Paired Watershed and Onsite Monitoring Approaches to Quantify the Influence of Onsite Wastewater Treatment Systems on Nutrient Loading to Tributaries to Falls Lake, NC

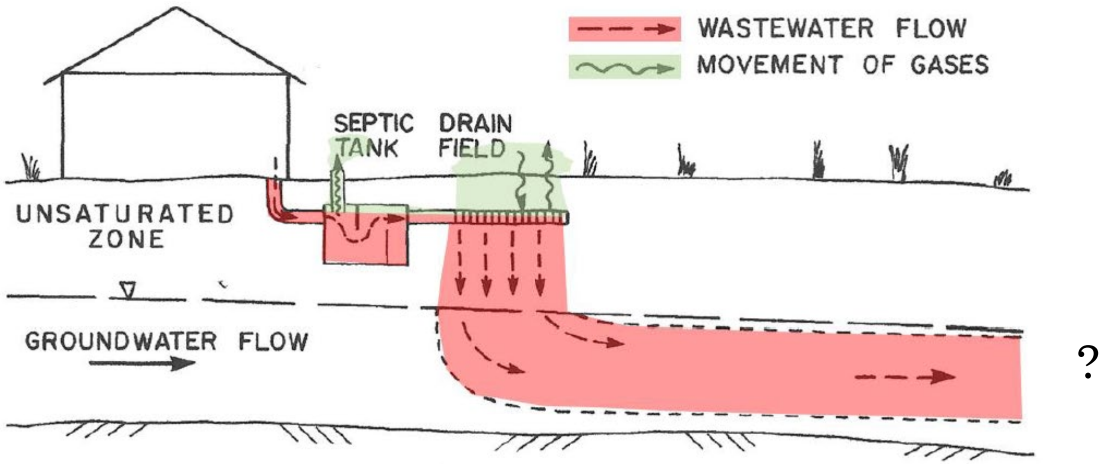
Michael O'Driscoll, ECU Coastal Studies/ Water Resources Center (odriscollm@ecu.edu)
Charles Humphrey, Guy Iverson, Jordan Jernigan, ECU Health and Human Performance
Natasha Bell, ECU Engineering/ Water Resources Center
John Hoben, ECU Biology/ Water Resources Center
Jennifer Richardson, ECU Geol. Sciences
Ann Marie Lindley, ECU Geol. Sciences

Introduction

- In North Carolina, excess chlorophyll-a and nutrients are cited as the top reasons for lake impairment (US EPA 2021).

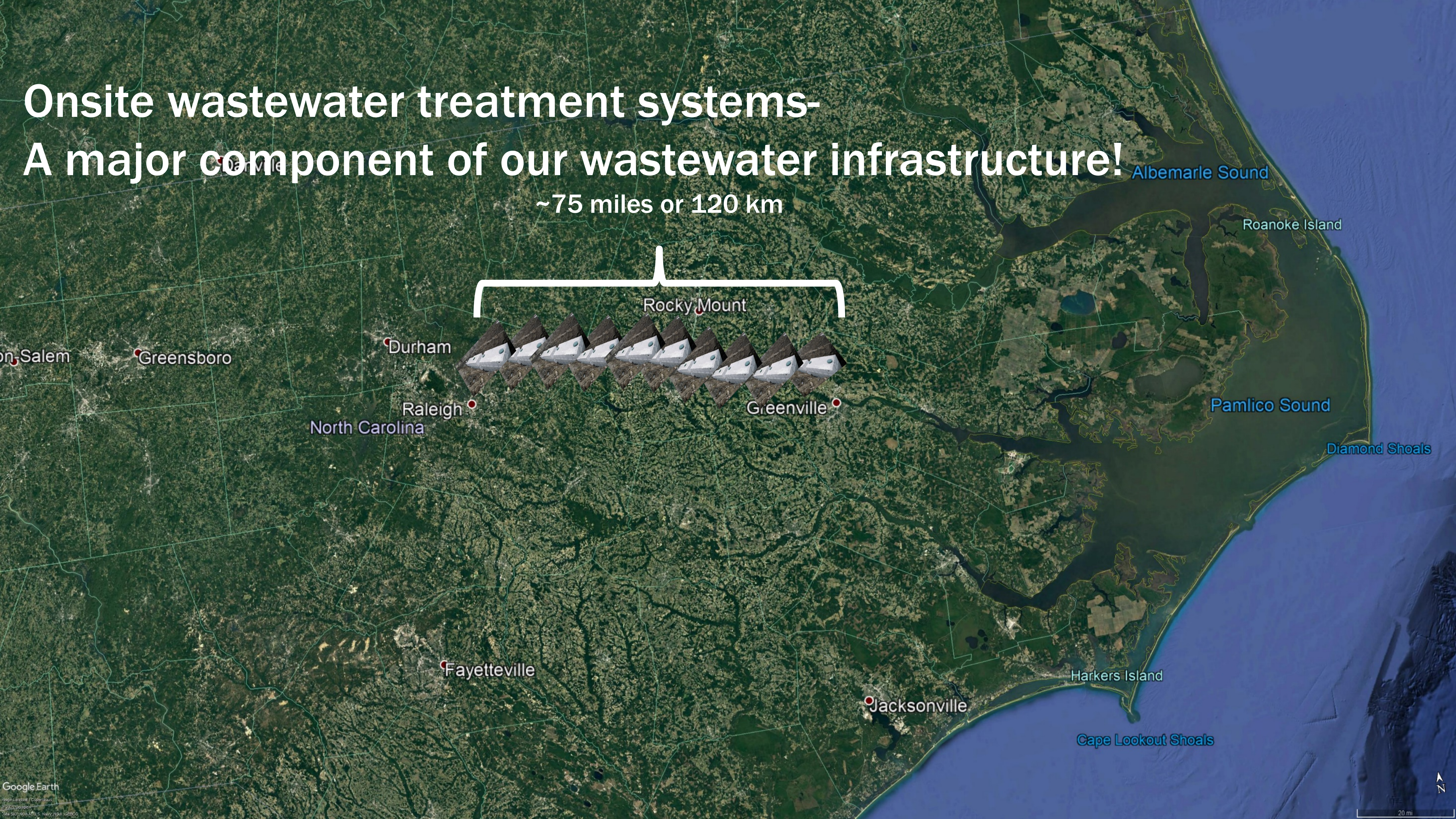
- Onsite wastewater treatment systems (OWTS) are often cited as an important source of nutrient loading to surface waters; however, there are limited quantitative studies.

- Estimating OWTS nutrient inputs at the watershed-scale is challenging due to the diffuse nature of this nonpoint source, the lack of OWTS monitoring data, and the complexity of nutrient transport in the environment.



Robertson 2021

Onsite wastewater treatment systems-
A major component of our wastewater infrastructure!

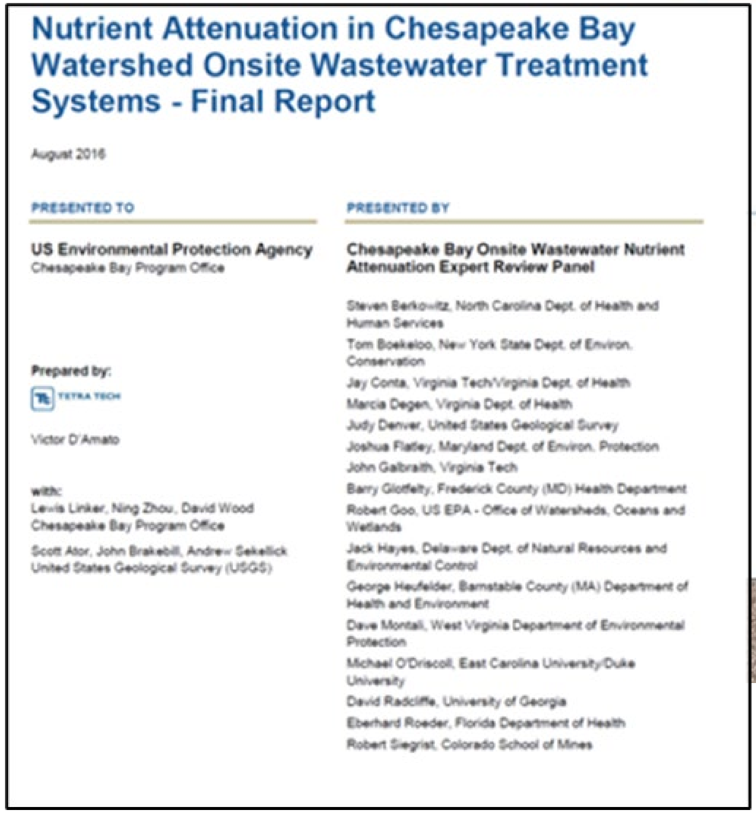


OWTS N Treatment- Mostly Occurs in the Soil Treatment Zone

- WW TDN- this study (5 sites)

Median TDN: 46 mg/l -129 mg/l

D'Amato et al. 2016



Nutrient Attenuation in Chesapeake Bay Watershed Onsite Wastewater Treatment Systems - Final Report

August 2016

PRESENTED TO

US Environmental Protection Agency
Chesapeake Bay Program Office

Prepared by:

TETRA TECH

Victor D'Amato

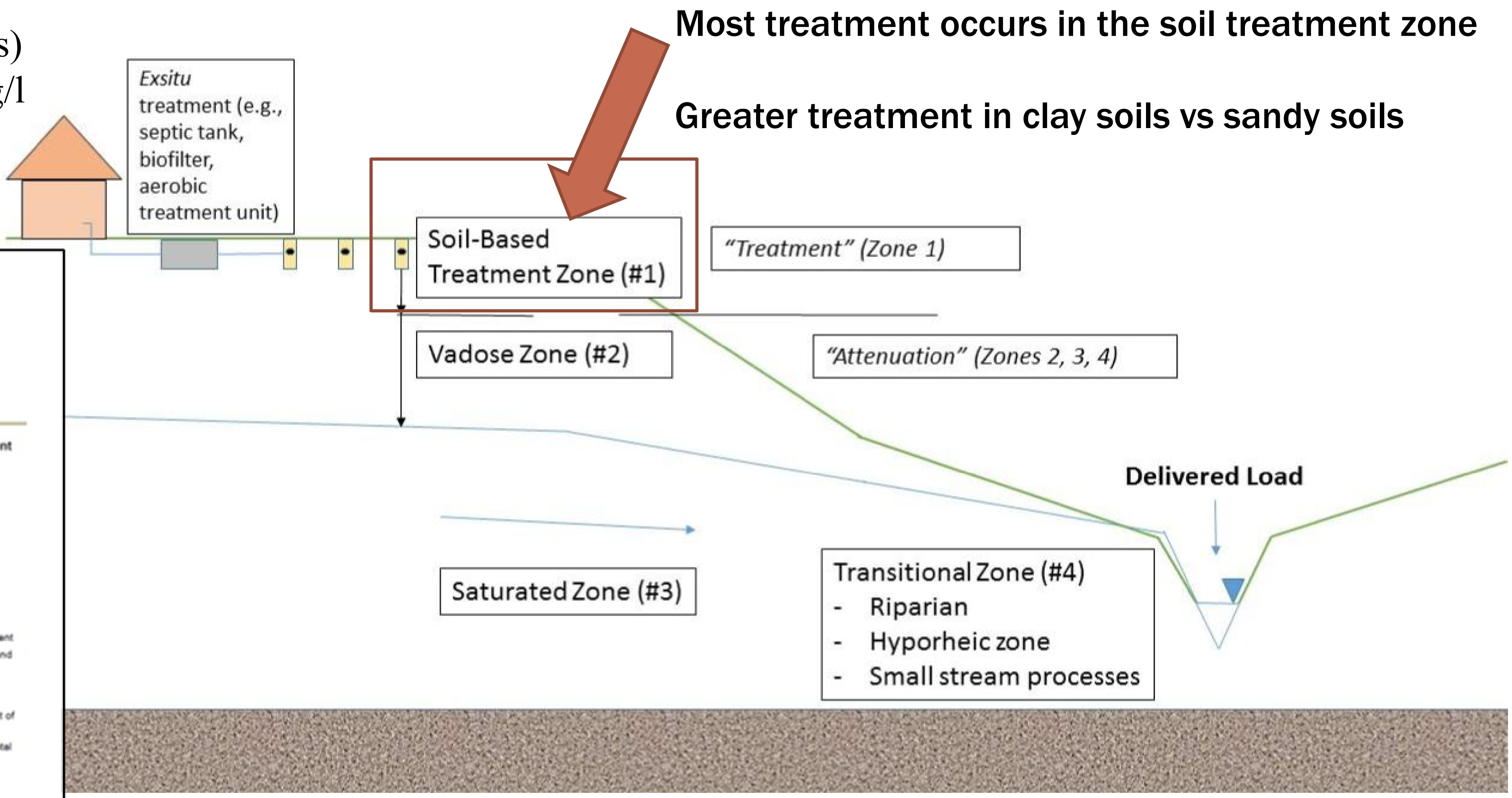
with:
Lewis Linker, Ning Zhou, David Wood
Chesapeake Bay Program Office

Scott Ator, John Brakebill, Andrew Sekellick
United States Geological Survey (USGS)

PRESENTED BY

Chesapeake Bay Onsite Wastewater Nutrient Attenuation Expert Review Panel

Steven Berkowitz, North Carolina Dept. of Health and Human Services
Tom Boekeloo, New York State Dept. of Environ. Conservation
Jay Conta, Virginia Tech/Virginia Dept. of Health
Marcia Degen, Virginia Dept. of Health
Judy Denver, United States Geological Survey
Joshua Flatley, Maryland Dept. of Environ. Protection
John Galbraith, Virginia Tech
Barry Glotfelty, Frederick County (MD) Health Department
Robert Goo, US EPA - Office of Watersheds, Oceans and Wetlands
Jack Hayes, Delaware Dept. of Natural Resources and Environmental Control
George Heufelder, Barnstable County (MA) Department of Health and Environment
Dave Montali, West Virginia Department of Environmental Protection
Michael O'Driscoll, East Carolina University/Duke University
David Radcliffe, University of Georgia
Eberhard Roeder, Florida Department of Health
Robert Siegrist, Colorado School of Mines



STUDY APPROACH

NC DEQ Project Contract Number:

DEQ Task Order No. 8193

Project Title:

A Paired-Watershed Approach to Evaluate the Influence of Onsite Wastewater Nutrient Inputs to Falls Lake, NC

FINAL REPORT

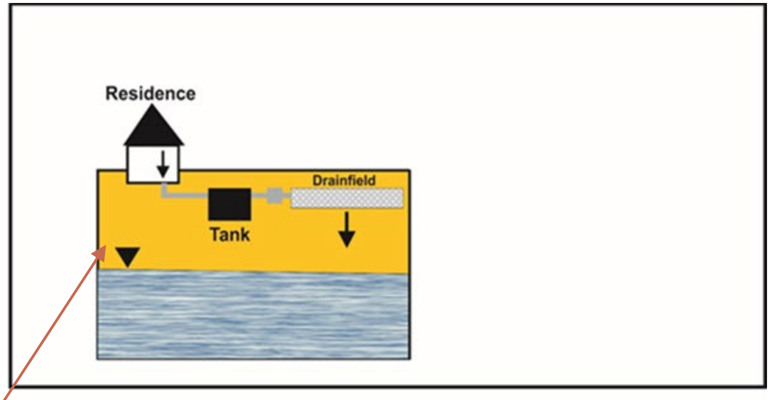
Submitted by:

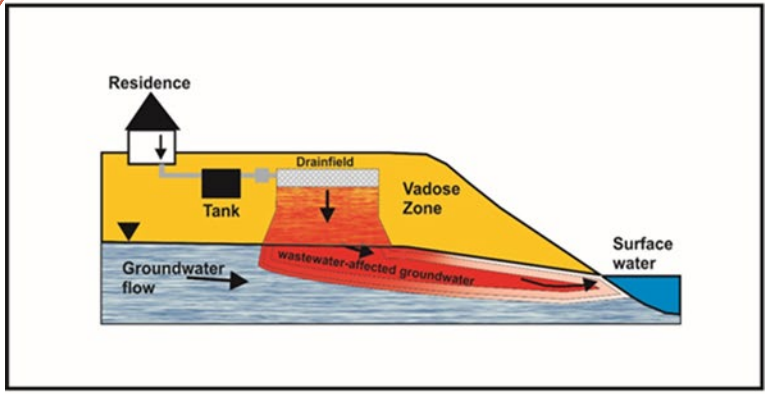
Michael O'Driscoll, Charles Humphrey, Guy Iverson, John Hoben, Natasha Bell, Jennifer Richardson, Ann Marie Lindley, and Jordan Jernigan

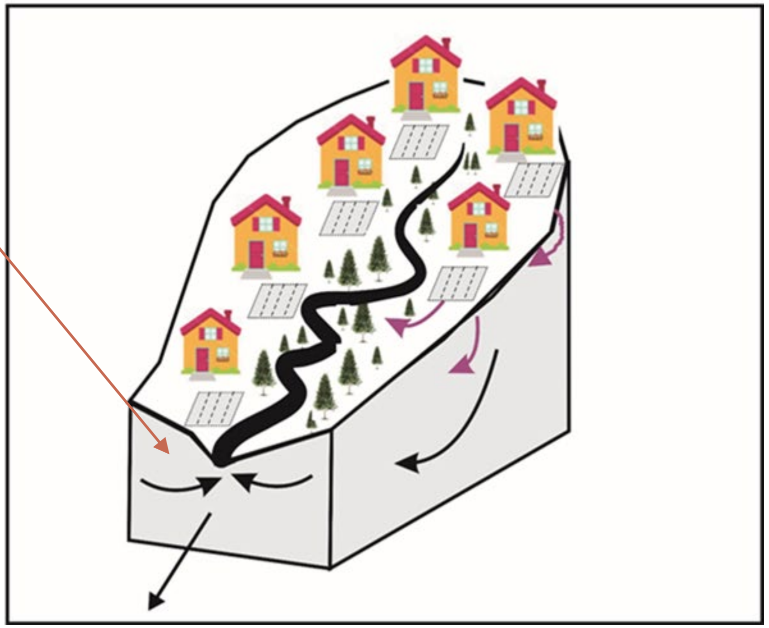
East Carolina University

Period of the Project:07/07/2020-08/31/2021

- Evaluate OWTS nutrient loading and attenuation at the site scale (5 sites)
- Evaluate cumulative nutrient loading to streams and attenuation at the sub-watershed scale (28 stream sites: 22 served by septic systems, 6 sewered for comparison)
- Is there evidence that onsite wastewater treatment systems contribute nutrients to tributary streams that drain to Falls Lake?
- If so, how much and where?







SURFACE WATER MONITORING SITES

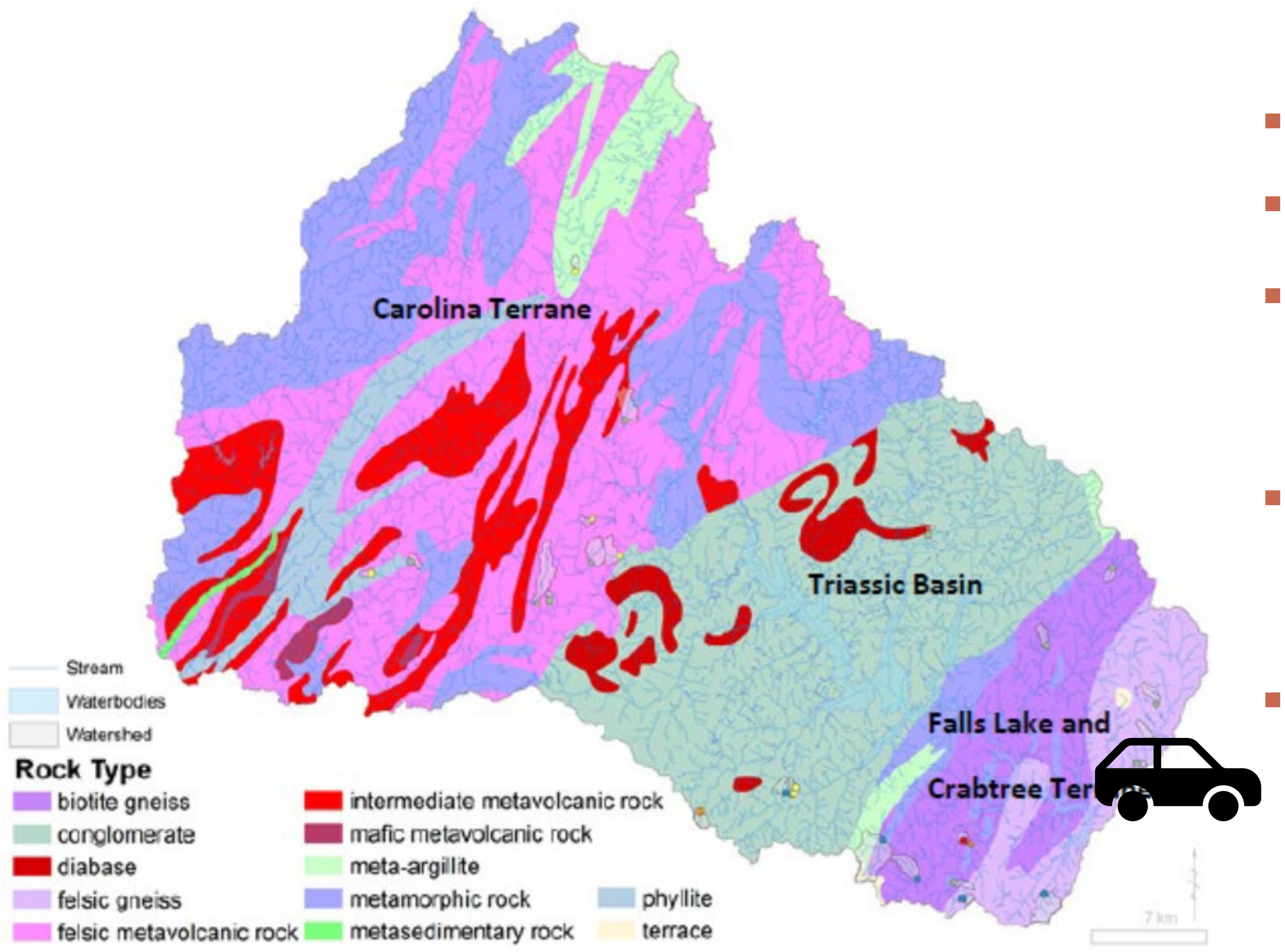
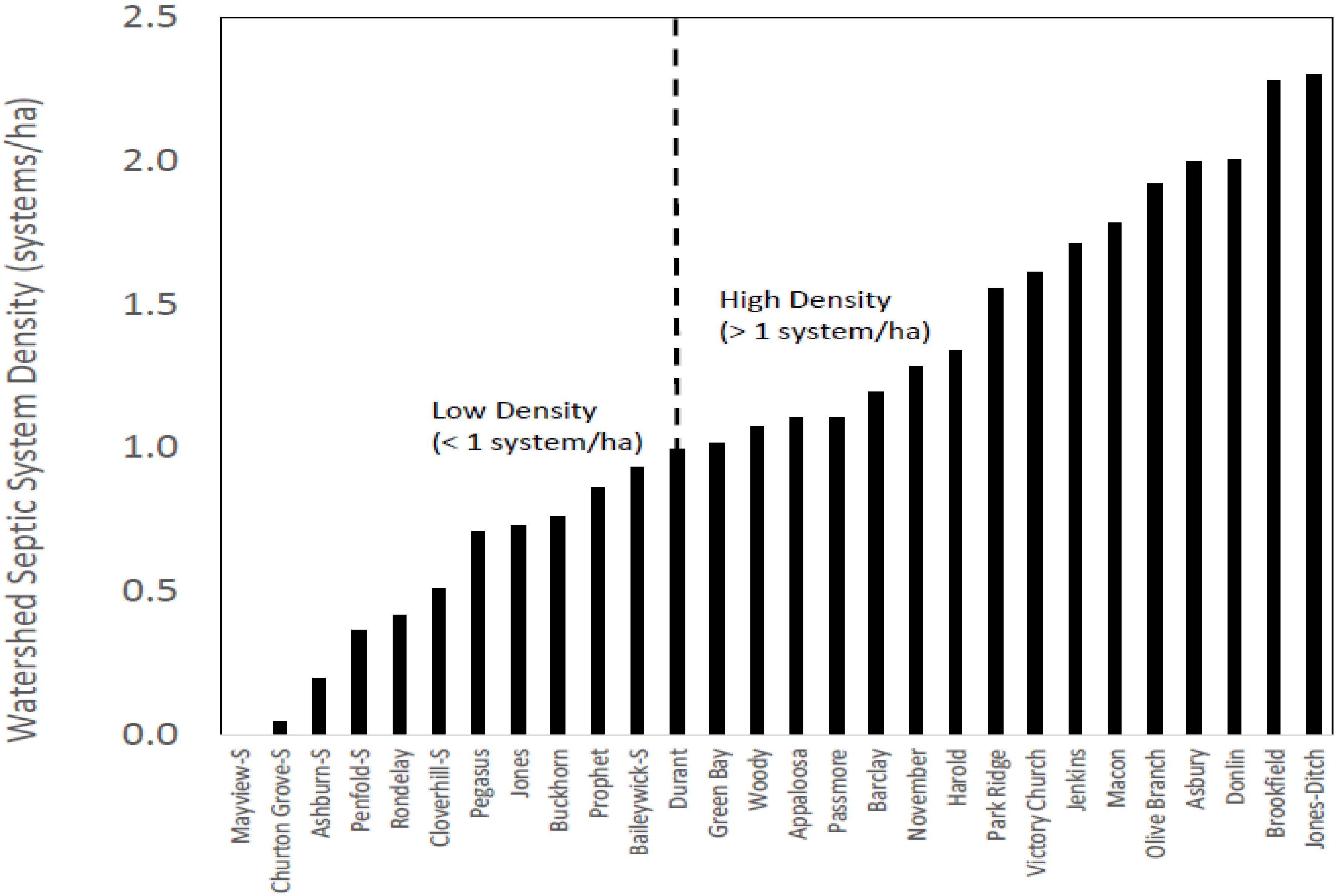
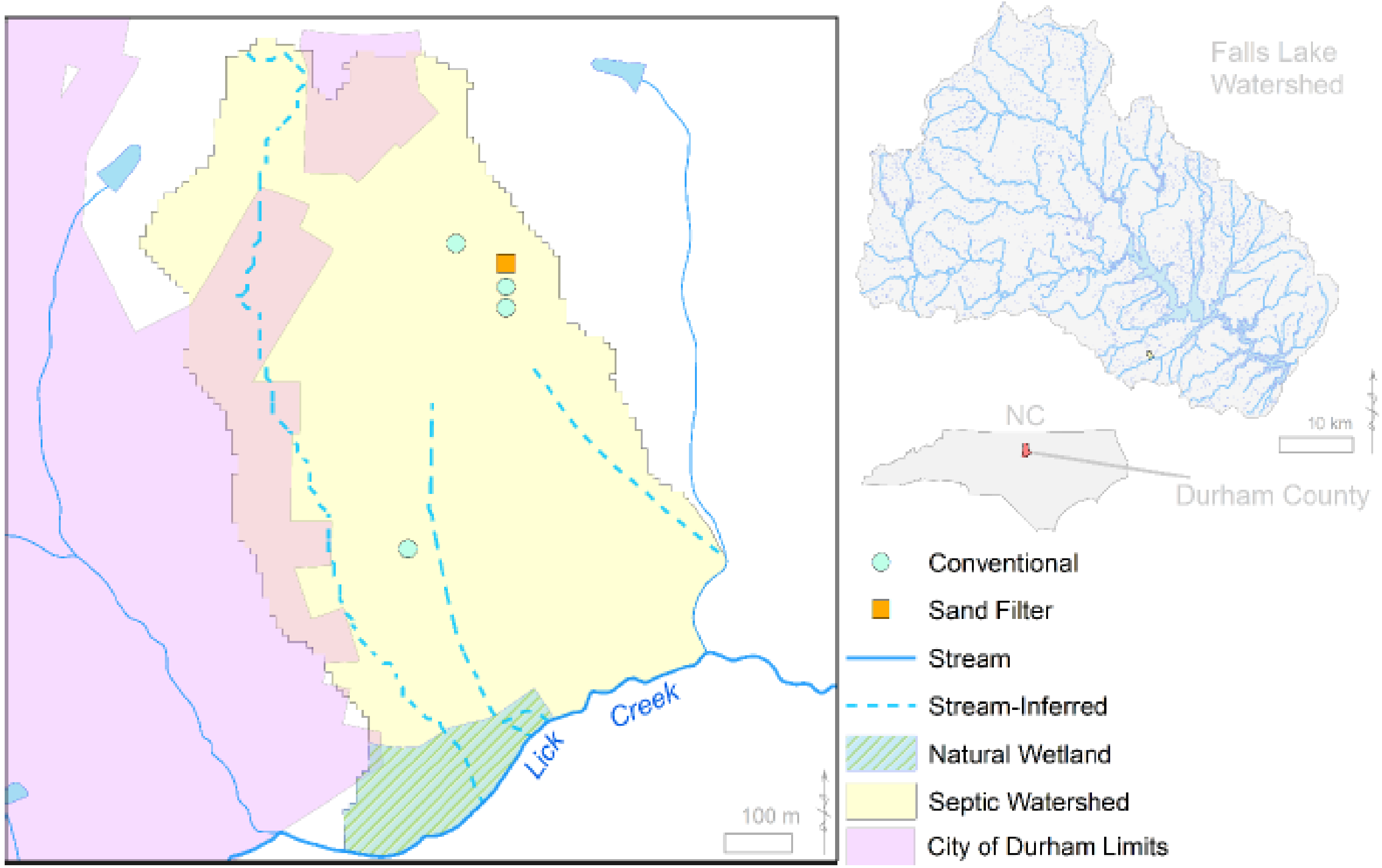


Figure 4. Falls Lake geology.

SURFACE WATER SITES- SELECTED ACROSS A GRADIENT OF SEPTIC SYSTEM DENSITY



GROUNDWATER AND WASTEWATER MONITORING SITES



Groundwater and wastewater sampling locations within the Lick Creek watershed of Falls Lake. 4 conventional OWTS and 1 sand filter system were monitored.

- GW and WW monitoring at 5 sites (bi-monthly, Sept. 2020-Aug. 2021) to quantify nutrient treatment at individual system and lot-scale (4 conventional, 1 sand filter)
- Data can help quantify onsite wastewater nutrient attenuation at the system and landscape-scales
- Effort led by Charlie Humphrey, Guy Iverson, and Jordan Jernigan

Site 100
Type: Conventional
Age: 52 years
Occupants: 1
Trench Depth: 3.3 ft
Avg GW Depth: 5.5 ft

Site 100

Site 200

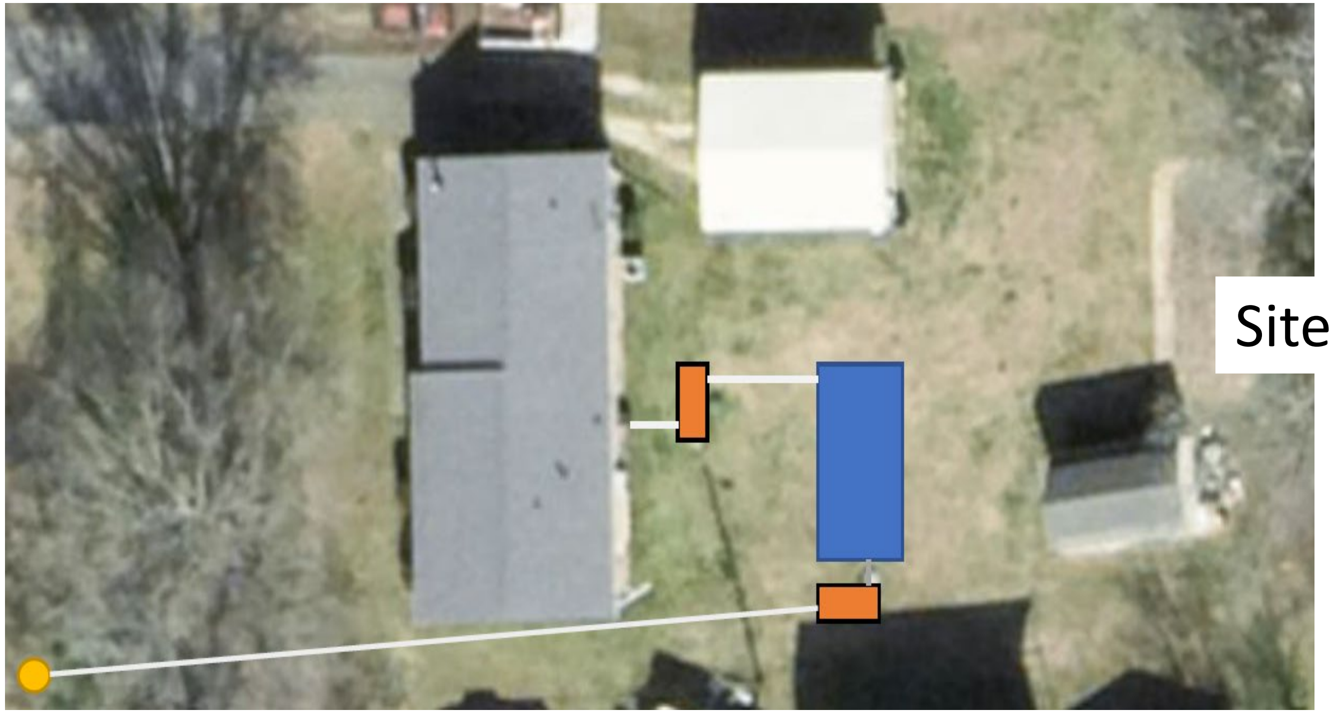
Site 200
Type: Chamber
Age: 4 years
Occupants: 2
Trench Depth: 1.7 ft
Avg GW Depth: 2.2

Site 300

Site 300
Type: Conventional
Age: 53 years
Occupants: 6
Trench Depth: 2.0 ft
Avg GW Depth: 3.0 ft

Site 400

Site 400
Type: Conventional
Age: 2 years
Occupants: 1
Trench Depth: 2.3 ft
Avg GW Depth: 4.0 ft



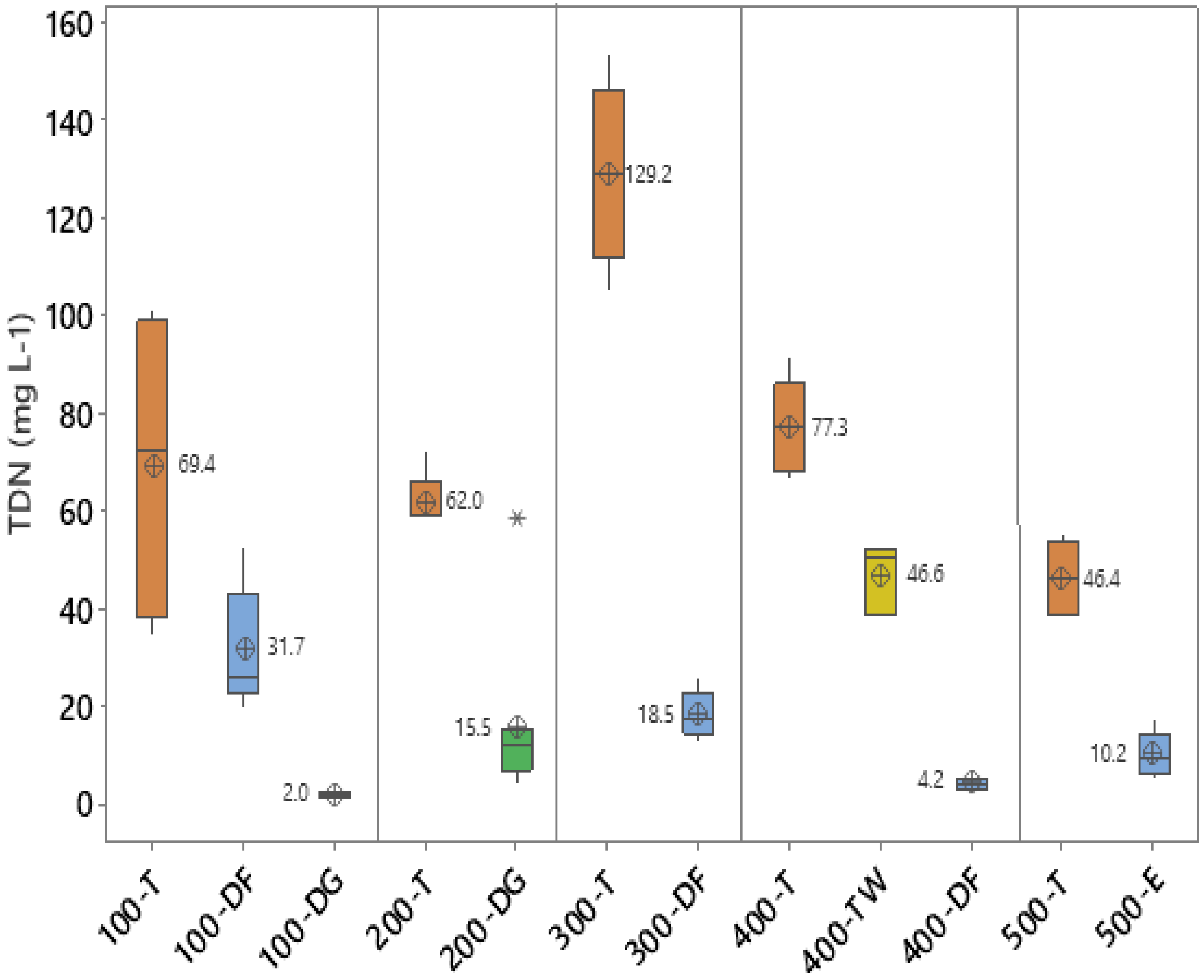
Site 500

Type: Sand filter
Age: ~14 years
Occupants: 2
Discharges to road ditch

WATER QUALITY ANALYSES AND CHARACTERIZATION

- Wastewater and groundwater/filter effluent collected 5 times and at least once each season (2020-2021)
  - Nutrient analyses: TDN, NO_3, NH_4,DOC, Cl, TDP, PO_4
  - Physicochemical analyses: pH, dissolved oxygen, specific conductance, temperature, oxidation reduction potential, depth to water
- Treatment efficiencies calculated using differences in concentrations between wastewater and groundwater, and differences in nutrient to chloride ratios

TDN CONCENTRATION REDUCTIONS



Site 100

Tank - DF: 54% TDN reduction

Tank – DG (80 ft): 97%

Site 200

Tank - DG (23 ft): 75% TDN reduction

Site 300

Tank - DF: 86% TDN reduction

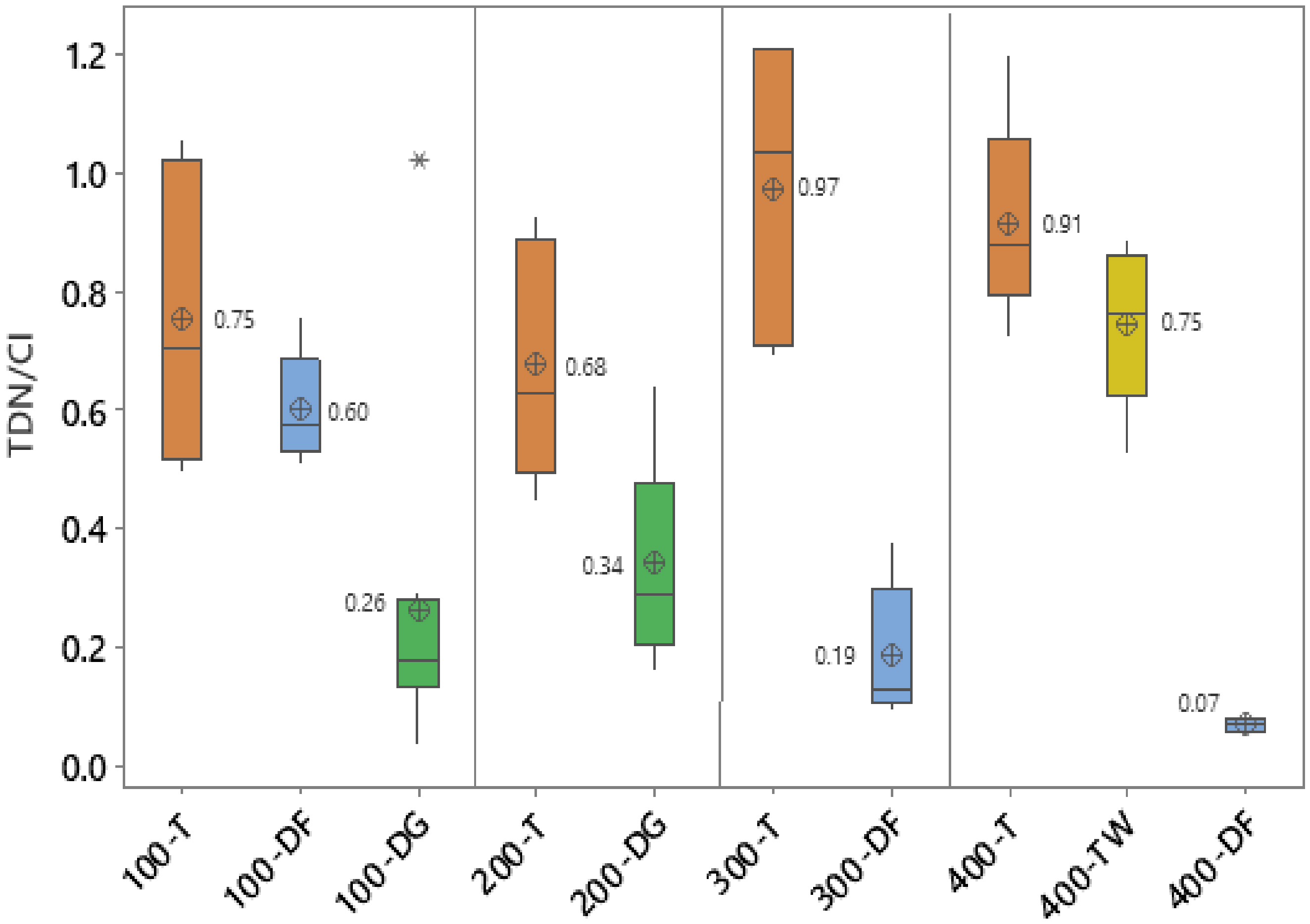
Site 400

Tank - DF: 95% TDN Reduction

Site 500

Tank - Effluent: 78% TDN Reduction

TDN MASS REMOVAL



Site 100

Tank - DF: 26% TDN reduction

Tank – DG (80 ft): 65%

Site 200

Tank - DG (23 ft): 50% TDN reduction

Site 300

Tank - DF: 81% TDN reduction

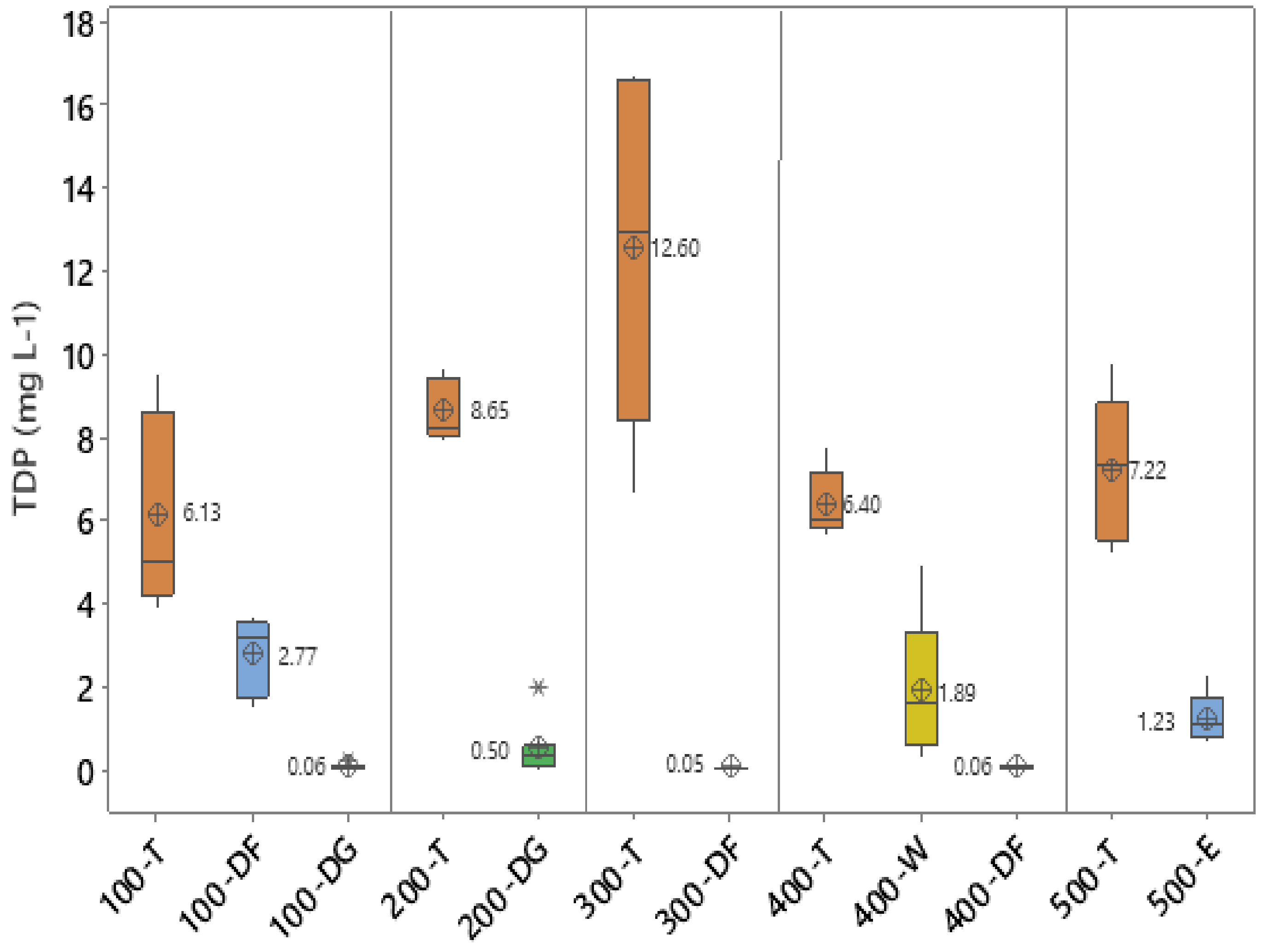
Site 400

Tank - DF: 92% TDN Reduction

Site 500

78% TDN Reduction

TDP CONCENTRATION REDUCTIONS



Site 100

Tank - DF: 55% TDP reduction

Tank – DG (80 ft): 99%

Site 200

Tank - DG (23 ft): 97% TDP reduction

Site 300

Tank - DF: > 99 % TDP reduction

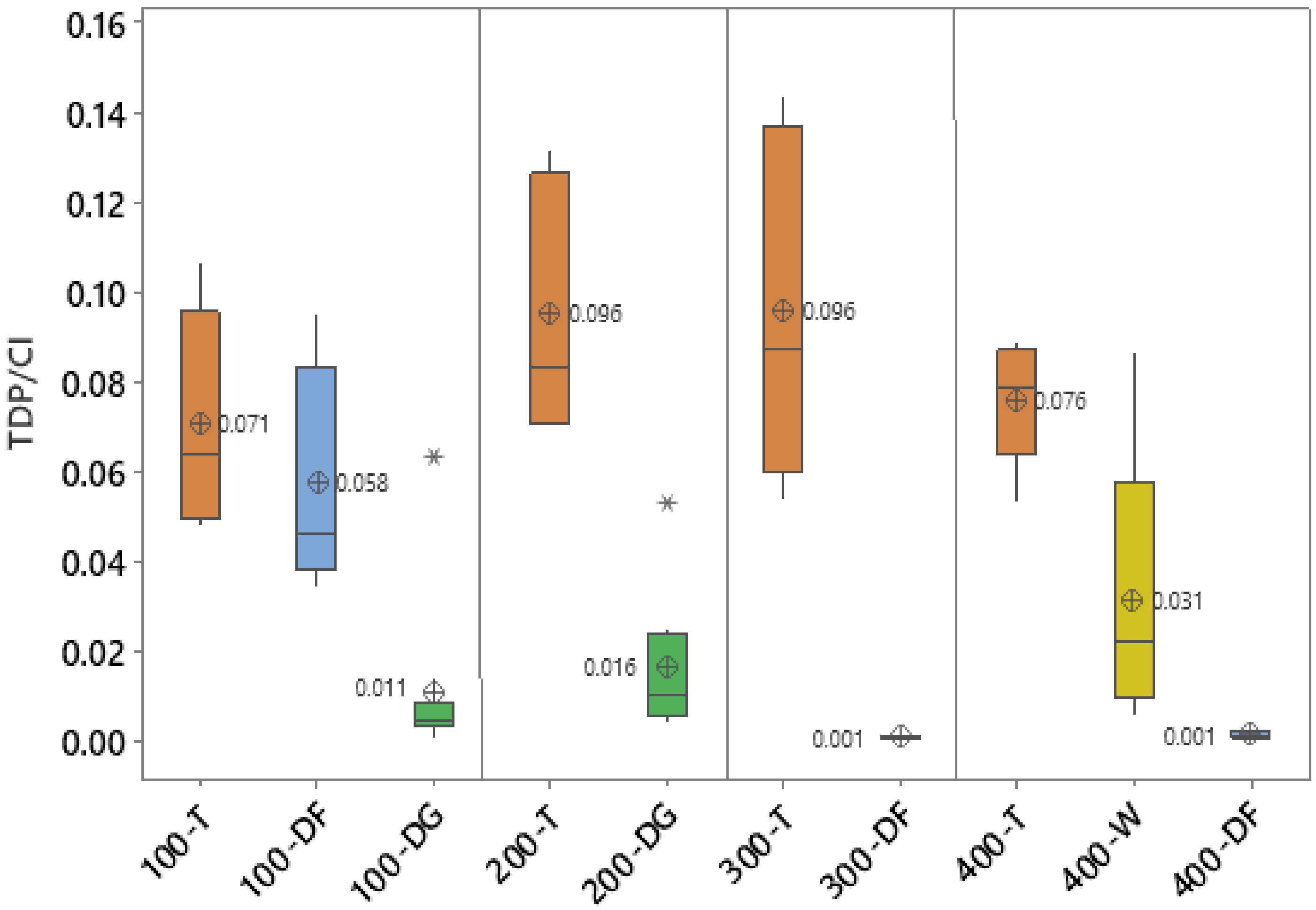
Site 400

Tank - DF: 99% TDP Reduction

Site 500

Tank - Effluent: 83% TDP Reduction

TDP MASS REMOVAL



Site 100

Tank - DF: 18% TDP reduction

Tank – DG (80 ft): 85%

Site 200

Tank - DG (23 ft): 91% TDP reduction

Site 300

Tank - DF: > 99% TDP reduction

Site 400

Tank - DF: 99% TDP Reduction

Site 500

83% TDP Reduction

SITE SUMMARY

- 77% average TDN concentration reductions Tank - DF; range of 54 to 95%
- 61% average TDN mass removal Tank - DF; range of 26 and 92%
  - Bradshaw and Radcliffe 2013 (avg 61% mass removal of TDN in Cecil soil of Georgia)
  - Humphrey et al 2016a (avg 61% mass removal of TDN in Cecil and Georgeville soils in NC)
- 87% average TDP concentration reductions Tank – DF; range of 55 to > 99%
- 77% average TDP mass removal Tank – DF; range of 18 to > 99% (3 of 4 > 90%)
  - Humphrey et al 2016b (Greater than 92% removal of TDP for 2 systems in Cecil and Georgeville soils)
- Site 400 (highest clay content, newest system, good separation to groundwater was most efficient)
- Site 100 (lowest clay content, deepest system, > 50 years old was least efficient)
- Sand Filter reduced TDN by 78% and TDP by 83%
  - Humphrey et al 2016ab (Avg 80% TDN reduction and 83% TDP reduction for 2 single pass sand filters)

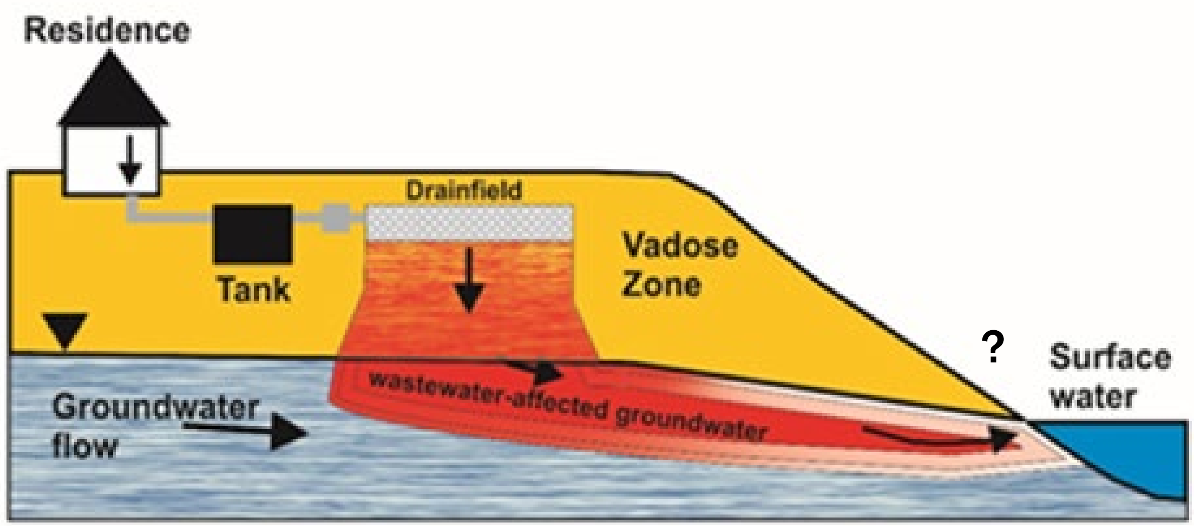
Bradshaw, J. K., & Radcliffe, D. E. (2013). Nitrogen fate and transport in a conventional onsite wastewater treatment system installed in a clay soil: experimental results. *Vadose Zone Journal*, 12, 3. doi:10.2136/vzj2012.0149.

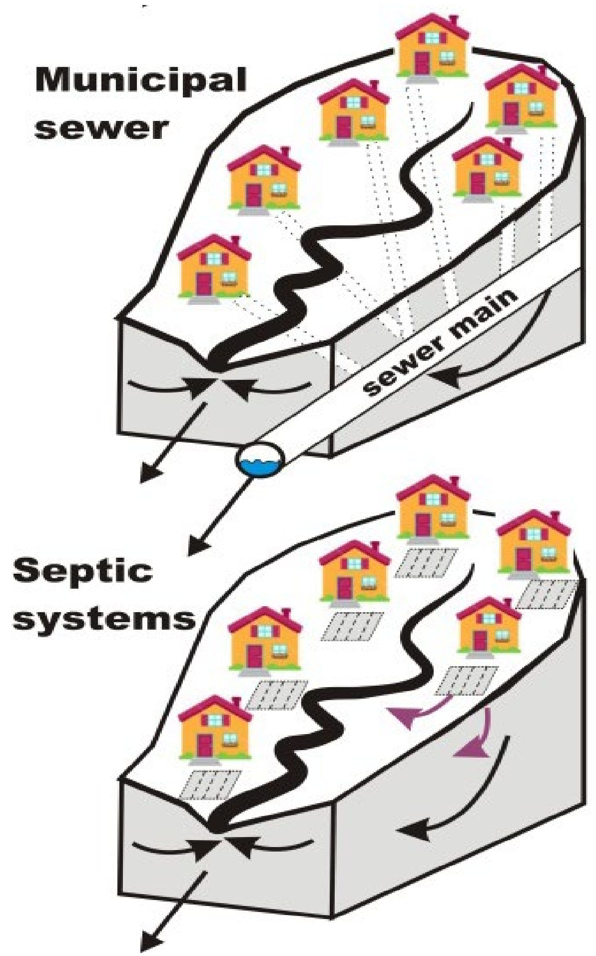
Humphrey, C.P., Jernigan, J., Iverson, G., Serozi, B., O'Driscoll, M., Pradhan, S., and Bean, E. (2016a). Field evaluation of Nitrogen Treatment by Conventional and Single-Pass Sand Filter Onsite Wastewater Systems in the North Carolina Piedmont. *Water Air & Soil Pollution*. doi:10.1007/s11270-016-2958-0

Humphrey, C., Serozi, B., Iverson, G., Jernigan, J., Pradhan, S., O'Driscoll, M., Bean, E. (2016b). Phosphate treatment by onsite wastewater systems in nutrient sensitive watersheds of North Carolina's Piedmont. *Water Science and Technology* 74 (7) 1527-1538

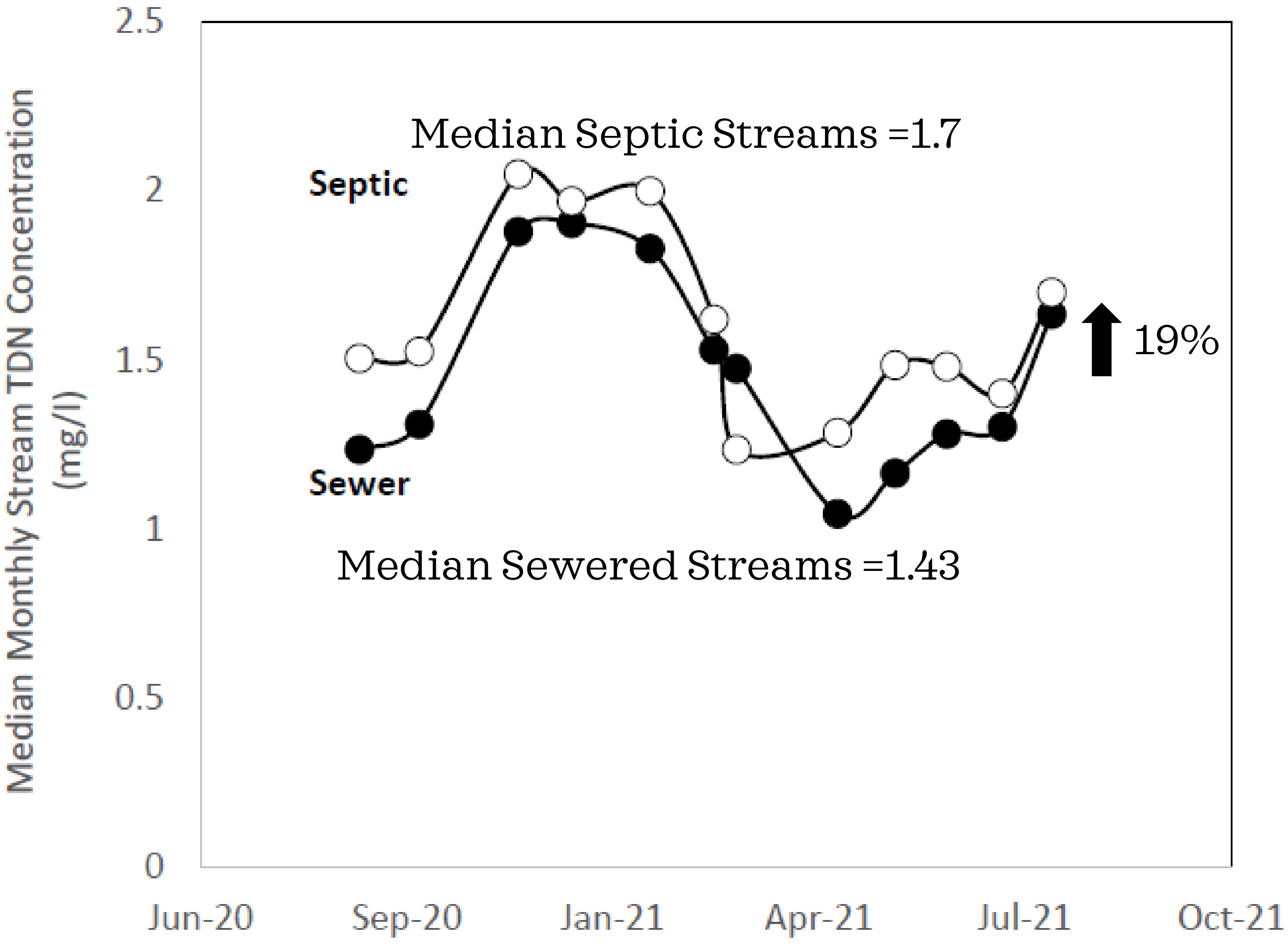
IF THE SOILS ARE TREATING~60% OF N AND >90% OF P

- What happens to the remaining nutrients that are loaded to the groundwater system?



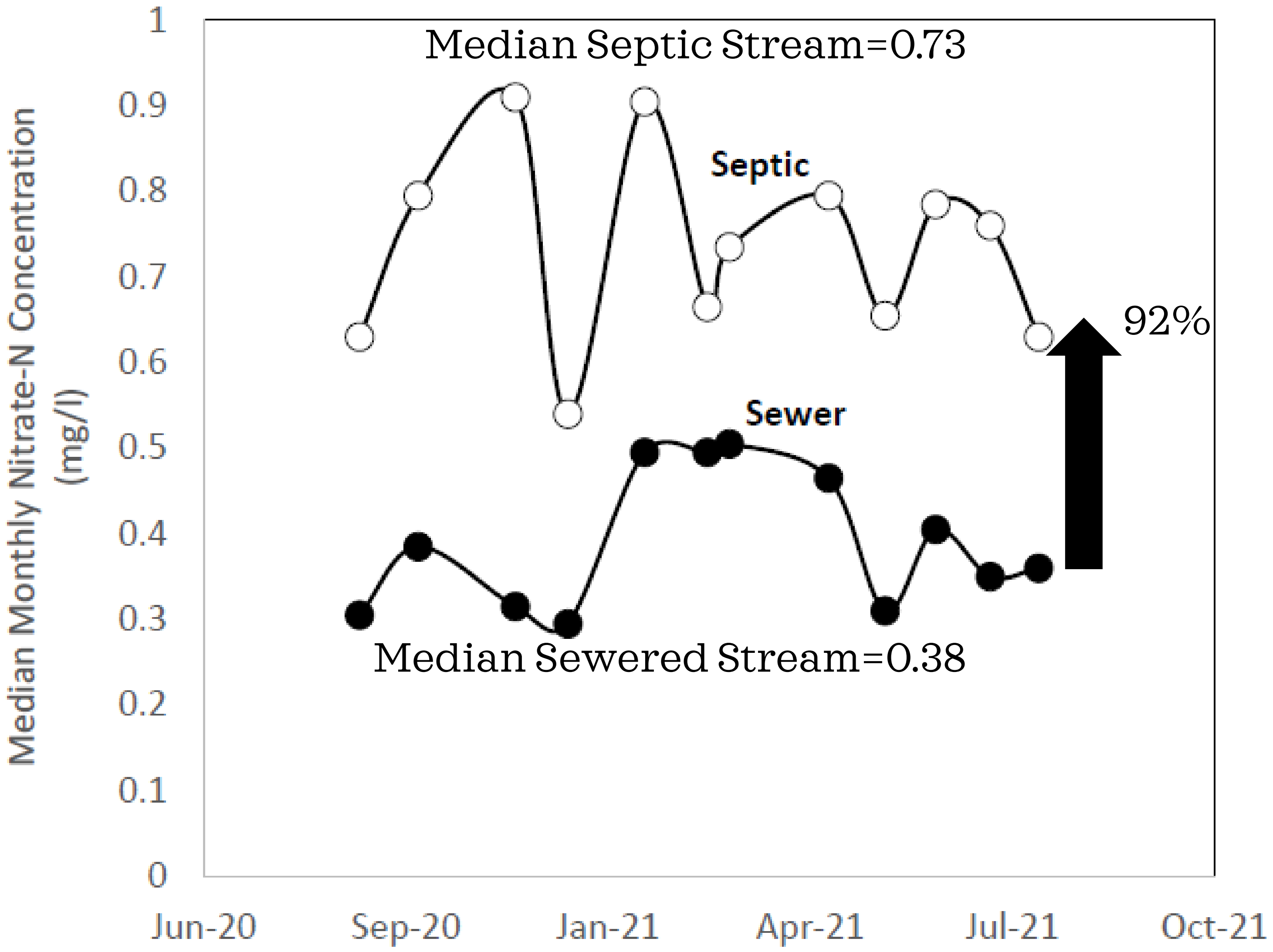


Compare nutrient concentration and loading between sub-watersheds served by sewer vs. septic systems. Differences in concentration and loading may be attributed to potential OWTS nutrient inputs



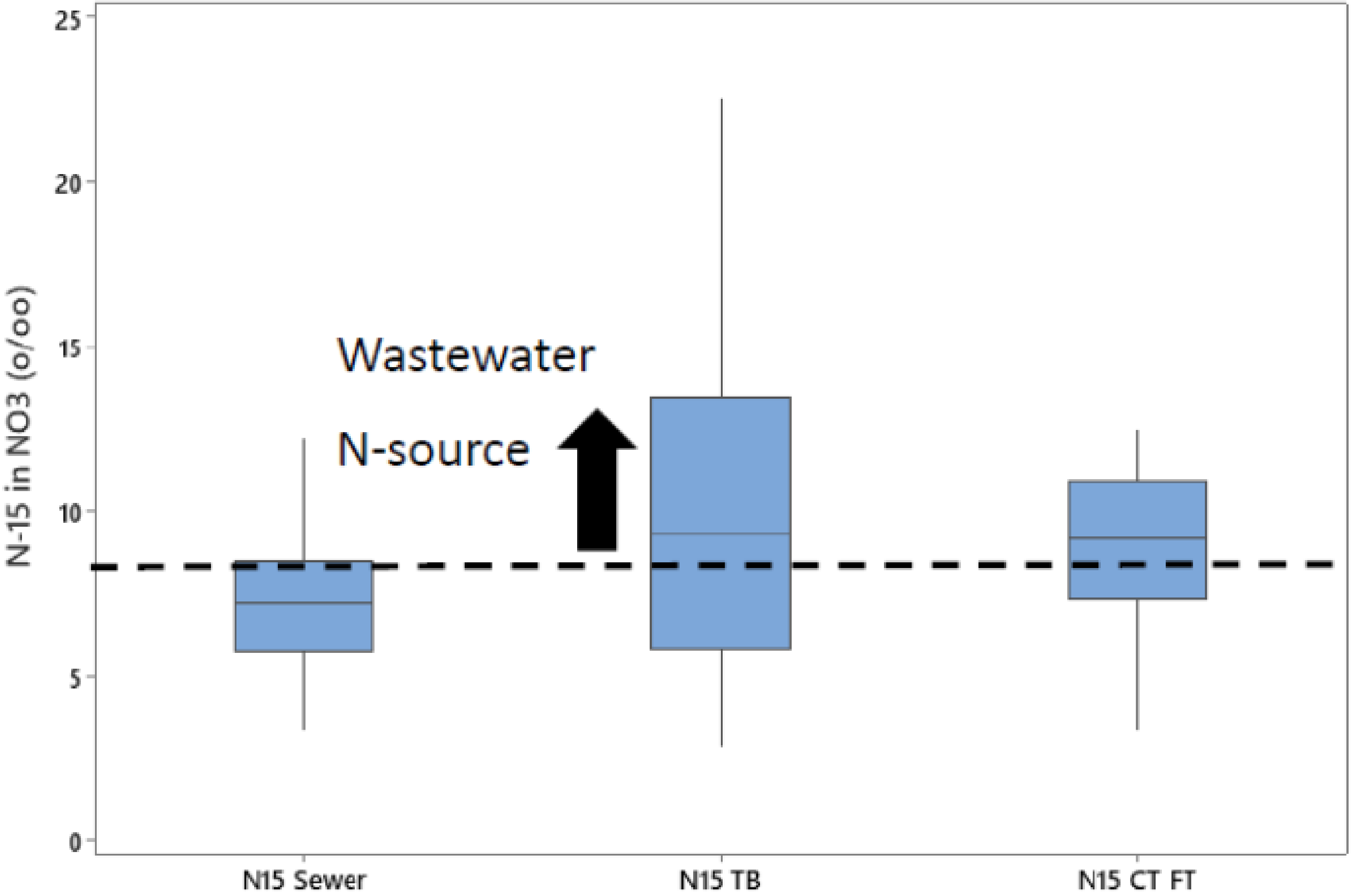
Stream TDN-Concentrations Slightly > for Watersheds Served by Septic Systems

Significant differences in median concentrations ($p<0.001$)indicating that OWTS are potentially contributing nitrogen to streams



Stream NO_3 Concentrations > for Watersheds Served by Septic Systems

Significant differences in median concentrations ($p<0.001$) indicate that nitrate from OWTS is potentially transported to streams



Boxplots of the N-15 in nitrate distributions (Nov. 2020 and March 2021 sampling events) for all sewered sites, and septic Triassic Basin (TB) and Carolina/Falls/Crabtree Terrane (CT/FT) sub-watersheds. Median N-15 in nitrate is elevated for the septic sub-watersheds relative to the sewered sub-watersheds. δN-15°/°° of greater than 8 suggests the nitrate source is likely wastewater or animal waste (Silva et al. 2002).

Isotopic Data Suggests Wastewater is a Potential Nitrate Source

Typically, ww or animal waste sources of NO_3 have elevated $\delta^{15}N$ relative to soil om or fertilizer (Silva et al. 2002).

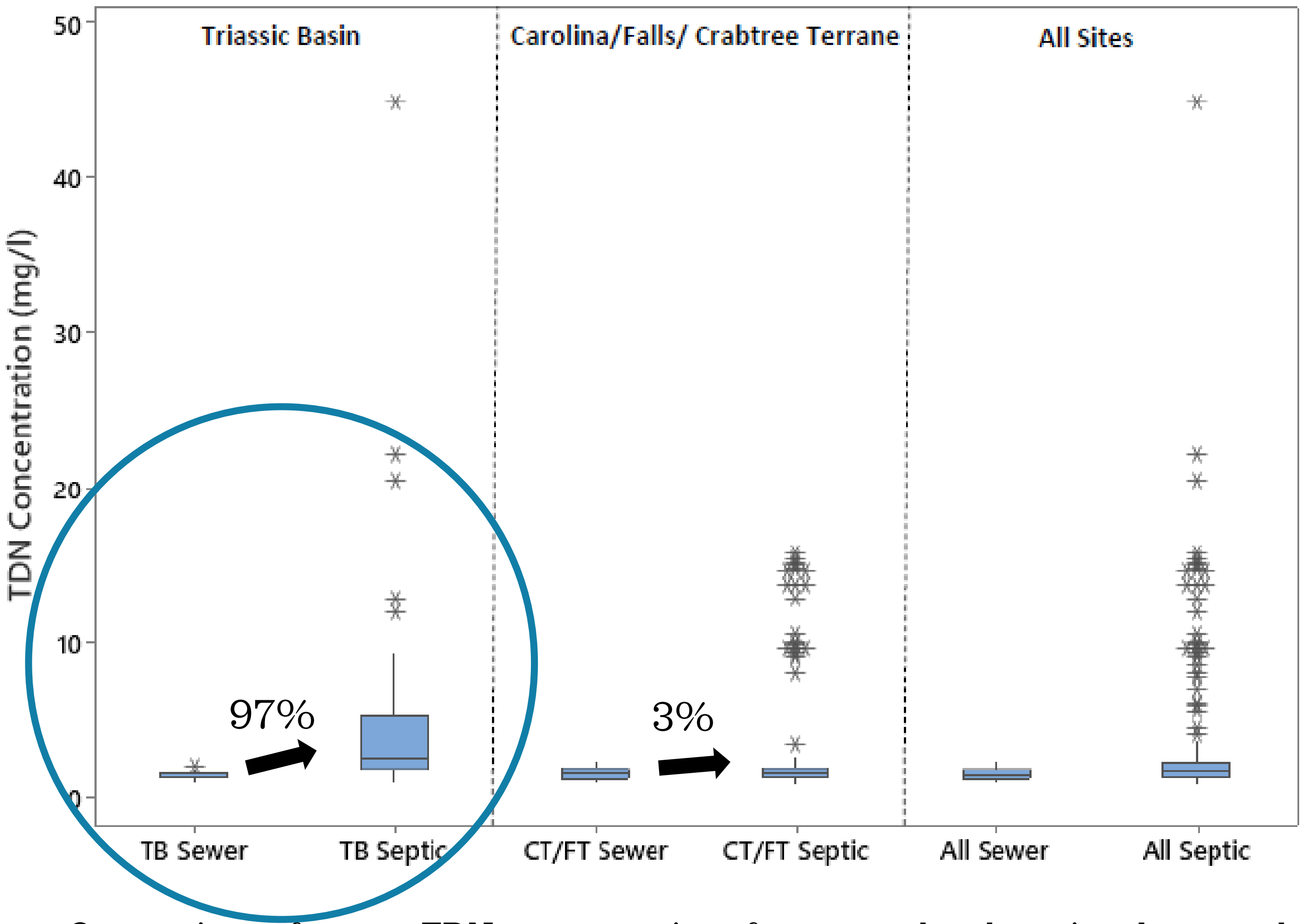
When $\delta^{15}N$ is >~ 8 °/°°, this provides an indication that the nitrate source is likely wastewater or animal waste.

Median $\delta^{15}N$ value for septic sub-watersheds was 9.27 °/°° and >TB.

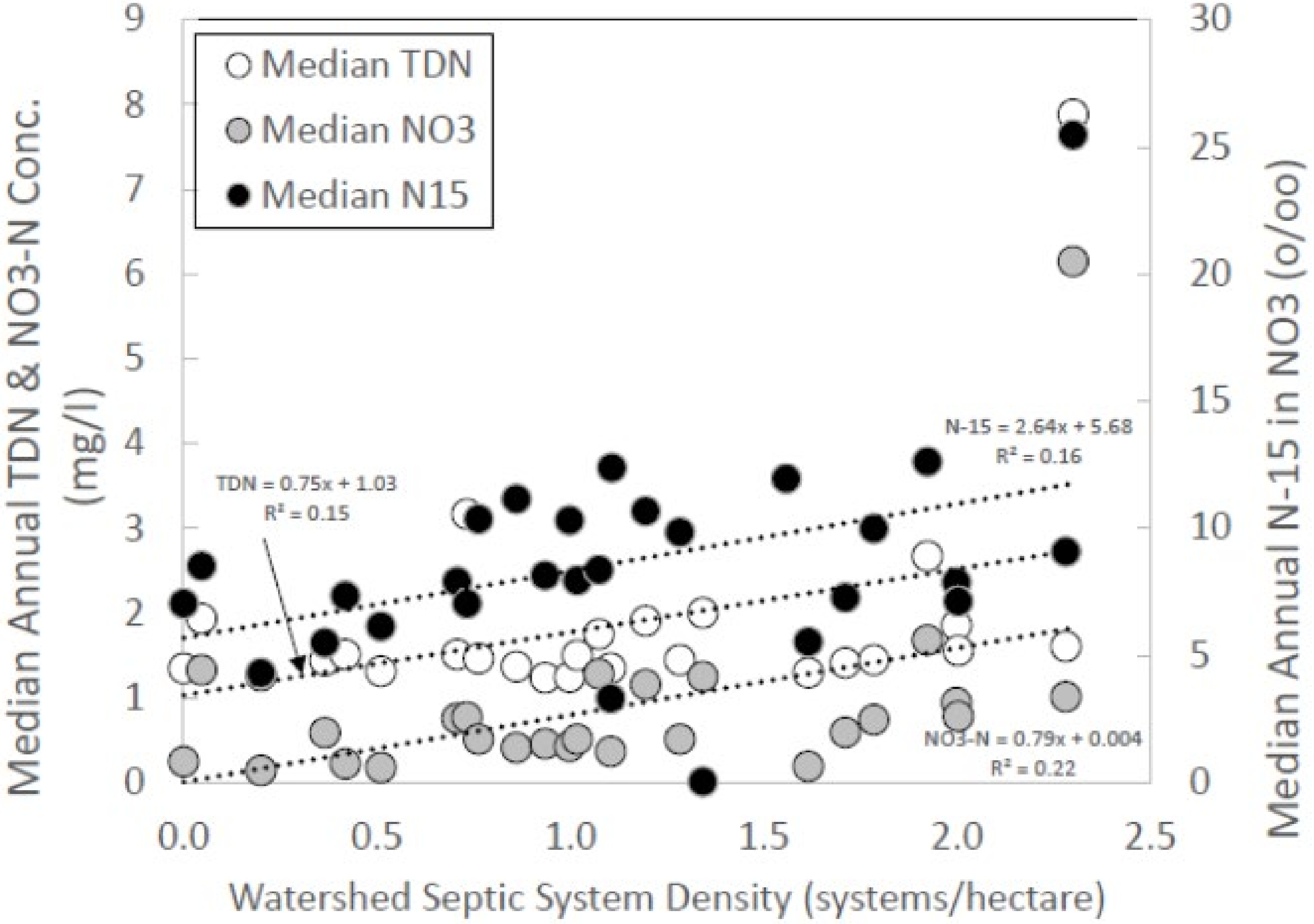
Enriched $\delta^{15}N$ compositions in NO_3 in septic watersheds suggested wastewater nitrate sources.

Influence of Geological Setting on Stream TDN Concentrations

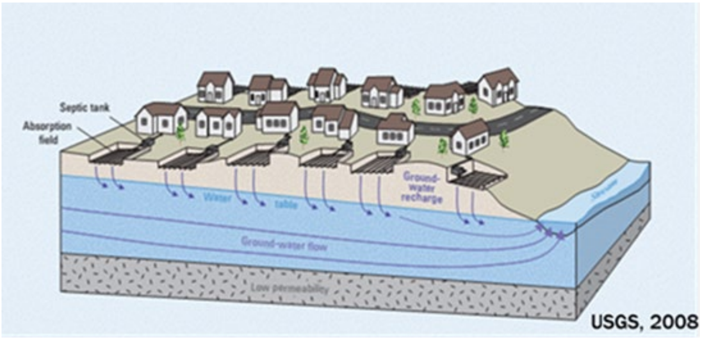
- Septic sub-watersheds in the Triassic Basin > median TDN conc. (2.57 mg/l) vs. CT/FT (1.59 mg/l)
- Median TDN conc. for sewered sub-watersheds in the Triassic Basin (1.30 mg/l) were <septic sub-watersheds (2.57 mg/l) ($p<0.001$).
- CT/FT settings, subtle difference between median TDN concentration for sewered (1.545 mg/l) vs septic sub-watersheds (1.59 mg/l) ($p=0.049$).
- Differences suggest OWTS may be more likely to affect stream nutrient concentrations in the TB.



Comparison of stream TDN concentrations for sewered and septic sub-watersheds for sites in the Triassic Basin (TB) (generally sedimentary geology) vs. sites in the Carolina Terrane, Falls Lake Terrane, and Crabtree Terranes (CT/FT) (generally igneous and metamorphic geology).



*For 20 septic sub-watersheds, 2 outliers excluded for Wake Co. (potentially other N sources)



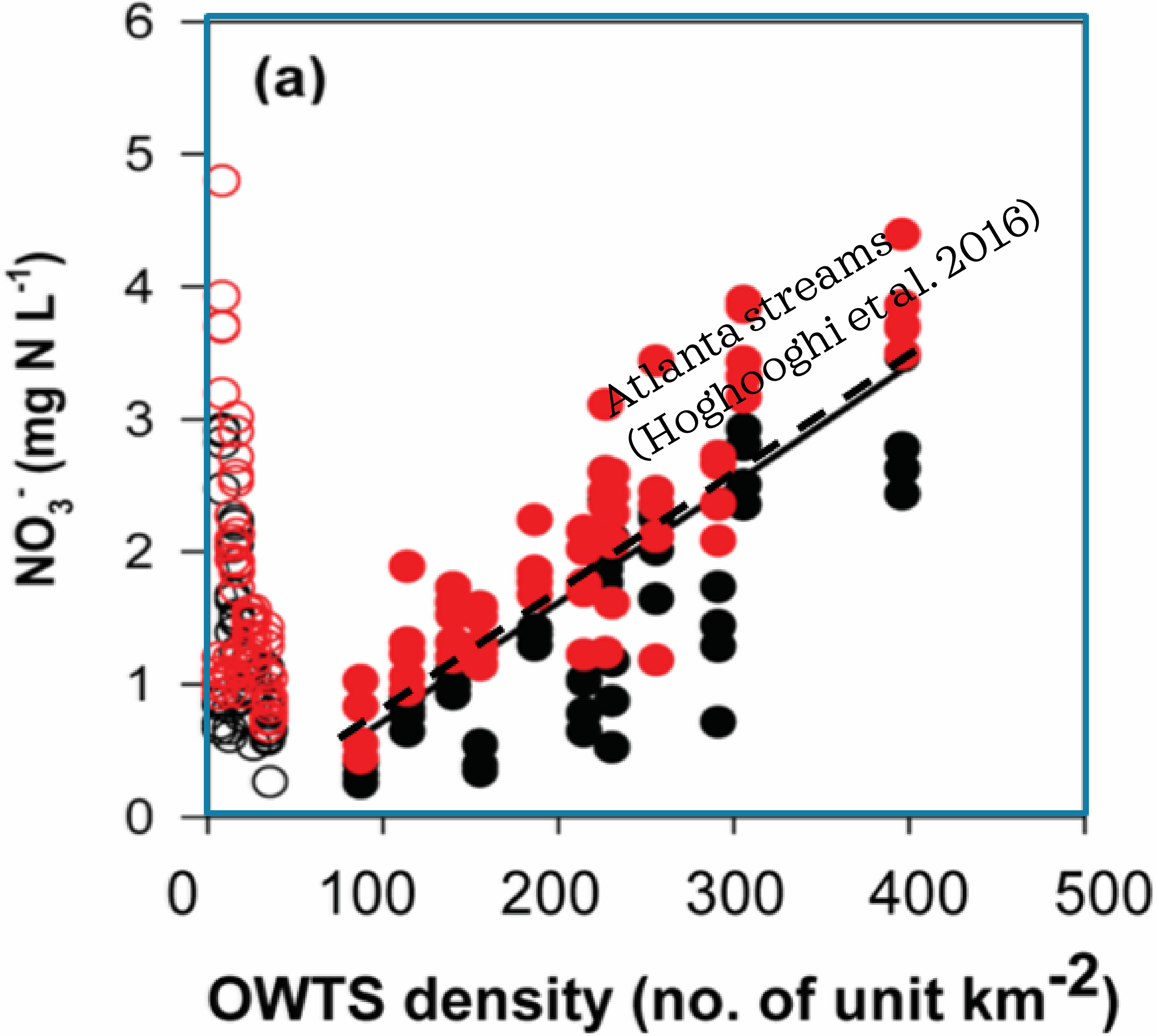
Effects of Septic System Density on Stream Dissolved N and ^{15}N

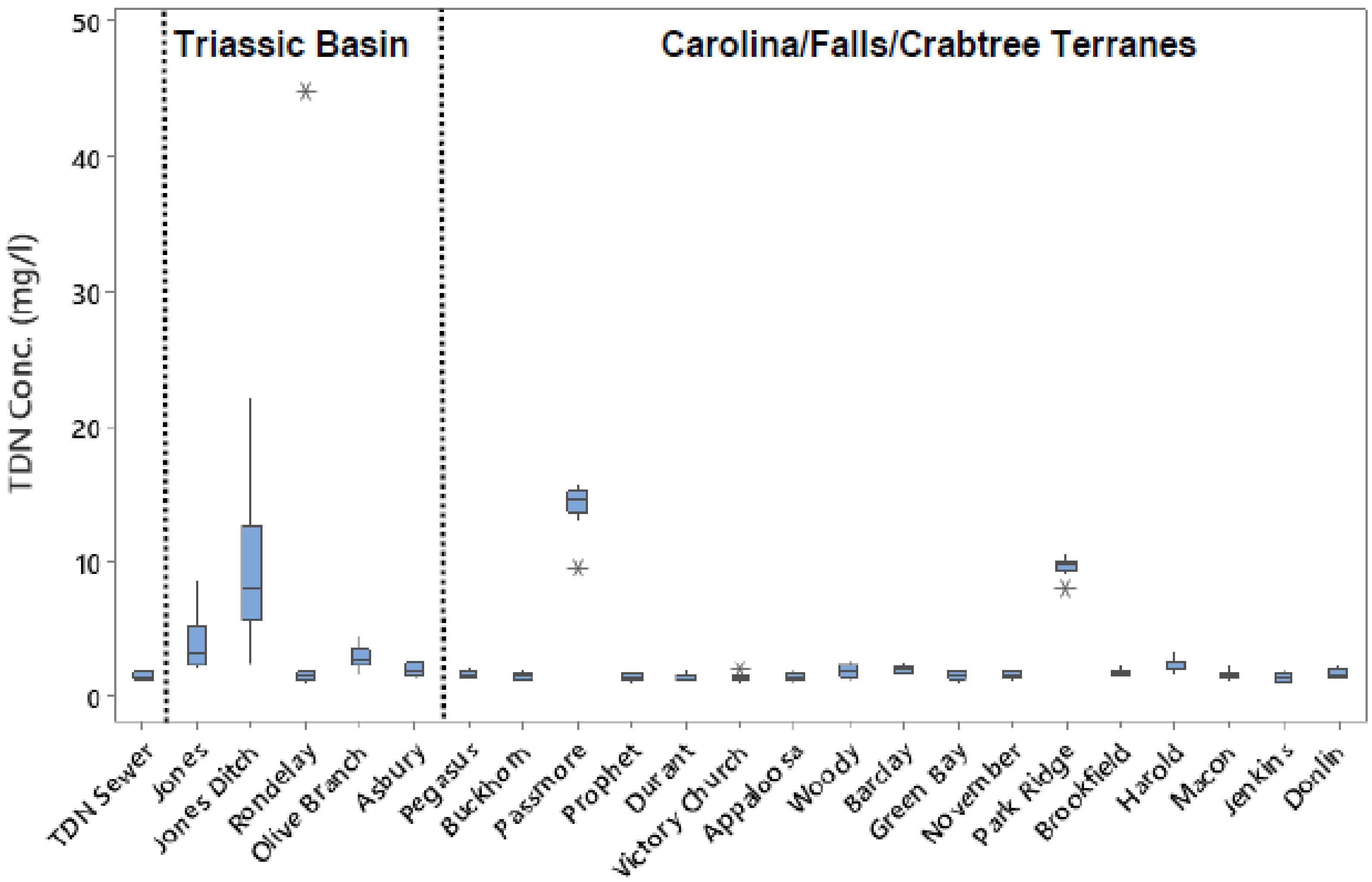
- Median TDN, NO_3, and ^{15}N in septic sub-watersheds increased w/ septic system density
- > likelihood of elevated nitrogen concentrations and ^{15}N enrichment at higher septic system densities

Effects of Septic System Density on Stream Nitrate Concentrations

- Similar relationship was found by Hoghooghi et al. (2016) for watersheds in the Atlanta, GA region.
- > likelihood of elevated nitrate concentrations at higher septic system densities
- Suggests that with septic system density> 1 system/ha, nitrate concentrations increases may be detectable
- Good News! Rare to have densities > 3 systems/ha~ Atlanta in Falls Lake Watershed!!

Hoghooghi et al. 2016
(Atlanta watersheds)

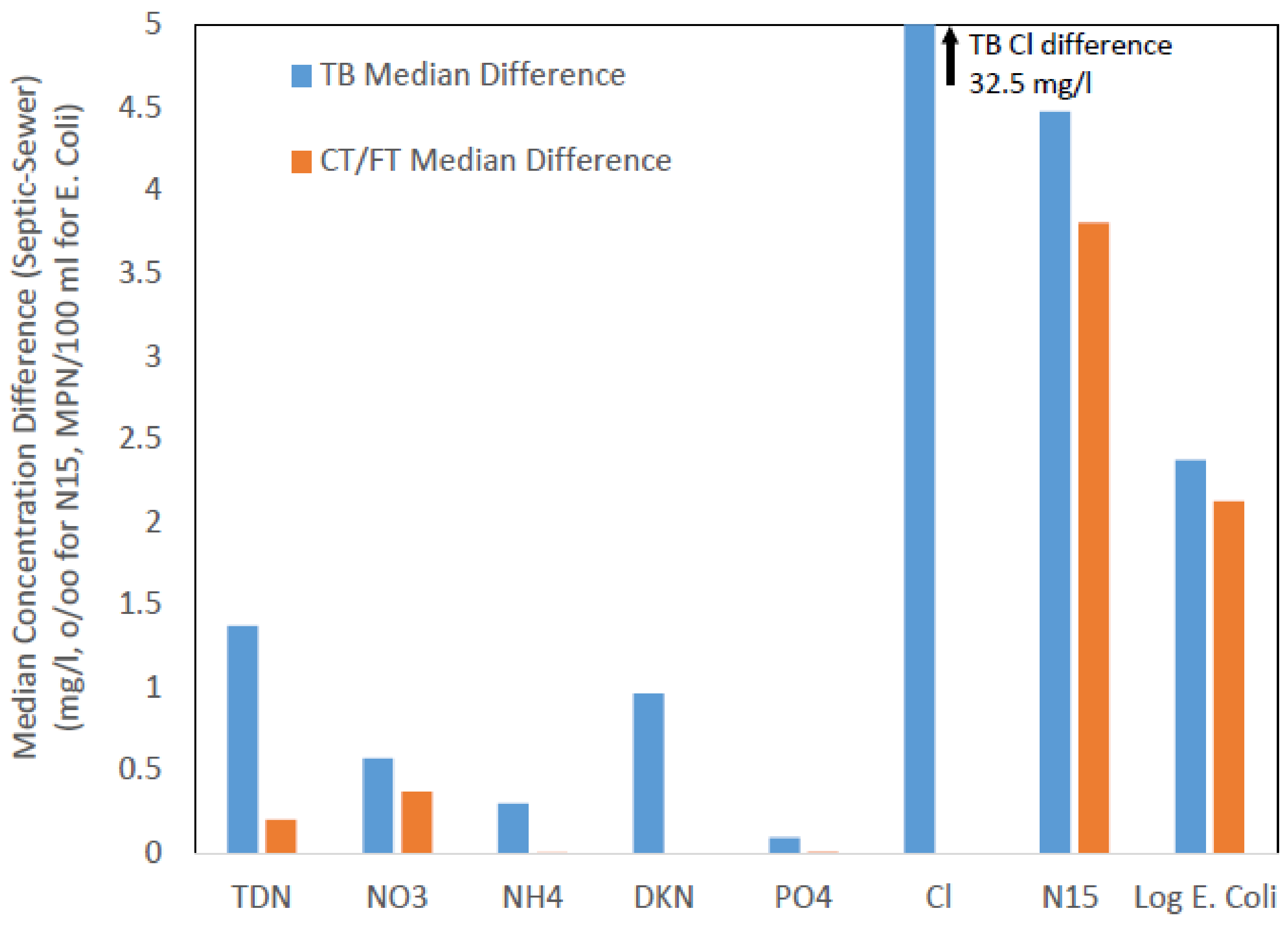




Boxplots of median sewer and sub-watershed stream TDN concentrations.

Identifying Sites with Potential Elevated OWTS Nutrient Inputs

- TDN in septic sub-watersheds, more consistently elevated in Triassic Basin
- Many streams in the other geological settings (CT/FT) did not show elevated concentrations above sewered (w/ a few exceptions).

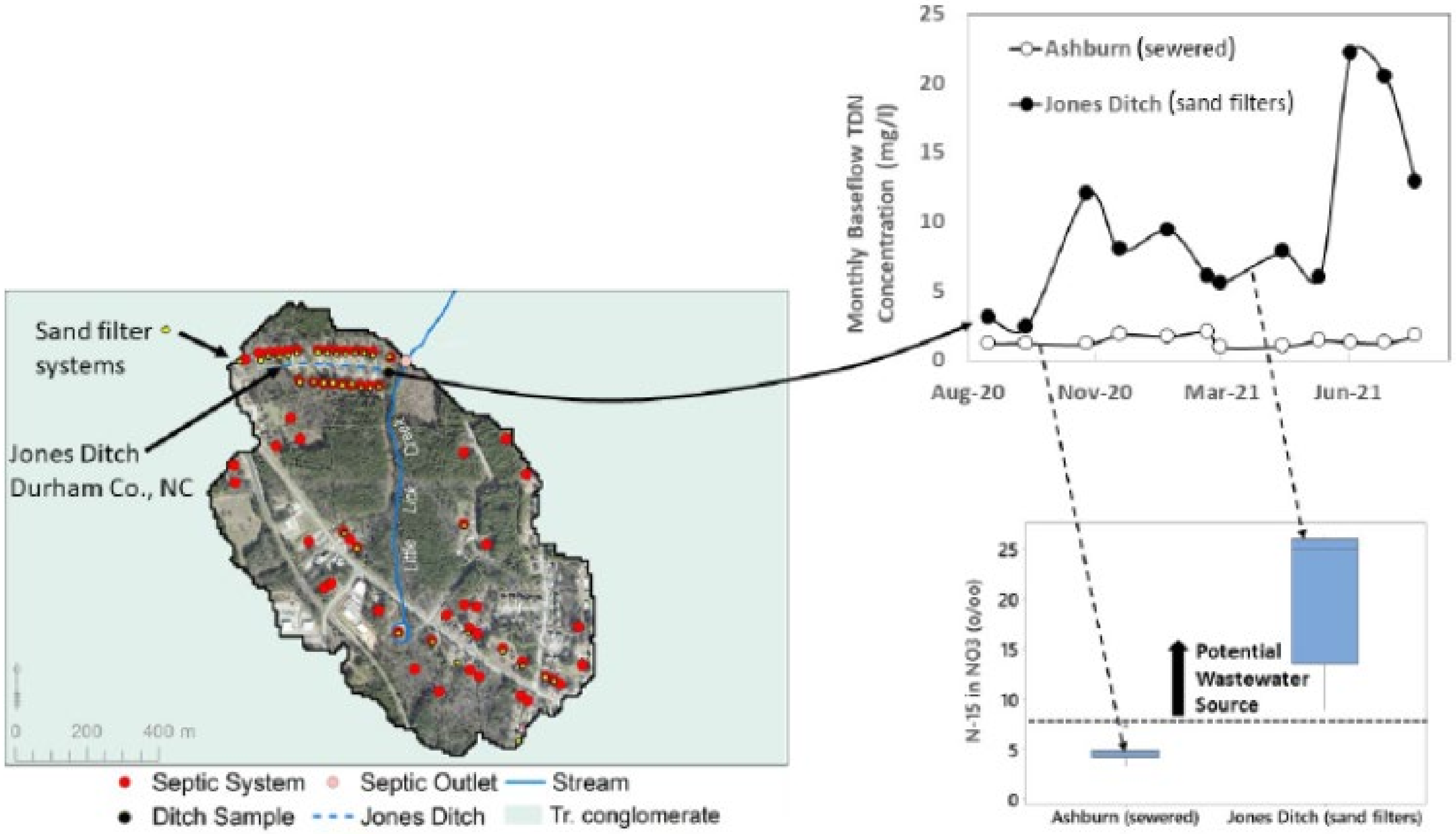


Comparison of the median difference between septic and sewered sub-watershed stream nutrient, chloride, N15, and E. Coli concentrations for Triassic Basin (TB) and Carolina Terrane, Falls Terrane, and Crabtree Terrane (CT/FT) settings.

Potential OWTS-related nutrient transport to streams was more likely for Triassic Basin

- Comparisons of median differences in indicators between sewered and septic sub-watersheds, > differences in TB
- Many streams in the other geological settings (CT/FT) did not show elevated concentrations above sewered (w/ a few exceptions).

Identifying Sites with Potential Elevated OWTS Nutrient Inputs

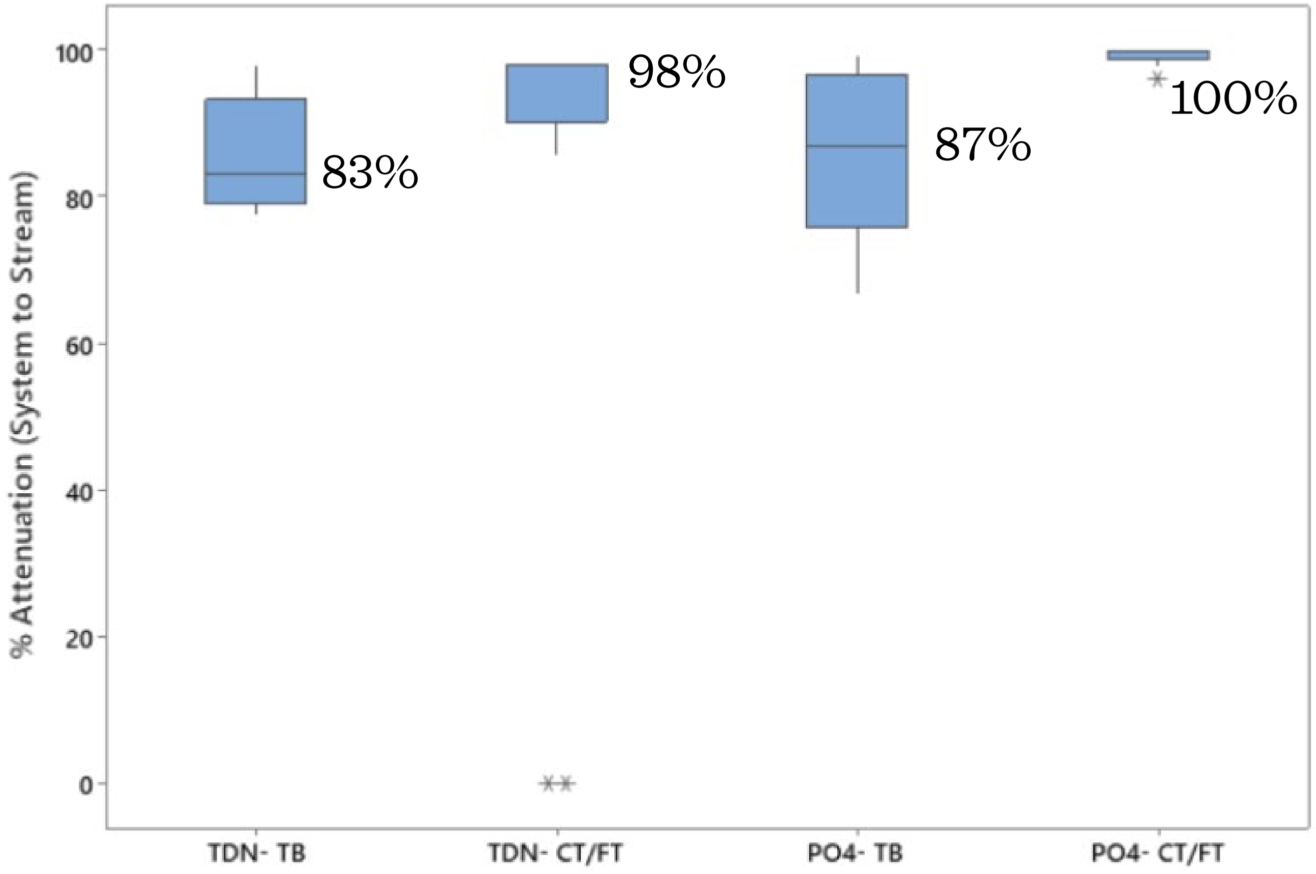


Jones ditch surface water sampling site in Durham Co. had the highest nutrient concentrations and N-15 enrichment of all Triassic Basin sub-watersheds. The data suggested an influence of onsite wastewater inputs on nutrient loading.

- Example of a site in TB, where water quality data suggested increased nutrient concentrations associated with wastewater inputs

Estimating OWTS Nutrient Attenuation at the Sub-Watershed Scale

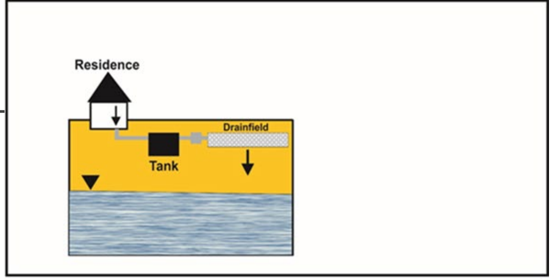
- Comparisons of estimates of sub-watershed scale nutrient attenuation based on median differences in concentration times discharge (during baseflow) and literature estimates of loading to soils
- Estimates suggest > median PO4 attenuation than TDN
- Overall, better attenuation in CT/FT geological settings than TB settings
- Worst: 67% P; 75% N; Jones Ditch (TB).
- * Outliers - sub-watersheds (Passmore/Park Ridge, Wake Co.) in CT/FT: median 14.6-9.8 mg/l N, other N sources?
- In most cases, suggests that at baseflow – OWTS nutrient treatment can be similar to municipal wastewater treatment plants
- This approach used baseflow conditions, more work is needed to evaluate during storms

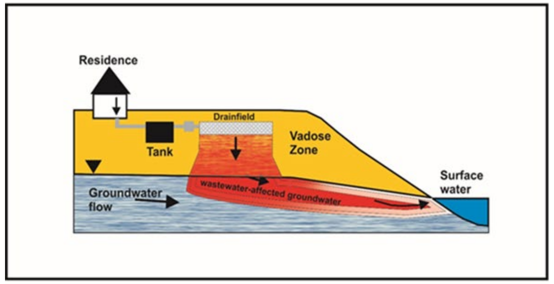


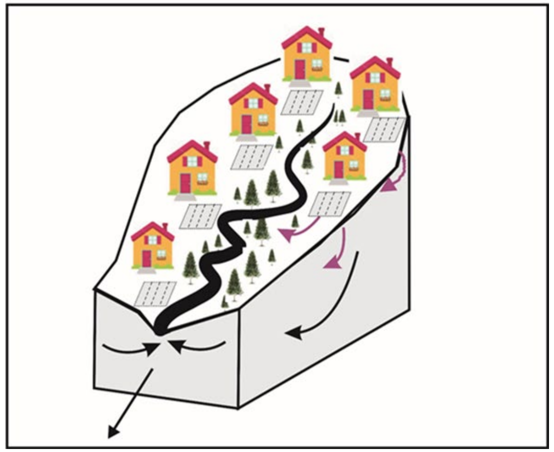
Estimates of the percent of OWTS nutrient load that is attenuated between the OWTS systems and the stream. Comparisons are for TDN and PO4-P for Triassic Basin (TB) and Carolina/Falls/Crabtree Terrane (CT/FT) septic sub-watersheds based on estimates in **Tables 11** and **12**.

Conclusions

- WW/GW monitoring suggested soils could treat ~ 60% of N and >90% of P loads from OWTS to groundwater, worst performing site (100): 18% P; 26% N mass reduction.
- Evidence of OWTS nutrient transport to 11 of 22 streams: relationship of increased N conc. and N-15 with increasing septic system density. Sub-watersheds with > 1 system/ha were more likely to have elevated N conc.
- Fewer streams in CT/FT geol. (6/17) showed influence of OWTS on nutrient conc., streams in the Triassic Basin w/ upgradient septic systems (5/5) were more likely to have elevated nutrient conc. relative to sewered streams.
- Similar to soil treatment estimates, sub-watershed scale nutrient attenuation estimates (from OWTS to stream) suggested slightly better treatment for P (87-100% median) vs N (83-98% median). Worst: 67% P; 75%N. * Sub-watersheds (Passmore/Park Ridge, Wake Co.) in CT/FT: median 14.6-9.8 mg/l N, other N sources? BMPs?
- Functional OWTS may achieve similar treatment to municipal treatment plants at the sub-watershed scale.
- Due to in-stream, riparian & hyporheic zone nutrient attenuation (denitrification, biological uptake, transformations), some fraction of the OWTS nutrient inputs may not be delivered to the lake (distance, etc.)
- Limited info on stormwater-related loading and spatial/temporal variability of failing systems- more research needed.
- Approaches to deal w/ low performing sites- ongoing work w/ NC Policy Collaboratory (G. Iverson/N. Bell)…….

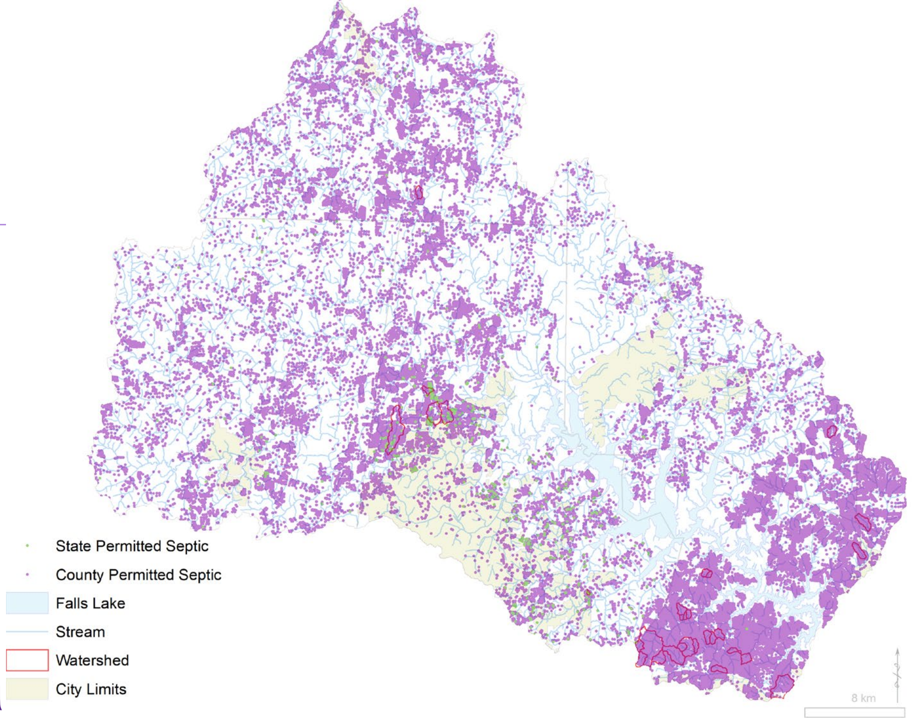


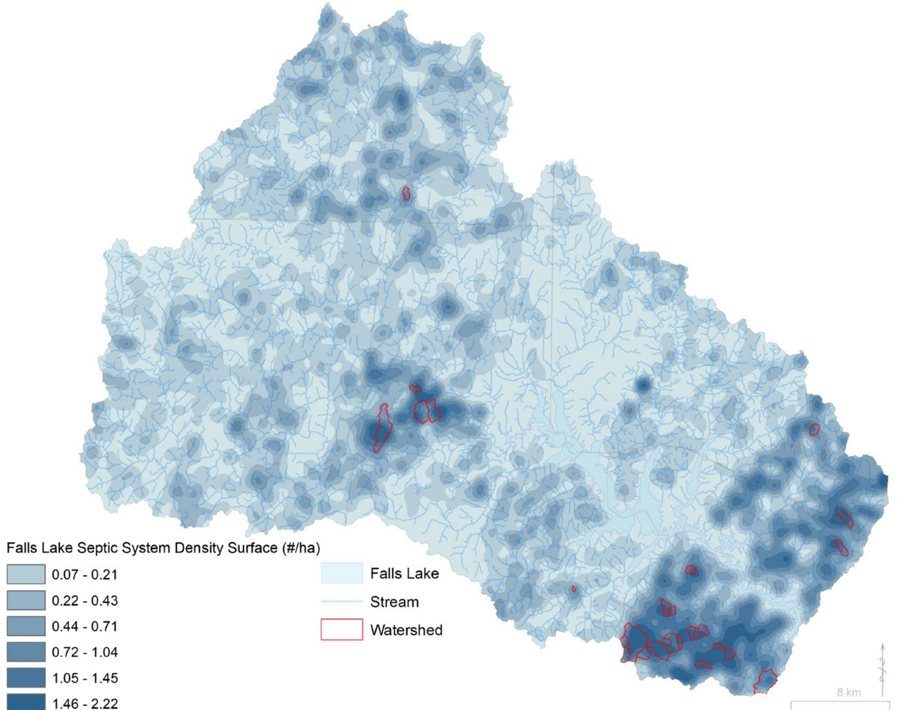




Septic System Density

- Using estimated locations of septic systems provided by Brown & Caldwell, the density of septic systems were estimated at the watershed scale
- 30 sub-watersheds were selected in areas that had estimated densities > 1 system/ha
- Sampling occurred twice across all 30 sub-watersheds in December 2020 and February 2021
  - Physicochemical parameters
    - DO, temp, SC, ORP, turbidity, pH, discharge
  - Nutrient parameters
    - TN and TP, along with their speciation



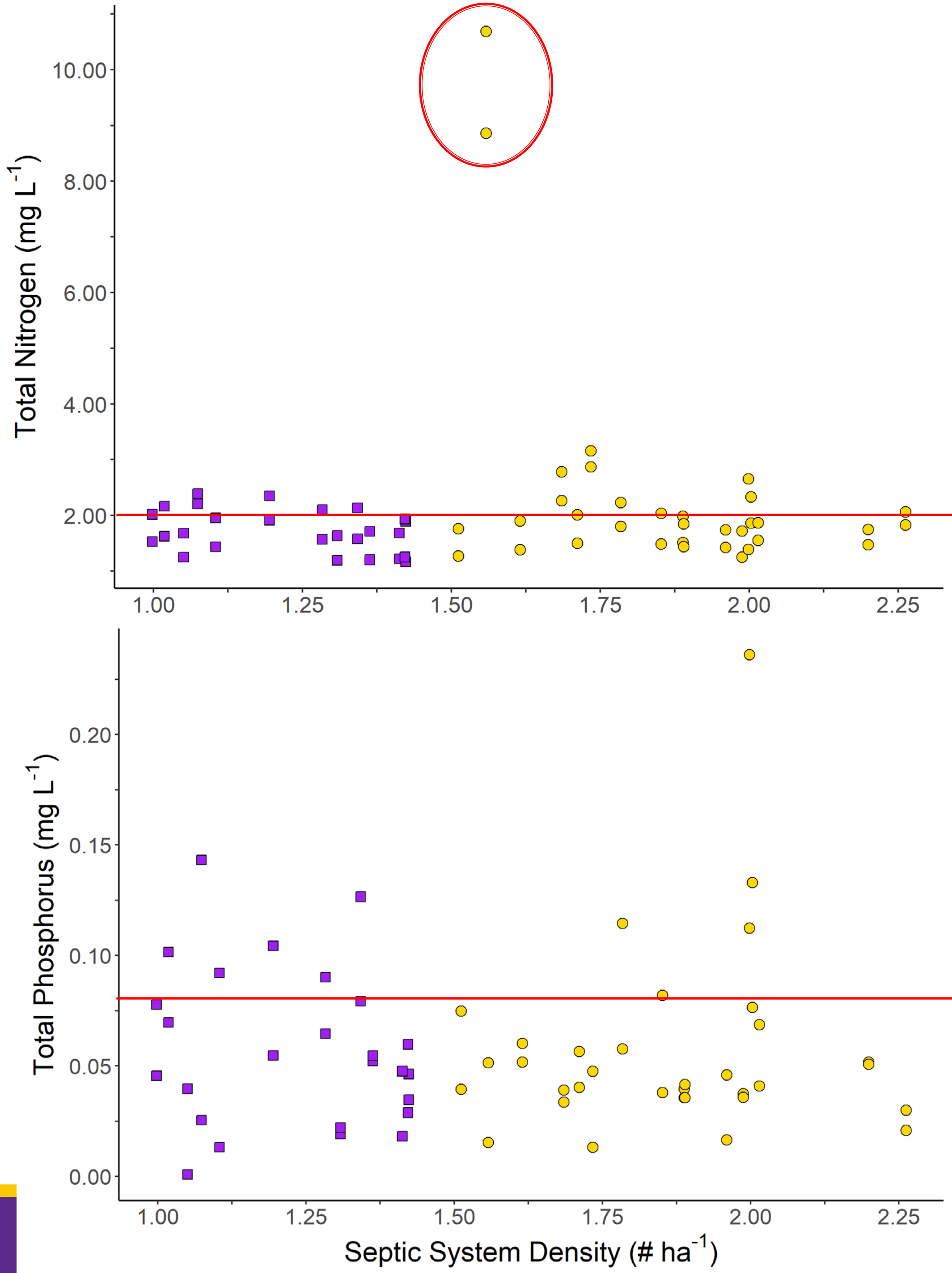


Watershed Characteristics

Watershed Name	County	Septic System (#)	Area (ha)	Septic System Density (system ha^{-1})	Latitude	Longitude
Durant	Wake	229	229.48	1.00	35.91	-78.61
Victory Church	Wake	740	458.12	1.62	35.94	-78.72
November	Durham	345	268.91	1.28	36.07	-78.96
Appaloosa	Granville	54	48.91	1.10	36.09	-78.57
Donlin	Franklin	160	79.88	2.00	36.02	-78.54
Jenkins	Wake	110	64.27	1.71	36.00	-78.54
Woody	Person	43	40.04	1.07	36.26	-78.93
Barclay	Durham	150	125.55	1.19	36.10	-78.90
Harold	Durham	43	32.03	1.34	36.12	-78.92
Green Bay	Durham	162	159.14	1.02	36.10	-78.92
Asbury	Durham	17	8.51	2.00	35.97	-78.78
Macon	Wake	272	152.44	1.78	35.92	-78.70
Park Ridge	Wake	72	46.21	1.56	35.94	-78.66
Brookfield	Wake	119	52.60	2.26	35.92	-78.68
Tacketts Pond 1	Wake	31	16.74	1.85	35.98	-78.68
Tacketts Pond 2	Wake	39	28.62	1.36	35.98	-78.68
Green Downs 1	Wake	112	59.31	1.89	35.95	-78.70084
Green Downs 2	Wake	19	13.45	1.41	35.95	-78.70
Green Downs 3	Wake	52	23.64	2.20	35.95	-78.70
Appaloosa Run E	Wake	89	47.10	1.89	35.96	-78.70
Ethan	Wake	46	43.80	1.05	35.94	-78.74
Indigo Moon Way	Wake	101	66.80	1.51	35.93	-78.73
Bushveld	Wake	95	72.62	1.31	35.92	-78.72
Cranesbill	Wake	270	189.69	1.42	35.93	-78.69
Liatris	Wake	53	37.27	1.42	35.93	-78.70
Old Creedmoor	Wake	69	34.71	1.99	35.93	-78.68999
Kinsdale 1	Wake	76	45.10	1.69	35.93	-78.68
Kinsdale 2	Wake	65	37.49	1.73	35.93	-78.67
Leslie 1	Wake	58	29.59	1.96	35.93	-78.66
Coachmans Way	Wake	108	53.60	2.01	35.93	-78.64

Nutrient Concentrations

- TN concentrations ranged from approximately 1.5 – 10 mg/L
  - 8 sub-watersheds contained a median value that exceeded 2 mg/L
  - 6 of these had densities > 1.5 systems/ha
  - The Park Ridge sub-watershed contained median concentrations > 8 mg/L
    - Likely other sources, density is 1.56 systems/ha
- TP concentrations ranged from 0.02 – 0.17 mg/L
  - 6 sub-watersheds contained median values that exceeded 0.08 mg/L
  - 3 of these had densities > 1.5 systems/ha
  - Park Ridge not among these 6 – more evidence for other sources?



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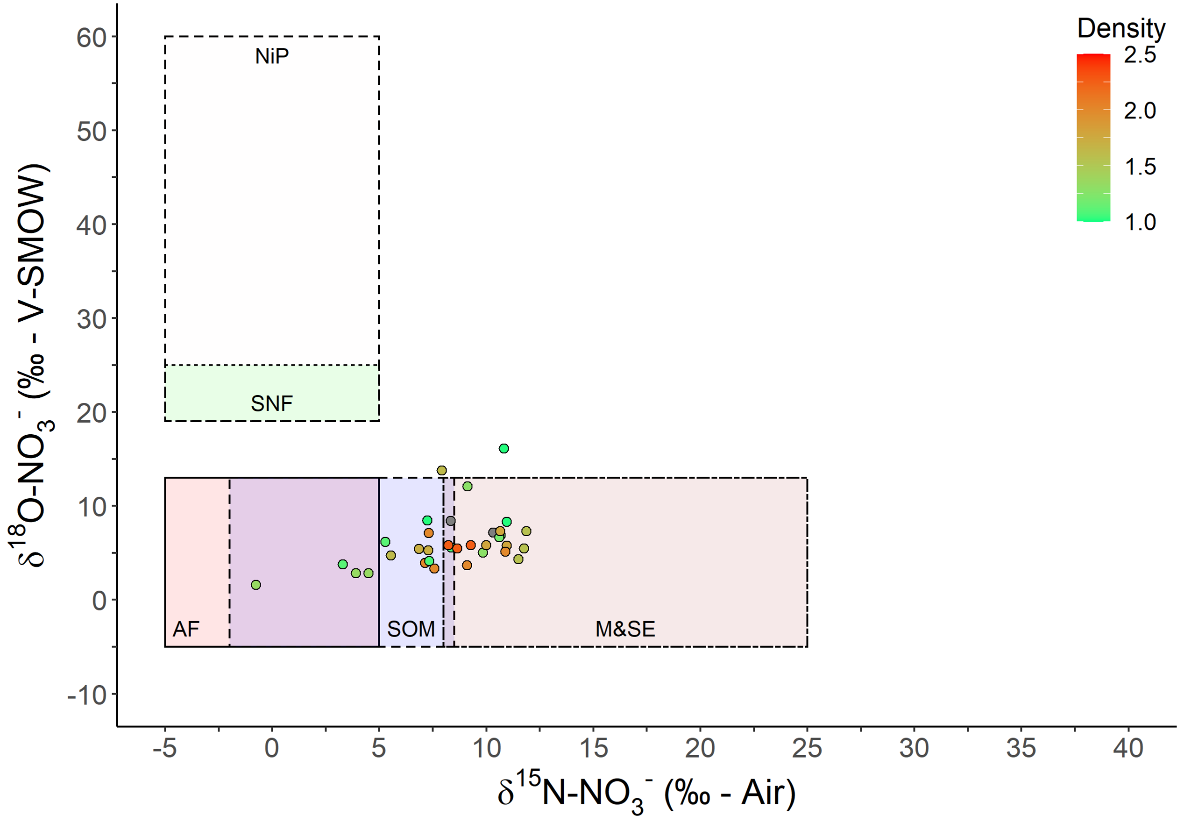
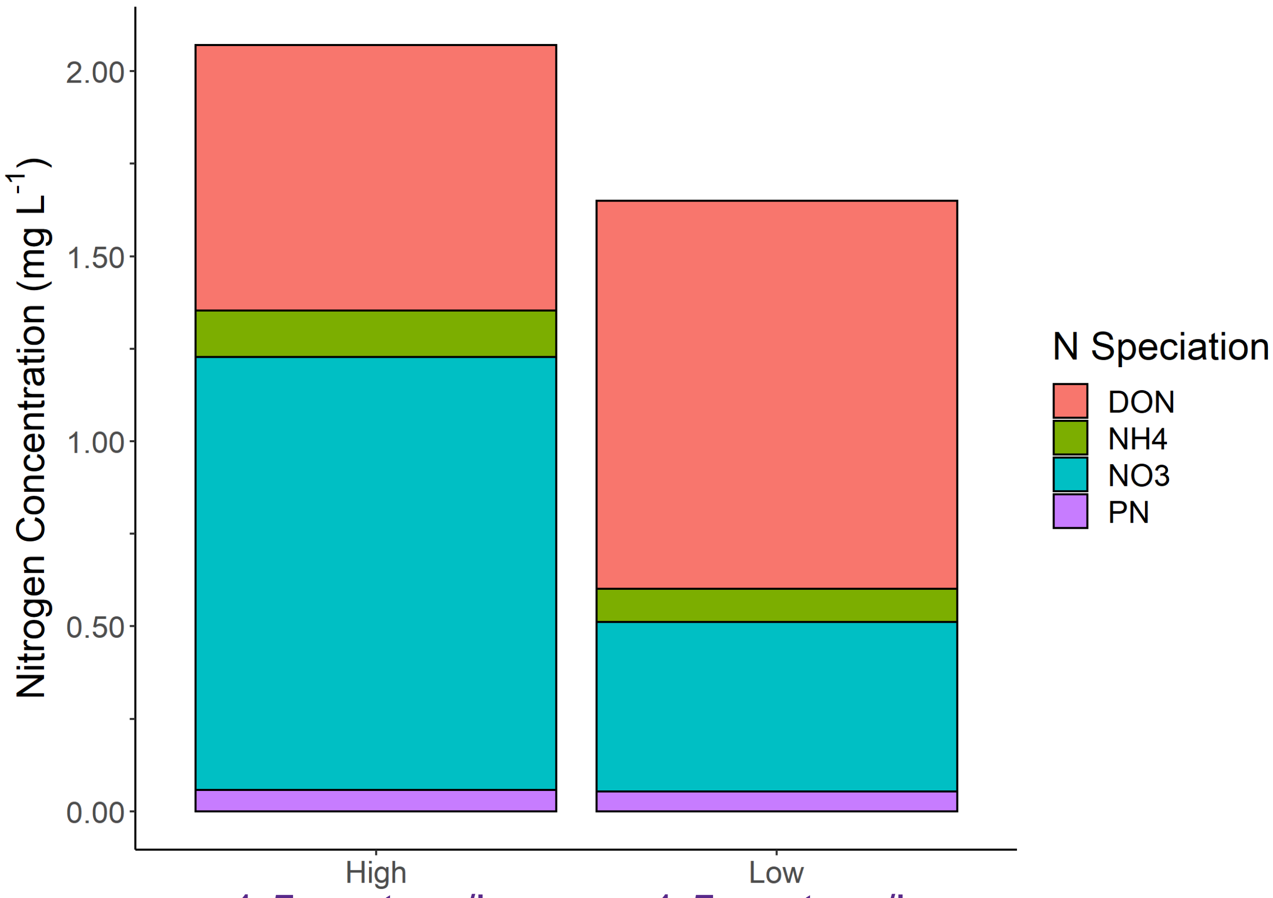
Nutrient Sources

- Sub-watersheds contained an array of potential sources including ammonia fertilizers, soil organic matter, and manure & septic effluent
- As density increased, values of $\delta^{15}N$ values tended to be elevated (moved further right on the figure)



Potential Treatment?



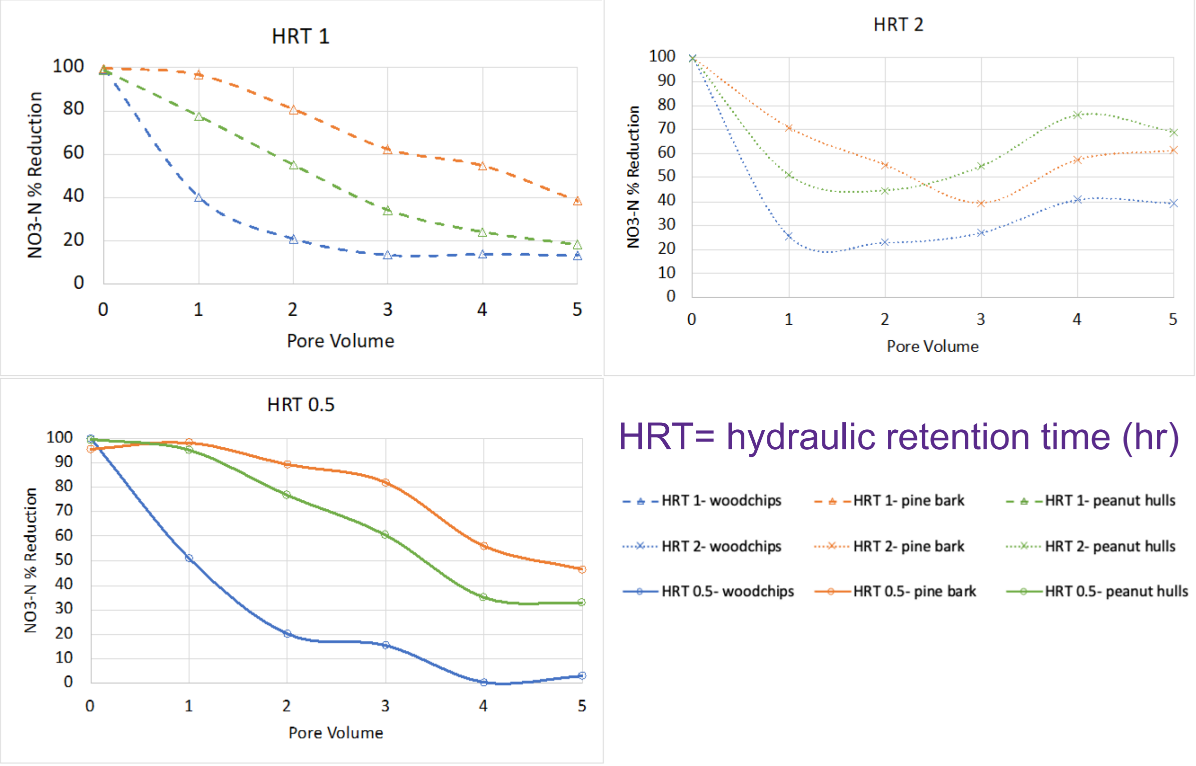
> 1.5 system/ha < 1.5 system/ha

Nitrate Removal Literature Estimates

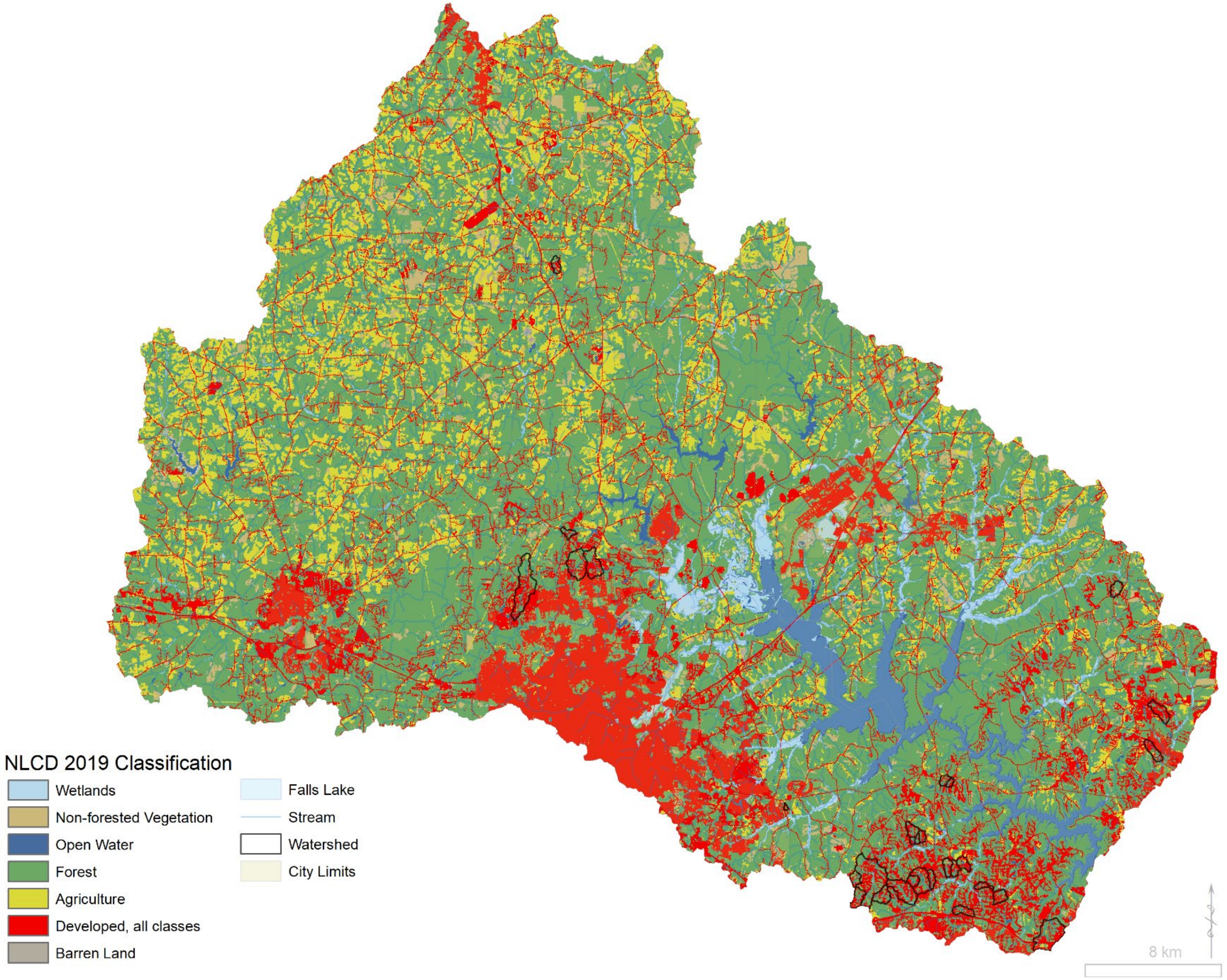
Reference	Setting	Media	Flow ($L\ min^{-1}$)	HRT	Inflow ($mg\ L^{-1}$)	N Red (%)	Nitrate Mass Rem
Robertson & Merkley [40]	Field; IBR	WC	24	N/A	4.8	78	6 $g\ m^{-2}\ d^{-1}$ (up to 360 $g\ d^{-1}$)
Iverson [41]	Field; IBR	WC (MS)	26	N/A	0.9	78	0 – 12 $g\ m^{-2}\ d^{-1}$
Bell et al. [42]	Field; BR	WC (MS)	5.8-23.3	2-8 h	<0.1- 17	20-98	11.6 $g\ m^{-3}\ d^{-1}$
Christianson [18]	Pilot; BRs	WC (pine)	N/A	2-15 h	7.7-35.6	14-37	2.1-6.7 $g\ m^{-3}\ d^{-1}$
Ramirez-Godinez et al. [43]	Lab; BR	PS	N/A	3 d	50	95	N/A
Lynn et al. [44]	Lab[a]	2:1 PG; WC (E)	Not specified[a]	1 – 9 h[a]	4	Up to 98	N/A
Hoover et al. [45]	Lab; BR	WC (MS, HW)	N/A	2-24 h	11.5-35.1	39	15.6 $g\ m^{-3}\ d^{-1}$

Bioreactor Pilot

- 9 bioreactors were installed and water with 20 mg/L of nitrate is pumped into each using variable hydraulic retention time and carbon media
- Pine bark media (orange colors) showed the best potential for treatment across all pore volumes and hydraulic retention times
- Pine bark also released the lowest amounts of TKN, TKP, and DOC
- More research is needed on adapting phosphate sorption media in denitrifying bioreactors



Where to Site Bioreactors?



- Areas where riparian buffers and/or wetlands have been lost or degraded with elevated nitrate and/or phosphate concentrations
- Estimated reductions in selected sub-watersheds:

Watershed	NO3 (mg L^{-1})		TN (mg L^{-1})		TN Red	PO4 (mg L^{-1})		TP (mg L^{-1})		TP Red
	In	Out	Before	After	(%)	In	Out	Before	After	(%)
Park Ridge	9.52	2.09	9.77	2.35	76.0	0.00	0.00	0.03	0.03	1.1
Asbury	0.87	0.19	2.02	1.35	33.5	0.10	0.03	0.17	0.10	44.0
Barclay	0.98	0.22	2.13	1.37	35.8	0.02	0.01	0.08	0.07	18.1
Woody	1.36	0.30	2.30	1.23	46.3	0.05	0.01	0.08	0.05	40.3
Kinsdale 1	1.91	0.42	2.52	1.03	59.1	0.01	0.00	0.04	0.03	15.2
Kinsdale 2	2.60	0.57	3.01	0.98	67.4	0.00	0.00	0.03	0.03	10.1
Green Bay	0.53	0.12	1.89	1.48	21.9	0.04	0.01	0.09	0.06	34.7
Harold	0.49	0.11	1.86	1.47	20.6	0.04	0.01	0.10	0.07	29.6

Thanks for your attention!

- Questions/comments?