)	13.4 (4.2)

Table 2. Median concentrations (Conc) of total dissolved nitrogen and the concentration reduction from each site.

Site	Median Conc (mg L^{-1})			Conc Reduction (%)	
	Tank	DF/FE	DG	Tank-DF/FE	Tank-DG
100	72.75	26.32	1.96	63.8%	97.3%
200	59.40	4.00	12.13	93.3%	79.6%
300	129.40	17.76		86.3%	
400	77.54	4.10		94.7%	
500	46.31	9.49		79.5%	

Table 3. Median total dissolved nitrogen (TDN) to chloride (Cl) ratio and estimated mass reduction from each site. Percent difference in TDN/Cl were assumed to be mass reduction. Site 500 mass reduction assumed to be the same for filter effluent. Site 500 sand filter uses chlorination, thus cannot use TDN/Cl.

Site	Median TDN/Cl Ratio			Mass Reduction (%)	
	Tank	DF/FE	DG	Tank-DF/FE	Tank-DG
100	0.70	0.57	0.18	18.1%	74.4%
200	0.63	0.21	0.29	66.0%	53.4%
300	0.97	0.13		86.7%	
400	0.91	0.07		92.2%	
500				79.5%	

TDN Treatment in Conventional and Sand Filter Systems

- Conventional style septic systems contained a median TDN concentration of 75.15 (35.03 – 153.60) mg L^{-1}
- Groundwater beneath drainfields contained median TDN concentrations an order of magnitude lower than tanks (median: 6.33 [2.50 – 52.55] mg L^{-1})
- Groundwater downgradient of conventional systems was an order of magnitude lower than tanks (median: 3.68 [1.29 – 58.50] mg L^{-1})
- Median TDN in groundwater beneath drainfields was approximately double that of groundwater downgradient of septic systems ($p= 0.034$).
- Differences between wastewater TDN and groundwater TDN were statistically significant ($p< 0.001$)
- The sand filter system contained a median TDN of 46.31 (38.58 – 55.17) mg L^{-1} in the septic tank, which was *ca.* 5 times greater than filter effluent ($p= 0.008$)
- Conventional style septic systems reduced TDN concentrations by *ca.* 64% - 95% between the septic tank and drainfield and 80 – 97% between the septic tank and downgradient piezometers (site 100: *ca*. 24 m and site 200: *ca*. 7 m downgradient)
- The single pass sand filter system reduced concentrations by 79.5%
- Mass reductions by conventional systems ranged from 18.1% - 92.2%, with site 400 having the greatest estimated percentage.
- TDN/Cl ratio data suggest that most of the TDN reduction was due to nitrogen removal (e.g., denitrification, plant uptake, microbial uptake)

Conclusions

- Median TDN concentrations in groundwater and sand filter effluent were significantly lower after onsite wastewater treatment
- Concentration and mass reductions were efficient suggesting that only a fraction of septic-derived nitrogen may reach surface waters
- However, median concentrations in groundwater downgradient of septic systems and in sand filter effluent were elevated enough to contribute to eutrophication issues without sufficient treatment in riparian buffers and/or in-stream before reaching Falls Lake, which should be considered for future work
- Additional research needs include quantifying the treatment efficacy of septic systems in other geologic settings in Falls Lake.

Acknowledgments & References

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