Reduction in Groundwater Transport of Nitrate 9 Years After Installation of a Permeable Reactive Barrier

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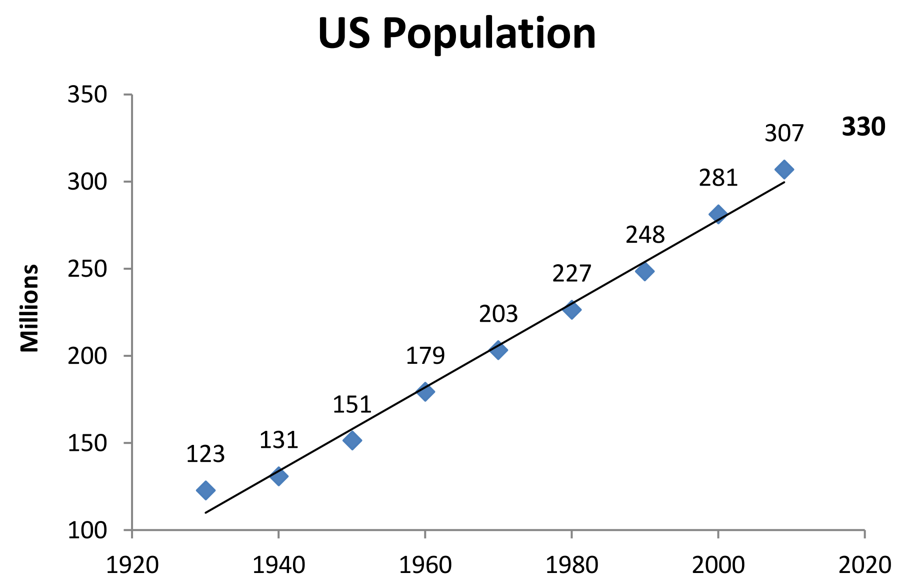
Outline

- Nitrogen and Environmental & Public Health
- Onsite Systems and Nitrogen Transport
- Remediation of Nitrogen in Groundwater
- Permeable Barrier Case Study in Eastern NC
- Summary
- References
- Questions

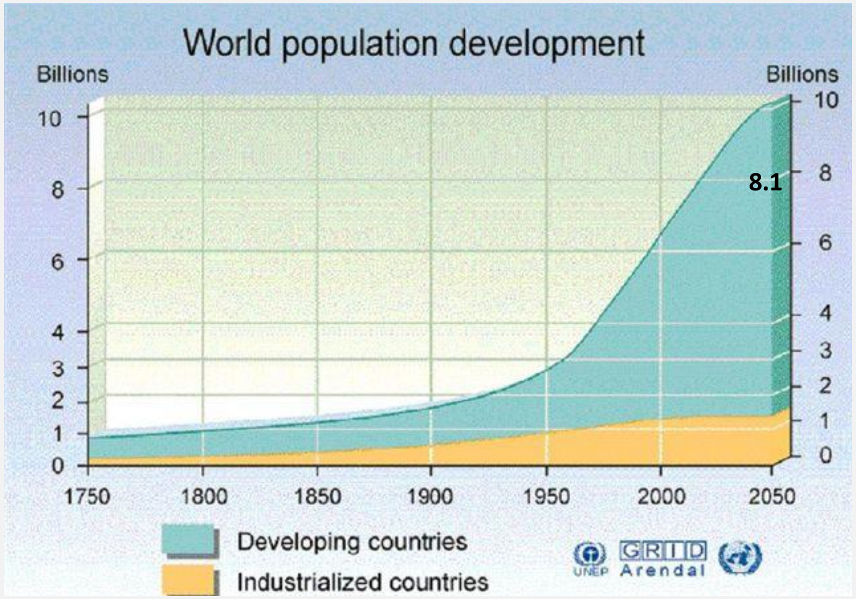
Nitrogen and Environmental and Public Health

- Nitrogen
  - Essential nutrient for plants, animals, humans
- Often limits productivity in terrestrial and aquatic environments
- Anthropogenic nitrogen applications have increased
  - Fertilizers
  - Wastewater

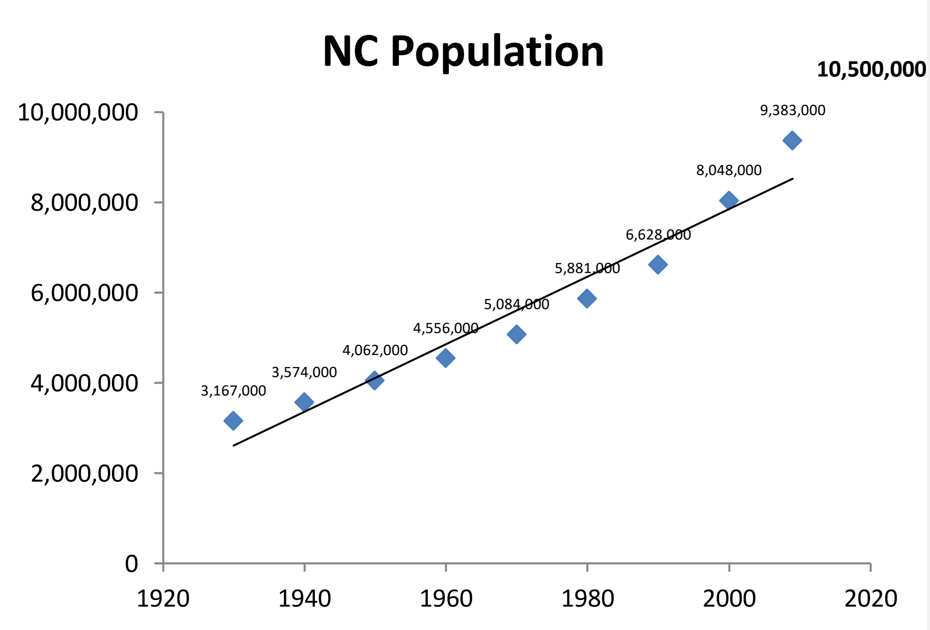

http://SoilScience.info



US population doubled in last 65 yrs



World population doubled in last 50 years



NC population doubled in last 50 years

Nitrogen and Environmental and Public Health

- Excess inorganic nitrogen in surface waters
  - Algal blooms (some toxic)
  - Fish kills
  - Water use impairment
- Elevated NO_3 concentrations in water supplies
  - Methemoglobinemia
  - Cancer

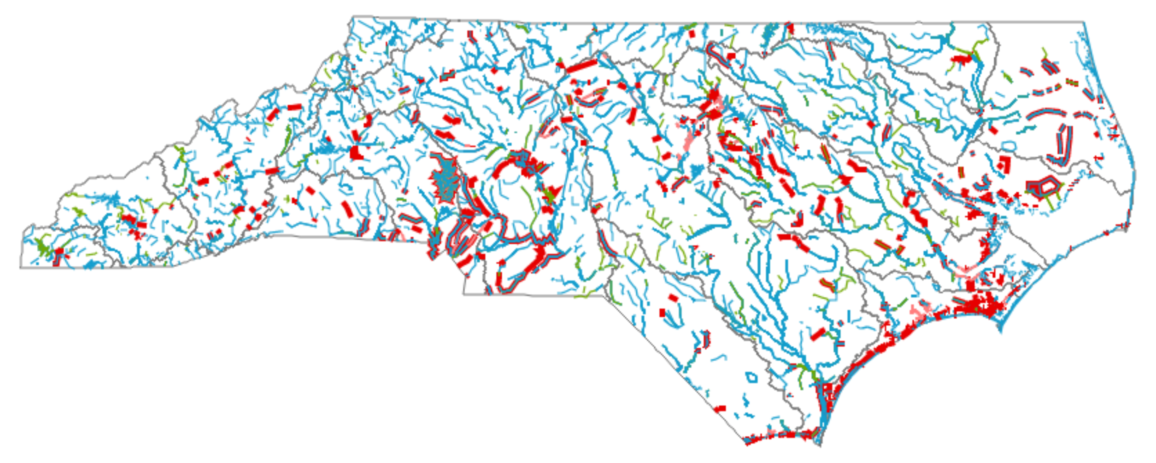
Nitrogen and Water Quality in the US

Labroots.com

- 53% of assessed rivers and streams in US are listed as impaired
- 71% of assessed lakes, reservoirs, and ponds listed as impaired
- 80% of bays and estuaries assessed listed as impaired
- Excess nutrients are commonly cited sources (top 3 for each category)

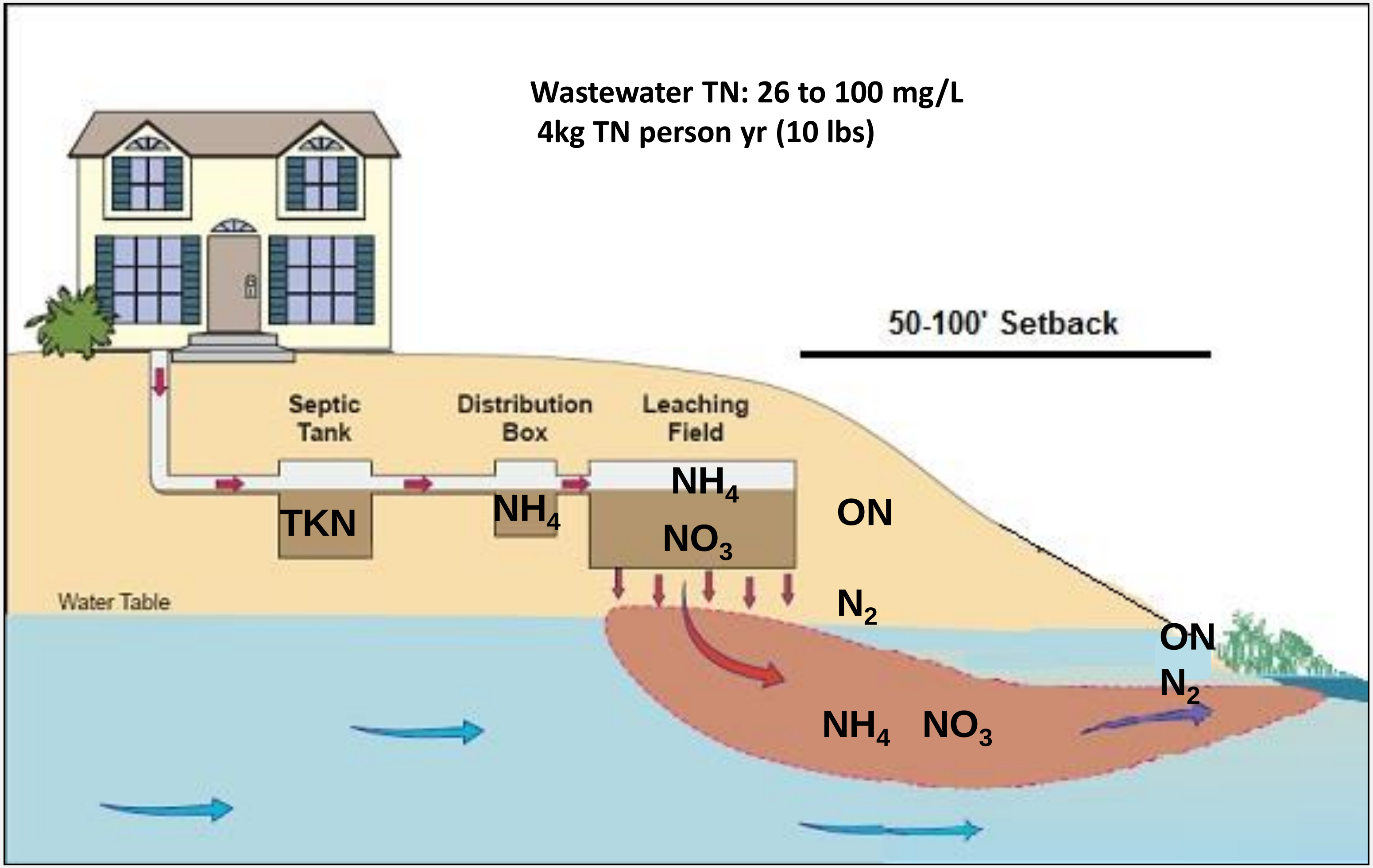
(US EPA, 2018)

Nitrogen and Water Quality in North Carolina



- Impaired waters across North Carolina
- Nutrient sensitive waters
  - Neuse River
  - Tar-Pamlico River
  - Falls Lake
  - Jordan Lake

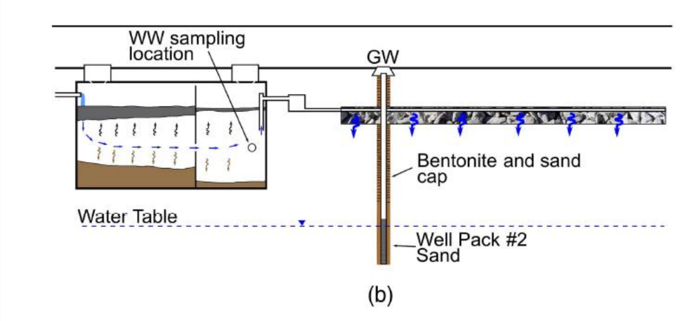
Onsite Systems and Nitrogen Treatment

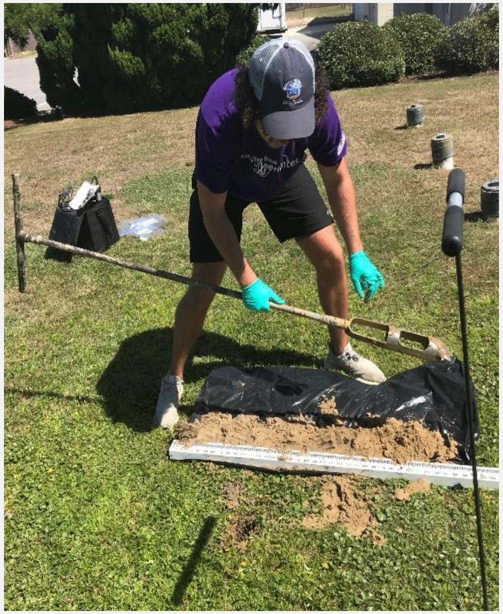

Wastewater TN: 26 to 100 mg/L

4kg TN person yr (10 lbs)

Ammonification, adsorption, nitrification, immobilization, denitrification

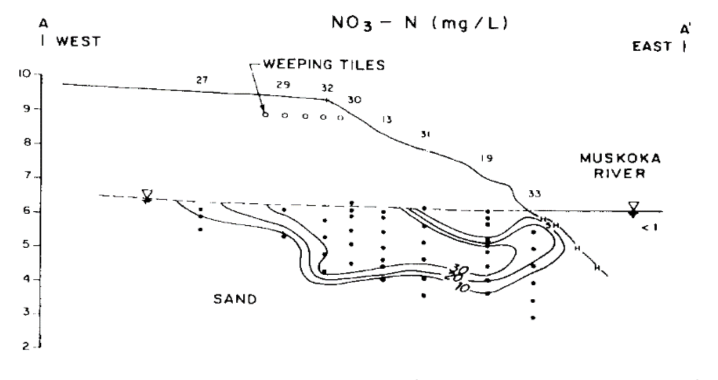
Groundwater Monitoring



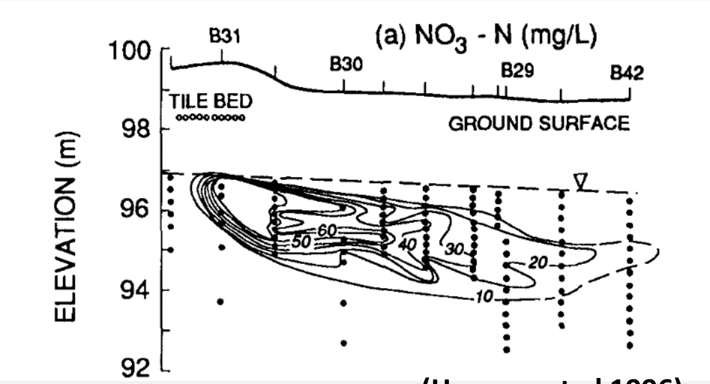


Groundwater Nitrogen Transport

- **Ontario, Canada**
  - Robertson et al 1991: groundwater NO_3 concentrations > 30 mg/L down-gradient from 2 residential systems at 20+ m
  - Harman et al 1996: groundwater NO_3 concentrations 30 mg/L at 50 m down-gradient from a school OWS
- **Coastal Plain of Virginia**
  - Reay 2004: groundwater NO_3 concentrations > 10 mg/L beneath and down-gradient from 3 OWS



(Robertson et al 1991)

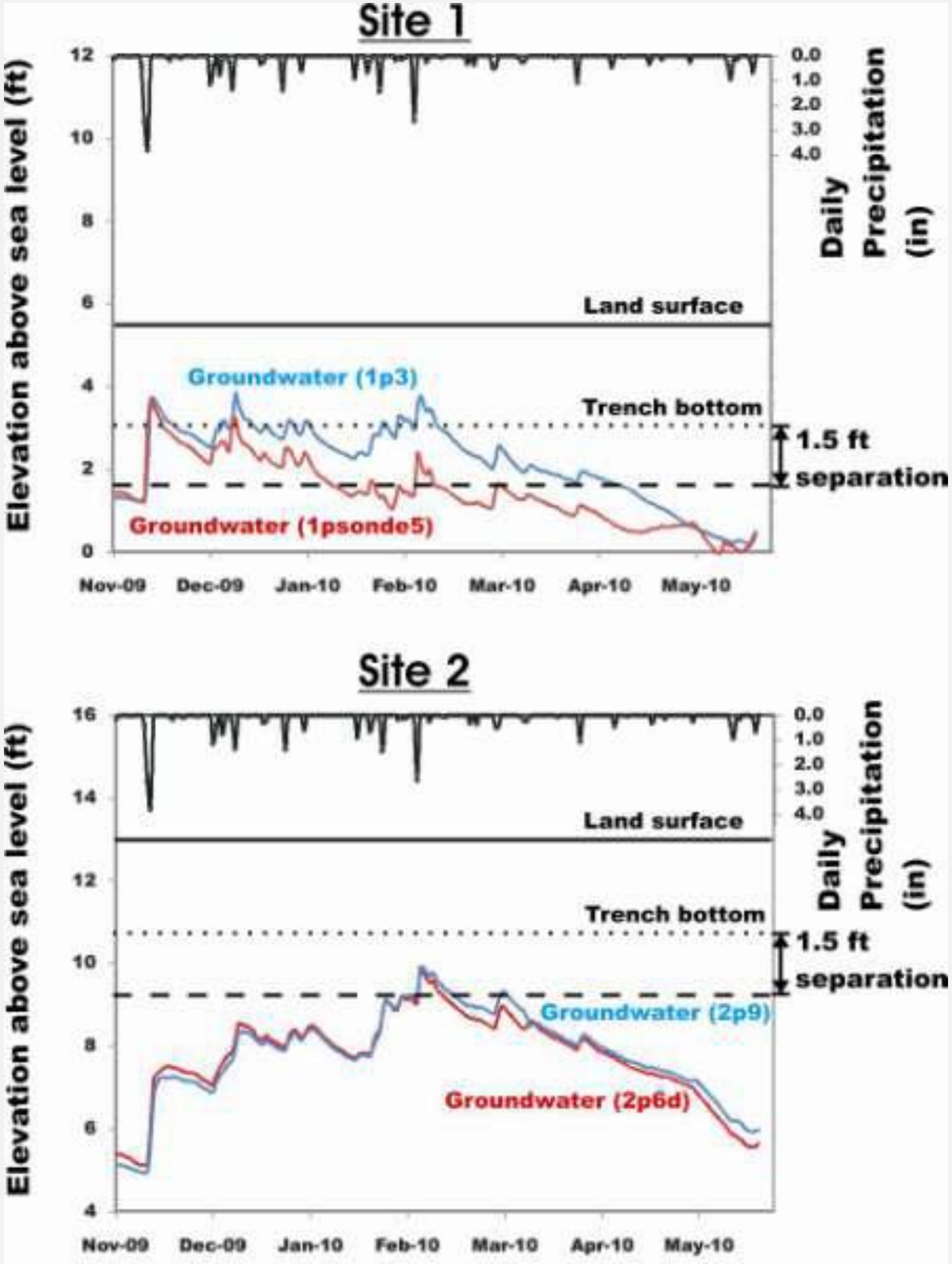


(Harman et al 1996)

Eastern NC Studies

Site 1

Site 2



Humphrey et al. (2013)

Vertical Separation and N Speciation & Transport

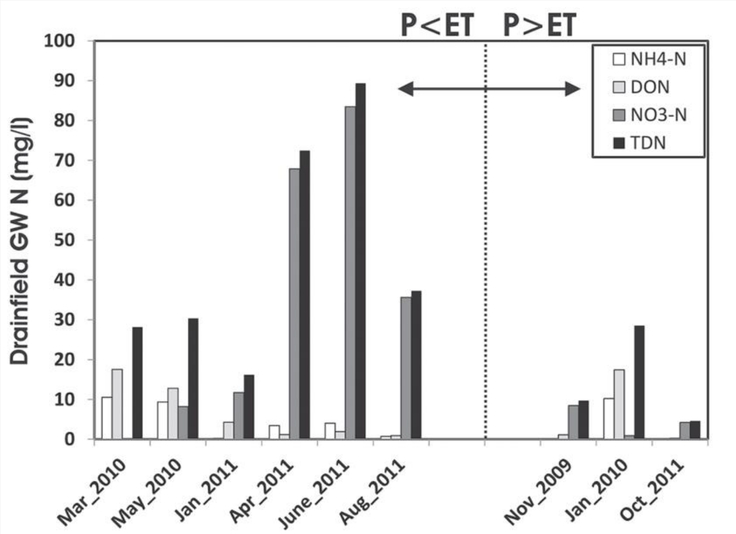
GW beneath drainfields
Site 1: DON
Site 2: NO3

GW downgradient
Site 1: DON
Site 2: NO3

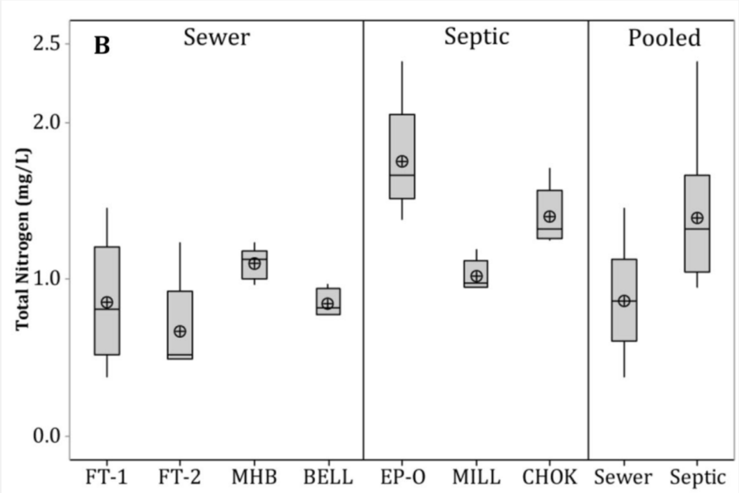
Site 2 on-site system maintained a larger separation from trench to water table than system at Site 1

Groundwater Nitrogen Transport

- **Coastal Plain of North Carolina**
  - O’Driscoll et al 2014
    - Groundwater N concentrations elevated > 30 m down-gradient from OWS especially during dry and abnormally dry periods
  - Iverson et al 2015
    - OWS increase groundwater N and surface water N concentrations relative to watersheds on sewer



(O’Driscoll et al 2014)



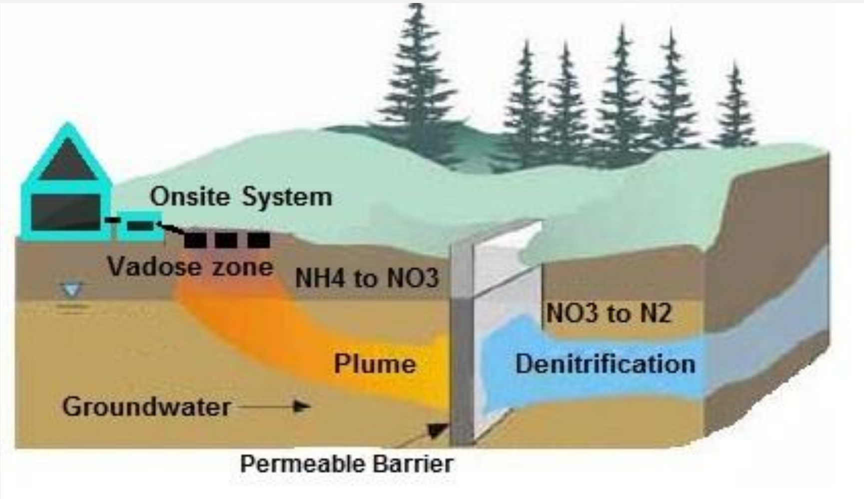
(Iverson et al 2015)

Groundwater Nitrogen Remediation

- **Natural via Riparian Processes**
  - Organic matter abundance
  - Low oxygen content
  - High denitrification potential
  - Plant uptake
- **Onsite Wastewater N Removal in Riparian Zones**
  - Robertson et al 1991: nearly 100% removal of NO_3 in stream bed
  - Buetow, 2002: approximately 75% removal of NO_3 in riparian zone
  - O'Driscoll et al 2014: approximately 85% removal of NO_3 due to denitrification near estuary

Groundwater Nitrogen Remediation

- Anthropogenic via Permeable Reactive Barriers
  - Porous media used as an electron source for denitrification is placed within the flow-path of a NO_3 plume
  - Various types of organic matter including saw dust, woodchips, alfalfa, and wheat straw have been used



(Modified from PSSS, 2015)

Groundwater enriched with NO_3 flows through barrier, microbes use organic matter as electron donor and NO_3 as electron acceptor, NO_3 converted to gas (N_2 or N_2O) and removed

Groundwater Nitrogen Remediation

Study by (Moorman et al 2010)

- Woodchip permeable reactive barrier installed in an agricultural field in Iowa
- 55% reduction in N exports in comparison to control (no barrier)
- 37 yr half-life of woodchips in deeper portion of reactor
- 5 yr half-life of woodchips in shallow portion of reactor

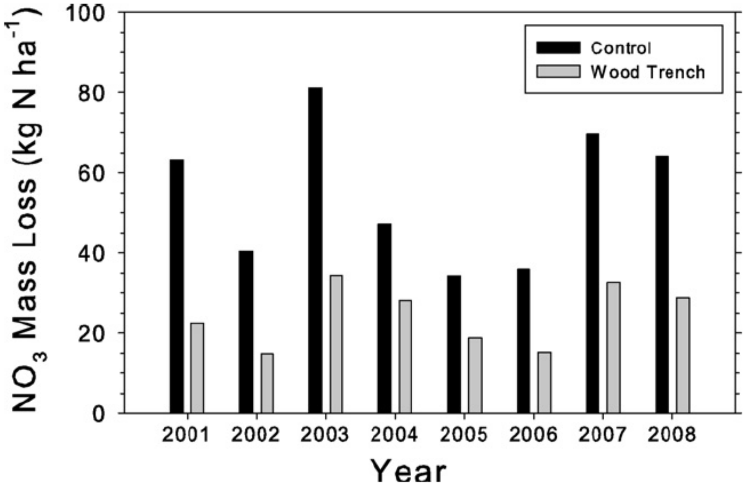


Fig. 1. Annual losses of NO_3-N in subsurface drainage for a conventional drainage system (control) and drains with wood chip denitrification walls.

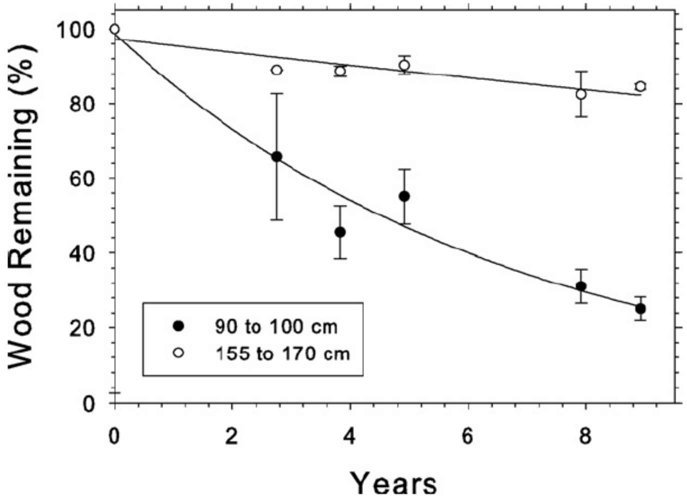
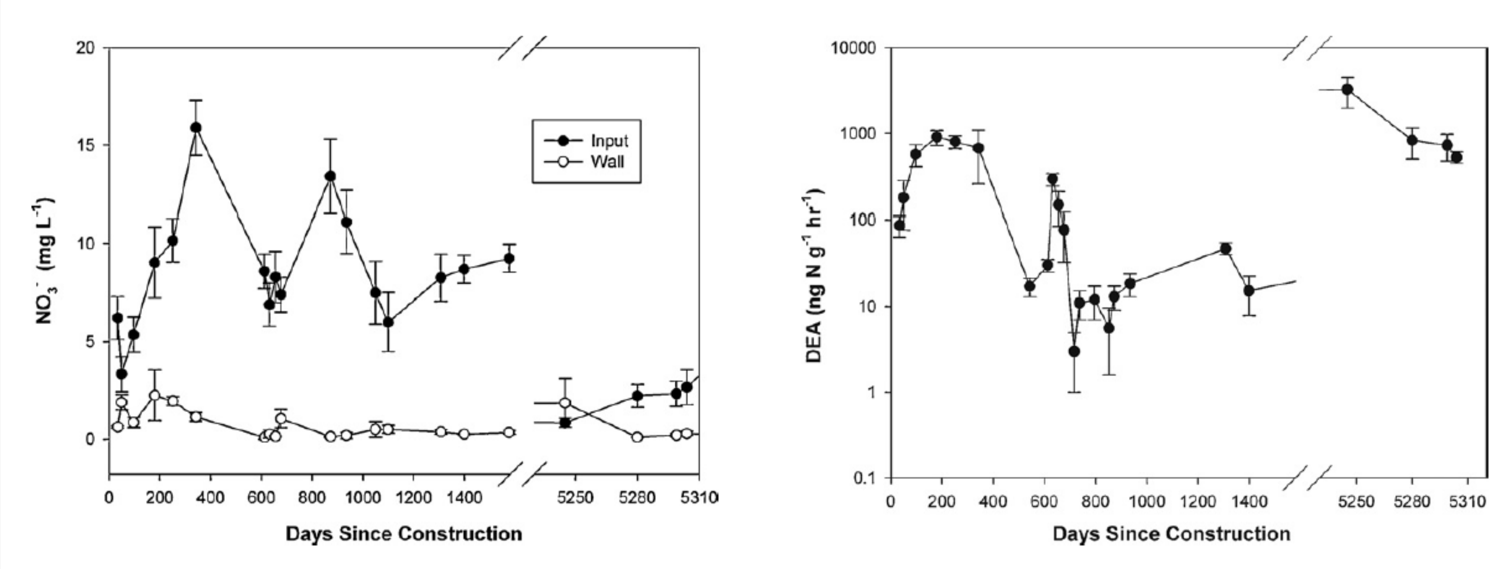


Fig. 7. Loss of wood chip mass from a denitrification wall in the field. Wood chips were placed in mesh bags and recovered from the indicated depths over time. Loss was determined by weight difference. Solid lines show the first-order non-linear least squares regression. Points indicate means of four samples and associated standard errors.

Groundwater Nitrogen Remediation



Study by (Long et al 2011)

- Permeable barrier to reduce NO_3 leaving dairy farm in New Zealand
- 92% reduction of NO_3-N after 14 yrs
- Predicted that carbon in wall would last 66 years
- NH_4 concentrations did not increase
- Denitrifying enzyme activity suggest denitrification as removal mechanism

Groundwater Nitrogen Remediation

Study by (Robertson et al 2008)

- Barrier installed to reduce NO_3 transport from OWS serving campground in Ontario Canada
- Groundwater monitoring and lab analyses of barrier media samples
- Barrier efficiency declined over 15 yrs, but still lowered NO_3 concentrations relative to influent and control
- Denitrification influenced by temperature and available carbon from larger media

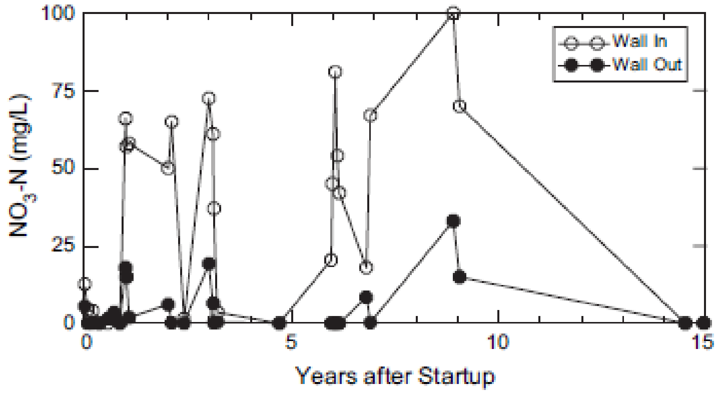


Figure 4. Nitrate removal in the Long Point PRB over 15 years of operation. Monitoring locations are shown on Figure 1. Years 1 to 7 data have been reported previously (Robertson et al. 2000).

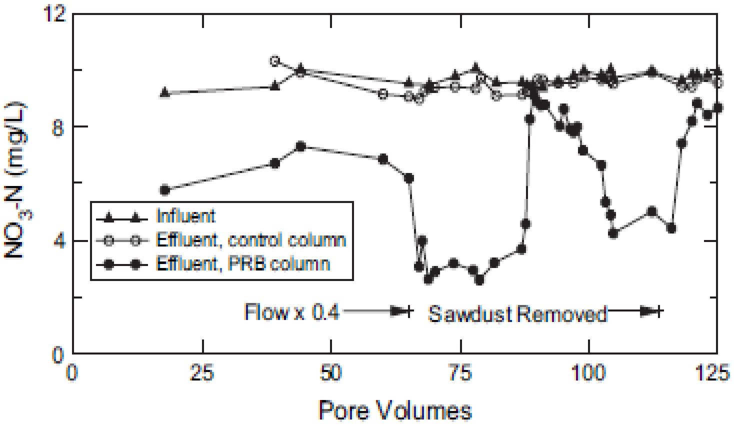
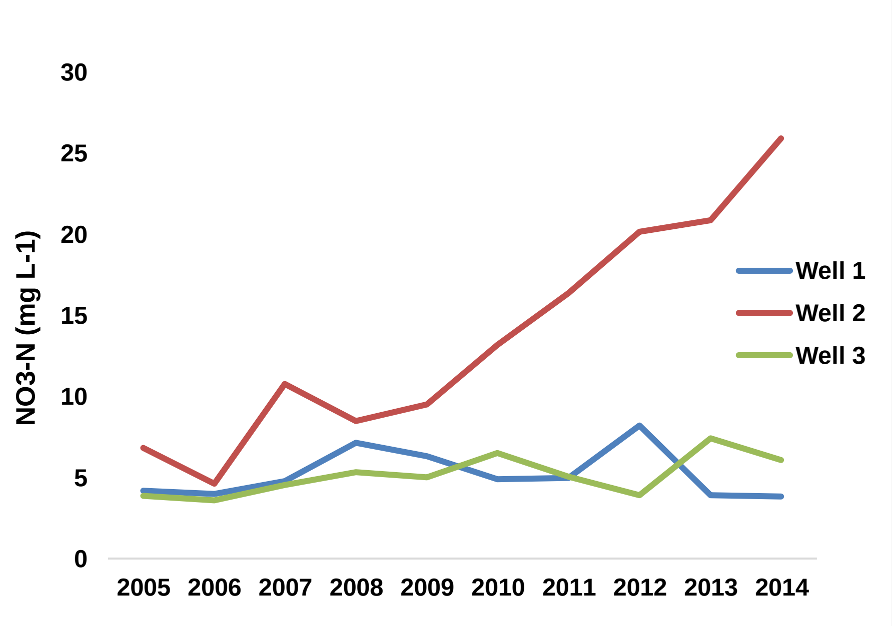


Figure 5. Nitrate removal in the year 15 column tests.

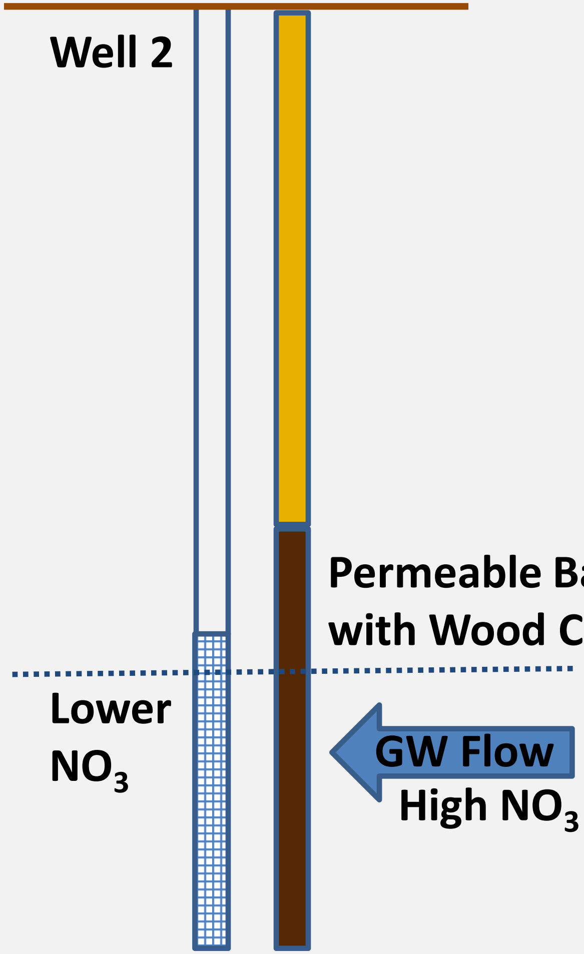
Groundwater Nitrogen Remediation: NC Case Study

Study by (Humphrey, Pradhan, Bean, O'Driscoll, and Iverson, 2015)

- School in Eastern NC with OWS and groundwater NO_3 > 10 mg/L
- NO_3 concentrations increasing each year by average of 2 mg/L
- Permeable barrier?



Barrier Installation



Well 2

Permeable Barrier with Wood Chips

Lower NO_3

GW Flow

High NO_3

Denitrification

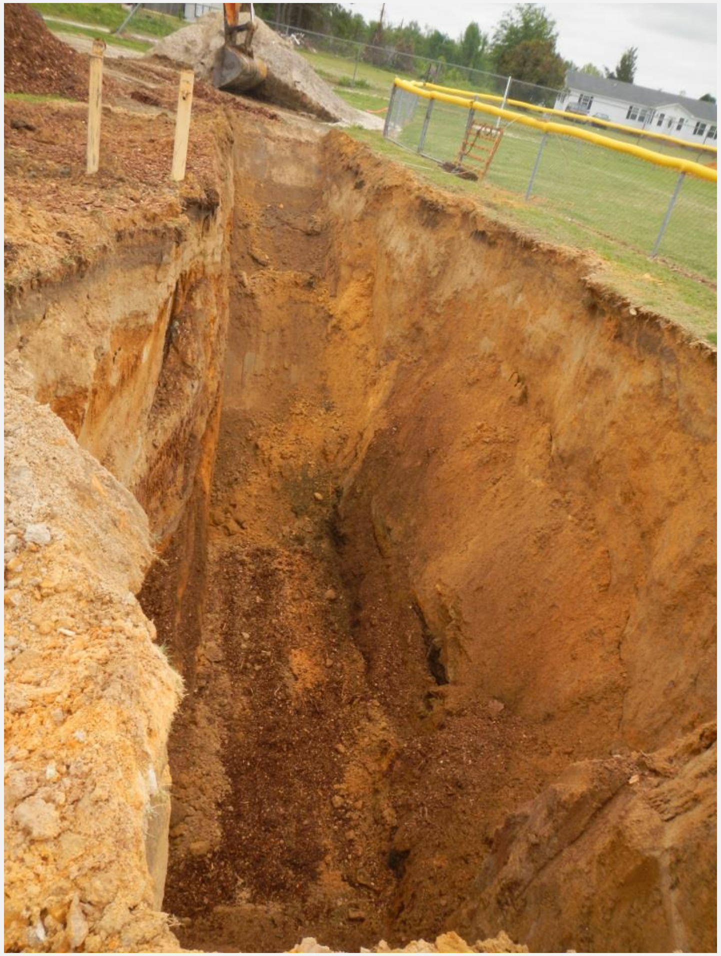
Barrier Installation

- Trench ~1.2 m wide, ~8 m deep, and ~6 m long excavated
- Trench immediately up-gradient of Well 2 (high NO_3)

Barrier Installation

Woodchips of different sizes emptied into trench below and above the water table

Barrier Installation



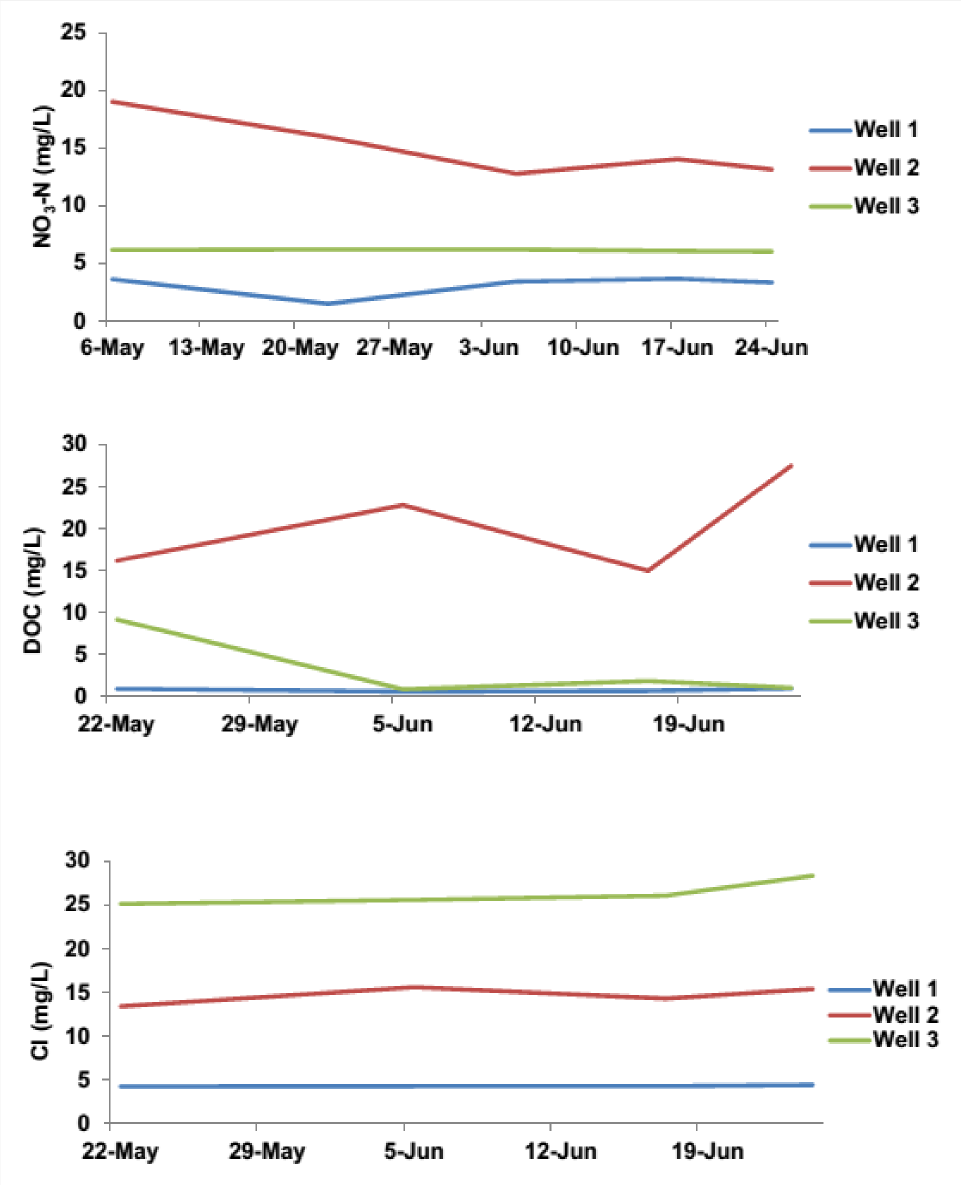
Trench backfilled with woodchips and soil to existing grade

Monitoring

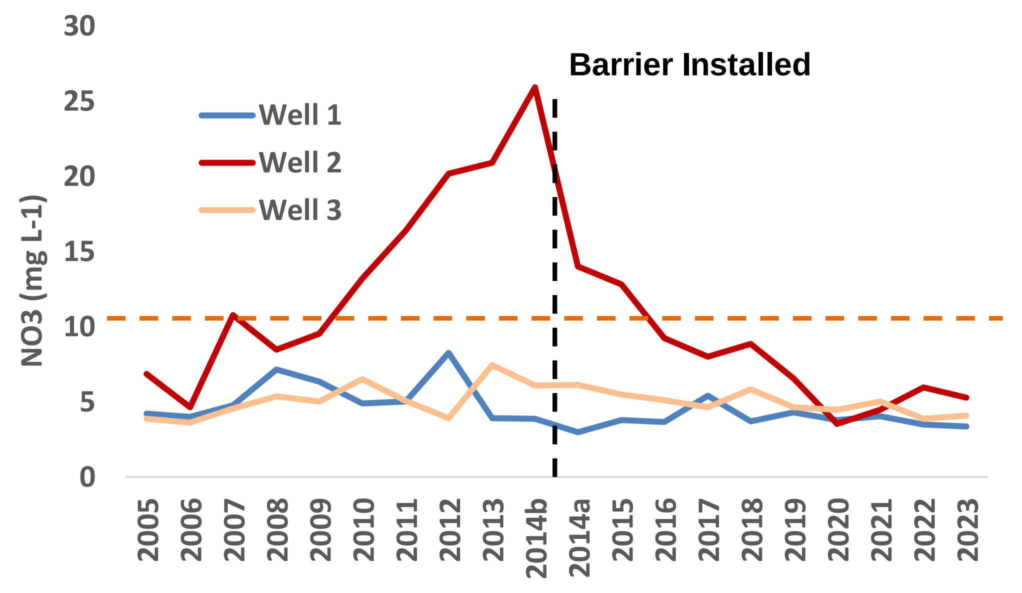
Water depth
Specific conductance
NO_3-N
NH_4-N
TDN
DOC
Cl
ORP
Temperature
DO
pH

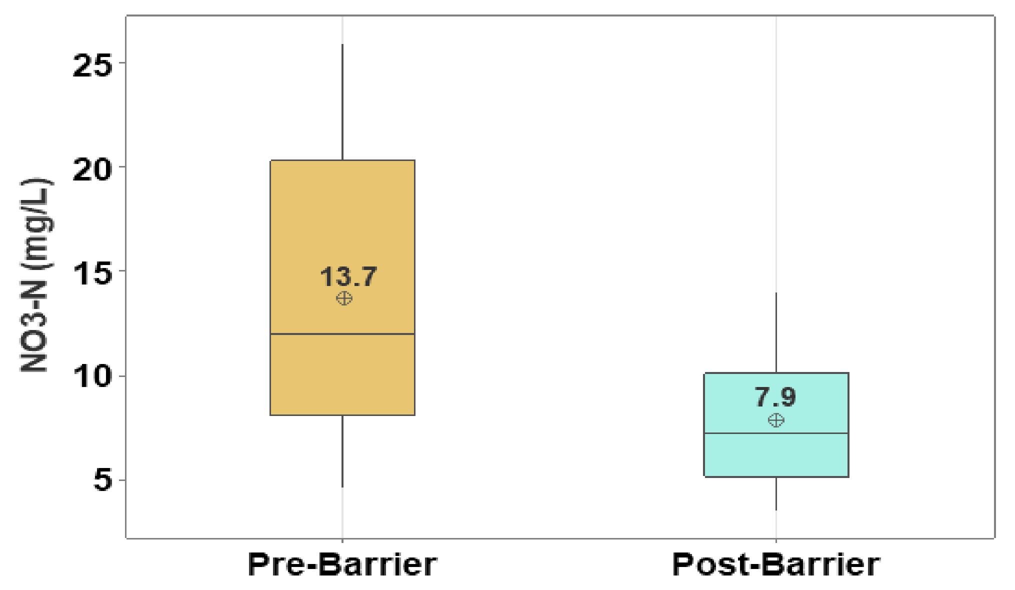
Early Findings

- NO_3 declines at Well 2, steady at other Wells
- DOC increases at Well 2, declines or steady at other wells
- Slight Cl increases at Well 2 and Well 3, steady at Well 1
- Increased DOC and Cl and decreases in NO_3 suggest denitrification
- Mean groundwater oxidation reduction potential (- 4 mv) within the range that denitrification occurs



Recent Barrier Results

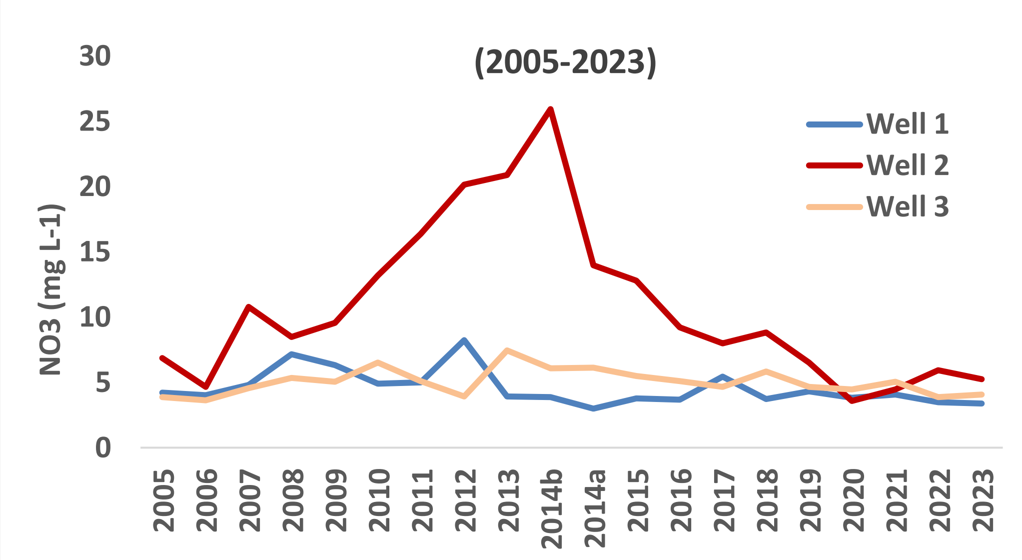


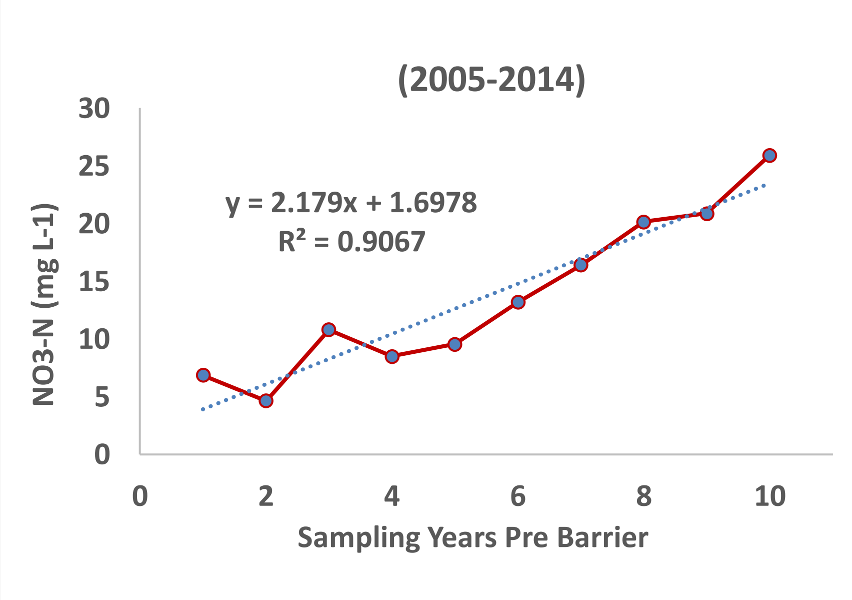


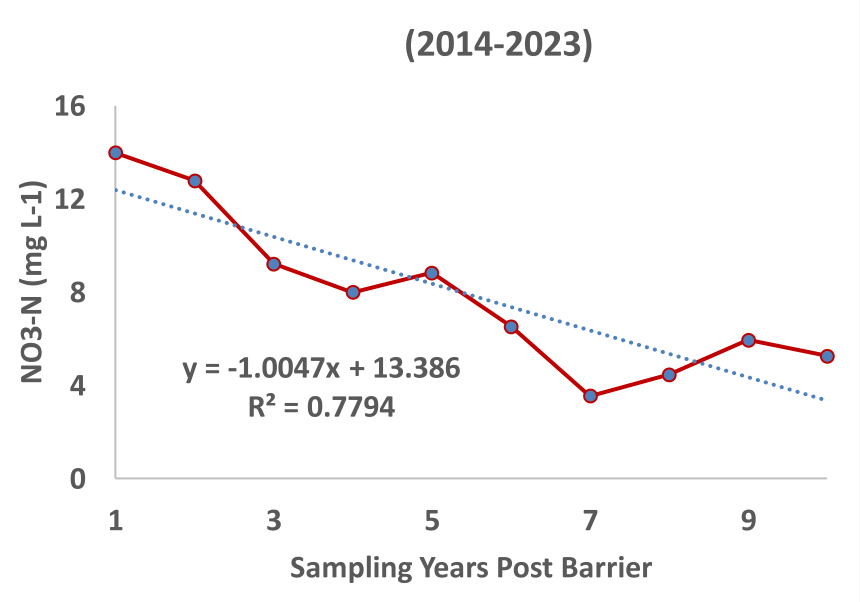
*Since 2016, mean yearly NO_3-N concentrations in samples from Well 2 have been below 10 mg L^{-1} for NO_3-N

*22 of 24 samples collected from Well 2 between 2016 and 2023 were below 10 mg L^{-1}

*32% reduction in mean concentration of NO_3-N in Well 2 samples when comparing post-barrier to pre-barrier conditions







NO3 increased by an average of 2 mg L^{-1} each year pre-barrier and decreased by an average of 1 mg L^{-1} each year post-barrier

Summary

- Elevated N loading to surface waters continues to be a problem at the global, national, state, and local levels
- Prior research has shown that riparian buffers and permeable reactive barriers can reduce the delivery of N from terrestrial to aquatic systems
- 9+ years of field data after installation of the PRB shows continued effectiveness in reducing N transport
- More work is needed to assess the treatment performance and economic viability of permeable reactive barriers as retrofit BMPs and for installation with new onsite systems

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Questions?

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