Stormwater Ponds in Coastal South Carolina

A brief review of research conducted by the North Inlet – Winyah Bay National Estuarine Research Reserve

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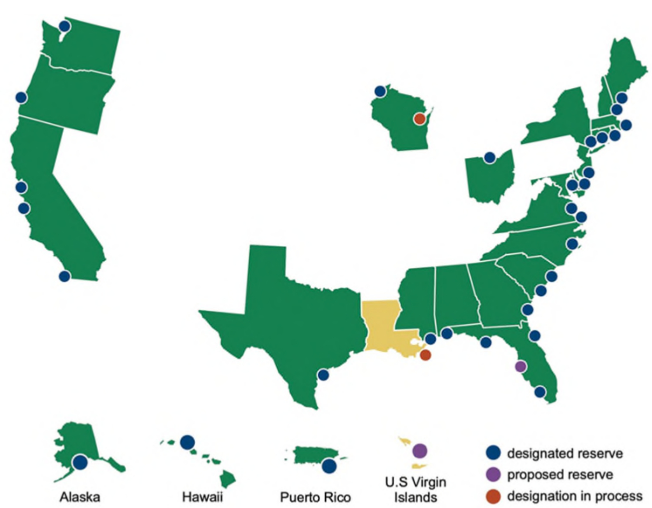
The National Estuarine Research Reserve System

Currently a network of 30 coastal sites around the continental US, Alaska, Hawai'i and Puerto Rico

- ACE Basin (SC)
- Apalachicola (FL)
- Chesapeake Bay (MD)
- Chesapeake Bay (VA)
- Connecticut
- Delaware
- Elkhorn Slough (CA)
- Grand Bay (MS)
- Great Bay (NH)
- Guana Tolomato Matanzas (FL)
- He'eia (HI)
- Hudson River (NY)
- Jacques Cousteau (NJ)
- Jobos Bay (PR)
- Kachemak Bay (AK)
- Mission-Aransas (TX)
- Narragansett Bay (RI)
- North Carolina
- North Inlet – Winyah Bay (SC)
- Lake Superior (WI
- Old Woman Creek (OH)
- Padillia Bay (WA)
- Rookery Bay (FL)
- San Francisco Bay (CA)
- Sapelo Island (GA)
- South Slough (OR)
- Tijuana River (CA)
- Waquoit Bay (MA)
- Weeks Bay (AL)
- Wells (ME)

- Louisiana, in process
- Green Bay (WI), in process

- US Virgin Islands, proposed
- Nature Coast (FL), proposed



The National Estuarine Research Reserve System

- Established by the Coastal Zone Management Act of 1972
- Administered by NOAA and operated as a State – Federal Partnership
- Mission: To practice and promote stewardship of coasts and estuaries through innovative research, education, and training using a place-based system of protected areas.”

North Inlet – Winyah Bay NERR

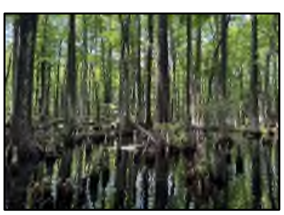
- Designated in 1992
- Operated by the USC Baruch Institute for Coastal & Marine Science
- Headquartered at the Baruch Marine Field Lab
- Made possible through a long-term agreement with the Belle. W. Baruch Foundation

3 Goals of the NI-WB NERR Strategic Plan

- Scientific understanding of the impacts of coastal development on water quality and coastal ecosystems is increased and used to guide management practices and natural resource conservation
- The capacity of communities to respond to severe weather events and adapt to a changing climate is increased
- Environmental conservation and stewardship are fostered in the North Inlet – Winyah Bay watershed

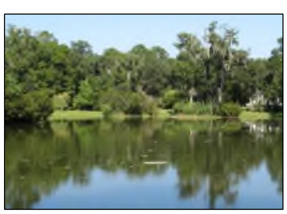
One central research focus: The role of stormwater ponds play in the impacts of development on coastal water quality conditions

→ How does the proliferation of stormwater ponds affect the transport and transformation of material from land to coastal waters?



Typical original aquatic habitat: Forested wetlands

- Seasonally flooded
- Groundwater dominated
- Closed canopy, low light
  - Low development = low nutrients



Created aquatic habitat: stormwater ponds

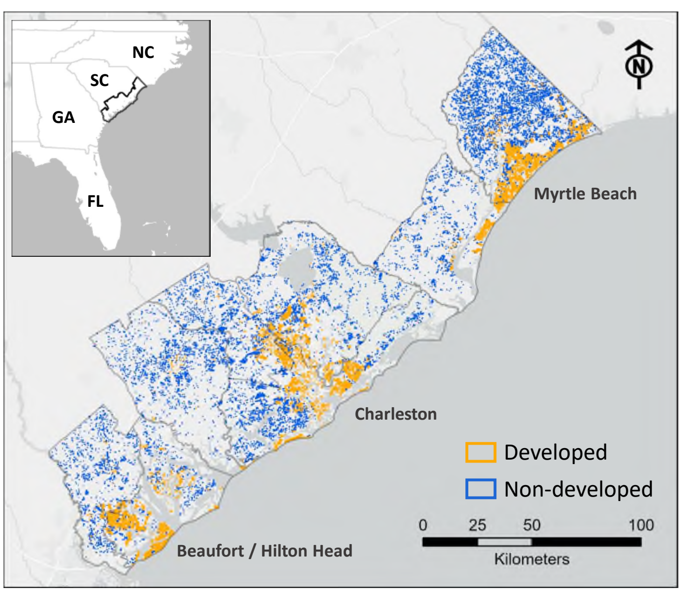
- ↑ permanent surface water
- ↑ water residence time
- High light availability
  - Development = higher nutrients

Creating a geospatial inventory of ponds in coastal SC

- Based on 2021 natural color USDA NAIP imagery
- Restricted to the eight coastal counties of South Carolina
- Manually delineated at a consistent scale of 1:3000
- Classified ponds into 2 categories based on visual interpretation of surrounding land
- Delineations excluded water bodies judged to be impoundments, industrial or water treatment plants

Ponds are now a major feature of our coastal landscape

2021 Inventory based on digitized NAIP imagery



Total #
= 27,651 ponds

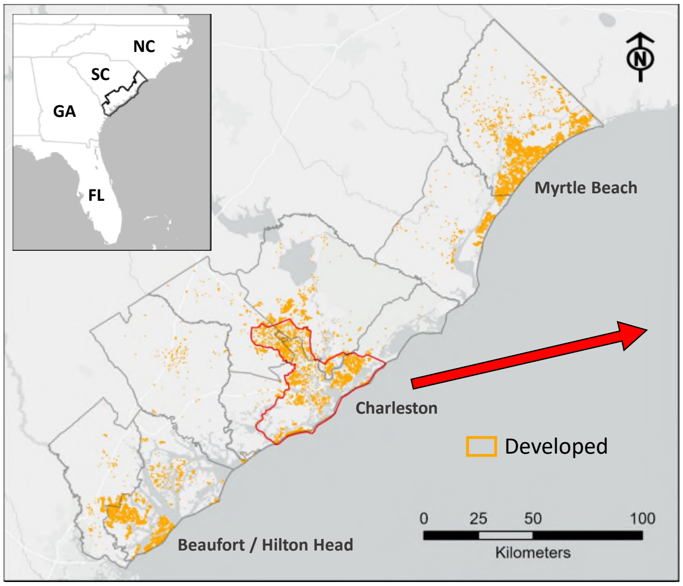
Cumulative area
= 146.7 km^2 / 14,670 ha

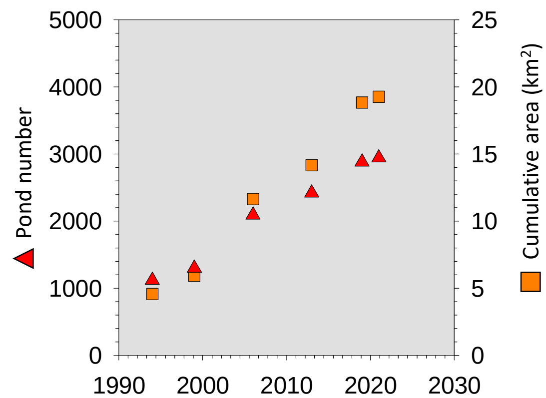
Development-related ponds
= 12,278 ponds (45 %)
= 63.96 km^2 / 6,396 ha (44 %)

Non-developed / Rural ponds
= 15,374 ponds (55 %)
= 82.70 km^2 / 8,270 ha (56 %)

GIS data available at SCDNR Geospatial Data
https://data-scdnr.opendata.arcgis.com/

Stormwater pond inventory : Change over time

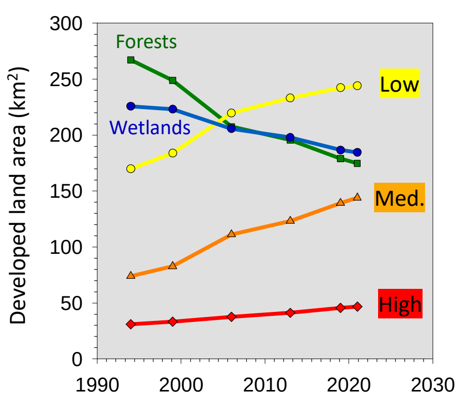




Mean annual rate of increase:
Cumulative area = 3.7 % y^{-1}

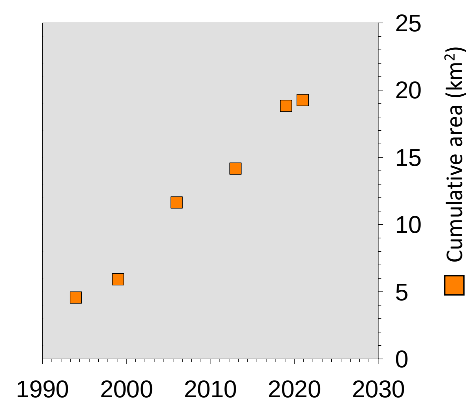
Pond area increase compared to developed land increases

Charleston land area classes



Mean annual rate of increase:
Total developed land area = 1.7 % y^{-1}

Charleston pond area

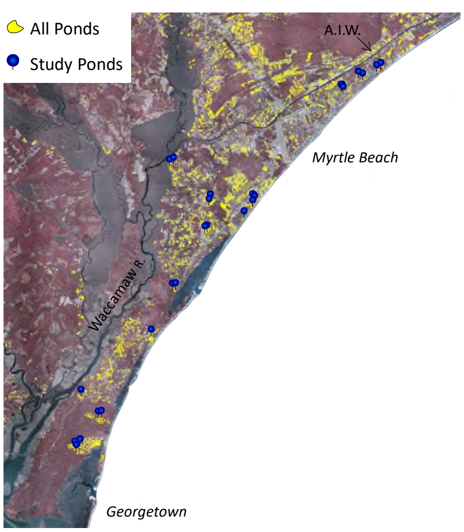


Mean annual rate of increase:
Cumulative area = 3.7 % y^{-1}

Land cover from USGS National Land Cover Database (NLCD)

How variable are ponds (with respect to water quality conditions)? Can this variability be predicted as a function of land use?

A broad survey of residential stormwater ponds



26 residential ponds sampled in 2010

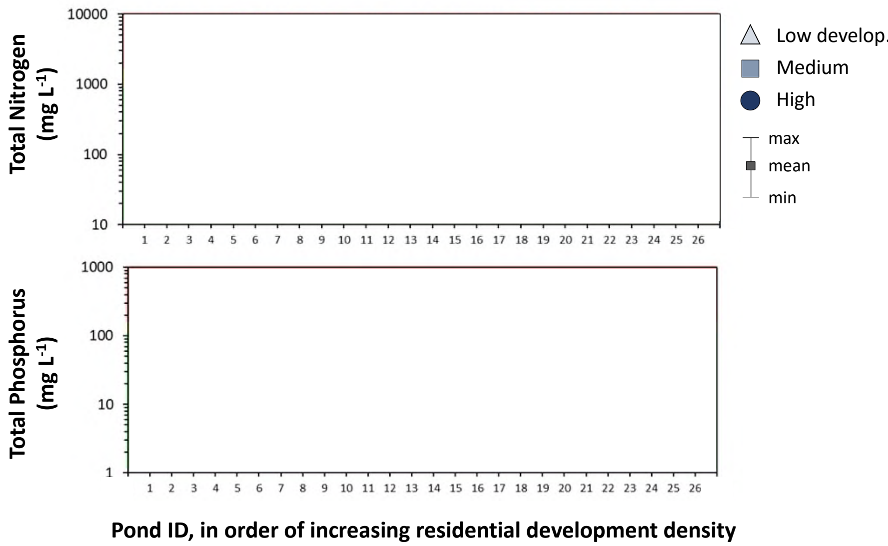
9 Low residential development
10 Medium residential development
7 High residential development

Pond size : 0.2 – 18.5 acres
median = 2.2 acres

Pond depth : 3 – 14 ft

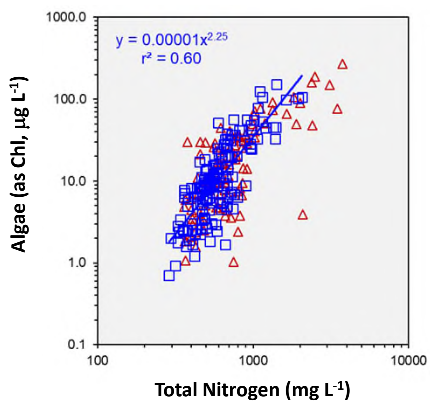
- Ponds sampled 8 times from May – September
- Water samples collected near pond outfall during dry weather periods
- All ponds are freshwater

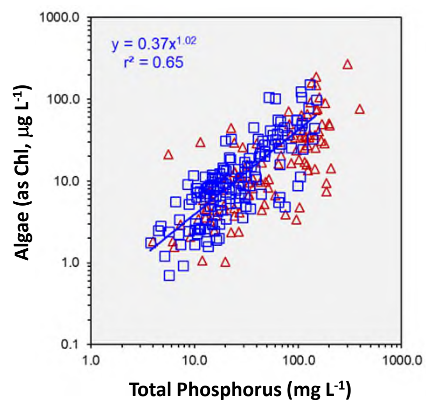
Total Nitrogen & Total Phosphorus across all ponds



TN and TP are both strong predictors of algal abundance

Across all ponds and sampling events





□ = ponds not subject to algaecide treatments

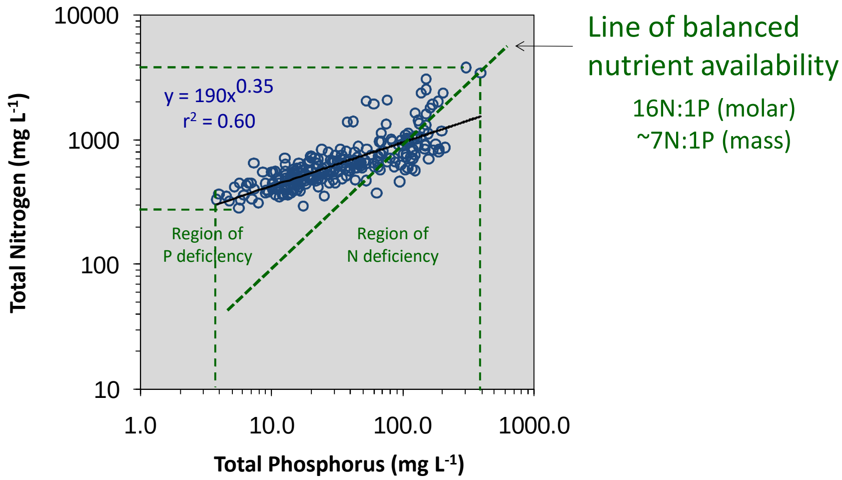
△ = ponds subject to routine algaecide treatments

Nitrogen & Phosphorus tightly correlated across all ponds

But: Nitrogen is much less variable than phosphorus.

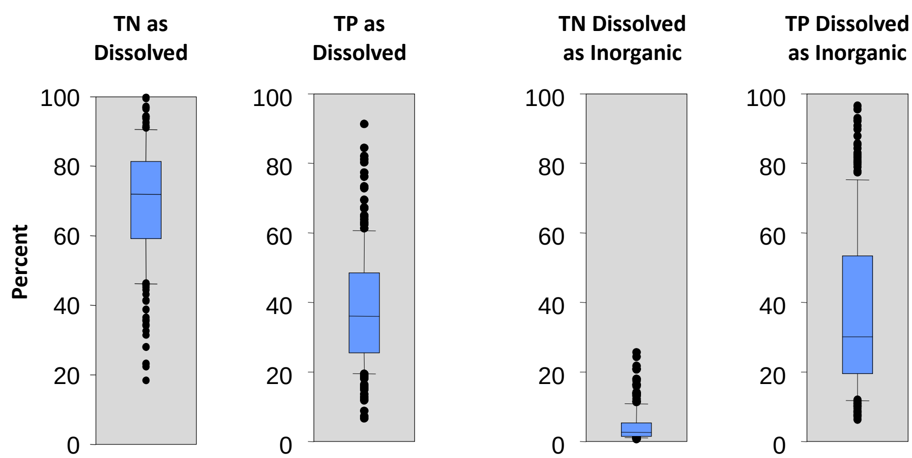
Nitrogen is relatively more abundant than phosphorus in most ponds.

→ suggests algae should be limited by phosphorus availability in most ponds.



Nutrient distributions in ponds

Particulate vs. Dissolved & Organic vs. Inorganic

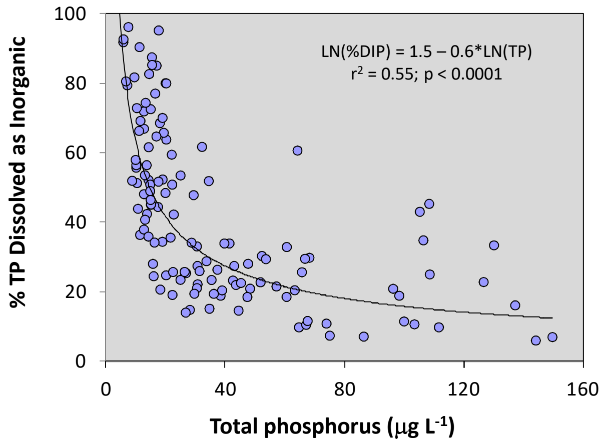


- **TN dominated by DISSOLVED N.**
- **TP dominated by PARTICULATE P.**
- **$TN_{dissolved}$ dominated by DON.**
- **$TP_{dissolved}$ much more variable.**

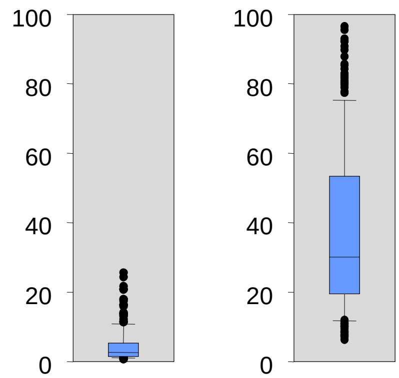
Nutrient distributions in ponds

Particulate vs. Dissolved & Organic vs. Inorganic

% $TP_{dissolved}$ decreases as TP increases



TN Dissolved as Inorganic | **TP Dissolved as Inorganic**



- **$TN_{dissolved}$ dominated by DON.**
- **$TP_{dissolved}$ much more variable.**

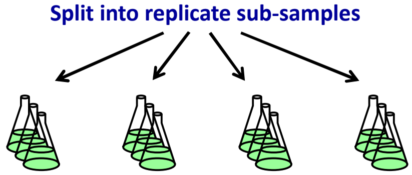
The Role of N versus P in controlling algal production in ponds

An experimental test of inorganic nutrient additions

Experimental design:

Collect pond water sample

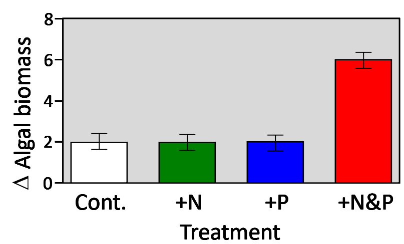
Split into replicate sub-samples



Control (no addition)	+ 50 mM Nitrogen (NH_4 & NO_3)	+ 5 mM Phosphorus (PO_4)	+ 50 mM N + 5 mM P

Measure change in algal abundance over 3 days
Test treatment responses relative to controls

6 Possible experimental results:

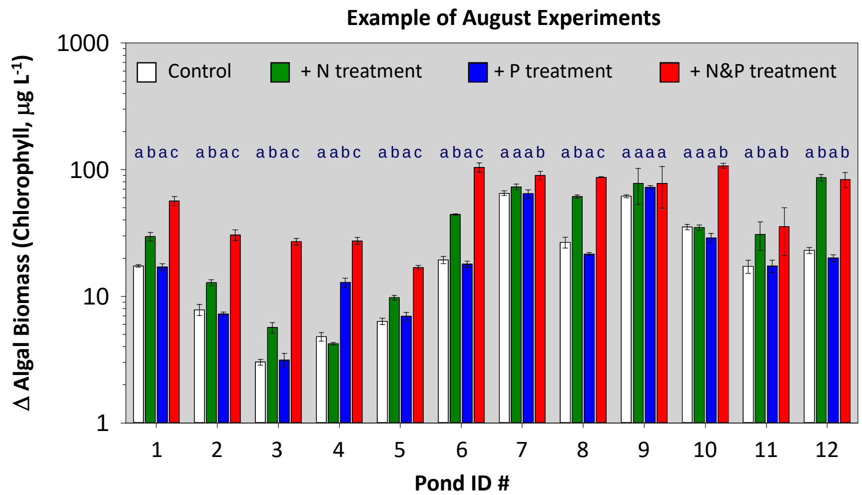


Interpretation of results:

1. **No significant treatment effects**
2. **Exclusive nitrogen limitation**
3. **Serial nitrogen limitation**
4. **Exclusive phosphorus limitation**
5. **Serial phosphorus limitation**
6. **Co-limitation by both N & P**

Results of experimental nutrient additions

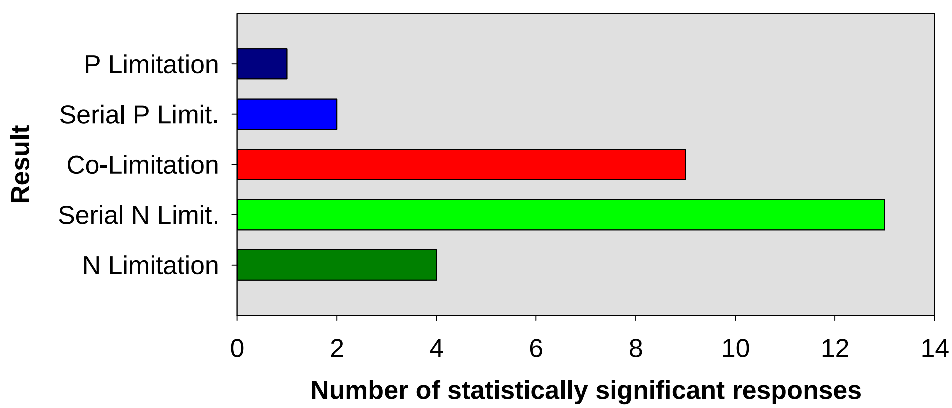
- Experiments performed in 12 individual ponds, repeated 3 times over a summer
- Total of 36 separate experiments; 7 experiments showed no significant results.



For each pond, treatments with the same letter are not significantly different ($p > 0.05$; ANOVA based on log-transformed data)

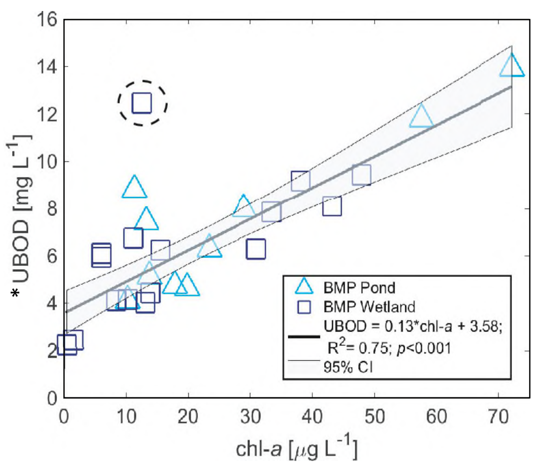
Summary of experimental responses to nutrient addition

Vast majority of responses indicated some degree of nitrogen limitation



→ Controlling algal growth requires managing both nitrogen & phosphorus

Chlorophyll *a* in stormwater BMPs is a strong predictor of BOD export to downstream receiving waters



Environmental Science & Technology
pubs.acs.org/est
Article

Particulate and Dissolved Organic Matter in Stormwater Runoff Influences Oxygen Demand in Urbanized Headwater Catchments

Kelly M. McCabe,* Erik M. Smith, Susan Q. Lang, Christopher L. Osburn, and Claudia R. Benitez-Nelson

Volume 55, issue 2. January 2021. *Open access*

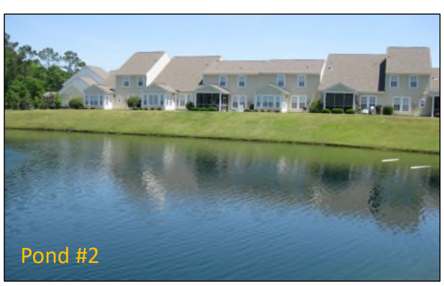
*UBOD = "Ultimate" BOD = 28-day BOD

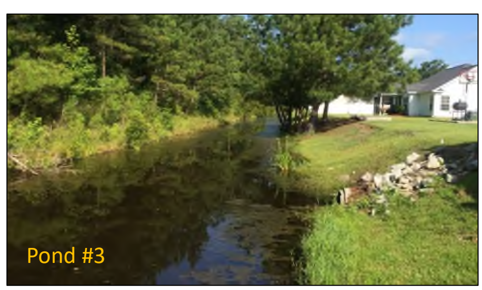
How effective are ponds at removing nutrients (& other pollutants)?

A study of 3 residential ponds

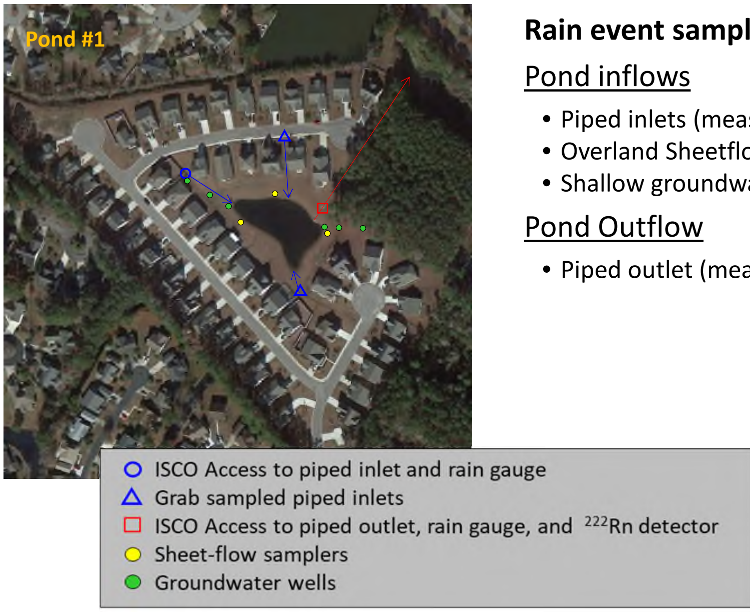
Quantifying input and outputs of

- Sediments (inorganic & organic)
- Nutrients
  - Total Phosphorus
  - Total Nitrogen
- *E. coli* (fecal indicator bacteria)





Study Sampling Design



Rain event sampling of:

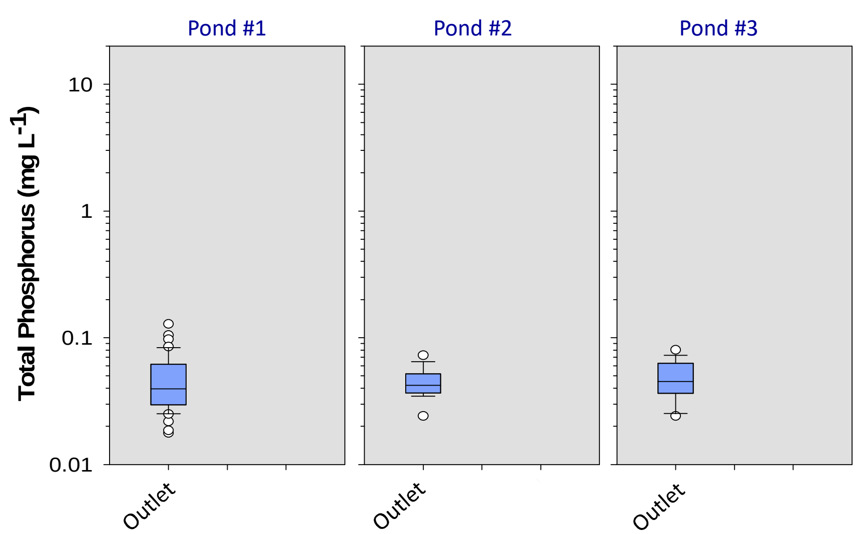
Pond inflows

- Piped inlets (measured as event-mean concentrations)
- Overland Sheetflow
- Shallow groundwater input

Pond Outflow

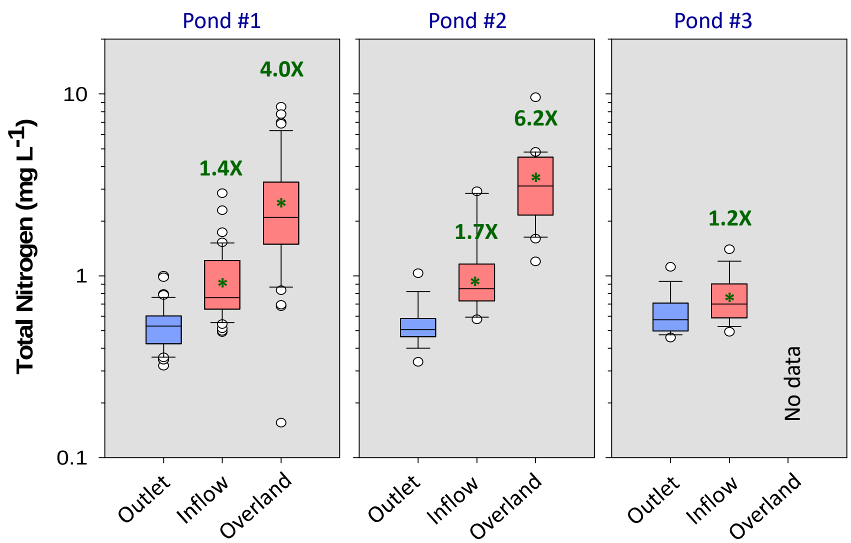
- Piped outlet (measured as event-mean concentrations)

Phosphorus in inflows and outflow



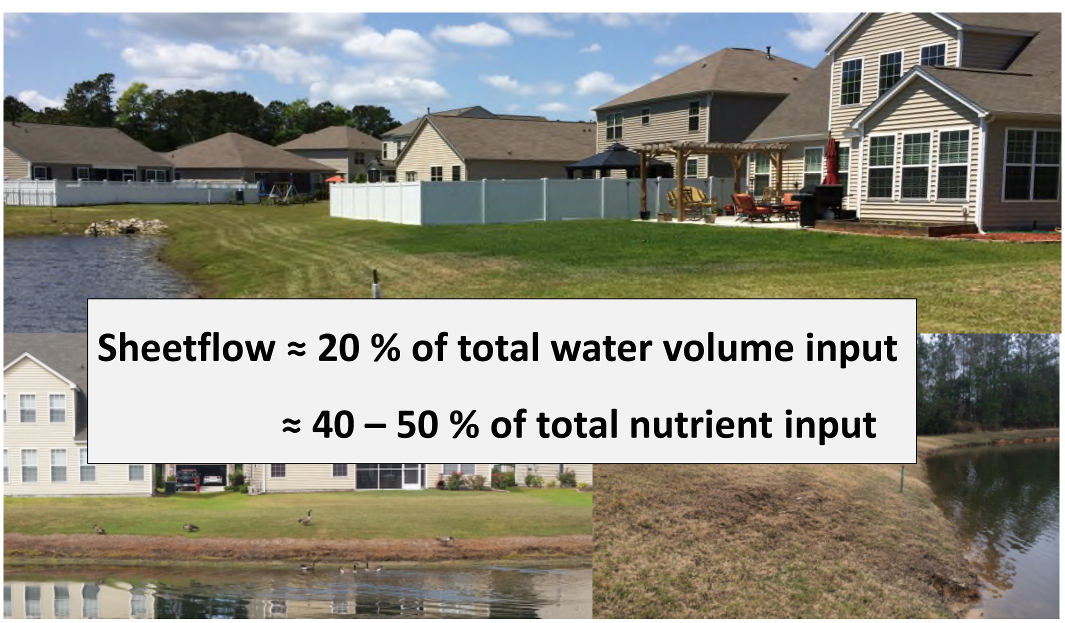
* Inflow sources statistically different from outlet (Wilcoxon nonparametric pair-wise comparisons)

Nitrogen in inflows and outflow



* Inflow sources statistically different from outlet (Wilcoxon nonparametric pair-wise comparisons)

Why are sheetflow concentrations so high?



Pond nutrient removal meet expectations (mostly)

Concentration Reduction calculation:

$$CR = \left(1 - \frac{geometric\ mean\ of\ outlet\ EMC}{geomentric\ mean\ of\ inlet\ EMC}\right) x\ 100$$

SC DHEC BMP Handbook :

Total Phosphorus	50-70%
Total Nitrogen	30-45%
Suspended Sediments	65-80%
Pathogens/Bacteria	45-75%

Horry County Stormwater Design Manual:

Sediment	60-80%
Total Phosphorus	40-60%
Total Nitrogen	20-40%

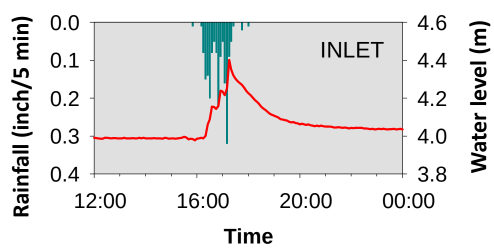
This Study:	Pond # 1	Pond # 2
Total Phosphorus	**66 %**	**64 %**
Total Nitrogen	**40 %**	**45 %**
Total Sediments	**84%**	**71%**
Bacteria (*E. coli* MPN)	**82%**	**98%**

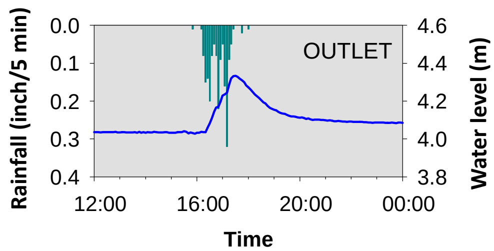
Note: % Reduction estimates based on piped inlet concentrations only

Controlling water flow is critical to water treatment!

Pond # 3 outlet
in dry conditions

Inlet versus outlet
storm-event water levels





There is a need to improve nitrogen removal in ponds

- Nitrogen availability often drives algal production.
- Conventional ponds not particularly effective at sequestering nitrogen.

→ Doest the addition of plants to ponds to increase nitrogen removal?

Goal: Enhanced denitrification

= $NO_3 \rightarrow N_2$ (and back to atmosphere)

The Nitrogen Cycle

Pathways of Nitrogen Removal:

- Denitrification:

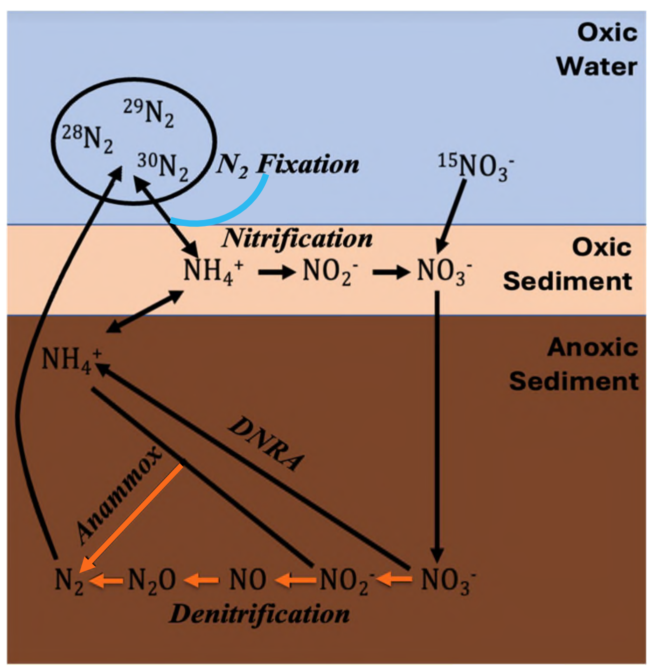
  $NO_3^- \longrightarrow N_2$
- Anammox:

  $NO_2^- + NH_4^+ \longrightarrow N_2$

Pathway of Nitrogen Addition:

- N_2 Fixation:

  $N_2 \longrightarrow NH_4$ (in organic N)



Investigating the use of vegetation to improve nitrogen removal

Principal Investigator: Dr. Annie Bourbonnais, USC
Co-Principal Investigator: Dr. Erik Smith, USC
Graduate Student: Darcy Pernin, Ph.D. candidate, USC

Project objective: Estimate net nitrogen removal rates, the role of denitrification, and the conditions that maximize these rates, in sediments from ponds that had vegetation and those without vegetation

Study design

Sampling sites:
- 4 Vegetated ponds
- 5 Unvegetated ponds
- 2 Naturally forested drainage channels

Sediment core collection:
- Pond center
- Pond edge / littoral shelf

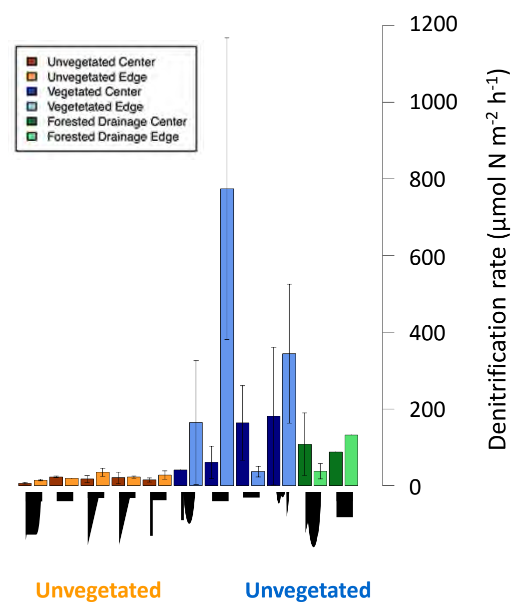
Laboratory methods

- Cores returned to laboratory, incubated 48 h to measure nitrogen flux rates
  - **Denitrification rate**: Addition of labeled $^{15}NO_3^-$ then measure ^{15}N incorporated into N_2 via a membrane inlet mass spectrometer (MIMS)
  - **Net nitrogen flux** (balance between denitrification and nitrogen fixation): measure time-course changes in gas ratio (N_2/Ar) on MIMS
- Nutrient Analysis (NO_3^-, NO_2^-, PO_4^{3-}, NH_3, DON & DOP)
- Sediment % organic carbon
- Sediment grain size, bulk density, and porosity

Denitrification rate in vegetated vs. unvegetated ponds

- Sediments from vegetated ponds show significantly higher rates of denitrification than non-vegetated ponds
- Denitrification substantially higher in vegetated pond edges, compared to center of pond



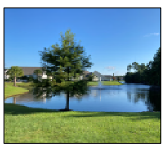


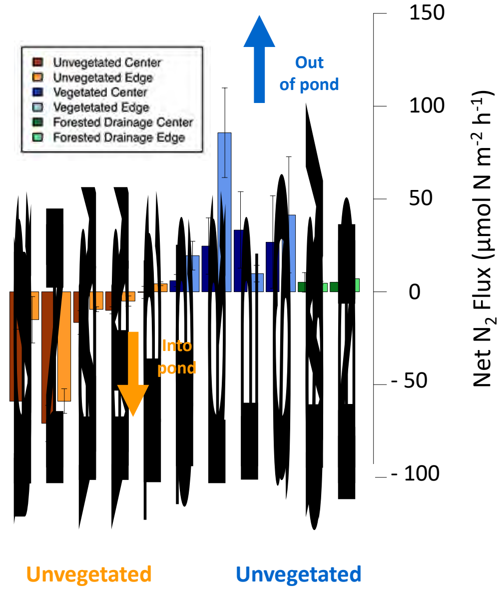
Net N flux in vegetated vs. unvegetated ponds

- Sediments from vegetated ponds show significant rates of net nitrogen (N_2) removal from ponds



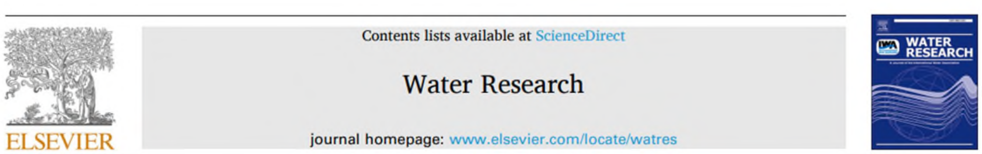
- Sediments from unvegetated ponds show significant net nitrogen fixation
  = *source of new nitrogen to pond*

Conventional stormwater ponds can be designed or retrofitted to enhance nitrogen removal

Water Research, Volume 295, May 2026. *Open access*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Vegetation enhances nitrogen removal in stormwater ponds in coastal South Carolina

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[b] Baruch Institute for Coastal and Marine Sciences and the North Inlet – Winyah Bay National Estuarine Research Reserve, University of South Carolina, Georgetown, SC 29442, USA

A few summary points:

- **Pond water quality is largely dependent on stormwater inputs.**
  - → Pond nutrient levels broadly tracks degree of development density, but homeowner practices can substantially affect the amount of nutrients entering ponds (fertilizers, feeding wildlife, etc.).
  - → Algal production in ponds is strongly linked to nutrient availability
  - → Algal production in ponds is strongly linked BOD export from ponds
  - → Nutrient addition bioassays suggest managing excessive algal growth requires controlling both nitrogen and phosphorus.
- **Conventional stormwater ponds exhibit a range in pollutant removal performance.**
  - → Removal efficiencies relatively high for particulate-associated pollutants, like phosphorus, but much less so for dissolved nutrients, like nitrogen.
  - → Overland sheetflow may be a minor contributor of water volume but can be a major contributor of total pollutant mass flux.
  - → Proper hydrologic performance (storm detention) is essential to water quality performance
- **Adding vegetation to ponds (by design or just not actively removing them) can significantly improve biological nitrogen removal**