Evaluating Nitrogen Treatment by Onsite Wastewater Systems in the Raleigh Belt of North Carolina's Piedmont

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Clean Water for Healthy Communities

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Outline

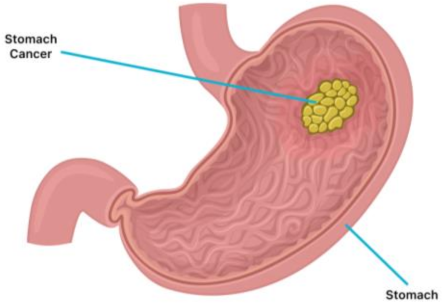
- Introduction
  - Significance and sources of nitrogen (N) pollution
  - Onsite wastewater management systems
- Key Methods
- Results
- Conclusions

All materials presented herein and henceforth represent my own opinion, and do NOT reflect the opinions of NOWRA

Significance of Nitrogen Pollution

- ☐ Human health effects
  - ☐ Methemoglobinemia
  - ☐ Stomach cancer

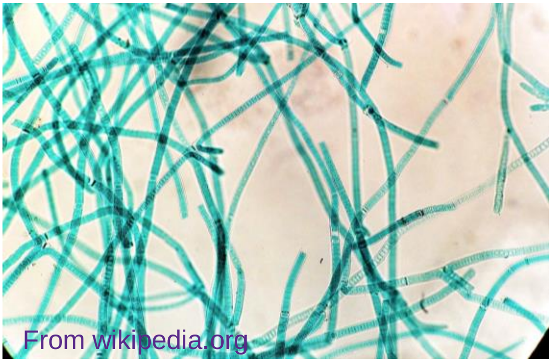
Biggs & Castillo (2016)



Llamas (2023)

- ☐ Environmental effects
  - ☐ Eutrophication
  - ☐ Algal blooms
  - ☐ Harmful effects
    - ☐ Cyanobacteria
    - ☐ Fish kills
    - ☐ Recreational impacts

From deq.nc.gov



From wikipedia.org

From theguardian.com

From news.psu.edu

(Mallin et al. 1998, 2007; Cahoon et al. 2006)

Sources of Nitrogen

Industrial

From aamaktiba.com

Row crop

From umequip.com

Pet waste

Wildlife waste

© Brittany Crossman

Atmospheric Dep.

From theregister.co.uk

Urban wastewater

From phys.org

Onsite wastewater

CAFOs

From nepork.org

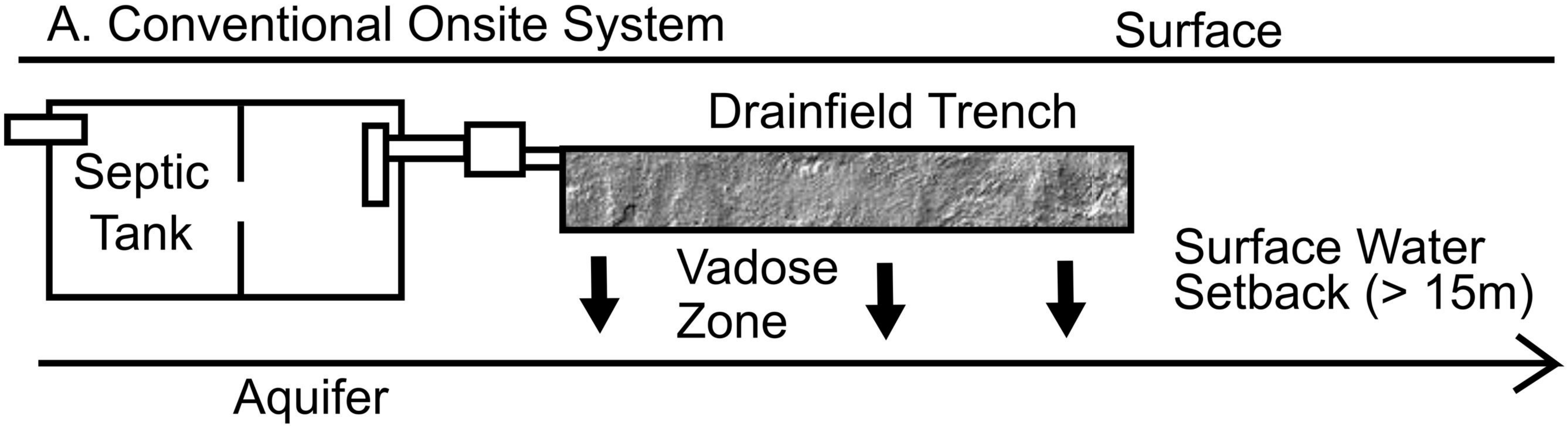
Urban runoff

From savenewport.com

Home fertilizer

From homedepot.com

Onsite Wastewater Systems (OWSs)



Past studies and future needs:

- ❑ Total dissolved nitrogen (TDN) in wastewater range from 26 – 94.4 mg/L; N reduction ranged from 74 – ~100% between tank and stream
- ❑ GW and SW still may contain elevated TDN, esp. in HD areas
- ❑ Recent studies in Piedmont NC focused on Triassic Basin soils

(US EPA, 2002; Humphrey et al., 2013, 2016, 2018, 2019; O'Driscoll et al., 2014, 2020; Iverson et al., 2015, 2018; Lusk et al., 2017; Robertson et al., 1991, 2019; Harman et al., 1996; Buetow, 2002; Hoghooghi et al., 2016)

Study Goals and Objectives

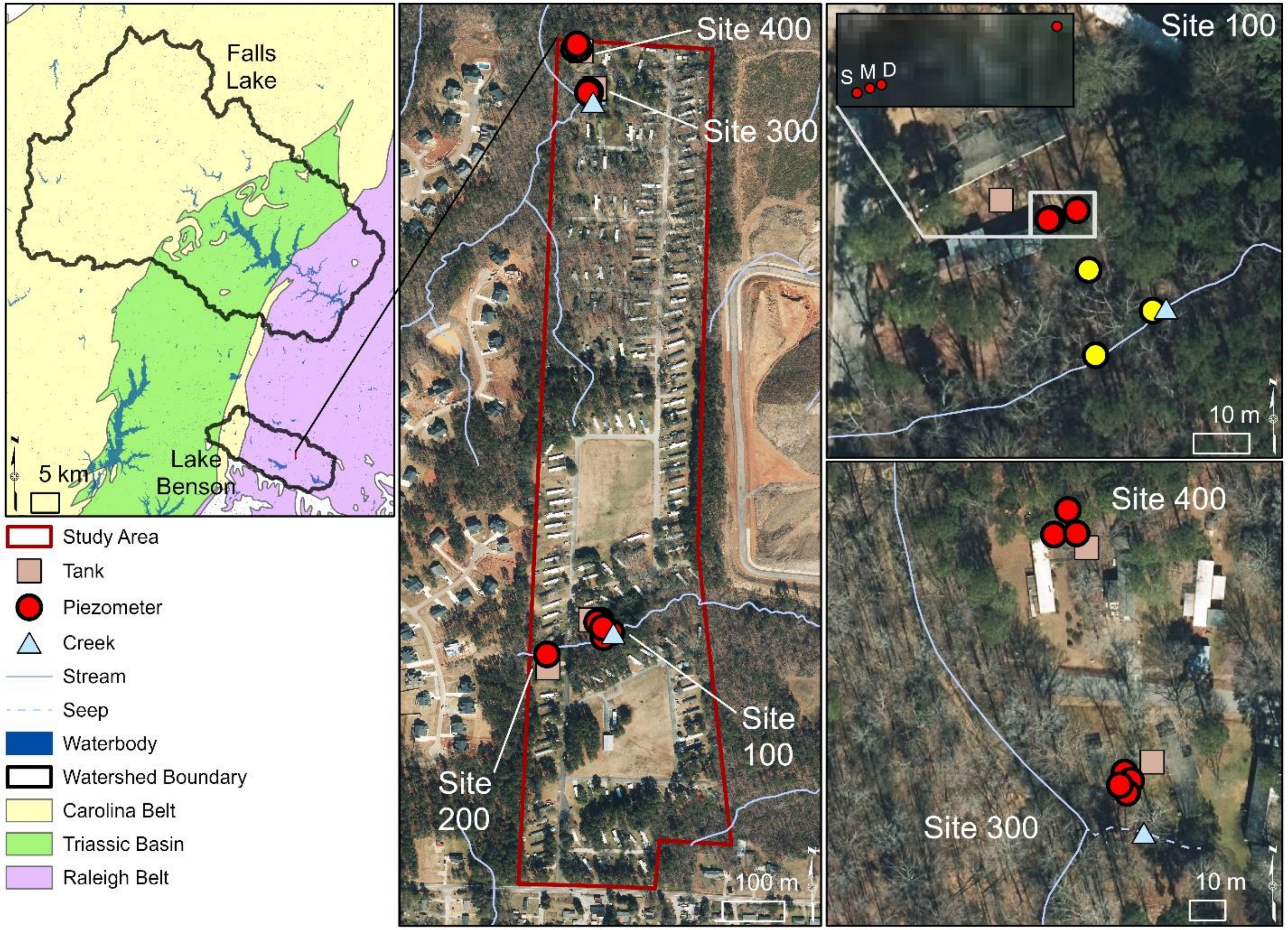
- ☐ Goal: Quantify TDN treatment by OWSs in Raleigh Belt geologic settings
- ☐ Objectives:

1. Compare N concentrations in groundwater and surface water downgradient of OWSs
2. Evaluate OWS performance based on concentration reduction of TDN
3. Estimate mass reductions of TDN based on N/Cl^- ratios
4. Quantify TN mass export in streams downgradient of studied OWSs

Methodology

Study Area

- Four volunteer sites were located within the Lake Benson WS
  - Site 200 → dry
- OWS density: ~3.7 systems/ha
  - 110 OWSs in 29.2 ha
- 2 small streams drain the community
- Predominant geology is biotite gneiss and mica schist

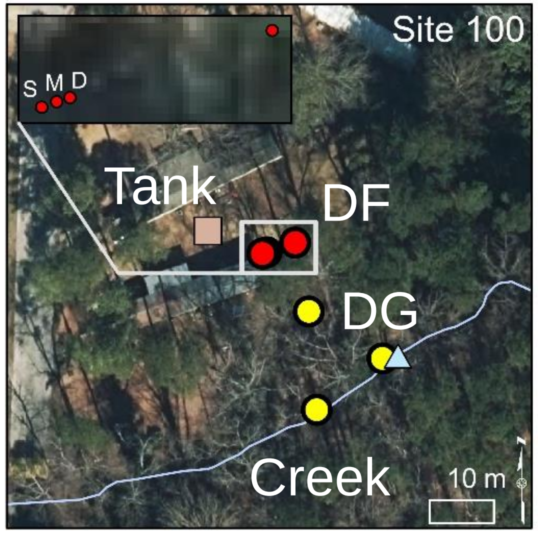


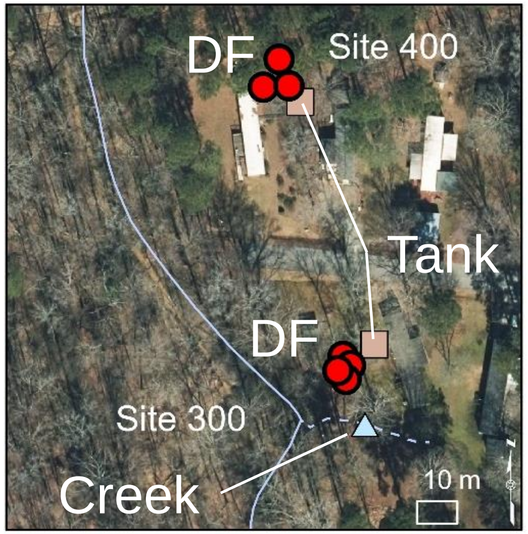
Soils Data

Location	Soil Series	Description	Soil Texture	Typical Depth to Water (cm [in])	Hydrologic Soil Group	Drainage Class
Site 100 Site 200	Pacolet	Urban land complex; 10 - 15% slopes; saprolite derived from granite and gneiss and/or schist	Sandy loam to clay (Group II - IV)	> 203 (> 80)	B	Well drained
Site 300	Chewacla and Wehadkee	0 - 2% slopes, frequently flooded; loamy alluvium derived from igneous and metamorphic rock	Ch: Loam to clay loam (Group II - III) W: Silt loam to clay loam (Group III)	Ch: 15 - 61 (6 - 24) W: 0 - 30 (0 - 12)	B/D (Ch & W)	Ch: Somewhat poorly drained W: Poorly drained
Site 400	Altavista	0 - 4% slopes; sandy loam; rarely flooded; derived from igneous and metamorphic rocks	Coarse sandy loam to clay loam (Group II - III)	45 - 76 (18 - 30)	C	Moderately well drained

Site Instrumentation

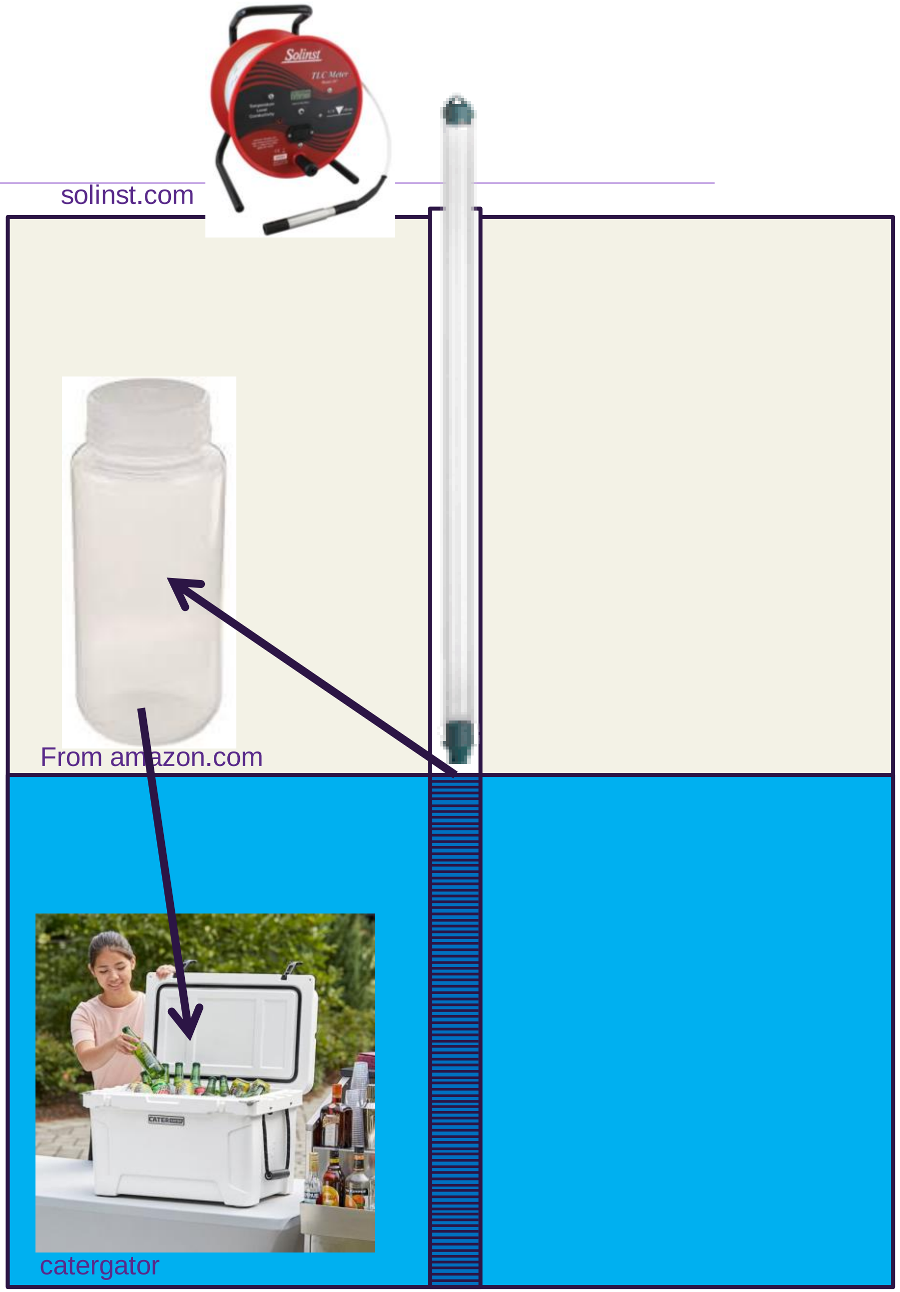
- Hand augers used to drill boreholes between, adjacent to, and downgradient of drainfields
- 15 piezometers installed
  - Installed 0.3 – 0.9 m beneath SHWT
  - Diameter was 3.18 cm or 5.08 cm
  - Total depth: 0.9 – 2.7 m
- Site 100 also contained 3 downgradient piezometers
- 2 creeks sampling locations (Sites 100 and 300)
- 1 BG piezometer installed near the site





Sampling Protocol

- 10 sampling events (Feb 22 – Apr 23)
- DTW measured (*Solinst* TLC)
- Purged with bailer and sampled
- Samples were collected for N assessment at the ECU ERL
- Creeks sampled via direct grab sampling
- Stream discharge estimated:
  - Volumetric bottle fill
  - Q = Avg. V * Avg Depth * Stream width



solinst.com

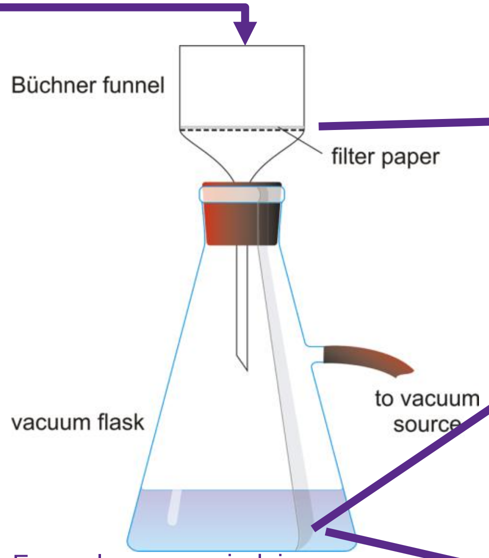
From amazon.com

catergator

Laboratory Methods

Vacuum Filtering


From amazon.com



From glossary.periodni.com

Quantification of Nutrient Concentration


From unityscientific.com

- NO_3-N
- NH_4-N
- Cl
- PN (filter)

} DIN


From shimadzu.com

- TDN
- DON = TDN – DIN
- TN = TDN + PN

Estimating Stream TN Mass

$$Mass = Q \times TN\ Conc$$

Results

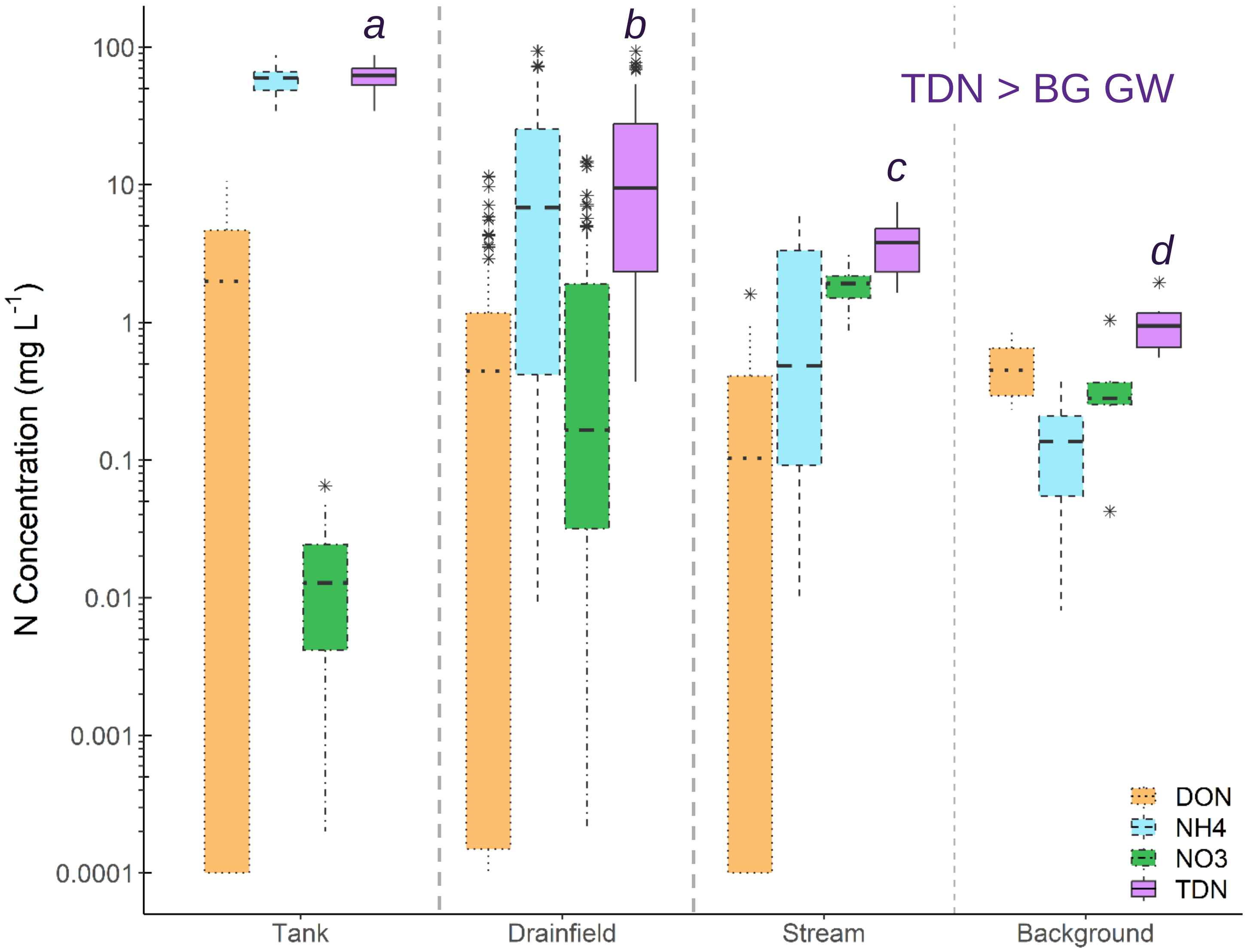
Nitrogen Concentration & Speciation

- ❑ Pooled by location
- ❑ Median TDN (mg/L)
  - ❑ Tank – 62.15
  - ❑ DF – 9.54
  - ❑ Stream – 3.81
  - ❑ Significant differences?

85%

94%

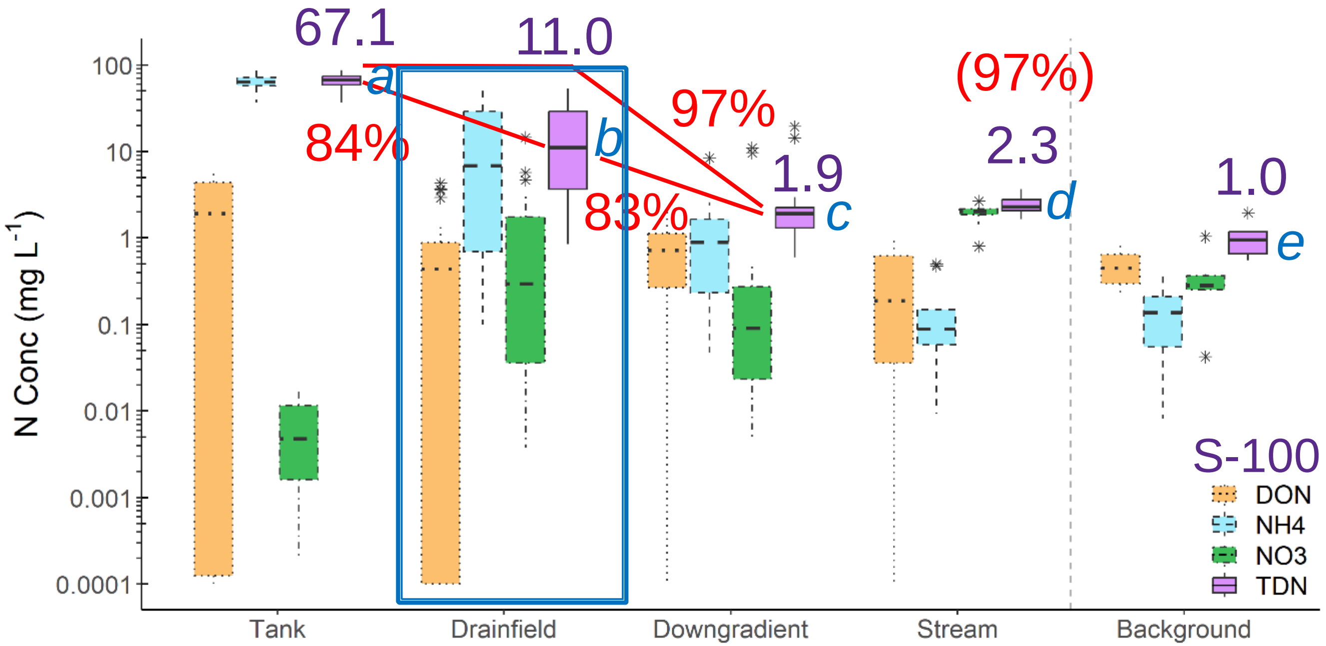
- ❑ Speciation
  - ❑ Tanks → mostly NH_4^+
  - ❑ DF → mostly NH_4^+
  - ❑ Streams → mostly NO_3^-, but NH_4^+ elevated
- ❑ Site differences?

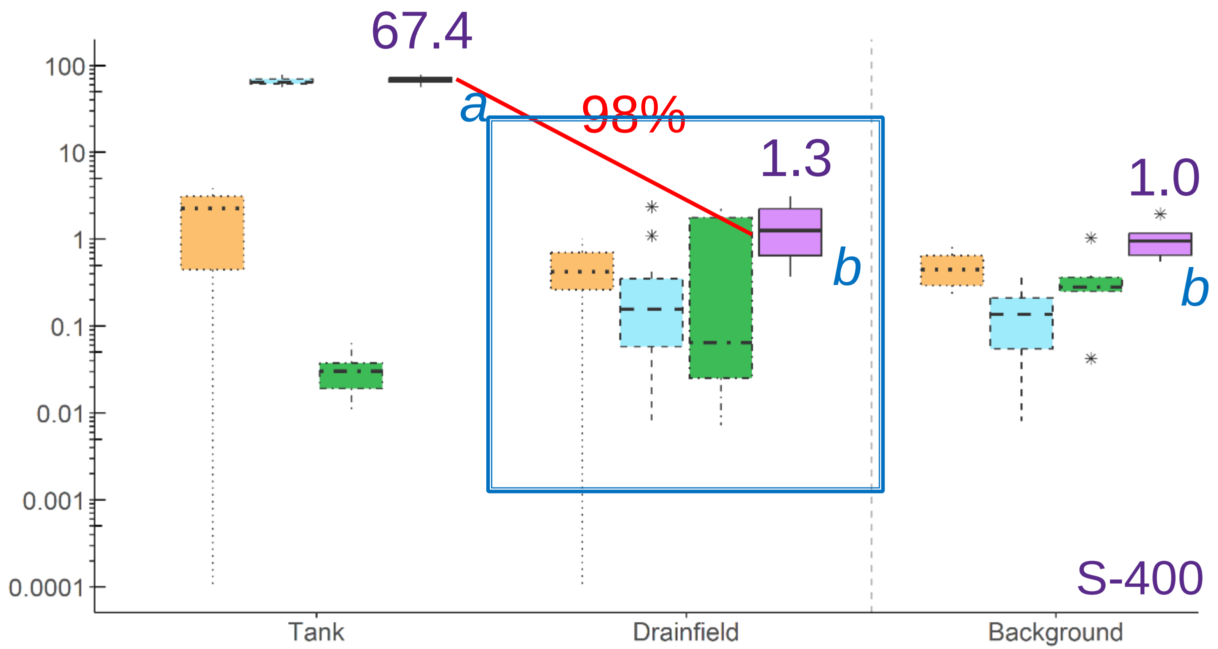


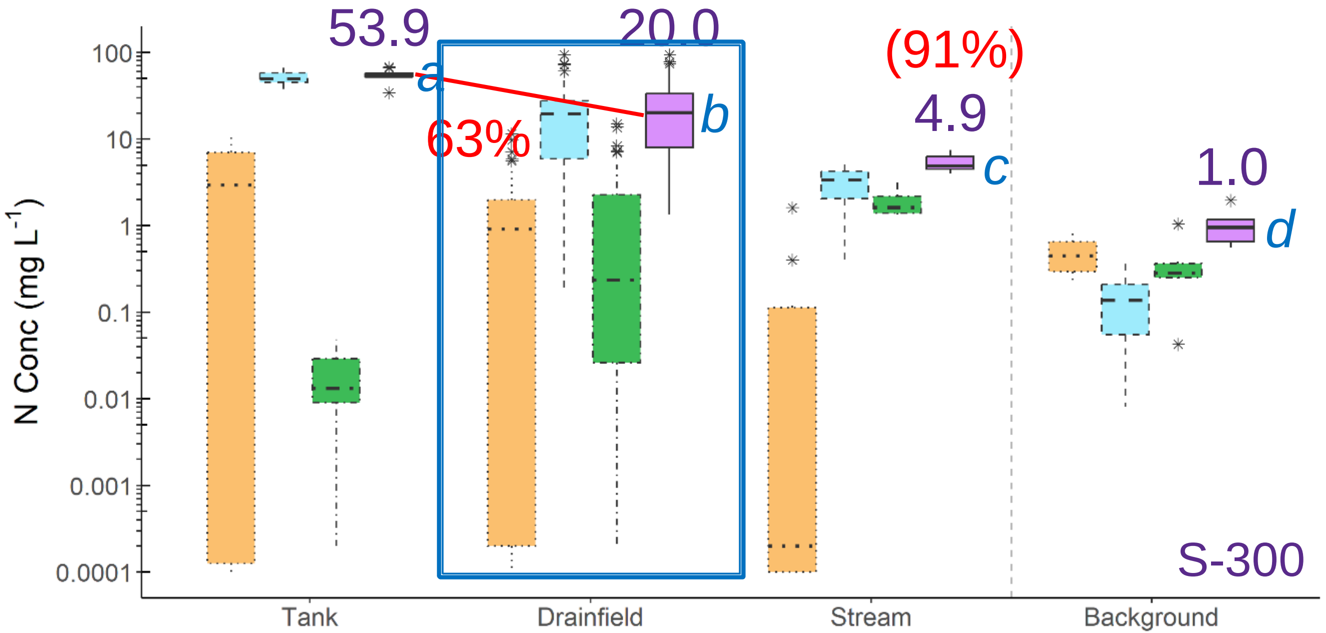
TDN > BG GW

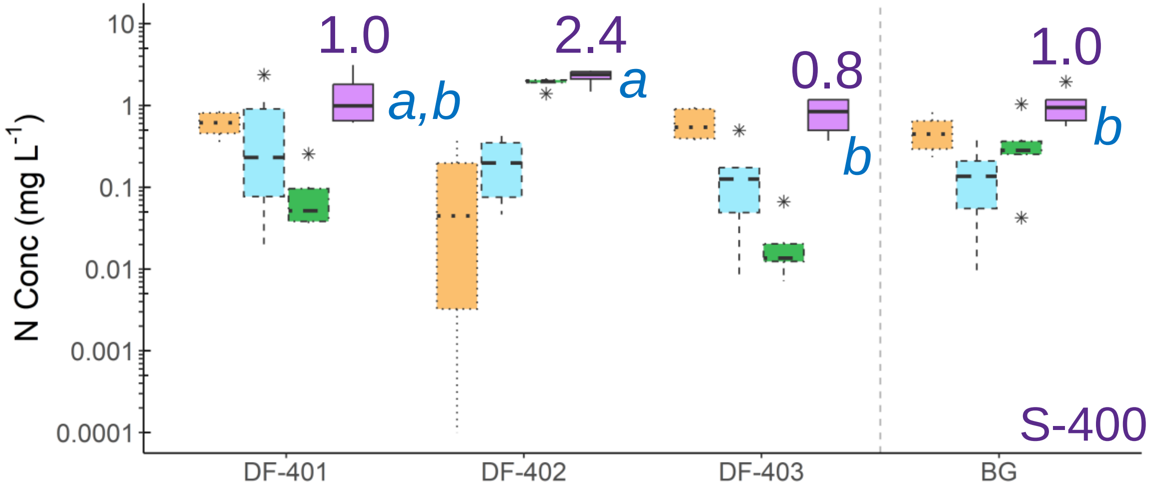
Differing letters denote statistically significant differences ($p \leq 0.05$)

Lot-scale Trends in Nitrogen





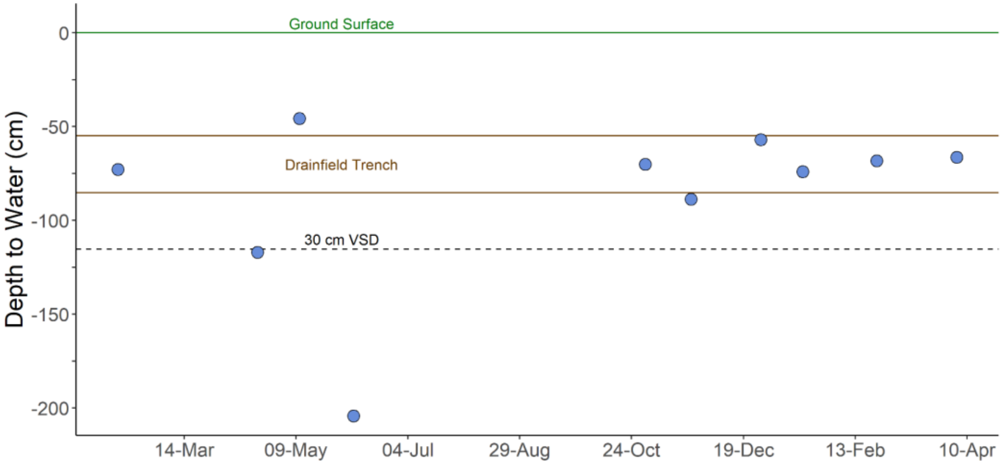




Differing letters denote statistically significant differences ($p \le 0.05$)

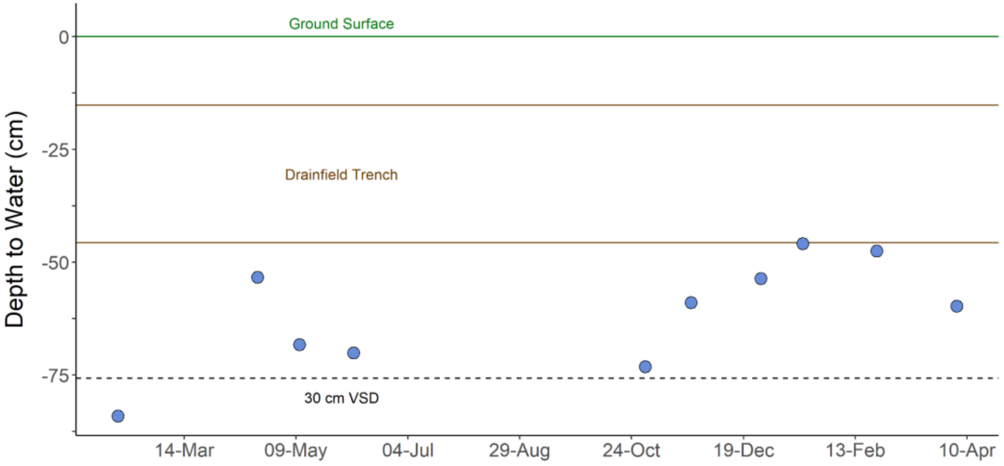
A Need for Distance

- Sites 100 & 300 had issues with maintaining minimal vertical separation distance (VSD)
- Group II – IV soils require 30 cm of separation from trench bottom to water table
- Need additional high frequency monitoring



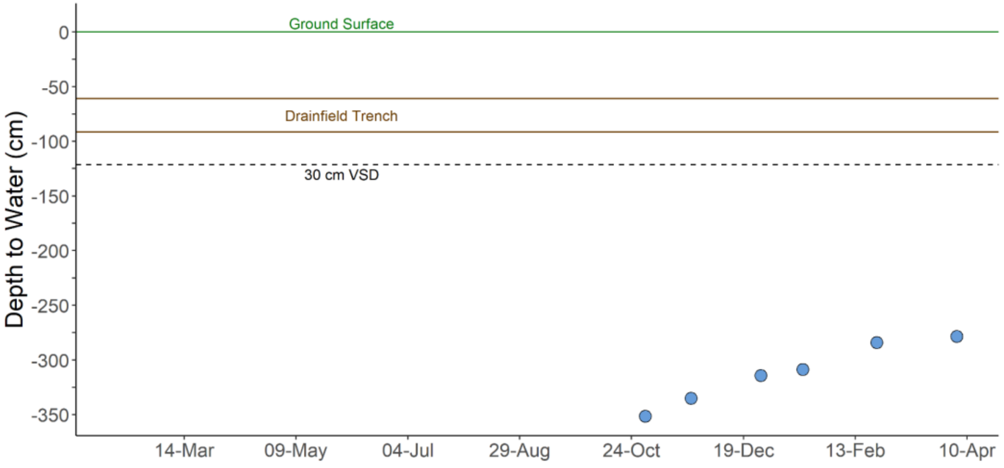
Site 100

- DTW within 30 cm of the trench or within trench on 80% of sampling events



Site 300

- DTW within 30 cm of the trench or within trench on 90% of sampling events



Site 400

- DTW never encroached VSD during sampling events (n= 6)

Estimating Mass Reductions

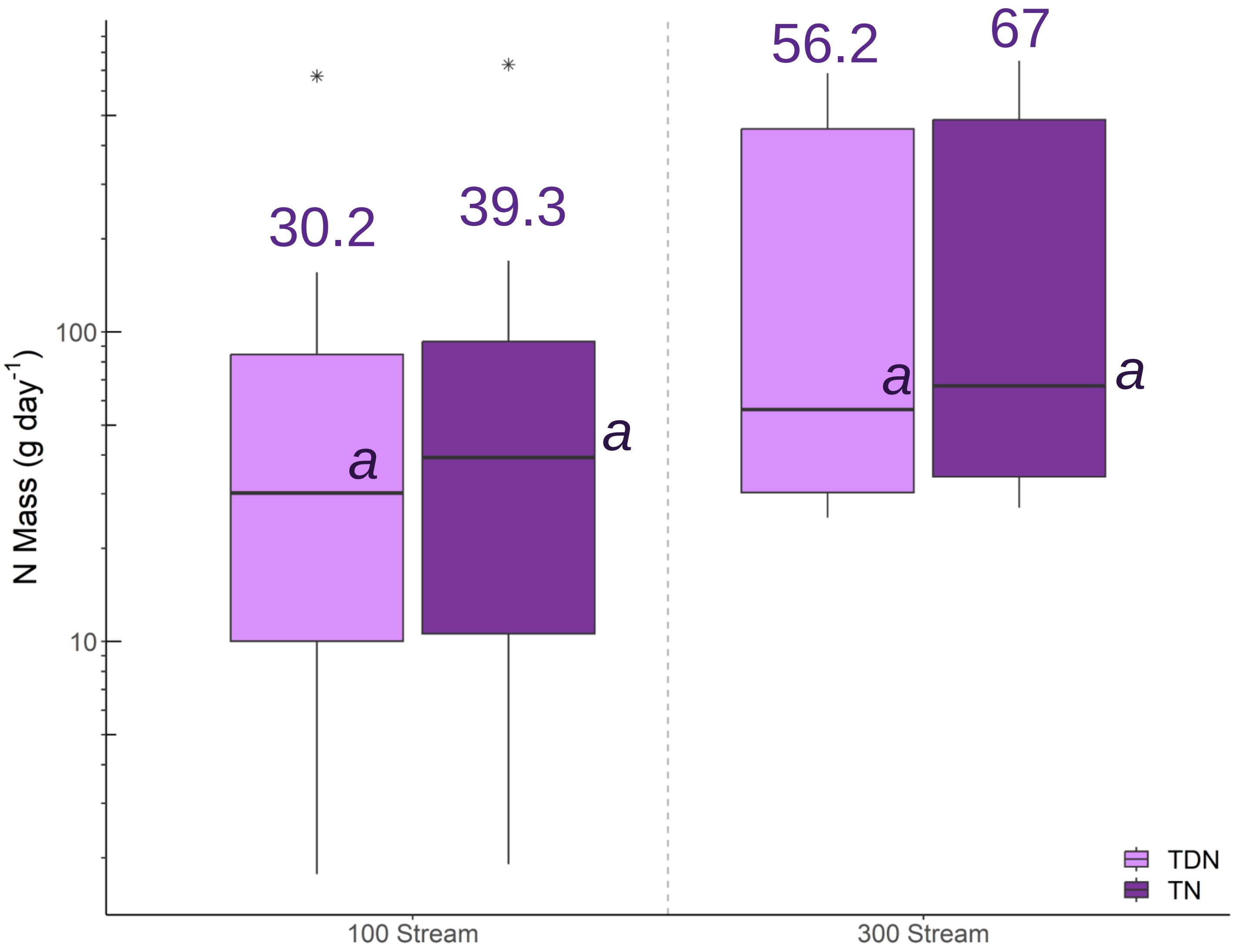
- Dilution impacts concentration reductions
- Cl- → conservative in fresh environments
- Mass removal estimates:
  - Site 100 → 25 – 88% TDN
  - Site 300 → 38% TDN
  - Site 400 → 97% TDN
- Malfunctions negatively affected mass removal estimates

Location	Cl (mg L^{-1})	Fraction WW	Fraction GW	Predicted TDN (mg L^{-1})	Observed TDN (mg L^{-1})	Cl/TDN Ratio	TDN Mass Reduction (%)
Site 100							
Tank	69.76	1.00	0.00		67.08	1.04	
DF	26.54	0.33	0.67	22.28	11.02	2.41	50.53%
15 m	26.65	0.33	0.67	22.39	16.88	1.58	24.60%
30 m	18.04	0.20	0.80	13.47	1.63	11.04	87.87%
BG	5.04	0.00	1.00		0.95	5.33	
Site 300							
Tank	62.07	1.00	0.00		53.90	1.15	
DF	39.39	0.60	0.40	32.46	20.04	1.97	38.27%
BG	5.04	0.00	1.00		0.95	5.33	
Site 400							
Tank	52.47	1.00	0.00		67.35	0.78	
DF	31.37	0.56	0.44	37.40	1.26	24.95	96.64%
BG	5.04	0.00	1.00		0.95	5.33	

- *Model estimates reductions by dilution alone (e.g., Predicted TDN)*
- *Estimated by multiplying observed TDN by fraction WW to predict TDN if dilution was the only treatment mechanism*
- *Differences in predicted and observed TDN assumed to be mass reductions*

Evaluating Off-site Transport in Streams

- ☐ Streams monitored during baseflow
- ☐ Median Q (L/min)
  - ☐ Site 100 → 11.9 (0.6 - 127.3)
  - ☐ Site 300 → 8.1 (2.6 - 99.6)
- ☐ Median N Conc (mg/L)
  - ☐ Site 100 → 2.45 TN; 2.29 TDN
  - ☐ Site 300 → 5.29 TN; 4.86 TDN
- ☐ Site 300 tended to contain elevated concentrations and masses of nitrogen relative to Site 100
  - ☐ Both routinely malfunctioned, but 300 closer its stream



Normalizing Transport by Area

- ❑ Both streams drain small areas
  - ❑ 100 Stream – 9.2 ha
  - ❑ 300 Stream – 1.9 ha
- ❑ Streams exhibited significant differences after area normalizing
- ❑ These data suggest that malfunctional OWSs can be potentially significant nutrient sources, especially if streams lack sufficient vegetated buffers

Parameter Export	Site 100-Stream	 300-Stream
Daily (g/day/ha)		
TDN	3.3 (0.2 - 73)	30.4 (13.6 - 370.6)
TN	4.3 (0.2 - 79.5)	36.2 (14.6 - 406.2)
Annual (kg/yr/ha)		
TDN	1.2 (0.1 - 26.6)	11.1 (5 - 135.3)
TN	1.6 (0.1 - 29)	13.2 (5.3 - 148.3)

- ❑ Past studies in the NC Piedmont estimated annual watershed exports of 1.9 – 6.7 kg-TDN/yr/ha
- ❑ Density is an important factor and high density watersheds may export up to 44.1 kg-TDN/yr/ha

(Line, 2013; Iverson et al. 2018)

Conclusions

- Highest TDN in WW, but DF GW at Sites 100 and 300 occasionally contained WW strength
- Concentration reductions were variable depending on location and malfunction status
  - Site 100 – Median TDN reduced by 84 – 97%
  - Site 300 – Median TDN reduced by 63 – 91%
  - Site 400 – Median TDN reduced by 98%
- Mass reduction was lower, likely inhibited by malfunction
  - Site 100 – Mass of TDN reduced by 25 – 88%
  - Site 300 – Mass of TDN reduced by 38%
  - Site 400 – Mass of TDN reduced by 97%
- Stream exports indicate that OWS can transport substantial masses of nitrogen, especially during malfunctions that occur during the wet season

Additional Research Needs

- High-frequency assessment of malfunction duration?
  - HOBO loggers to evaluate DTW over shorter timespans
- Longitudinal surveys in streams?
  - In-stream processing?
  - Additional malfunctional OWSs?
  - Nutrient mass load from these tributaries to larger watersheds?
- Storm impacts on nutrient transport?

Acknowledgments

☐ The University of North Carolina Policy Collaboratory grant program for funding this research

☐ Site volunteers who allowed access

☐ Wake County Environmental Services for assistance in locating sites

☐ Dr. Suelen Tullio, Dr. John Haywood, Kaleigh Bell, and ERL staff for their support in analyzing water quality samples

Questions?

- Thank you for your attention and attending today!

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2023
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NAWT National Association of Wastewater Technicians
SORA State Onsite Regulators Association
VOWRA Virginia Onsite Wastewater Recycling Association