Stony Brook University

Attenuation and Mobilization of Phosphorus in Nitrogen Removing Biofilters Treating Domestic Onsite Wastewater

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2023 Onsite Wastewater Mega-Conference

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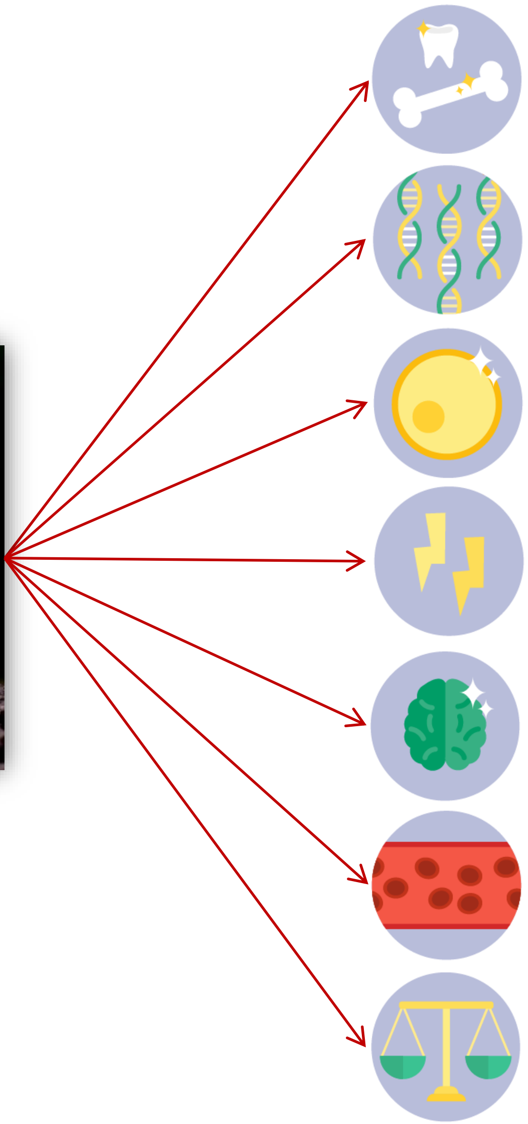
Outline

- Introduction
- Research questions and objectives
- Field study
- P attenuation in nitrification layer
- P attenuation in denitrification layer
- Summary and future works

Introduction

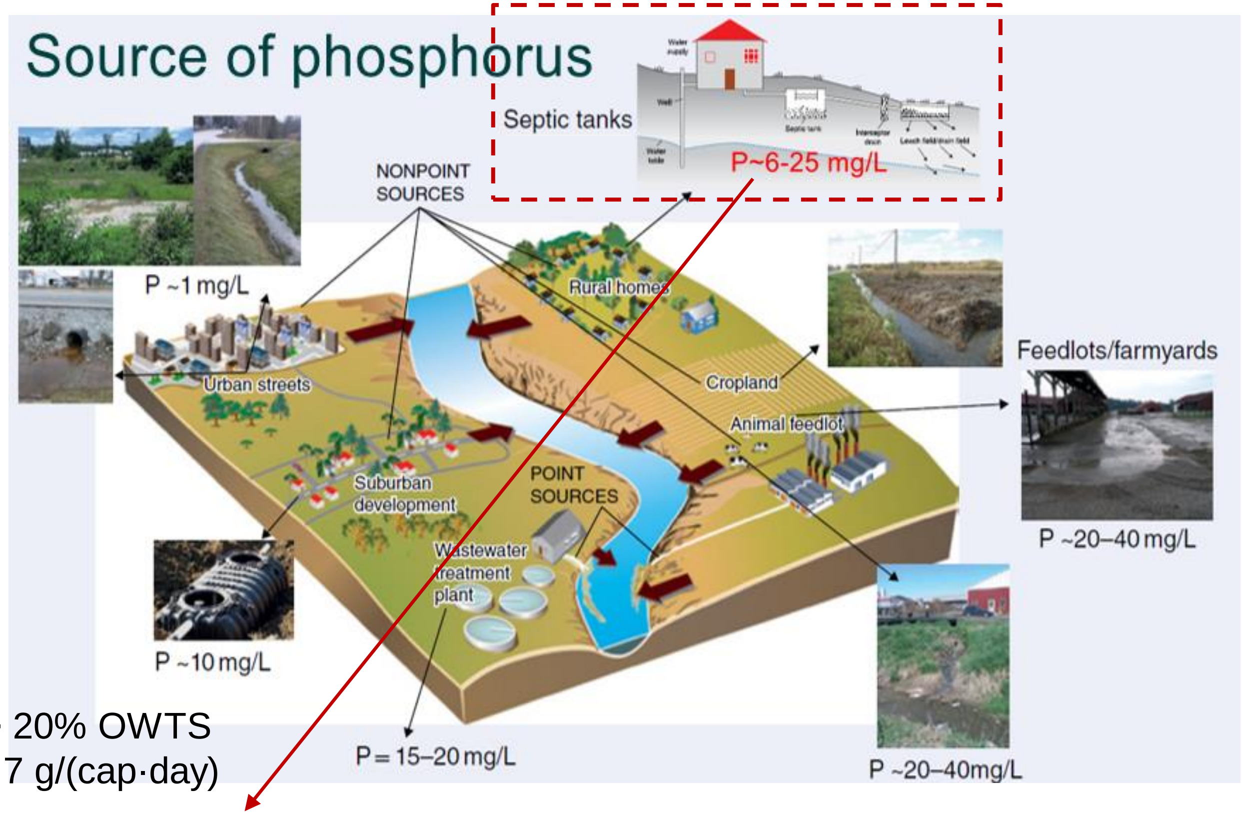
- Essential for living beings
- Limited and nonrenewable



- Bones and teeth
- DNA and RNA
- Cell membrane
- Energy
- Brain and nervous system
- Oxygen
- pH

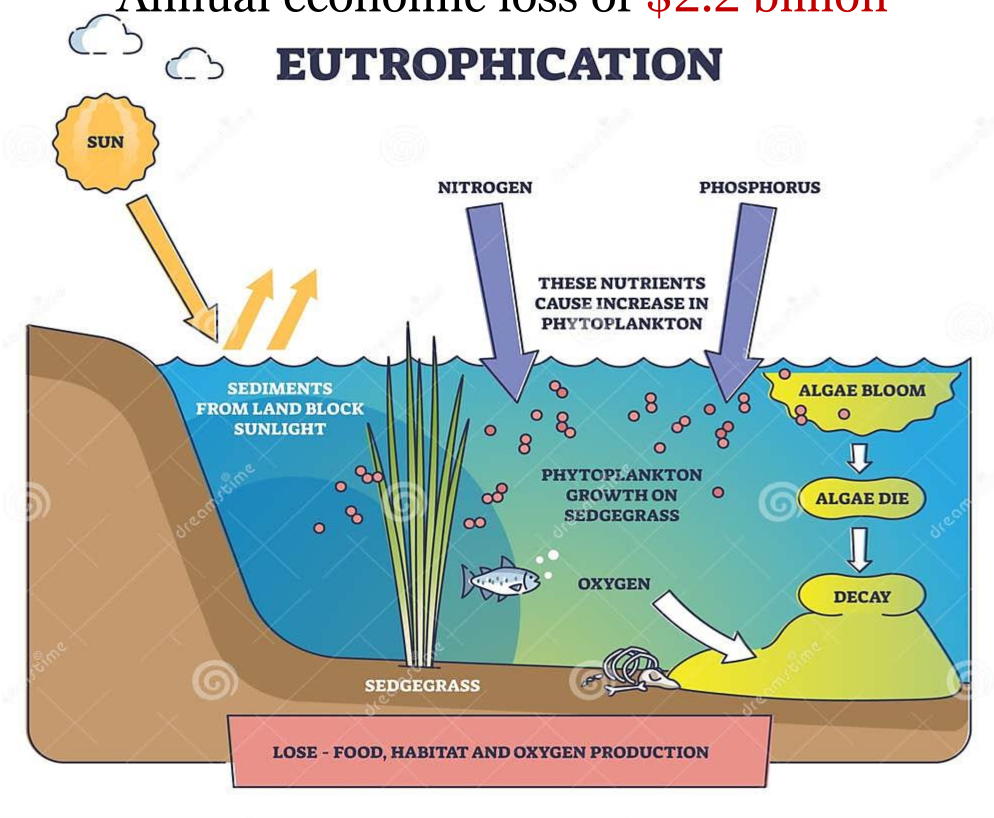
Introduction

- **Source and pollution problem**



> 20% OWTS
2.7 g/(cap·day)

Annual economic loss of $2.2 billion



65.42 kt P/year need to be treated by OWTS in US

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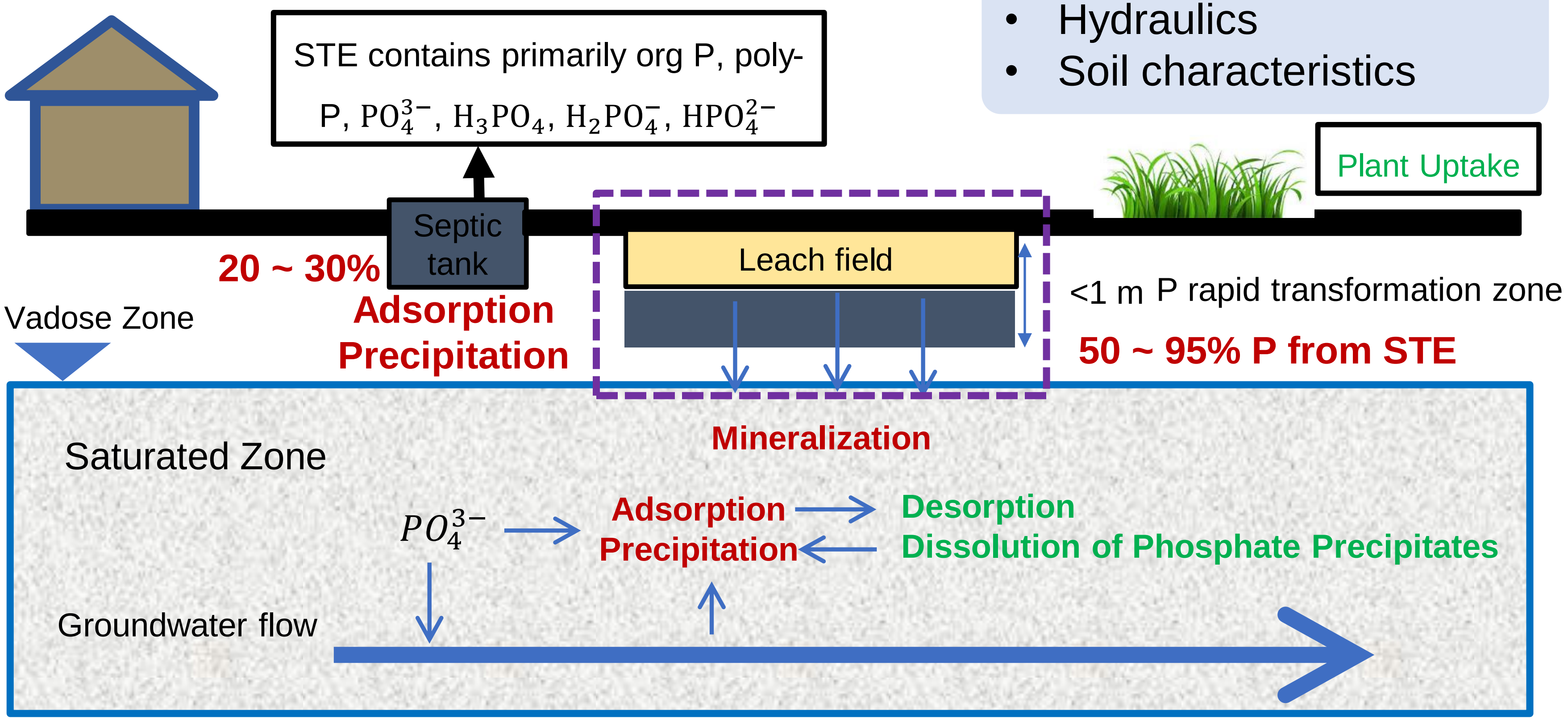
The figure was modified from Drizo, 2019.
Dodds, Walter K., et al. "Eutrophication of US freshwaters: analysis of potential economic damages." (2009): 12-19.
https://www.dreamstime.com/eutrophication-process-explanation-water-pollution-stages-outline-diagram-eutrophication-process-explanation-water-image250885246

The fate of P in OWTS

- **Can OWTS remove P?**

- pH
- Redox potential
- Particle size/surface area
- Hydraulics
- Soil characteristics



P transformations in septic systems and subsurface

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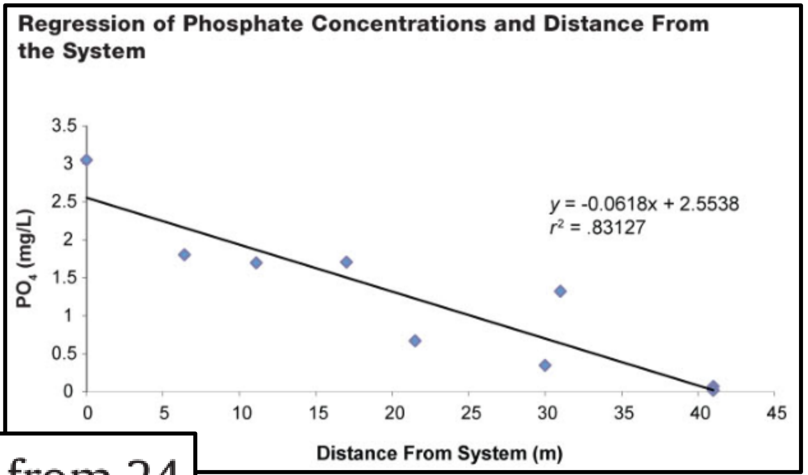
Lusk, Mary G., et al. "A review of the fate and transport of nitrogen, phosphorus, pathogens, and trace organic chemicals in septic systems." *Critical Reviews in Environmental Science and Technology* 47.7 (2017): 455-541.

Introduction

- **Is P discharge from OWTS a problem?**



Fate, mass balance, and transport of phosphorus in the septic system drainfields

Sara Mechtens

Soil and Water Quality L
672, Wimauma, FL 3359

Review of phosphorus attenuation in groundwater plumes from 24 septic systems

William D. Ro

[a] *University of Waterlo*
[b] *Environment and Clin*

Do septic tank systems pose a hidden threat to water quality?

Paul JA Withers[1*]

Comparison of Phosphorus Concentrations in Coastal Plain Watersheds Served by Onsite Wastewater Treatment Systems and a Municipal Sewer Treatment System

Charles P. Hump
Michael O'Drisc

Fate of Nutrients in Shallow Groundwater Receiving Treated Septage, Malibu, CA

by John A. Izbicki

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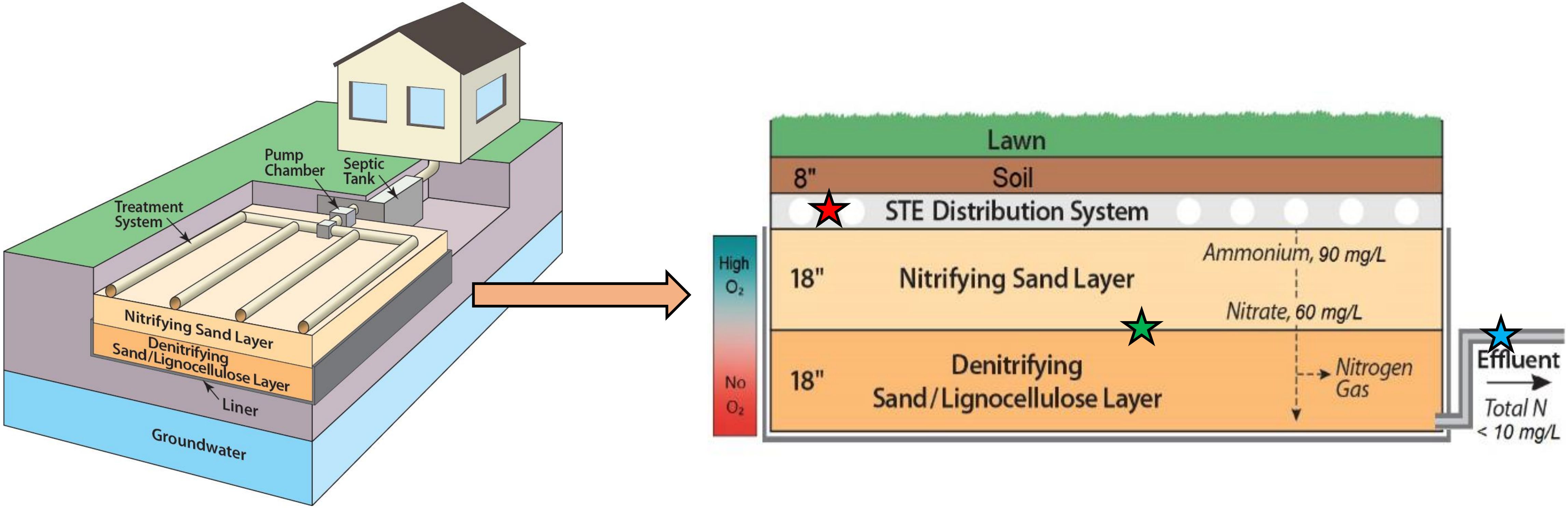
Humphrey, Charles, et al. "Fate and transport of phosphate from an onsite wastewater system in Beaufort County, North Carolina." *Journal of Environmental Health* 76.6 (2014): 28-33.

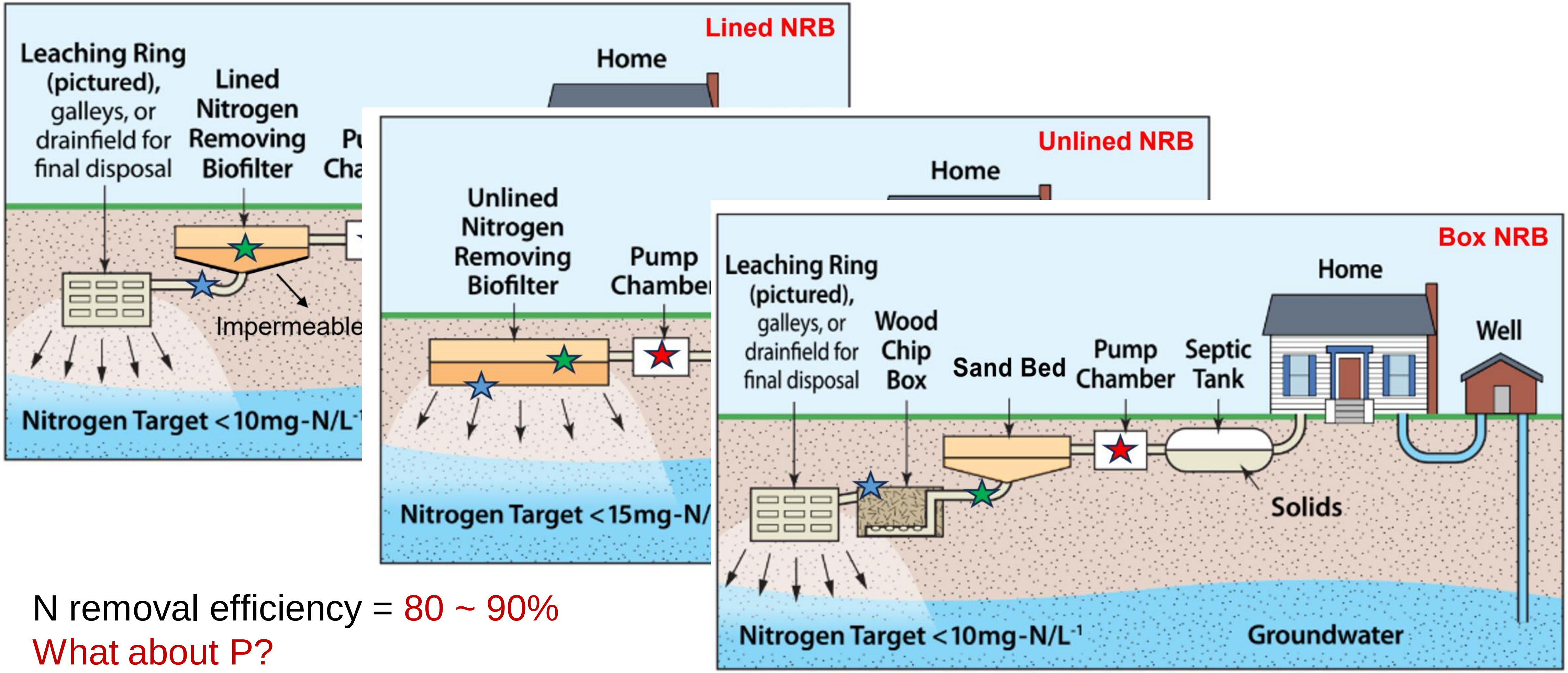
Nitrogen Removing Biofilters (NRBs)



Configuration of a **<u>lined</u>** nitrogen removing biofilter
(stars represented the sampling locations)

Gobler, Christopher J., et al. "Removing 80%–90% of nitrogen and organic contaminants with three distinct passive, lignocellulose-based on-site septic systems receiving municipal and residential wastewater." *Ecological Engineering* 161 (2021): 106157.

Configurations of NRBs



N removal efficiency = 80 ~ 90%

What about P?

The configurations (lined, unlined, box) of NRBs

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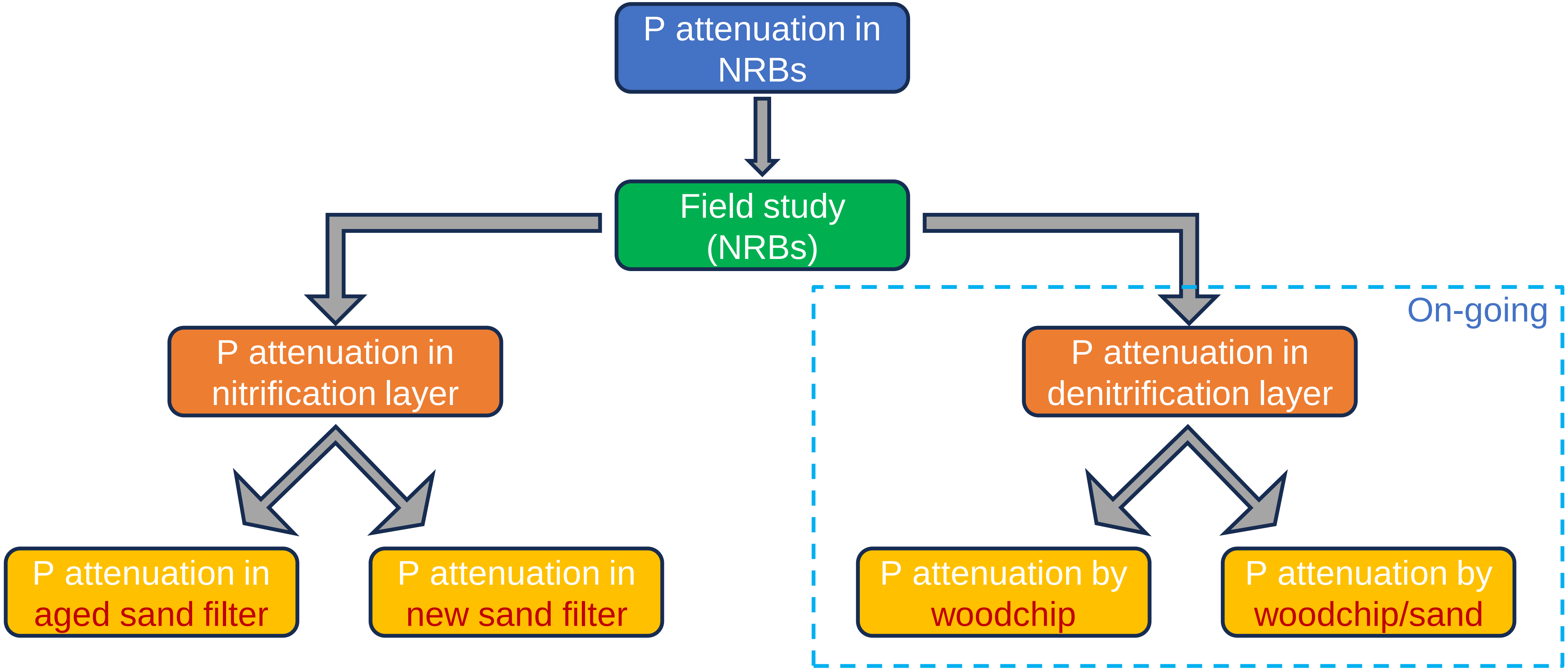
Gobler, Christopher J., et al. "Removing 80%–90% of nitrogen and organic contaminants with three distinct passive, lignocellulose-based on-site septic systems receiving municipal and residential wastewater." *Ecological Engineering* 161 (2021): 106157.

Research questions and objectives

- **Research questions**
  - 1. Can NRBs effectively remove P from septic tank effluent (STE)?
  - 2. How much of the P can be attenuated or leached from each layer within NRBs?
  - 3. How would environmental/operation conditions change impact P fate and transport?
- **Objectives**
  - 1. Evaluate long-term P removal performance in field NRBs with various configurations.
  - 2. Investigate P attenuation and leaching potential in a) newly installed and aged nitrification sand filters, and b) woodchip and woodchip/sand mixed denitrification filters

Study design



The research workflow for P attenuation and remobilization in NRBs

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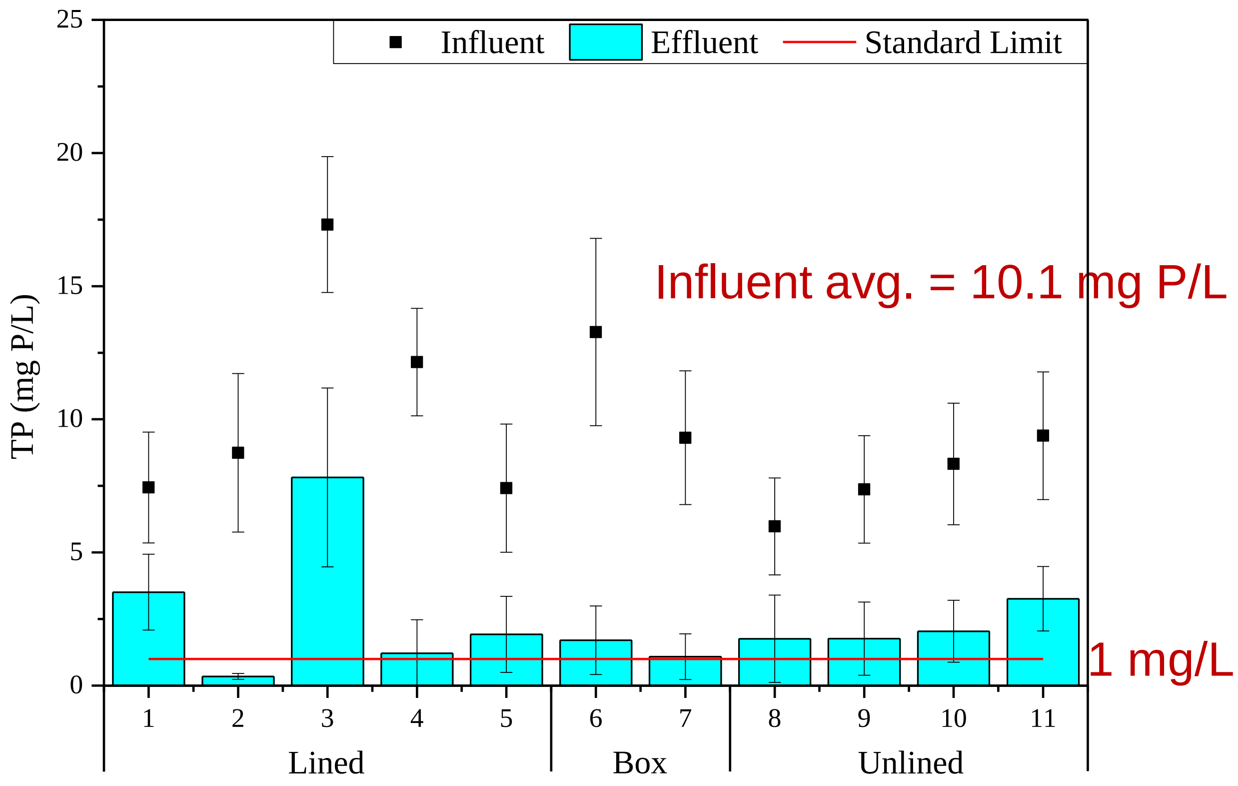
Field study – influent and effluent P levels in NRBs

configurations of field NRBs

Site number	Configuration	Installation time
1	Lined	Apr. 2021
2	Lined	Mar. 2021
3	Lined	Aug. 2019
4	Lined	May 2019
5	Lined	Mar. 2018
6	Box	Feb. 2020
7	Box	Apr. 2018
8	Unlined	Apr. 2021
9	Unlined	Mar. 2021
10	Unlined	Jan. 2019
11	Unlined	Apr. 2018



Average influent and effluent P levels measured during 18 months of sampling

EPA (1992) recommended TP ≤ 50 µg/L in a stream where it enters a lake/reservoir

Field study – Overall P removal efficiency (PRE)

The influent and effluent range of TP measured over the period of 18 months (June 2021-December 2022)

Site number	Configuration	Installation time	PRE (%)**	Average (%)	STD
1	Lined	Apr. 2021	50.4		
2	Lined	Mar. 2021	95.7		
3	Lined	Aug. 2019	55.5	72.6	20.1
4	Lined	May 2019	89.9		
5	Lined	Mar. 2018	71.6		
6	Box	Feb. 2020	84.8	85.6	1.1
7	Box	Apr. 2018	86.4		
8	Unlined	Apr. 2021	65.4		
9	Unlined	Mar. 2021	77.6	67.9	6.7
10	Unlined	Jan. 2019	66.2		
11	Unlined	Apr. 2018	62.3		

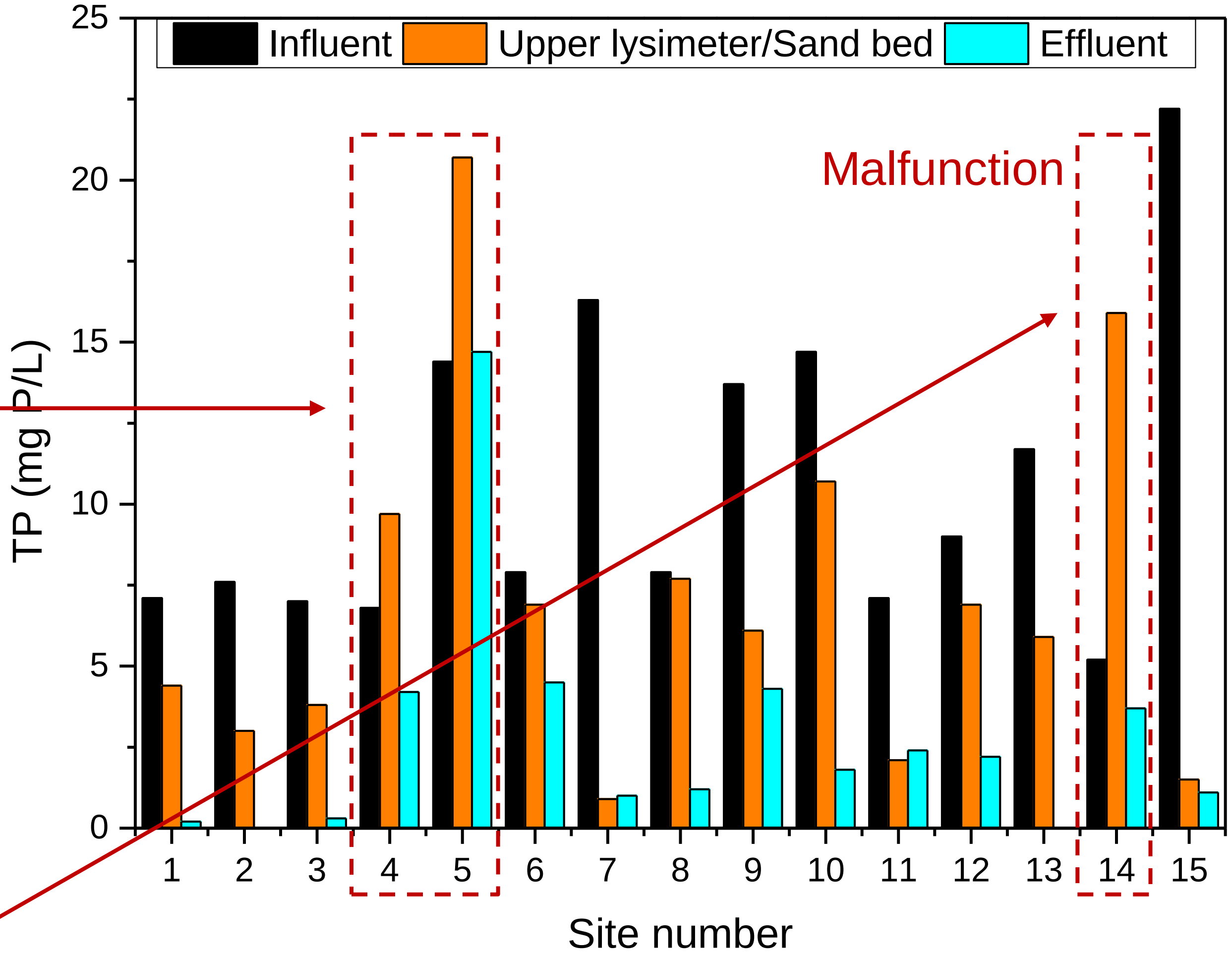
*BDL = Below detection limit (0.5 mg P/L)

**PRE = $\left(\sum_{each\ month}^{18} \frac{(\text{Influent}-\text{Effluent}) \times 100}{\text{Influent}}\right) \times \frac{1}{18}$

Field study – P removal by each treatment layer

configurations of field NRBs

Site number	Configuration	Installation time
1	Lined	Dec. 2021
2	Lined	Dec. 2021
3	Lined	Mar. 2021
4	Lined	Apr. 2019
5	Lined	Aug. 2019
6	Lined	Mar. 2018
7	Box	Dec. 2022
8	Box	Apr. 2018
9	Box	Dec. 2021
10	Box	Feb. 2020
11	Box	Dec. 2022
12	Unlined	Mar. 2021
13	Unlined	Mar. 2018
14	Unlined	Apr. 2021
15	Unlined	Sept. 2021



The aqueous samples were measured on a quarterly basis

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Field study – P removal by each treatment layer

PRE by various NRBs

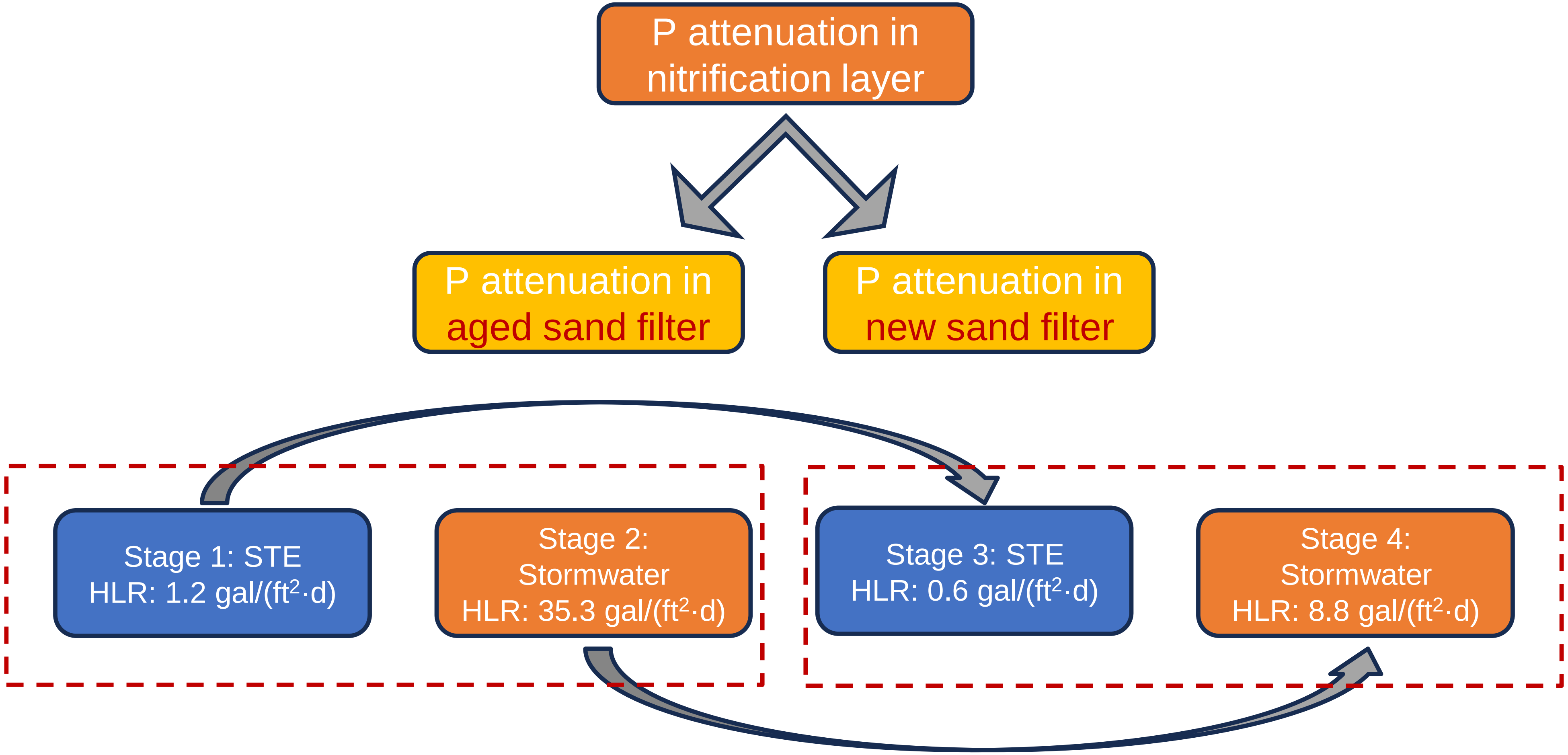
Site number	Configuration	Installation time	Nitrification layer PRE (%)	Denitrification layer PRE (%)	Total PRE (%)
1	Lined	Dec. 2021	38.03	95.45	97.18
2	Lined	Dec. 2021	60.53	99.67	99.87
3	Lined	Mar. 2021	45.71	92.11	95.71
4	Lined	Apr. 2019	-42.65	56.70	38.24
5	Lined	Aug. 2019	-43.75	28.99	-2.08
6	Lined	Mar. 2018	12.66	34.78	43.04
7	Box	Dec. 2022	94.48	-11.11	93.87
8	Box	Apr. 2018	2.53	84.42	84.81
9	Box	Dec. 2021	55.47	29.51	68.61
10	Box	Feb. 2020	27.21	83.18	87.76
11	Box	Dec. 2022	70.42	-14.29	66.20
12	Unlined	Mar. 2021	23.33	68.12	75.56
13	Unlined	Mar. 2018	49.57	n/a	n/a
14	Unlined	Apr. 2021	-205.77	76.73	28.85
15	Unlined	Sept. 2021	93.24	26.67	95.05

Leaching (sites 4–5)

Hydraulic clogging (sites 13–15)

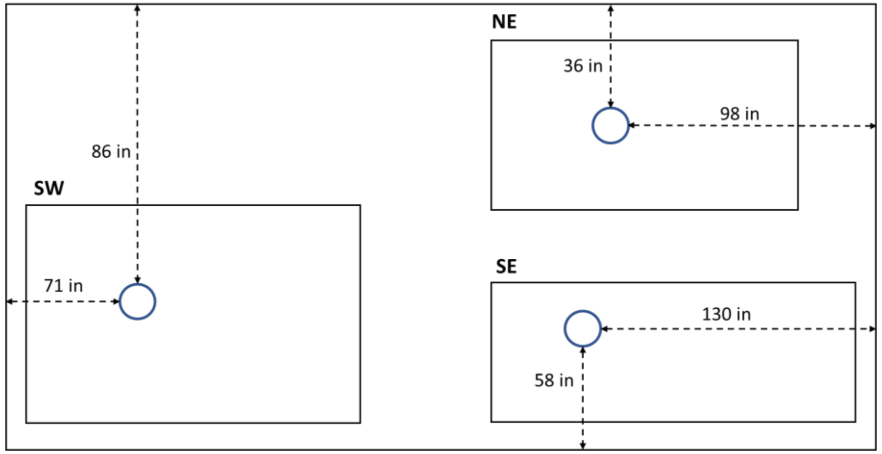
(Apr. 2023 – Aug. 2023)

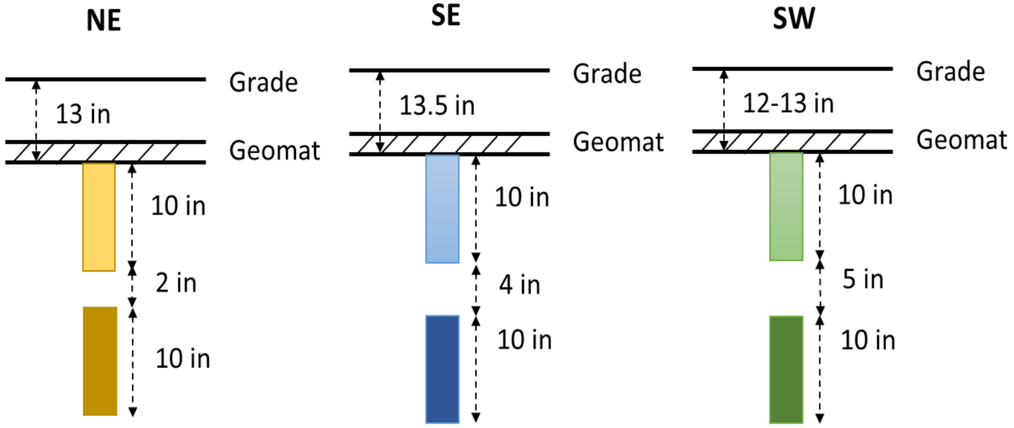
Nitrification layer – experiment design



The experiment design for P attenuation and remobilization in nitrification layer

Nitrification layer – source of materials



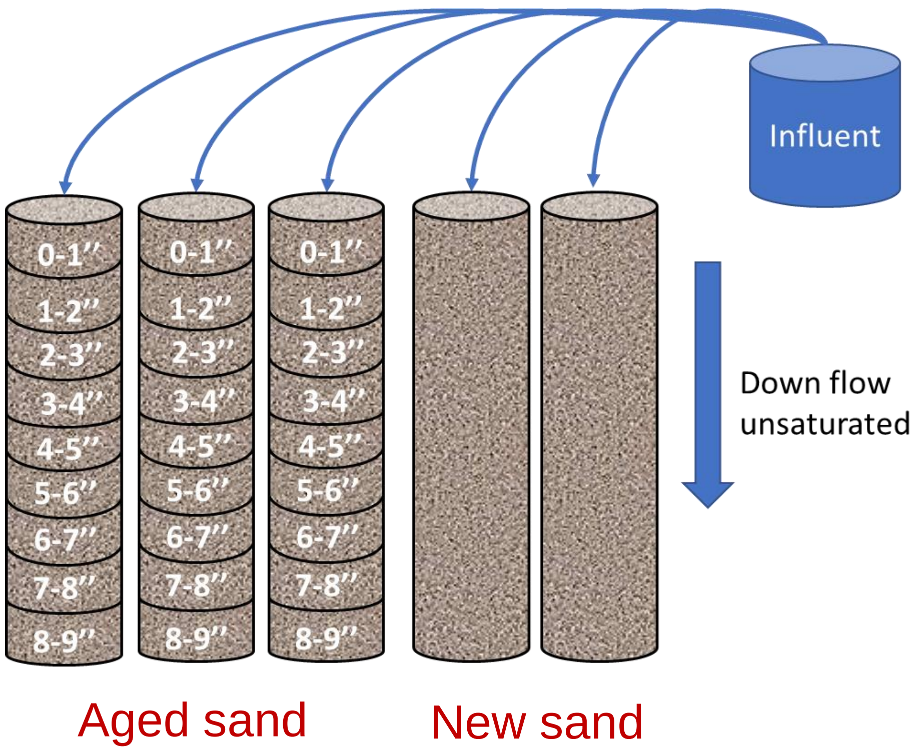


Sampling location (left) and profiles (right) within the 5-year-old NRB system in MASSTC

Characterization of new and aged sand

Sand	Type	pH	Fe (mg/g)	Al (mg/g)	Ca (mg/g)	Mg (mg/g)	Mn (mg/g)
C33	New	5.65	4.64	12.39	1.27	0.44	0.16
Northeast	Aged	6.33	13.34	21.05	3.97	2.00	0.15
Southwest	Aged	6.83	7.42	17.45	1.09	1.02	0.09
Southeast	Aged	6.30	3.86	13.20	1.33	0.50	0.08

Nitrification layer – column setup



Schematic view of setup for the aged and new sand columns

Summary of operational stages

Stage	Operation time (d)	Influent	HLR gal/(d·ft^2)	Flow pattern
1	46	Real STE	1.2 (designed)	6 doses per day
2	46	Synthetic storm water	35.3 (heavy rain)	Continuous
3	90	Real STE	0.6 (actual)	6 doses per day
4	21	Synthetic storm water	8.8 (light/moderate rain)	Continuous

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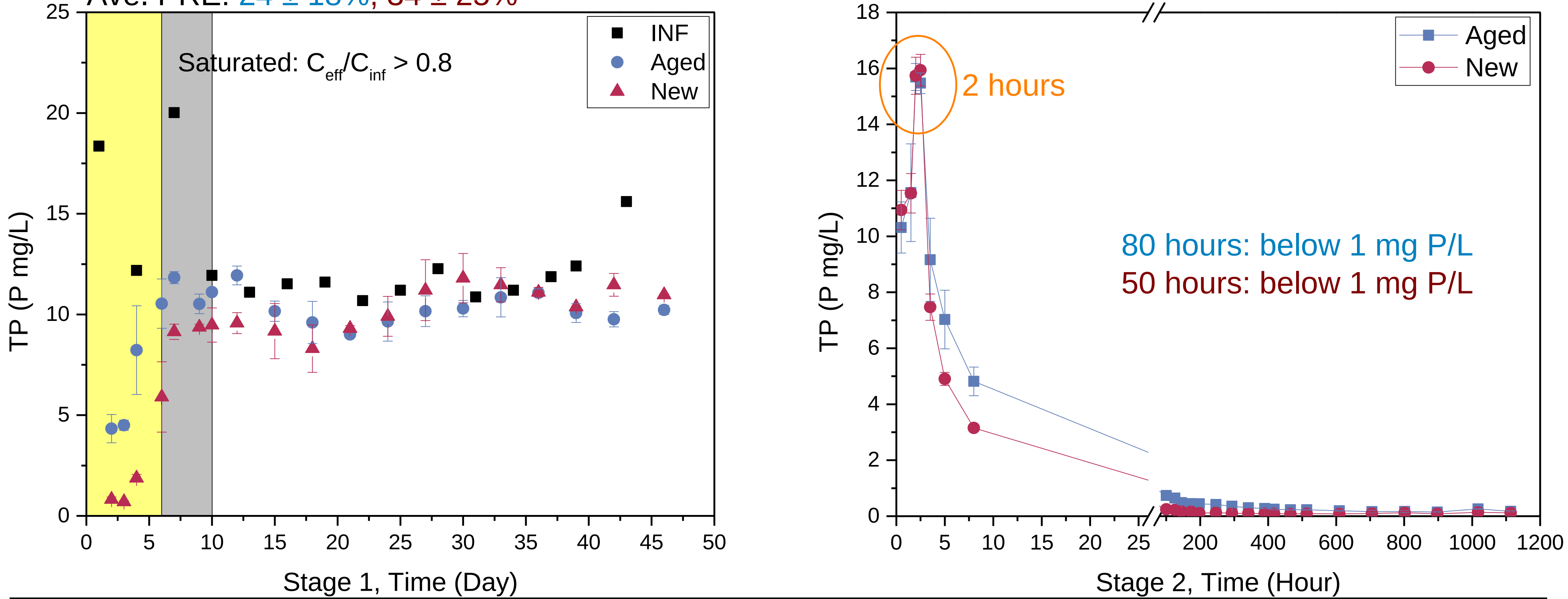
Nitrification layer – stage 1 and 2

Stage	HLR	Influent
1	1.2 gal/(d·ft^2))	STE
2	35.3 gal/(d·ft^2))	Storm water

Max. PRE: 66%, 94%

Ave. PRE: 24 ± 18%, 34 ± 25%



Stage	Stage condition	P mass balance	
		Aged sand columns	New sand columns
1	STE attenuation	Attenuated P = 3.0 mg P (24%)	Attenuated P = 3.5 mg P (34%)
2	Storm water leaching	Leaching P = 6.4 mg P	Leaching P = 3.4 mg P

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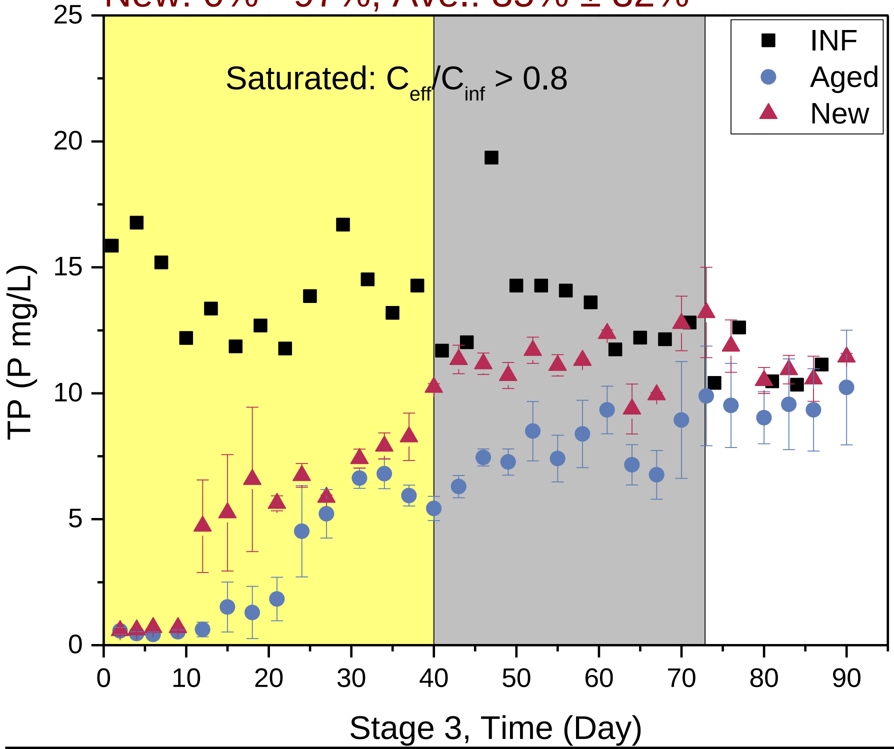
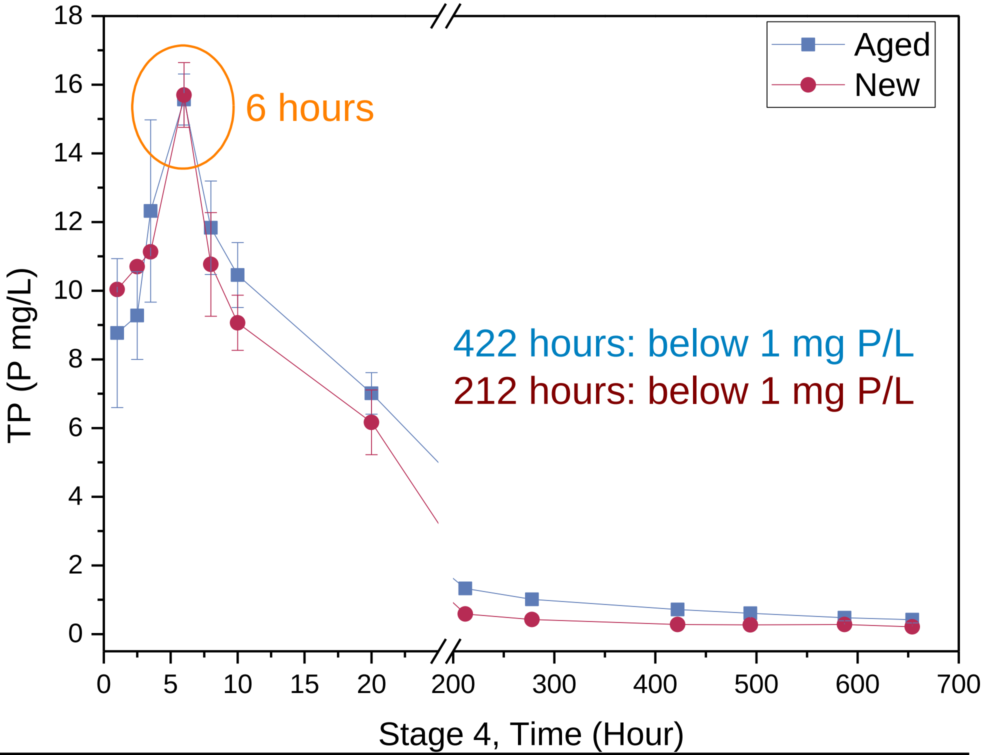
Nitrification layer – stage 3 and 4

Stage	HLR	Influent
3	0.6 gal/(d·ft²))	STE
4	8.8 gal/(d·ft²))	Storm water

Old: 8% - 97%, Ave.: 53% ± 29%

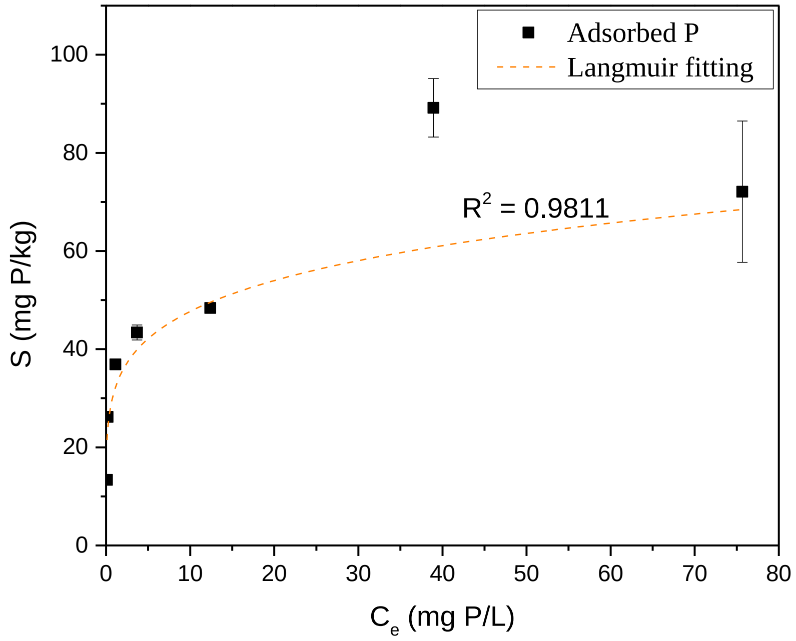
New: 0% - 97%, Ave.: 35% ± 32%





Stage	Stage condition	P mass balance	
		Aged sand columns	New sand columns
3	STE attenuation	Attenuated P = 6.0 mg P (54%)	Attenuated P = 3.9 mg P (35%)
4	Storm water leaching	Leaching P = 5.9 mg P	Leaching P = 3.6 mg P

Nitrification layer – sorption capacity and mass balance



Batch sorption experiment

Calculated maximum sorption capacity (S_{max}) by Langmuir equation

S_{max} = 76.11 mg P/kg

Mass balance of TP in four experiment stages

Stage	Hydraulic loading (gal/(d·ft^2))	*P mass balance in columns	
		Aged (mg P/kg)	New (mg P/kg)
1 (STE-attenuation)	1.2	20.6	25.3
2 (Storm water-leaching)	35.3	-43.7	-24.5
3 (STE-attenuation)	0.6	45.3 (2/3 of S_{max})	33.0 (1/2 of S_{max})
4 (Storm water-leaching)	8.8	-40.1	-26.4
Total		-17.9	7.4

*Calculated based mass of sand in column

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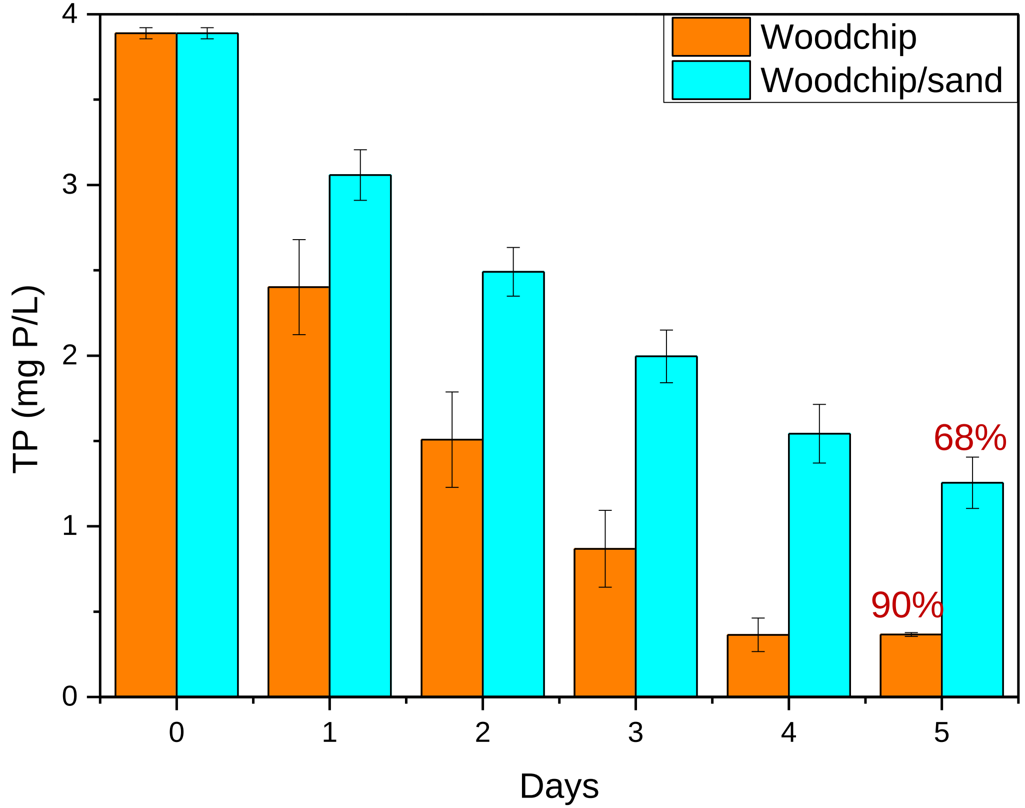
Denitrification layer (on-going)

Batch sorption experiment setup



P sorption by woodchip and woodchip/sand mixture

Conclusions and future works

- **Conclusions**
  - 1. A wide range of PRE (50% ~ 90%) was observed in long-term operating NRBs.
  - 2. Nitrification sand layer of an NRB can temporarily attenuate P from STE, and the majority of attenuated P could be leached out at environmental-relevant conditions (e.g., rain/flood).
  - 3. Preliminary work revealed the denitrification layer (i.e., woodchip or woodchip/sand mixture) could provide additional P attenuation capacity of the NRB.
- **On-going and Future works**
  - 1. Investigate the fate and transport of P in denitrification layer in column experiments.
  - 2. Develop P removal module and estimate its longevity based on the P dynamics in the NRBs.

Acknowledgement

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  New York State Department of Environmental Conservation

- CCTW Website: https://www.stonybrook.edu/cleanwater/
- CCWT Twitter: https://twitter.com/nysccwt

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Thank you!

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