Modeling and Regulatory Support
Year 2 Kickoff Meeting
Wednesday, October 25, 2017
9:30 AM – 12:30 PM
Butner Town Hall Multi-Purpose Room

Agenda

9:30 Welcome and Introductions

9:50 Overview of UNRBA Modeling and Regulatory Support Project

10:10 Data Acquisition for the Watershed Modeling component of the Project

10:55 Break Out Groups to Discuss Concerns and Ideas for Providing the Data

11:50 Rapid Report Outs

12:20 Next Steps in Modeling and Regulatory Support

12:30 Adjourn

2022 Falls Lake Nutrient Management Study Research Symposium

The Upper Neuse River Basin Association Pathway to a Re-examination of the Falls Lake Nutrient Management Strategy

April 7, 2022

The History of Falls Lake

- Initial primary focus on flood control
- Authorized in 1965
- Water Quality Agency Predicts eutrophic conditions and violations of water quality standards
- Began to fill in 1981 (filled during a drought)
- Reached full pool by 1983
- Water Quality better than predicted

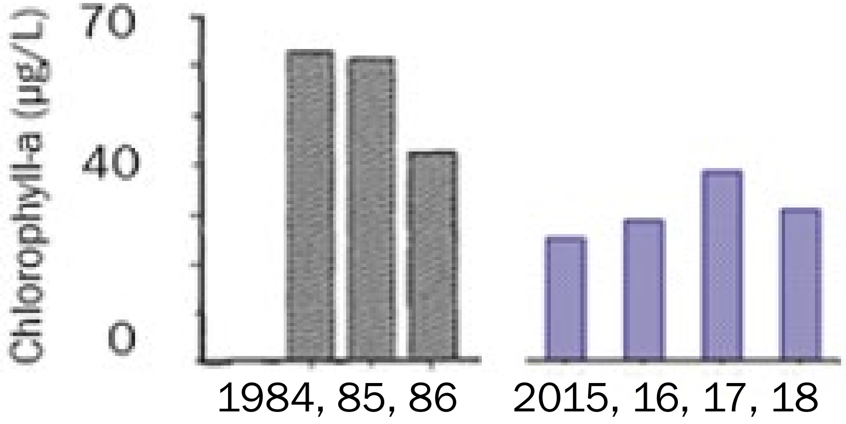
Photograph of workers on an old wooden dam uncovered during construction of Falls Lake Dam in the late-1970s. When this photo was taken, the wooden dam was over 150 years old and covered by silt, mud, and water. *Photograph courtesy of the US Army Corps of Engineers.*

Photograph courtesy of the US Army Corps of Engineers as cited by the Wake Forest Historical Museum.

Controversy and Concern Follows Falls Lake

- Environmental concerns about removal of a free-flowing river and resulting quality of the lake
- Environmental studies indicated it would be over-enriched with nutrients
- Listed on NC's 303(d) list for chlorophyll-a in 2008
- Falls Lake Rules adopted in 2010
- Data and analysis indicates water quality is better than predicted and has improved over time

Growing Season Average Chlorophyll-a



The predicted lake-wide average based on models developed in 1983 by NCDEM was 75 µg/L.

UNRBA Members and Perspectives

Members

- Six counties
- Six municipalities
- One water utility
- Soil and water conservation districts

Perspectives

- Urban and rural areas
- Point and non-point sources
- Local governments
- Agriculture
- Institutions
- State and federal entities

Falls Lake Reservoir Provides Multiple Purposes

- Provides drinking water for 550,000 customers
- Minimizes flooding
- Regional recreational facility
- Provides habitat to aquatic and terrestrial wildlife
- Protects water quality downstream

Regulatory Context

- In 2005, the NC legislature directed the NC Environmental Management Commission to
  - Study water quality in drinking water supply reservoirs serving more than 300,000 persons
  - Adopt nutrient control criteria for impaired reservoirs or those that may become impaired within 5 years (Falls Lake listed in 2008)
  - Complete studies, modeling, and management strategy development within 3 years
  - Timeline was extended to January 2011 in later bills
- In 2010, the legislature created the Falls Lake Watershed Association (FLWA) (the UNRBA also does business as the FLWA)
- In 2011, the Falls Lake Nutrient Management Strategy (Falls Lake Rules) were passed with the goal of attaining the chlorophyll-a standard everywhere in the lake

The Consensus Principles

- Initially there was friction among the UNRBA members with two different perspectives
  - This is our water supply, and its quality is critical to our service area and economy
  - These rules are a burden on the upper jurisdictions
- Consensus Principles were established by UNRBA members during development of the Falls Lake Nutrient Management Strategy
- All parties agreed to the protection of Falls Lake as a drinking water supply
- Resulted in language in the Rules that allowed for re-examination if certain steps were taken
- Provided the framework for the UNRBA re-examination process and a funding mechanism

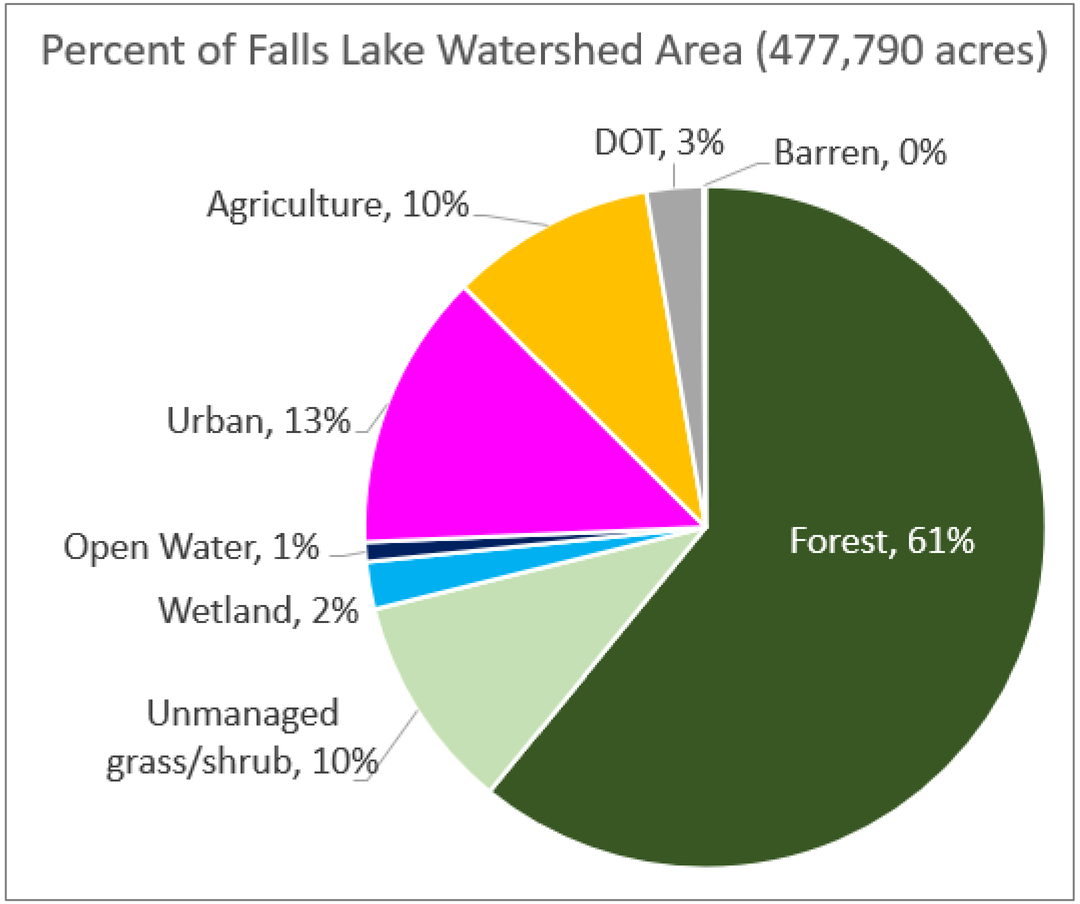
DWR 2011 Falls Lake Nutrient Management Strategy

- DWR models were finalized in 2009 using data from 2005 to 2007 (with limited time and resources)
- Establishes two stages of actions and assigns load reduction targets for individual sectors
  - Includes the highest nutrient reductions ever passed in NC (77% Phosphorus, 40% Nitrogen)
  - Required reductions exceed limits of technology
  - Uncertain that chlorophyll-a standard could be achieved everywhere in the lake
  - The total strategy is estimated to cost over $1.5 billion
- Strategy allows for a re-examination of Stage II based on the Consensus Principles

- Existing Development
- New Development
- Wastewater Treatment Plants
- Agriculture
- State and federal Entities

Falls Lake Challenges

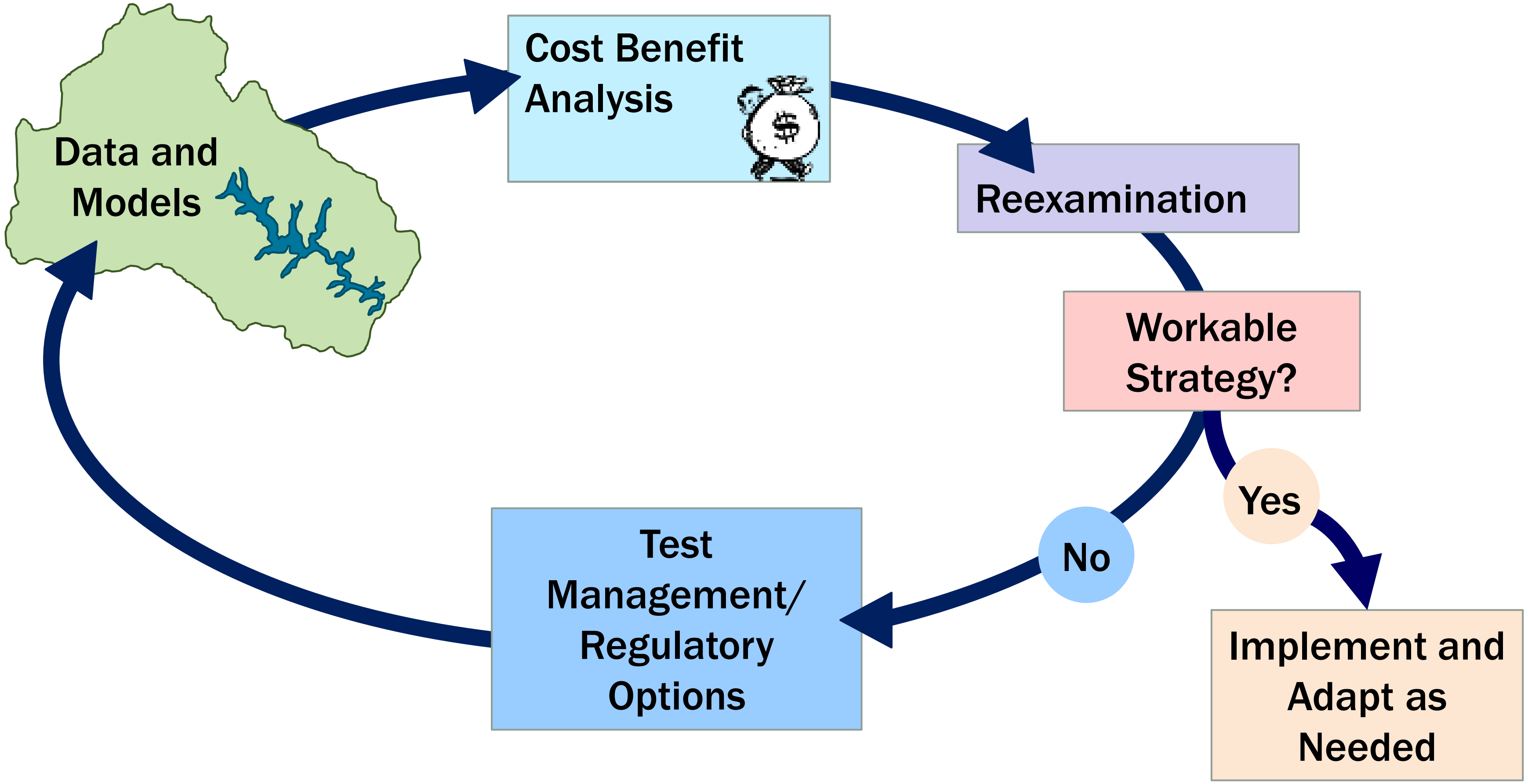
- Dam construction on the river resulted in flooded topography and shallow areas difficult for attaining the 40 µg/L chlorophyll-a standard
- Exceedances of the chlorophyll-a standard resulted in the lake being 303(d) listed
- The watershed is approximately 74% unmanaged (forest, wetlands, unmanaged grassland/shrubland, open water)
- Watershed and lake sediments are an ongoing source of nutrients



Components of the Re-examination

- Use a science-based approach to nutrient management
- Protect water quality in Falls Lake and continue to meet designated uses
- Use local resources effectively
- Balance science, policy, and water quality goals develop a revised nutrient management strategy that is technologically feasible and economically viable

Framework for the Re-examination



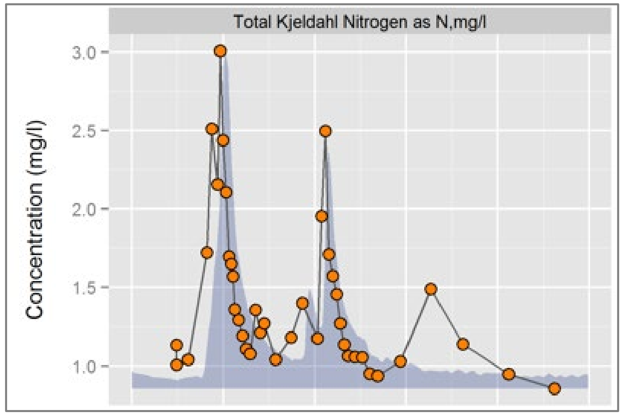
UNRBA Knowledge Base for the Re-examination

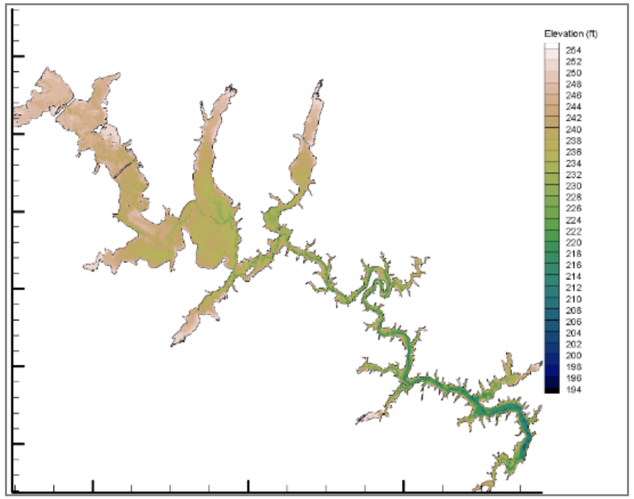
- UNRBA Description of the Modeling Framework, 2014 *
- UNRBA Monitoring Plan, 2014 *
- UNRBA Monitoring Quality Assurance Project Plan (QAPP), 2014 *
- Evaluation and Selection of Model Packages for the UNRBA Modeling and Regulatory Support Project, 2017
- Conceptual Modeling Plan, 2017
- Data Management Plan, 2018
- Four-year monitoring program (August 2014 through October 2018) *
- UNRBA Modeling QAPP, 2018 *
- Comprehensive UNRBA Monitoring Report, 2019
- UNRBA Decision Framework, 2020

** State Requirements for the Re-examination as described in the Rules*

UNRBA Watershed and Lake Data Collection and Studies

- UNRBA monitoring program
  https://www.unrba.org/monitoring-program
- Four-year program
- At least monthly sampling
- 38 stations in the watershed
- Supplemental data collected at
  12 DWR lake monitoring stations
- Designed to fill data gaps and support modeling efforts
  - Routine monitoring
  - Special studies
- UNRBA Data Summary Report





Integration of NC Policy Collaboratory Research into UNRBA Re-examination

WATERSHED MODELING	LAKE MODELING	EVALUATION OF DESIGNATED USES	NUTRIENT MANAGEMENT AND OUTREACH
Stormwater retrofit studies	Water movement	Algal toxin evaluation	Paying for nutrient management
Onsite wastewater treatment systems evaluation	Nutrient reaction rates	Carbon cycling	Community outreach and engagement
	Lake sediment processes		

In addition to the studies, the NC Collaboratory is also providing third-party review of the UNRBA models as an additional quality assurance measure.

In Situ Observational Study of Water Circulation and Associated Properties in Falls Lake, North Carolina

Rick Luettich, Tony Whipple

UNC-CH Institute of Marine Sciences

Harvey Seim, Ollie Gilchrest

UNC-CH Department of Earth, Marine and Environmental Sciences

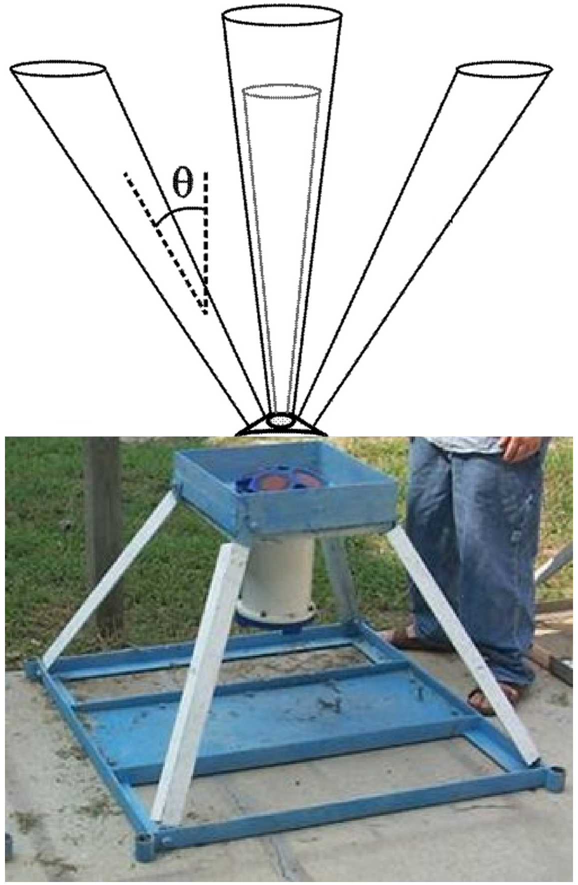
Research Questions

- What are the primary circulation pattern(s) in Falls lake?
  - time-scales shorter than long-term averages and longer than a few hours
- How does along lake circulation vary (Years 1-2)
  - Inflows / Outflows
  - Physical Properties
  - Seasons
- How does side-arm circulation impact central lake (Year 3)
- Implications for Water Quality
  - Localized velocities may affect localized water quality

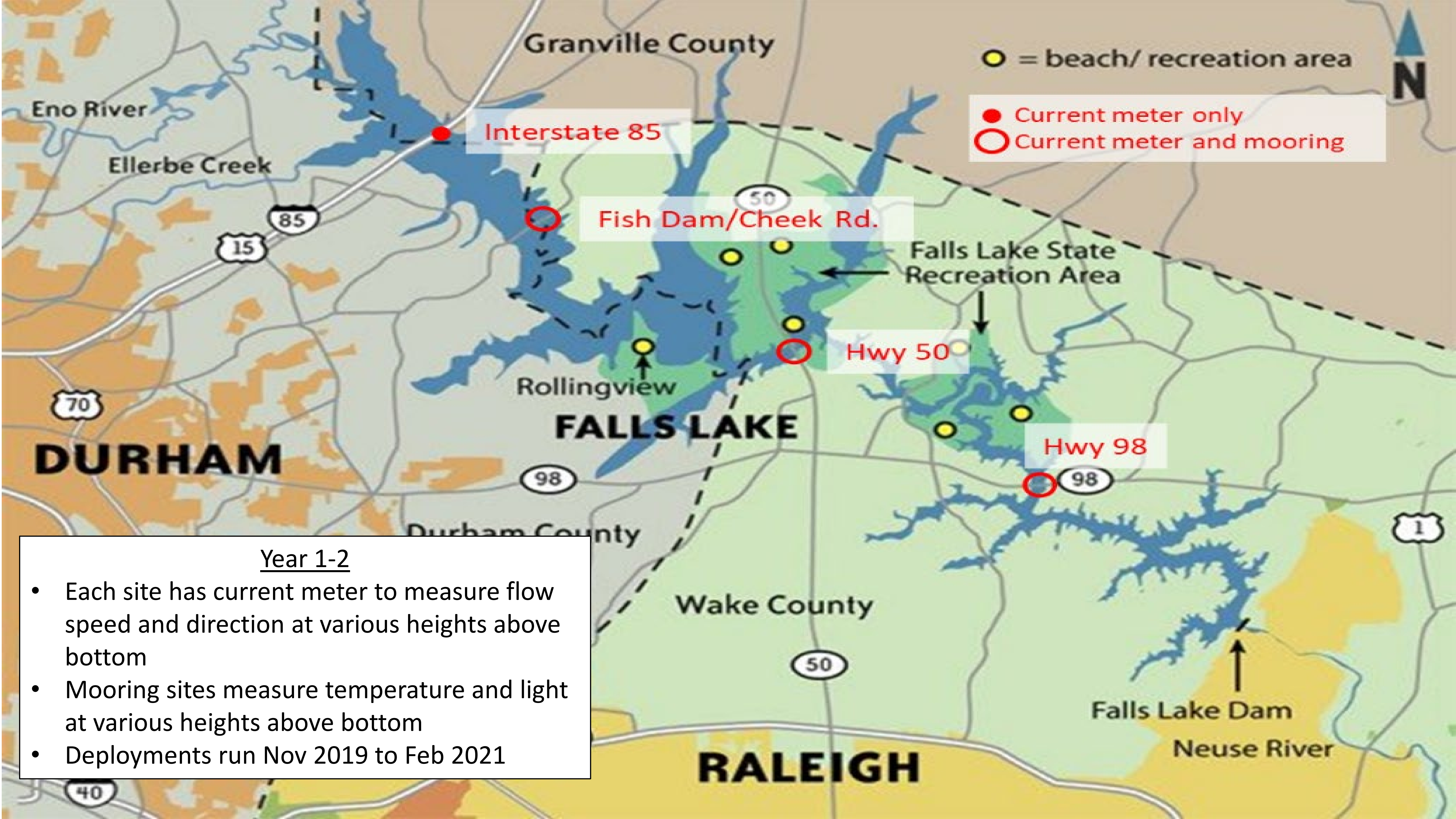
Instrumentation

- Year 1-2: November 2019 – February 2021
- Year 3: August 2021 – September 2022

- Water Temperature & light moorings @ 0.5 m vertical spacing – every 6 min



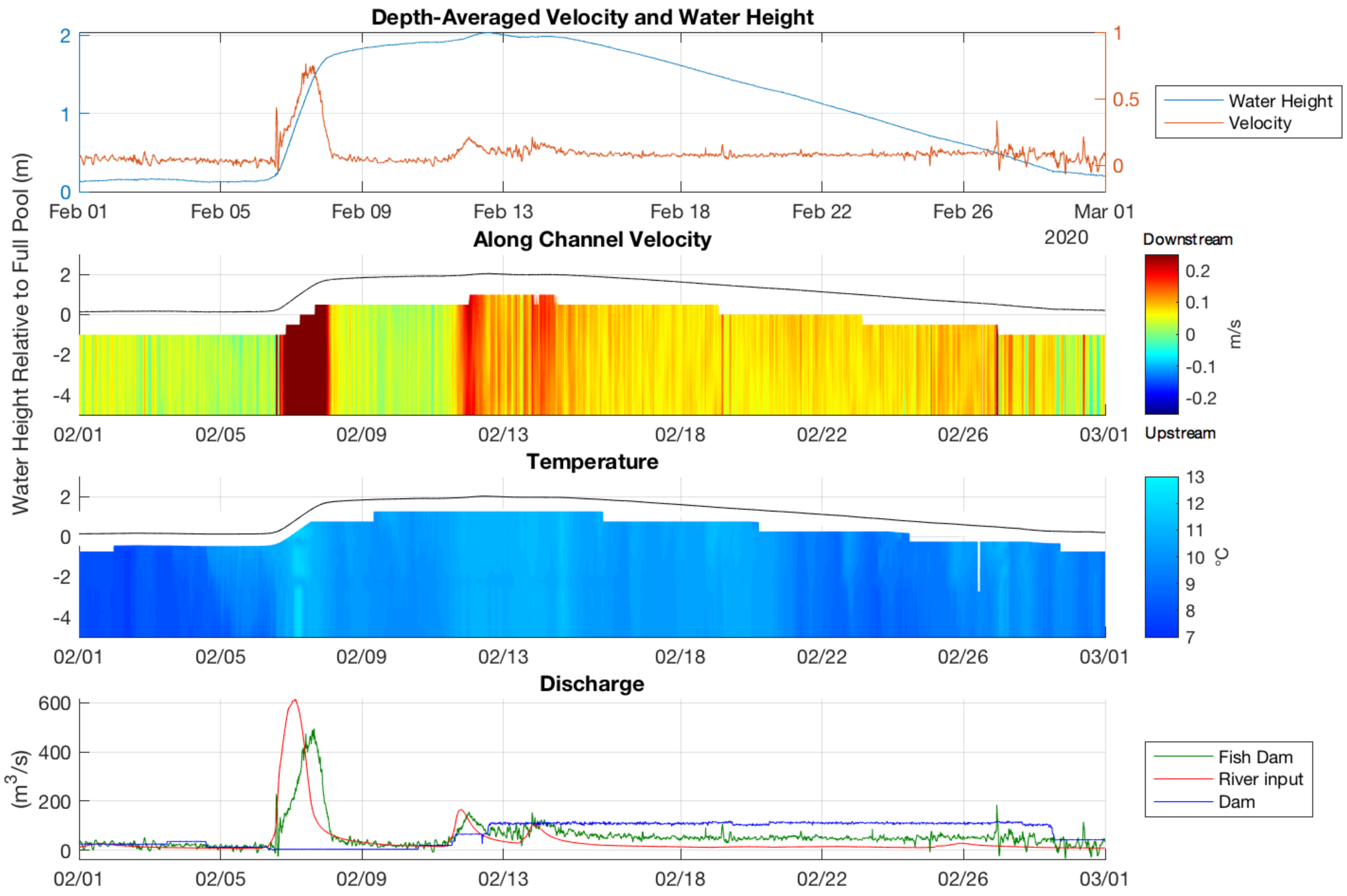
- Water velocity @ 0.5 m vertical resolution – every 10 min

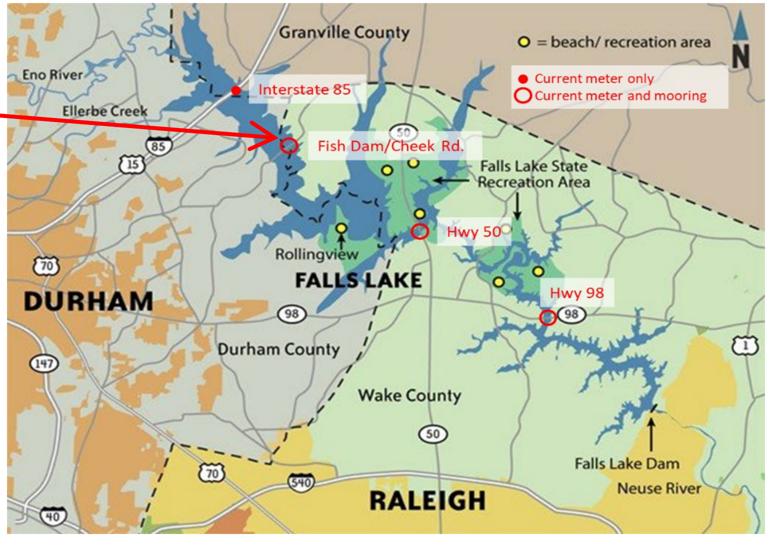


Year 1-2

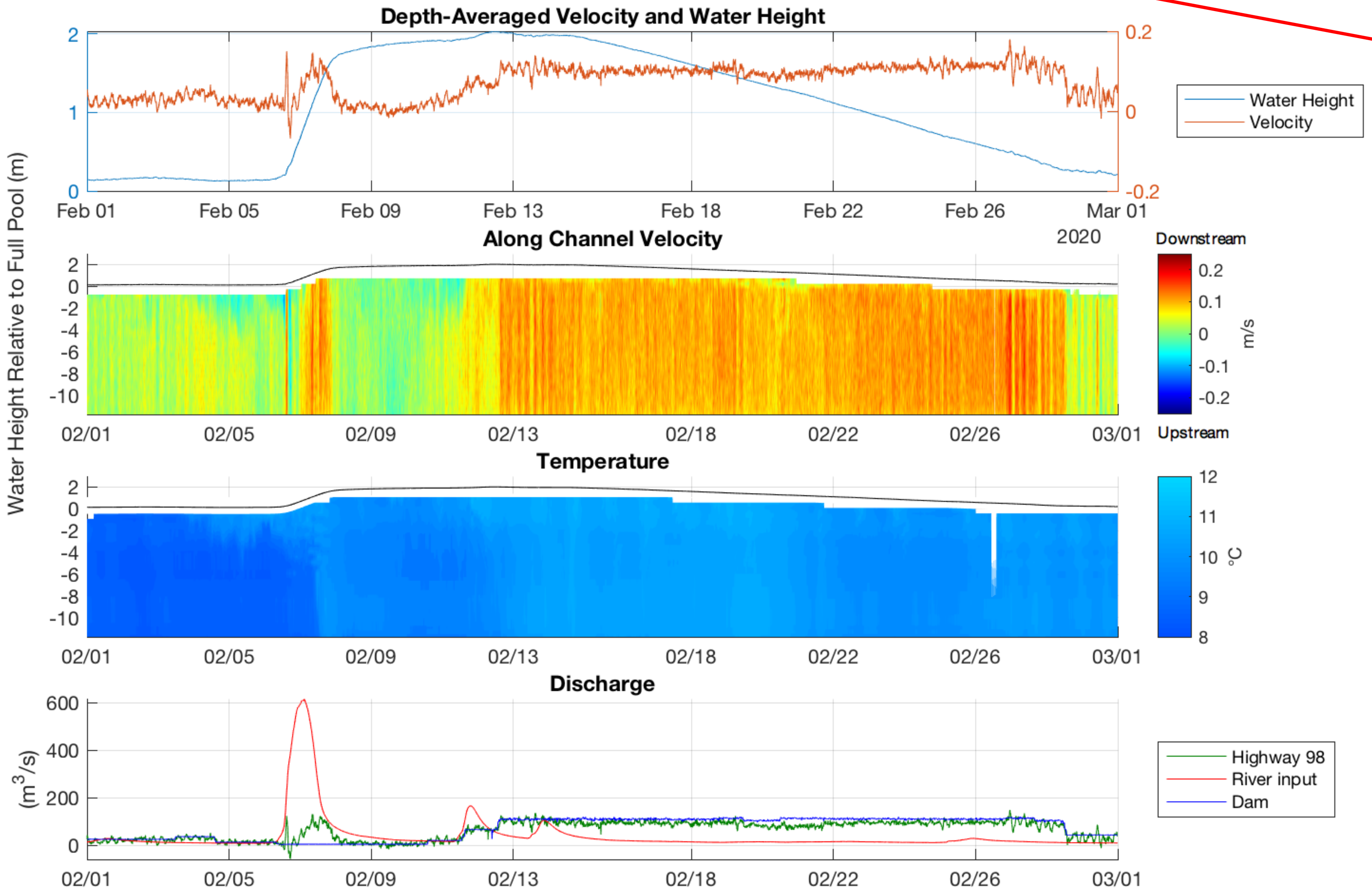
- Each site has current meter to measure flow speed and direction at various heights above bottom
- Mooring sites measure temperature and light at various heights above bottom
- Deployments run Nov 2019 to Feb 2021

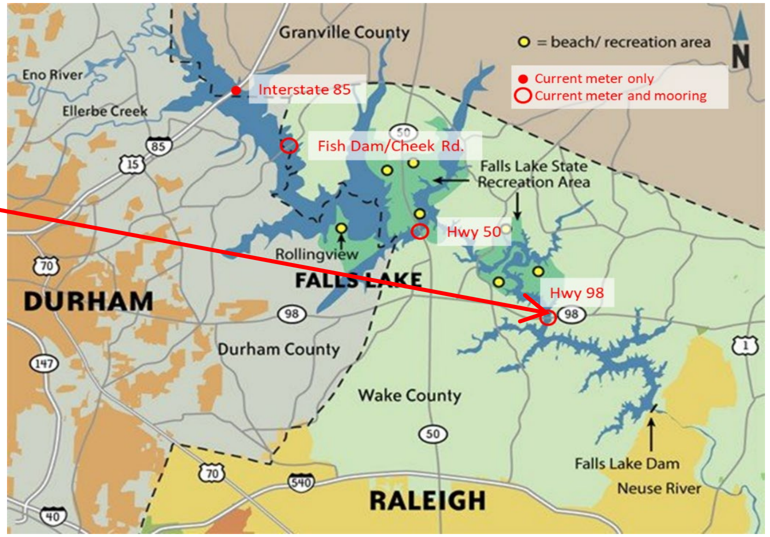
Fish Dam Rd- February 2020



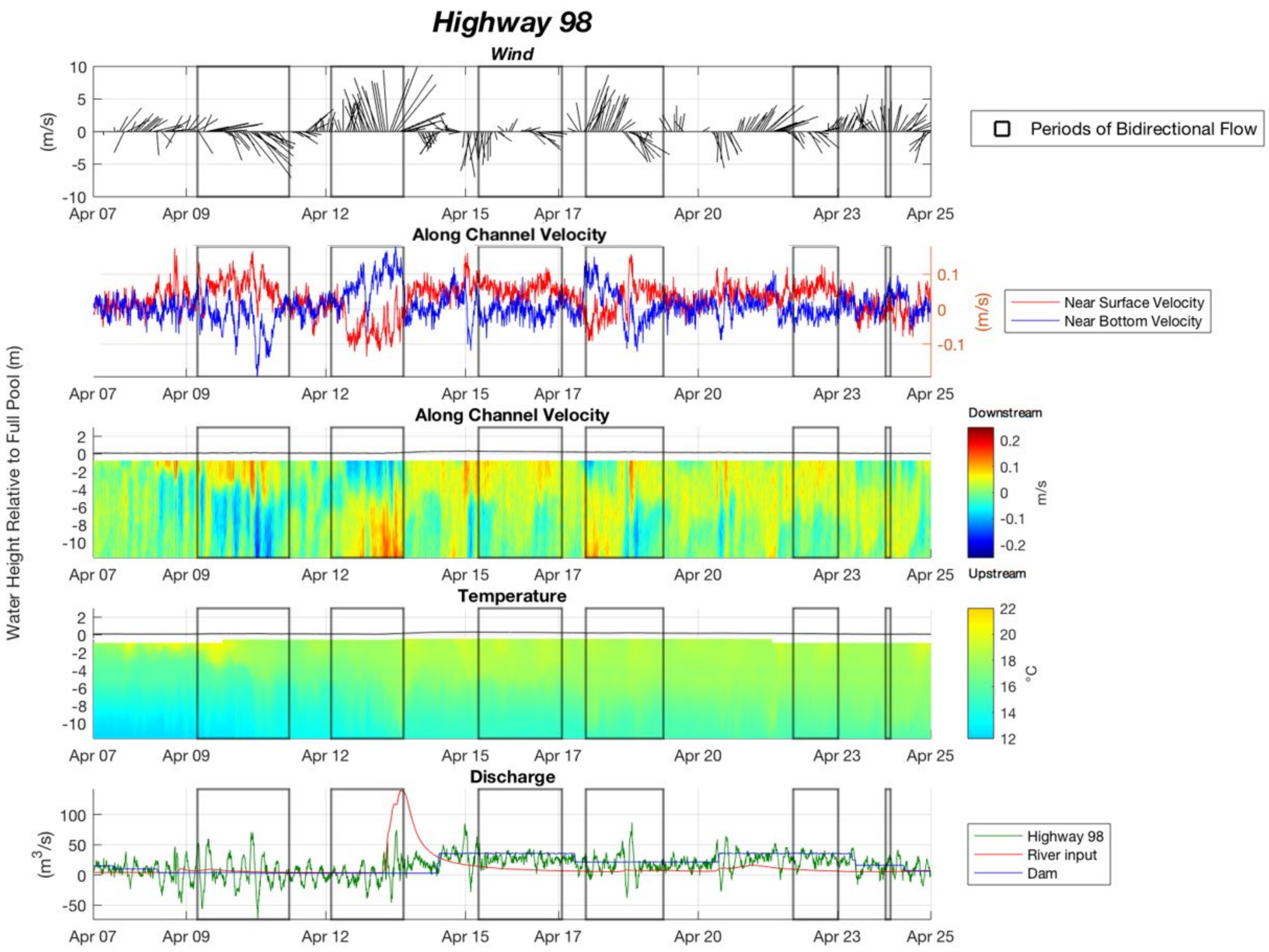


Hwy 98 - February 2020





Two-layer flow in Lower Lake



Key Findings – Year 1-2

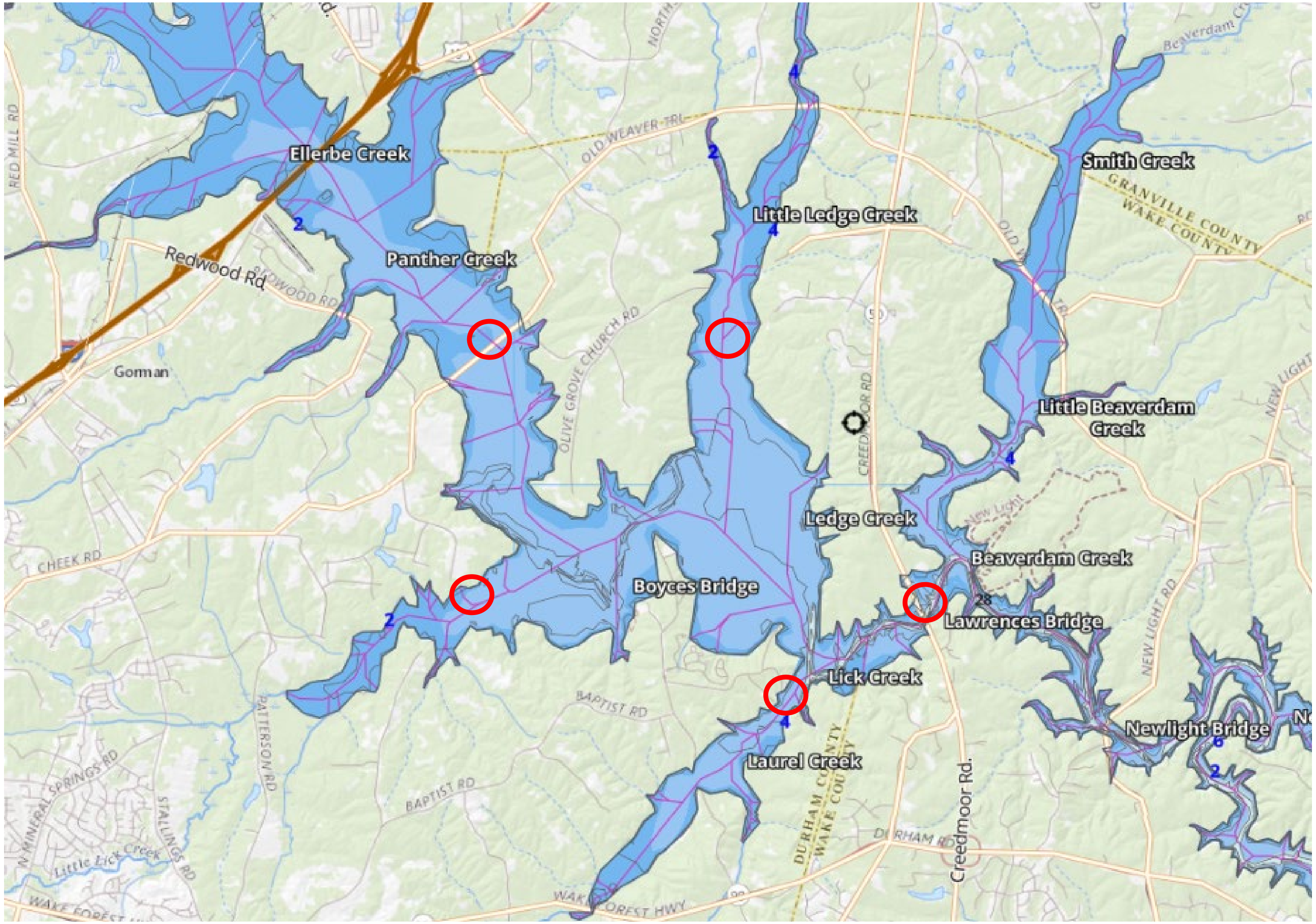
Much more complete picture of circulation in Falls Lake

- Median residence time ~11 months
- Along lake flow responds to inflows, dam operation, wind
  - Upper lake flows respond most strongly to inflows
  - Lower lake flows respond most strongly to dam outflow
  - A 5.5hr oscillation frequently occurs along the lake
  - Two-layer flow in lower lake ~40% of the time, occurs when temperature stratified

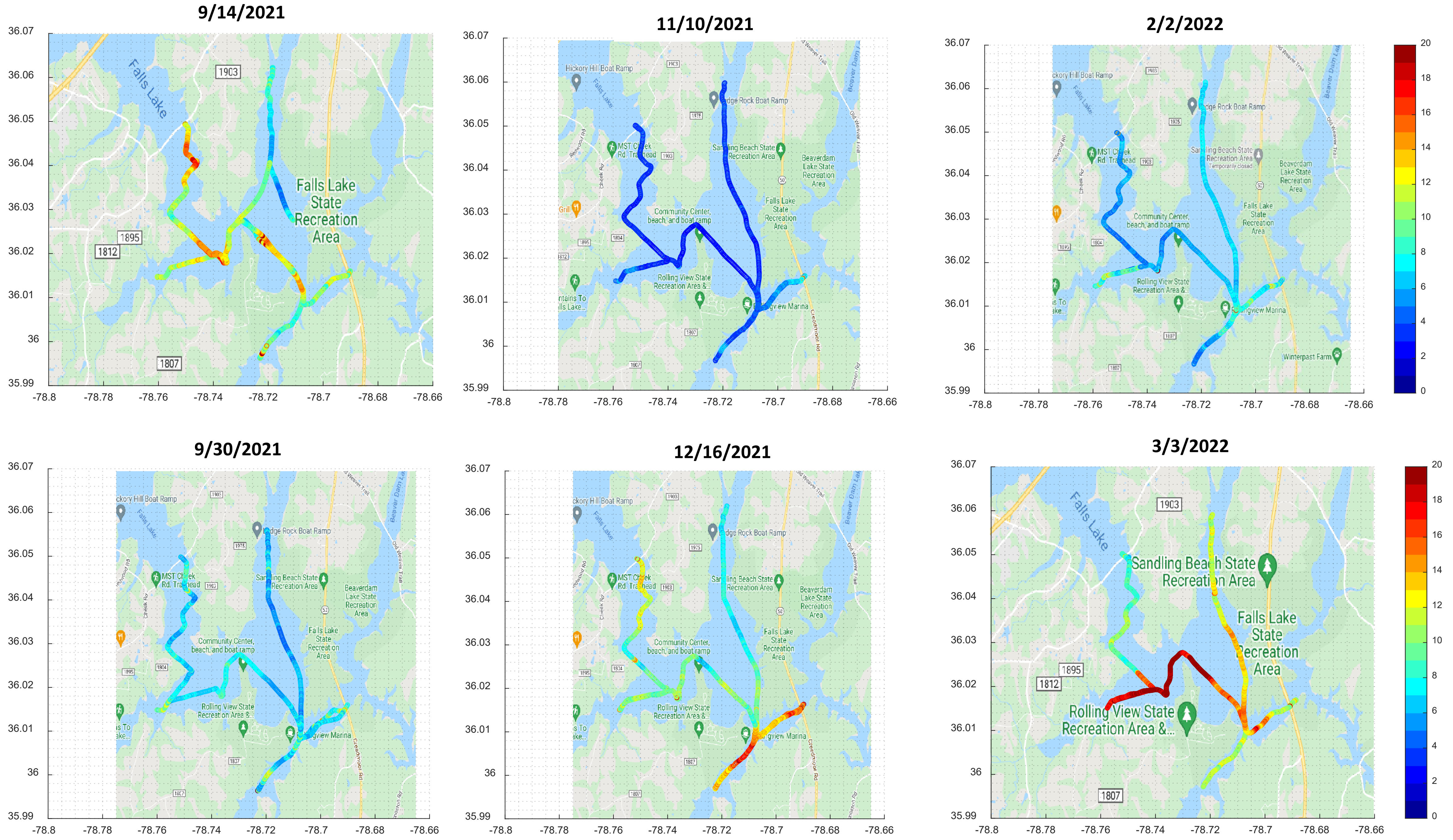
Research Questions

- What are the primary circulation pattern(s) in Falls lake?
  - time-scales shorter than long-term averages and longer than a few hours
- How does along lake circulation vary (Years 1-2)
  - Inflows / Outflows
  - Physical Properties
  - Seasons
- How does side-arm circulation impact central lake (Year 3)
- Implications for Water Quality
  - Localized velocities may affect localized water quality

Year 3 – Central Lake and Side-arms



in vivo fluorescence (µg/l) from underway shipboard sampling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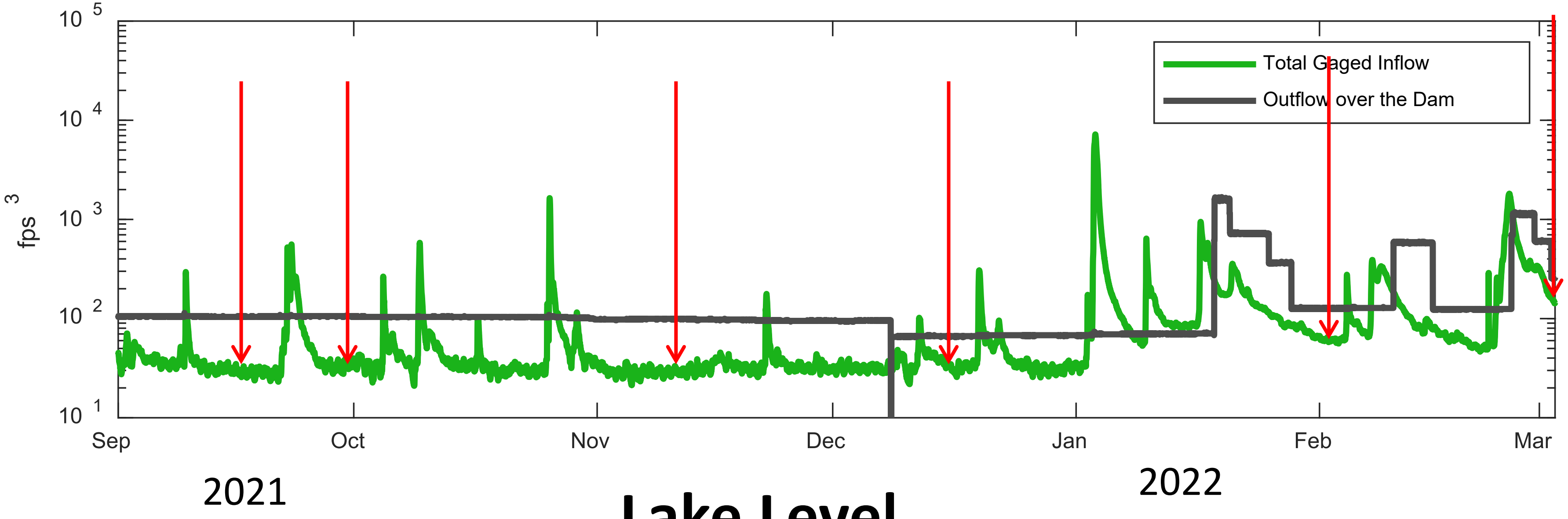
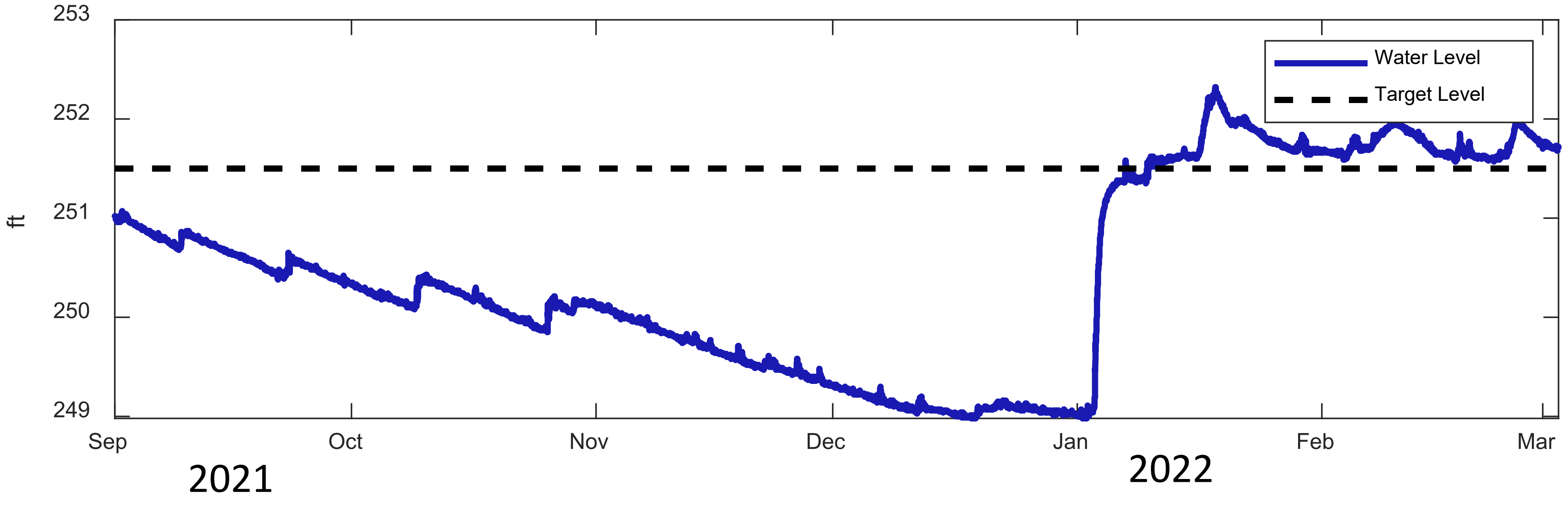
36.02
36.01
36
35.99
-78.8
-78.78
-78.76
-78.74
-78.72
-78.7
-78.68
-78.66
20
18
16
14
12
10
8
6
4
2
0
Falls Lake
Falls Lake State Recreation Area
1903
1895
1812
1807
Hickory Hill Boat Ramp
MST Creek Rd. Trailhead
Community Center, beach, and boat ramp
Rolling View State Recreation Area &...
Beaverdam Lake State Recreation Area
Sandling Beach State Recreation Area
Winterpast Farm

Discharge



Lake Level



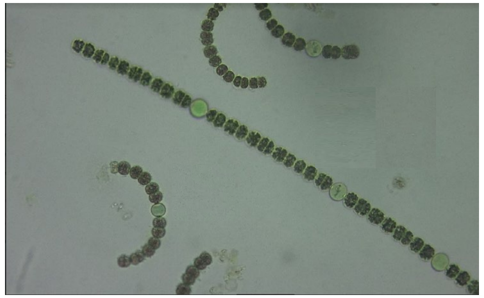
Key Findings – Year 3 (so far)

- Most data has yet to be recovered and processed
- Underway in vivo fluorescence shows interesting spatial structure
    - Further analysis needed to determine accuracy, cause and effect, water quality relevance

Summary Statement

This study has provided a more complete picture of the circulation in Falls Lake than has previously been available. Along-lake flow responds to inflows and discharge over the dam; long-term median residence time in the lake is a bit less than a year, although this can vary substantially depending on the size of inflows and discharge. A lake-wide 5.5hr along-lake oscillation and two-layer flow in the lower lake (surface water moving down wind and bottom water flowing in reverse) are often present and may be dominant when the along lake flow is small. Data in the central portion of the lake and associated side-arms are currently being collected to help explain patterns of near surface fluorescence and other water quality variables collected from underway sampling in this area.

Assessment of zooplankton- phytoplankton relationships in Falls Lake to guide development of site specific numeric nutrient criteria



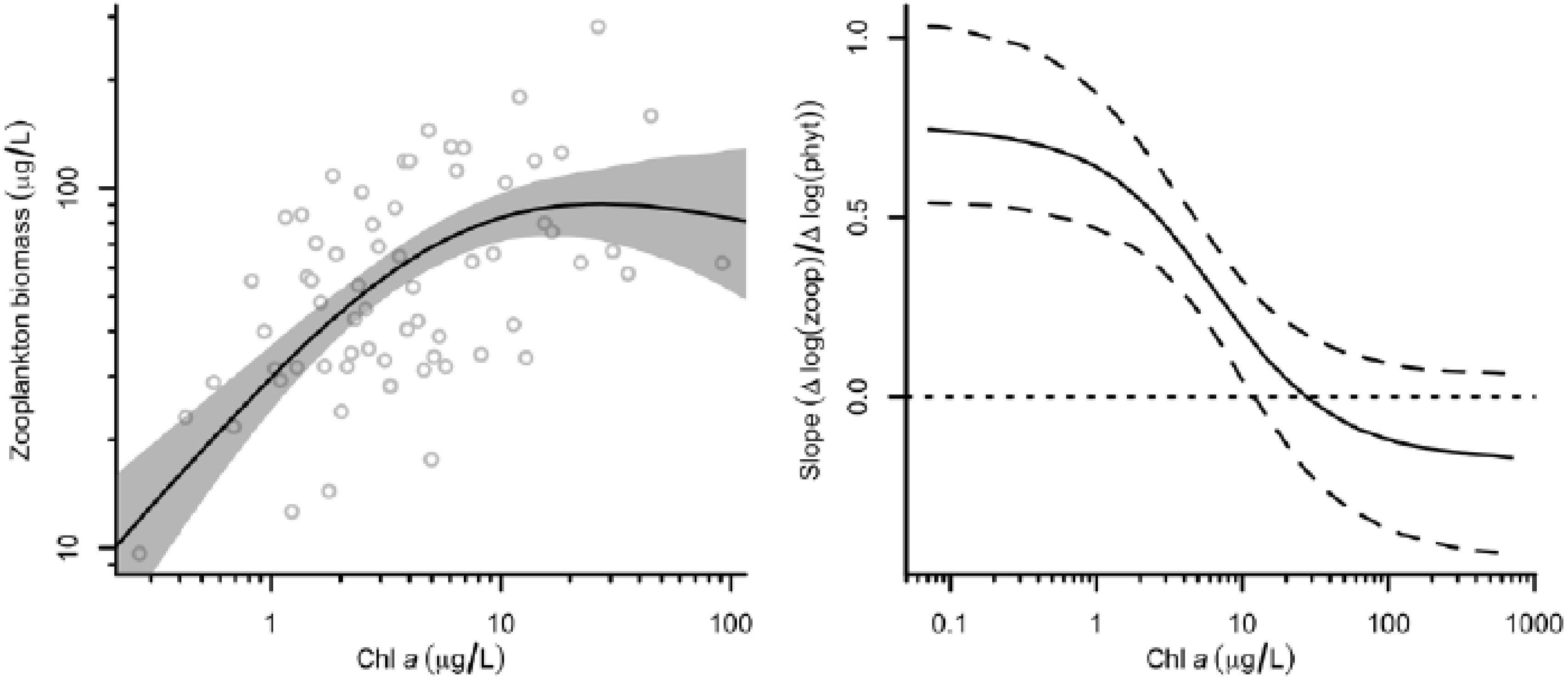
Nathan Hall and Michael Piehler
UNC Chapel Institute of Marine Sciences

Falls Lake Nutrient Study Research Symposium
7 April 2022

EPA proposes use of zooplankton: phytoplankton biomass to set standards for phytoplankton biomass

EPA

Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs (2021)



Data from National Lakes Assessment- summertime survey of >1000 U.S. lakes and reservoirs

Research Questions

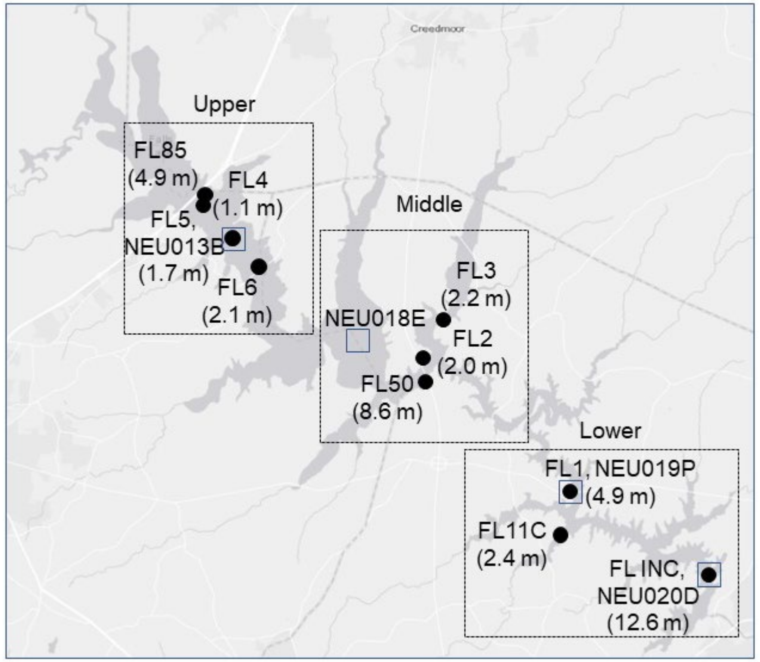
1) How does zooplankton/Chl *a* in Falls Lake compare to similar water bodies in the southeastern US?

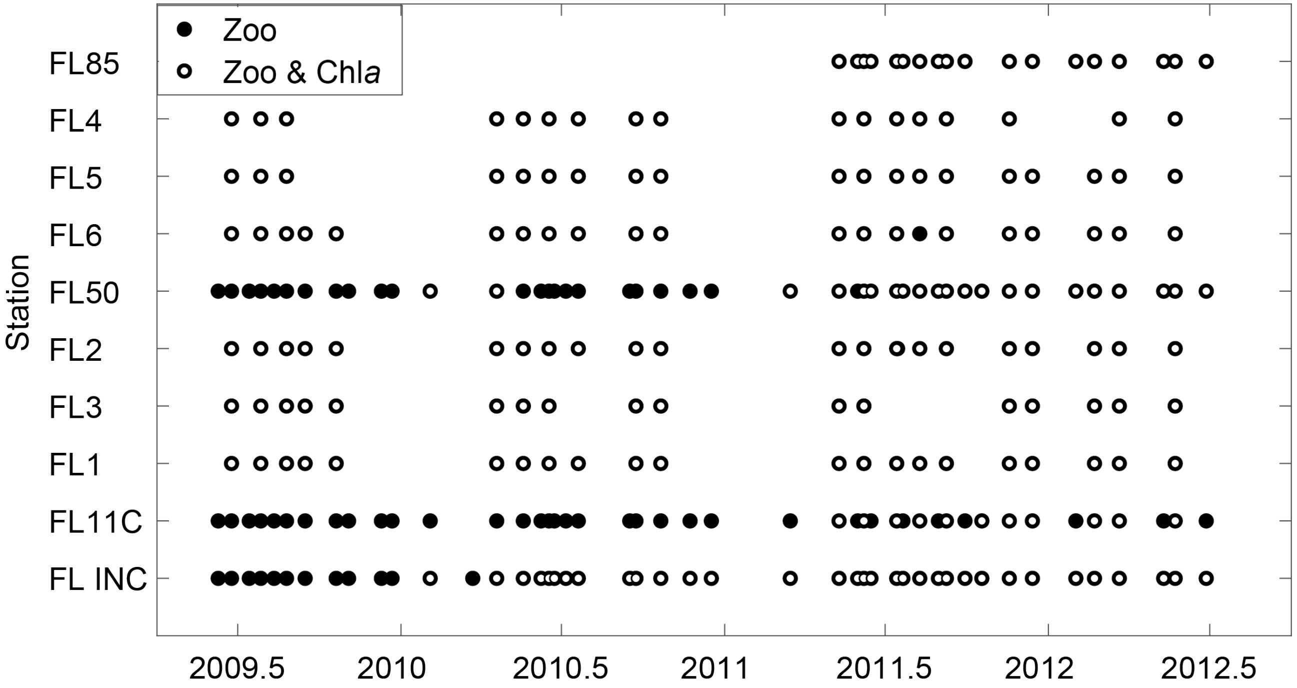
2) Is there a clear inflection point in zooplankton/Chl *a* for Falls Lake that to guide development of a site-specific Chl *a* criterion?

3) Is there a clear inflection point in zooplankton/Chl *a* for southeastern reservoirs to guide development of a region-specific Chl *a* criterion?

Description of Data Set

- Zooplankton collected, identified, counted by Dr. Sandra Cooke (Greensboro College)
- Phytoplankton biomass as chlorophyll *a* measured by NC State's Center for Applied Aquatic Ecology
- Same sampling methods as the National Lakes Assessment

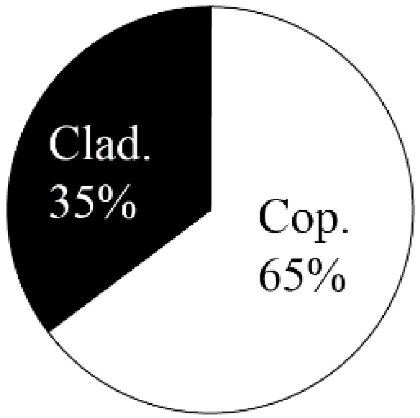




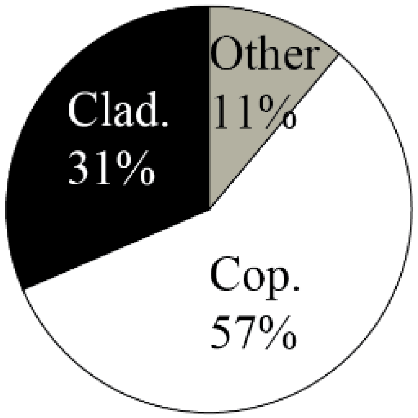
Falls Lake vs other southeast reservoirs

Median Values	Falls Lake	SE U.S. reservoirs
Chlorophyll *a*	35	12
Zoo. Biomass	10	36
Zoo. Biomass: Chlorophyll *a*	0.26	2.3

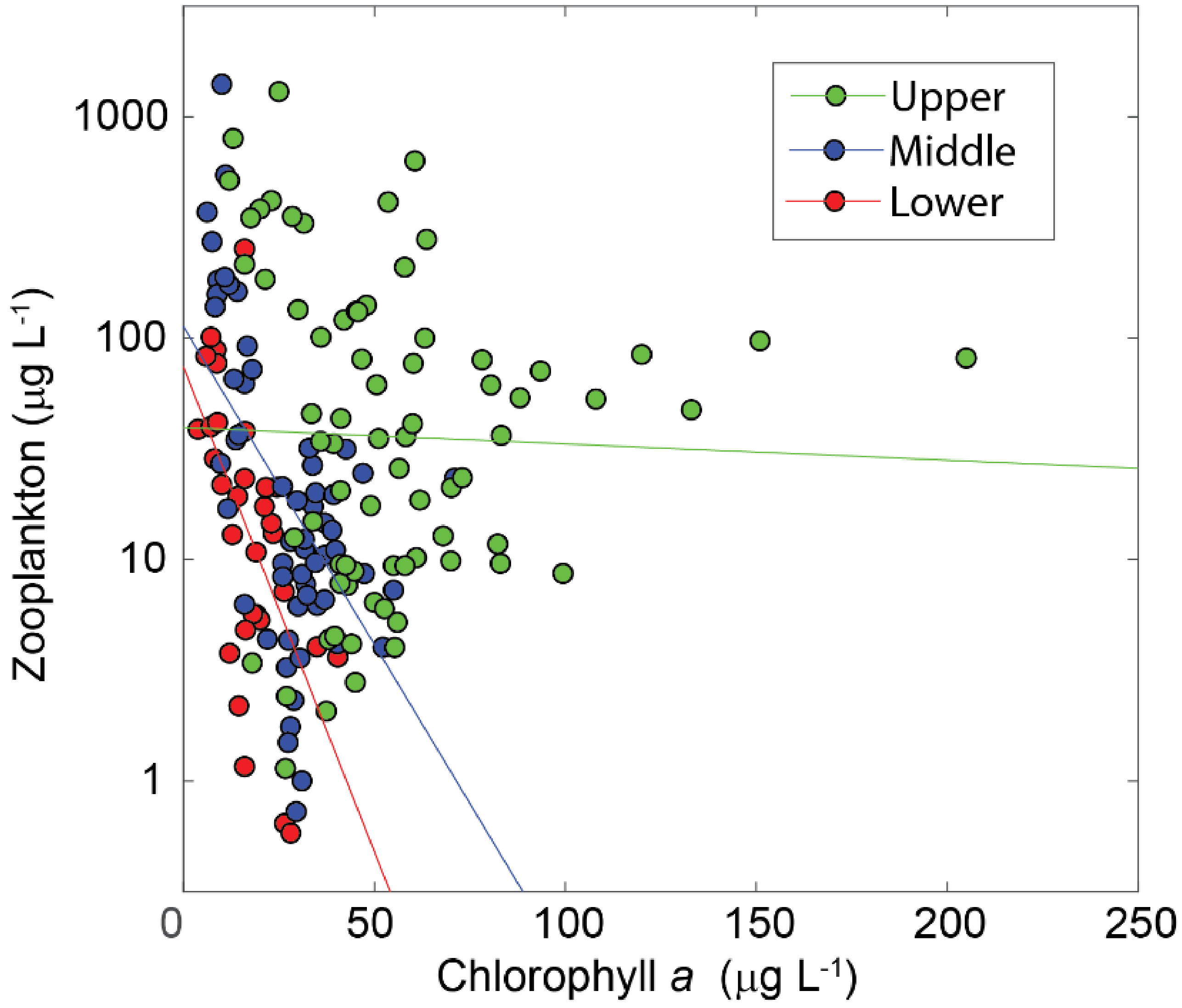
Falls Lake
Summer Biomass



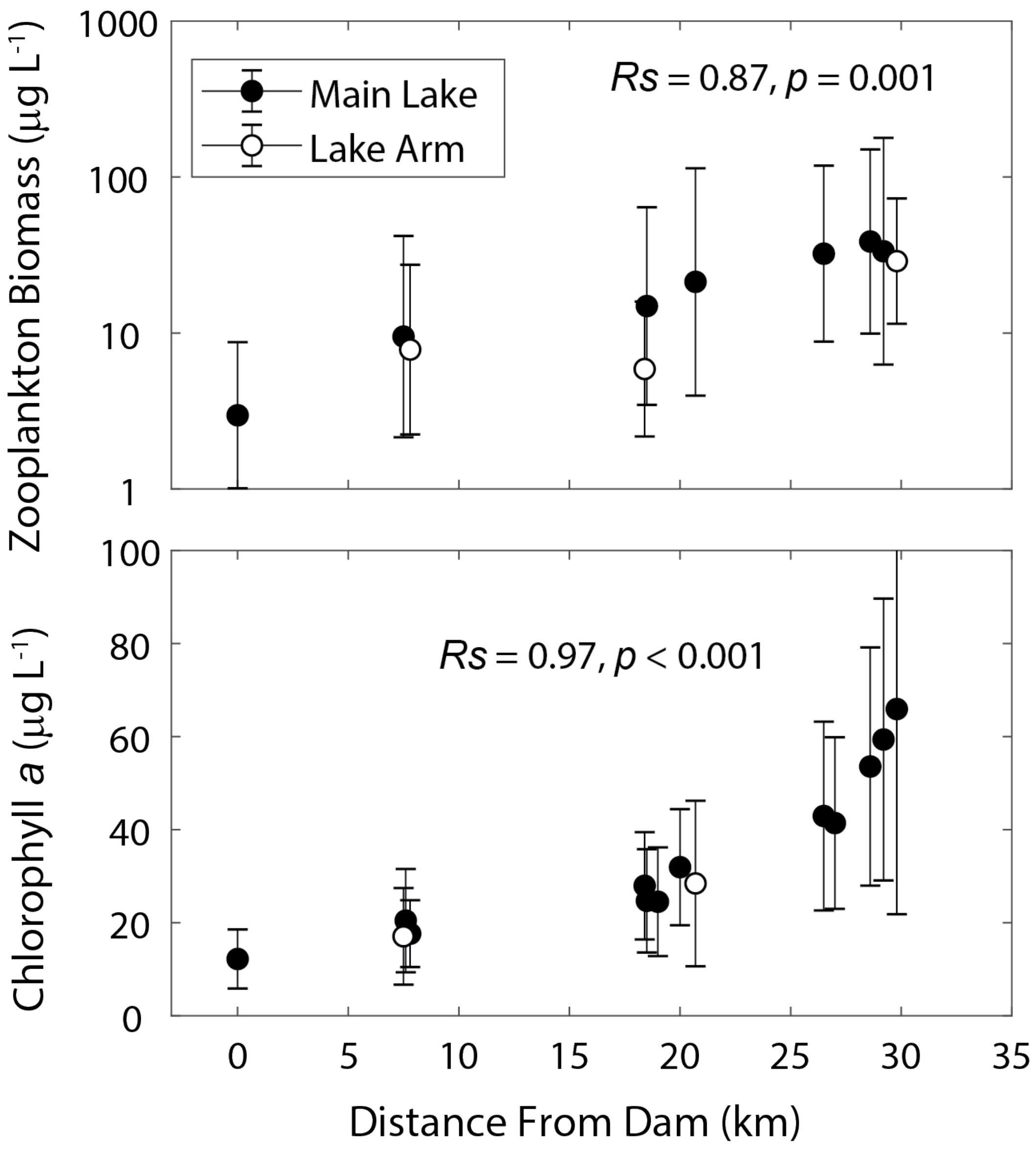
S.E. Reservoirs
Summer Biomass



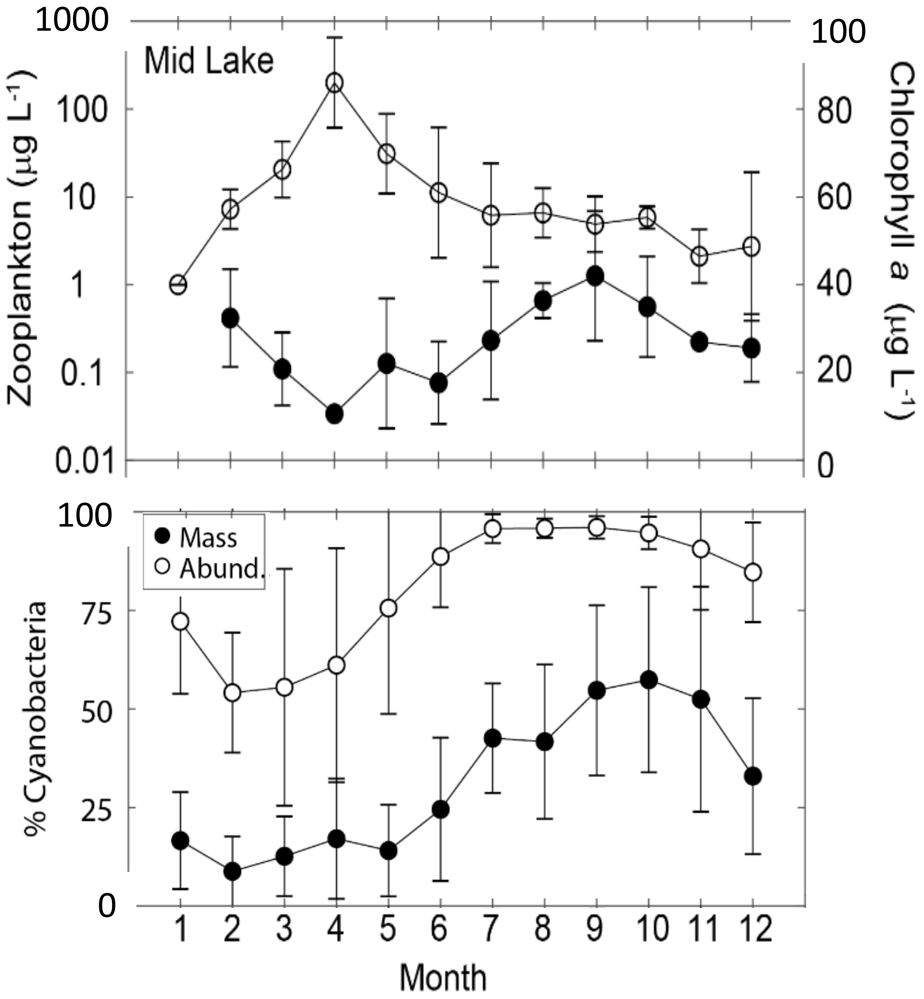
Negative relationship between Falls Lake zooplankton and phytoplankton biomass



Spatial variation indicates strong phytoplankton/ zooplankton coupling



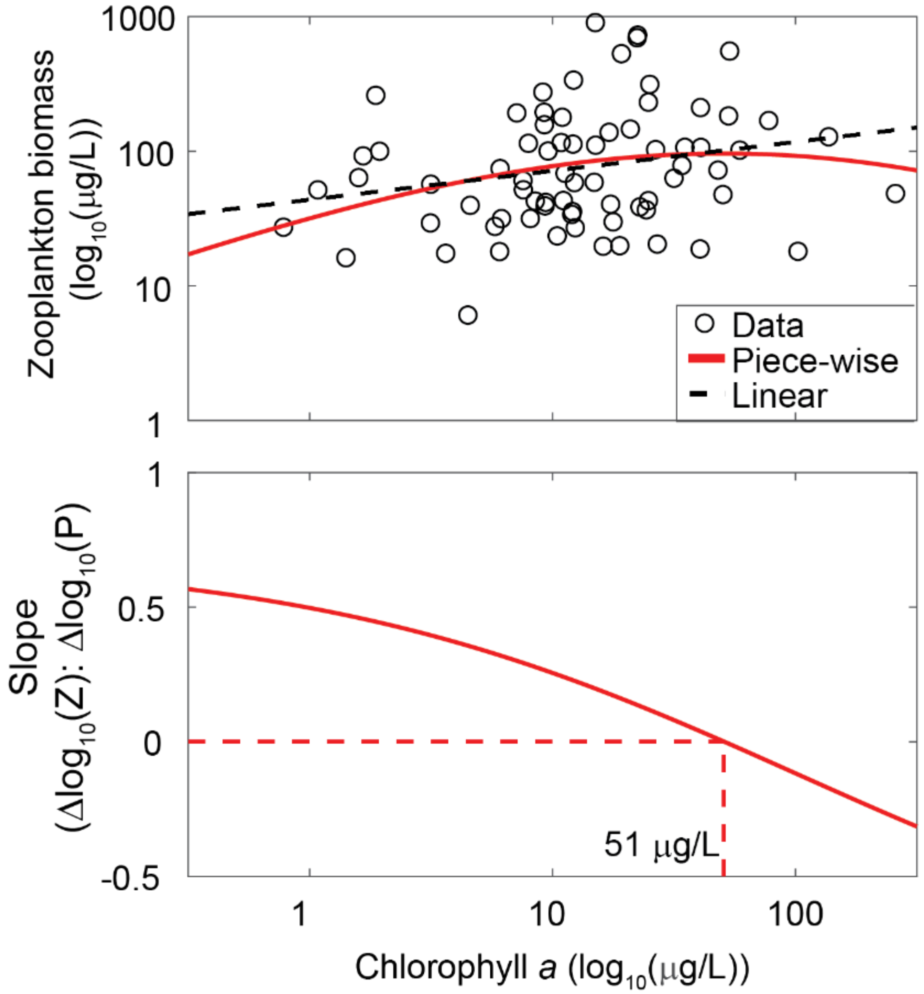
High zooplankton: Chl *a* in spring, low zooplankton: Chl *a* in summer



Possible causes- planktivorous fish more likely than inedible cyanobacteria

Summer might be a bad time to assess trophic transfer via Z:P ratios

Chl *a* threshold for Southeast U.S. reservoirs



Similar to threshold identified for shallow lakes (< 4 m) across the U.S.
But, relationship is very weak-other drivers important for zooplankton

Policy Implications

1) Zooplankton: Chl *a* is low in Falls Lake compared to other southeast reservoirs. Comparison possibly affected by seasonality
2) Analyses failed to identify a Falls Lake specific Chl a threshold based on zooplankton: Chl *a*

3) A region-specific threshold of 51 $\mu g\ L^{-1}$ Chl *a* was calculated. Confidence in this threshold is low

Monitoring for Algal Toxins in Falls Lake

Emily Pierce[1], Will McClure[1], Marco Valera[1], Joseph Mohn[2] and Astrid Schnetzer[1]

[1] Department of Marine, Earth and Atmospheric Sciences, NC State

[2] Department of Environmental Quality Division of Water Resources, NC

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NORTH CAROLINA Environmental Quality

Lakes & Algal Blooms

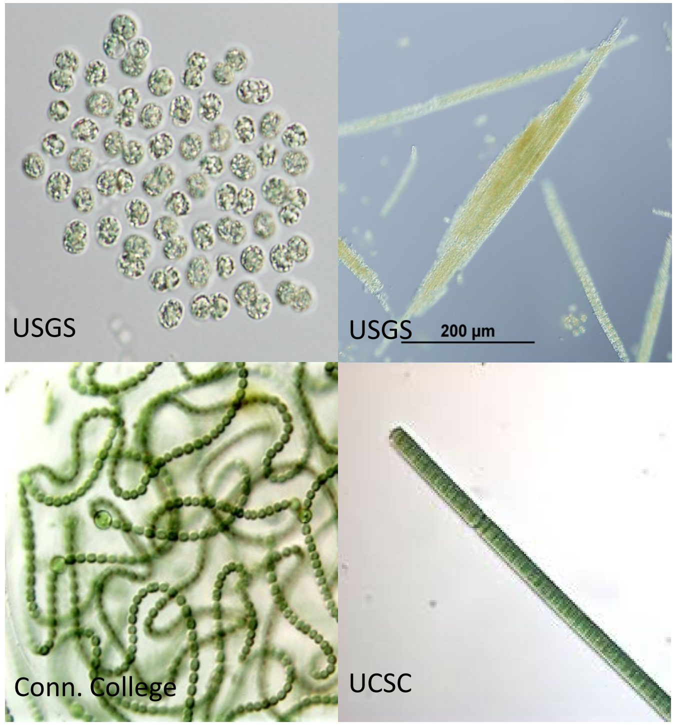
Low Productivity
Crater Lake, OR

Moderate Productivity
Falls Lake, NC

High Productivity
Lake Erie, MI

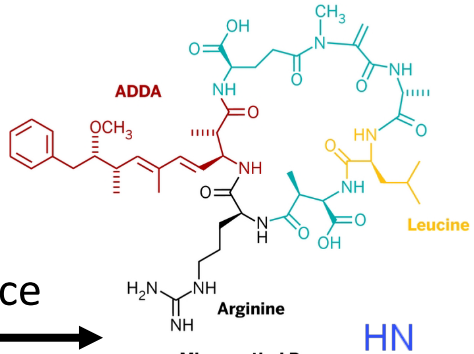
Why we care about algal toxins

Algae

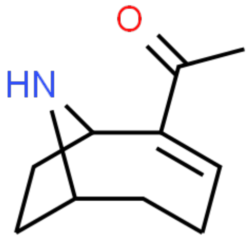


Can produce →

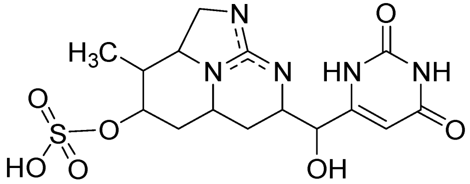
Algal Toxins



ACS



ChemSpider



MDPI

Have caused →

Severe Consequences

NEWS

Harmful algae found at Silverwood Lake; beaches closed, warning issued for pets, people

Victorville Daily Press

4 dogs die in Eastern WA after toxic algae bloom contaminates water. 7 lakes close

BY ANNETTE CARY

UPDATED AUGUST 27, 2021 9:01 AM

Tri-city Herald

Research Questions

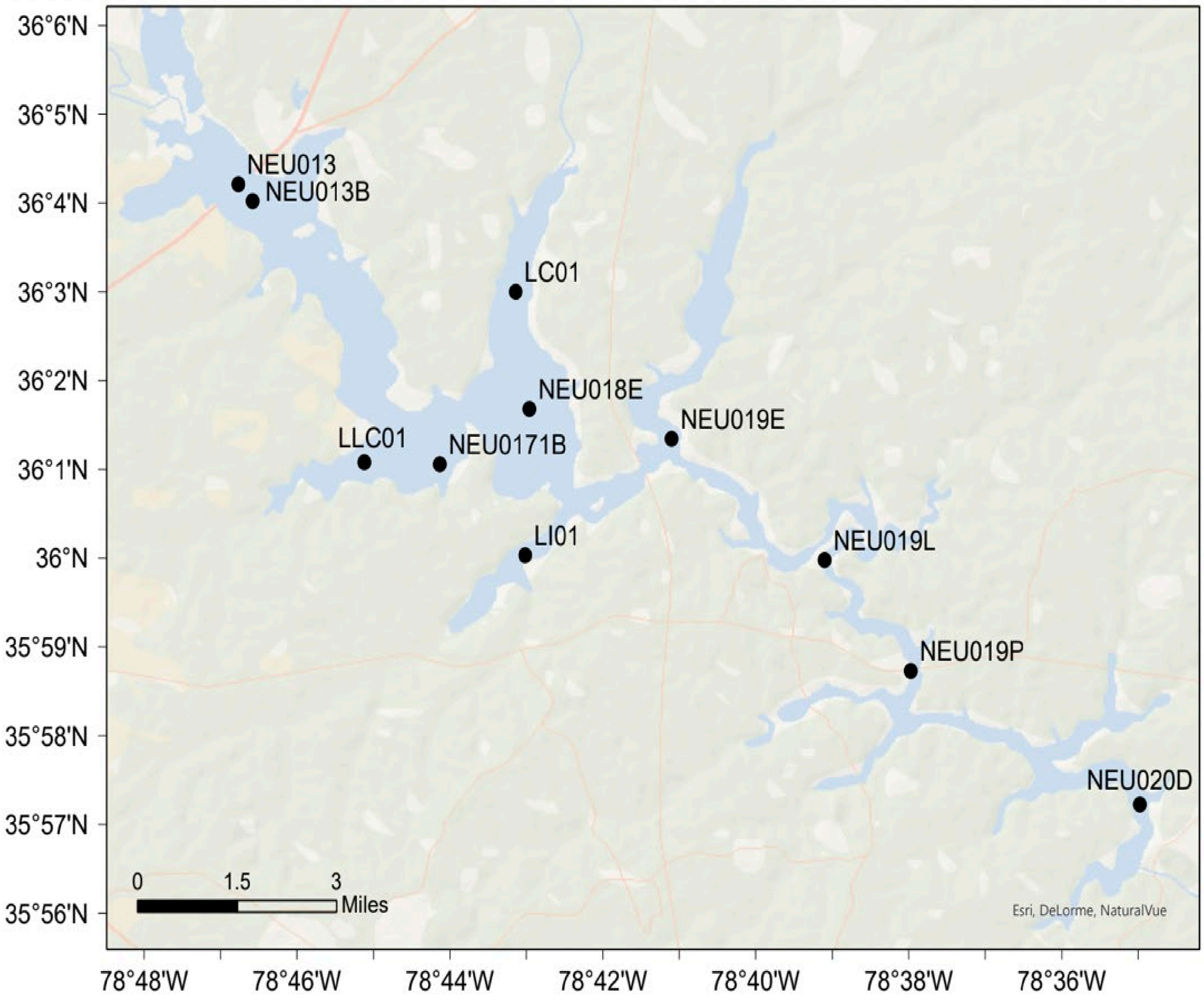
Are algal toxins present in Falls Lake?

At **what concentrations** are they present?

When are they present?

Where are they present within the lake?

What patterns can be drawn between toxin concentrations and environmental parameters?



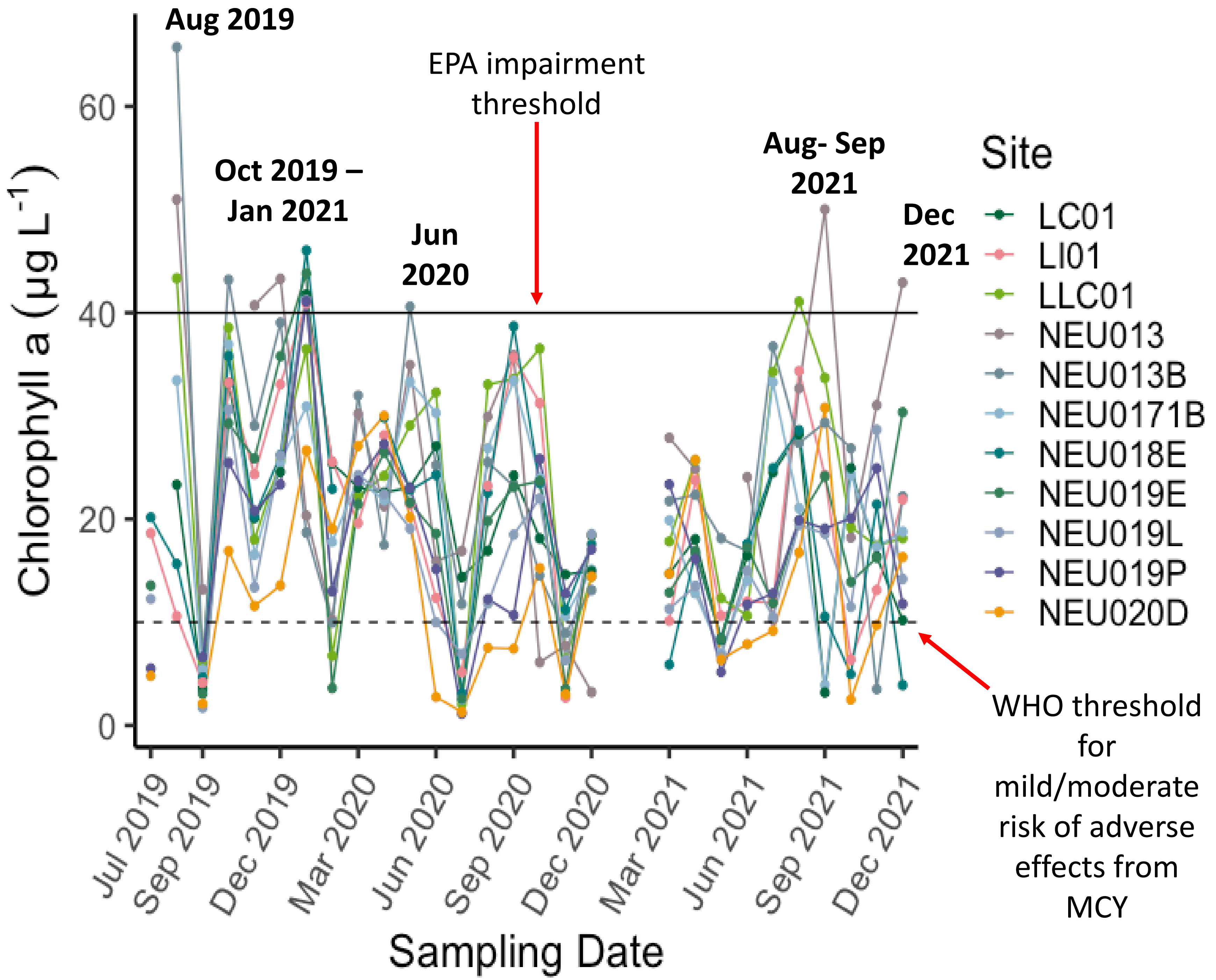
Data Collection

- Monthly Sampling at 11 stations

-Sampled algal biomass, toxin concentrations and species composition (underway)

- Collected environmental data (temperature, pH, nutrients, dissolved oxygen, conductivity)

NORTH CAROLINA
Environmental Quality



Algal Biomass

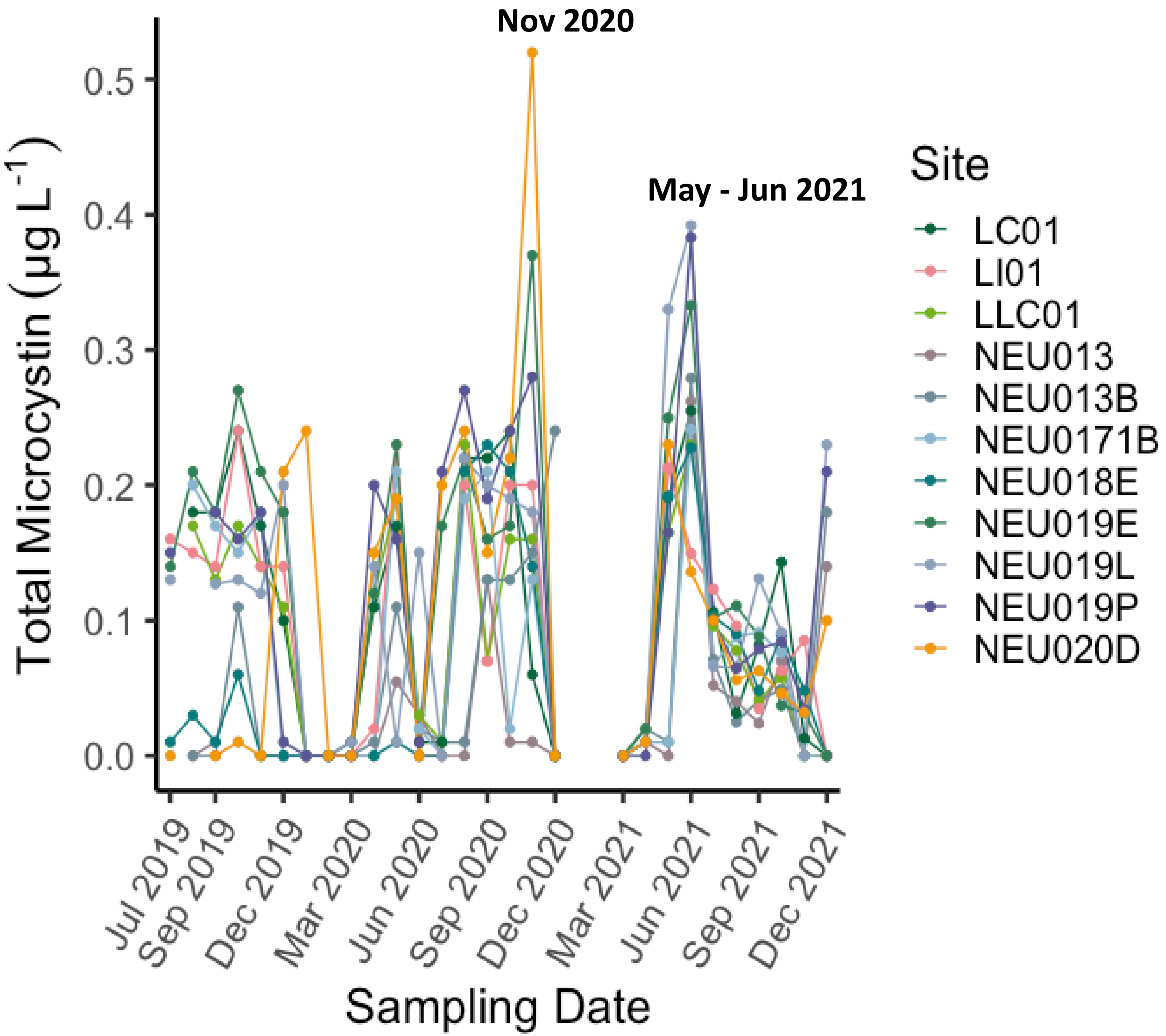
- Algal biomass has exceeded impairment levels based on algal growth (EPA)

- Changes in **conductivity, total P and total N** explain ~20% of variation in algal biomass

- **With potentially toxic algae present**, biomass values between 10 and 50 µg L^{-1} can be **indicative of moderate toxin exposure risks** (WHO)

Toxins Measured

Toxin	Toxin Class	Human health concerns
Microcystin (MCY)	Hepatotoxin	Abdominal pain, vomiting, diarrhea, pneumonia
Cylindrospermopsin (CYL)	Hepatotoxin	Gastrointestinal effects including diarrhea, vomiting, and
Anatoxin-a (ANA)	Neurotoxin	numbness, drowsiness, respiratory paralysis leading to death
Beta-Methylamino-L-alanine (BMAA)	Neurotoxin	Potential link to neurodegenerative effects
Saxitoxin (SXT)	Neurotoxin	Vomiting, headache, weakness, respiratory paralysis leading to death



Microcystin

- Microcystin was detected in **70% of samples**, year-round and highest at mid and lower lake sites
- Microcystin concentrations remained **below safe recreational use** threshold (8 µg L^{-1})
- Changes in **temperature, ammonia and turbidity** could explain ~20% of variation in microcystin
- Algal biomass-based estimates overestimate toxin exposure risk

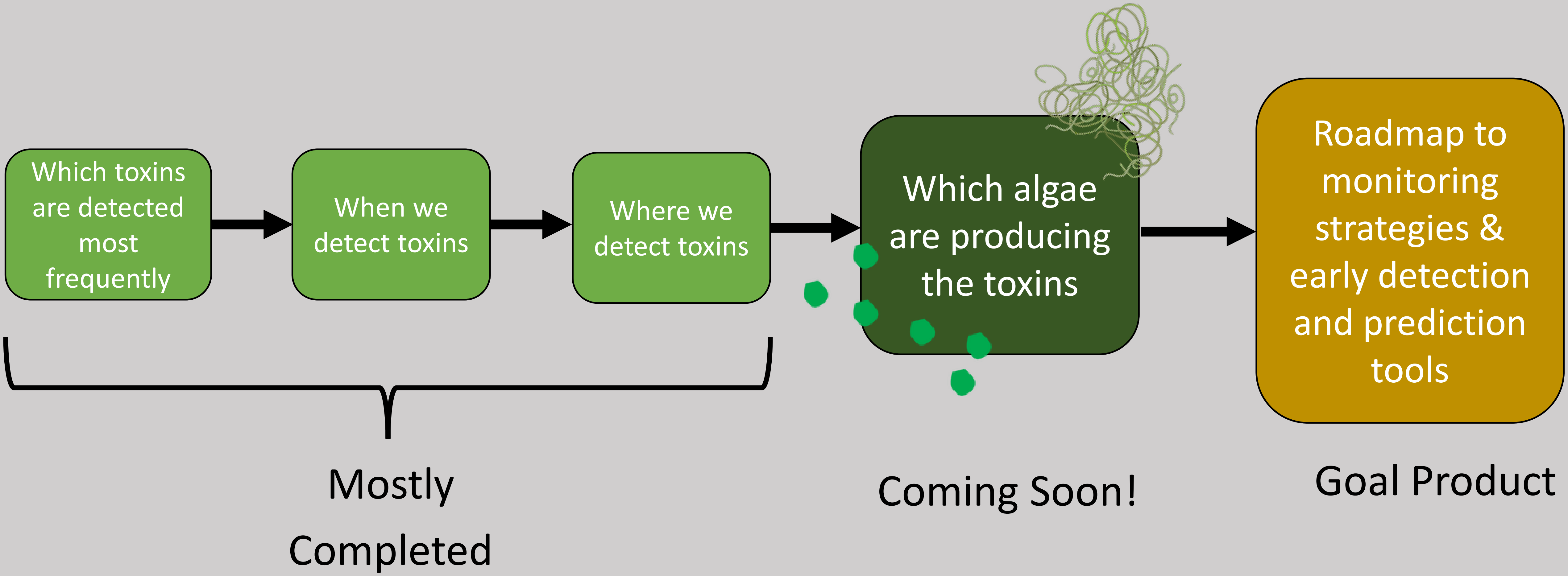
How often do we see toxins?

	MCY	ANA	BMAA	CYL	SXT
n	298	72	33	137	51
% samples with detectable toxin levels	70%	88%	70%	13%	0%

Often (MCY, ANA, BMAA) **Rarely** (CYL) **Never** (SXT)

- In samples in which all 4 detected toxins were measured, **50% of samples have at least 2 or more toxins detected**
- Spatiotemporal analyses for ANA, BMAA and CYL are underway

Next Steps


Which toxins are detected most frequently
When we detect toxins
Where we detect toxins
Which algae are producing the toxins
Roadmap to monitoring strategies & early detection and prediction tools
Mostly Completed
Coming Soon!
Goal Product

Take-home Message

- Algal biomass is not sufficient as sole predictor of toxin exposure risk.
- Microcystin and anatoxin are the most common toxins and should be prioritized to assess future changes in toxin dynamics.
- Preliminary analyses point to mid and lower lake stations as suitable monitoring sites with high frequency sampling in summer and fall.

Remaining Project Aims:

- ❑ Finalize spatiotemporal analyses for all toxins.
- ❑ Identify toxin producers for the development of highly sensitive DNA-based monitoring approaches (detection during early bloom stages).

NC Policy Collaboratory

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NORTH CAROLINA Environmental Quality

Acknowledgments

NC DEQ Water Resources Office especially the Intensive Survey Branch Team for sample collection.

Plankton ecology lab team for assistance with sample processing.

NC Policy Collaboratory for funding and research support.

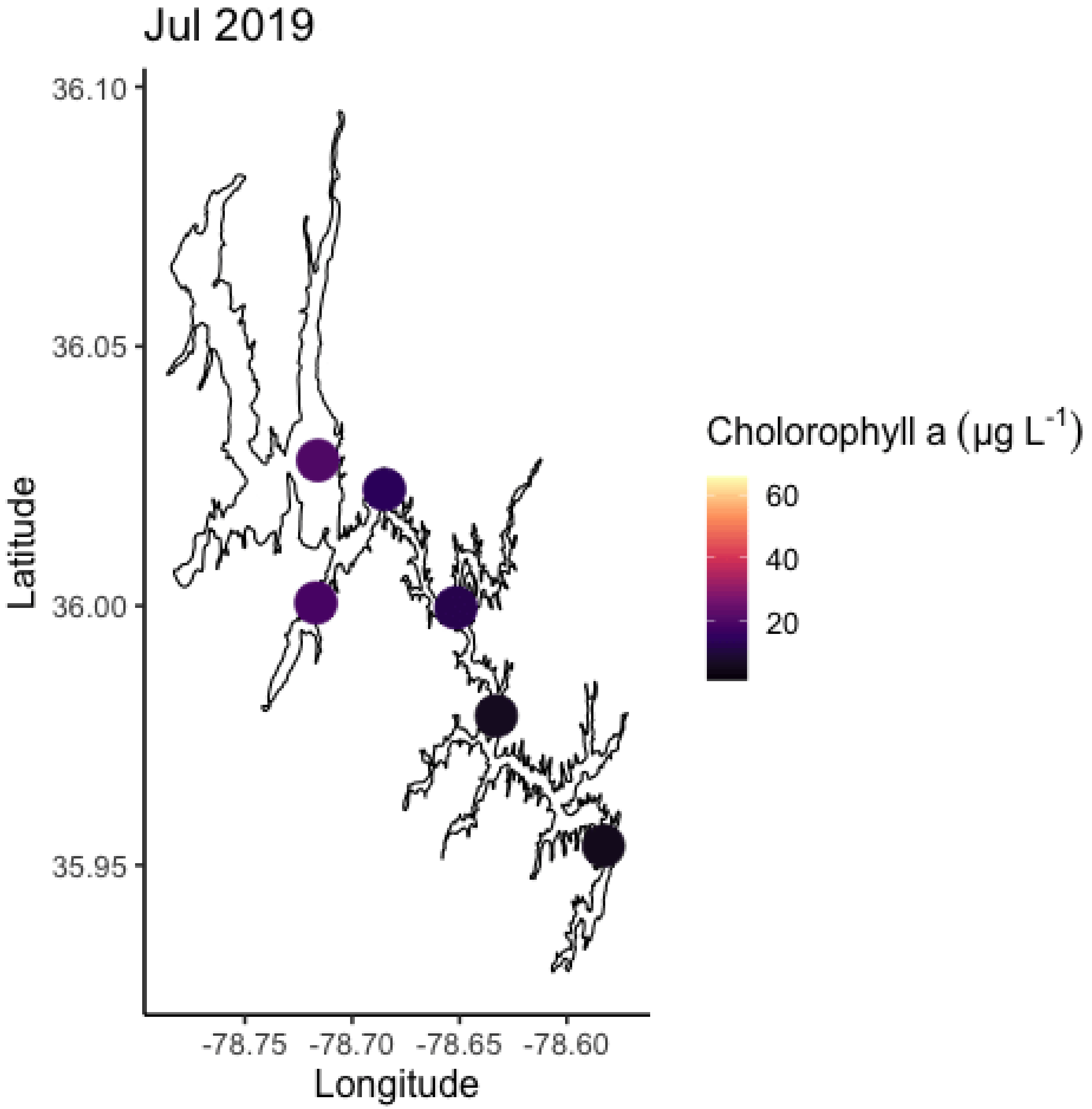
Take-home Message

Cyanotoxins are detected but only at low concentrations within Falls Lake

Algal Biomass and environmental parameters don’t strongly correlate with toxin concentrations and thus can’t inform an efficient monitoring approach

Chlorophyll a Model

Parameter	Coefficient	% Variance Explained
Temperature	-0.16	1.83
Conductance	0.05	11.08
pH	-5.69	1.72
DO Saturation	0.08	1.47
Total Phosphorus	316.84	4.60
Nitrite + Nitrate	-40.94	4.13
Turbidity	-4.02	1.10
Total		**25.93**

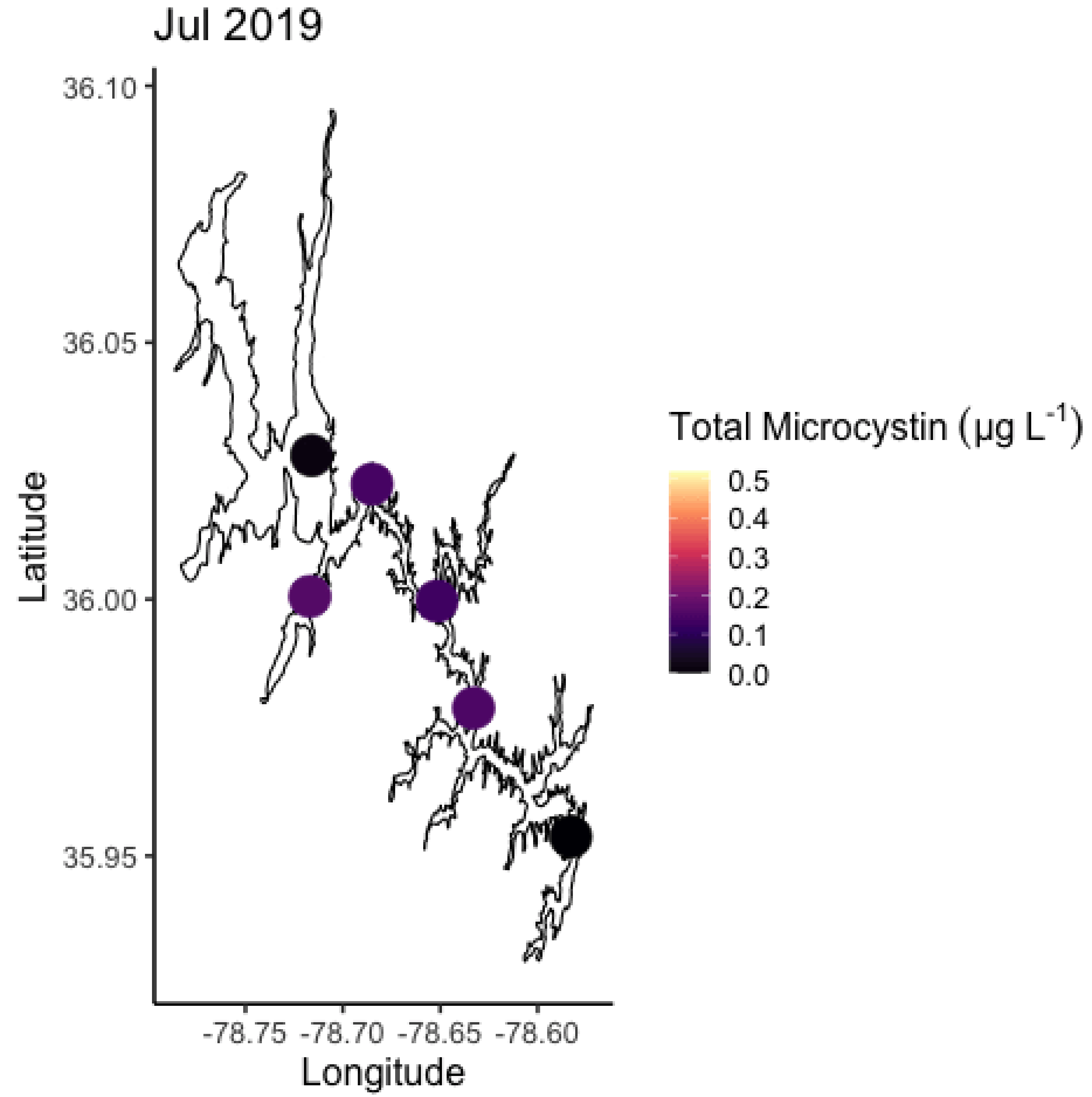


Algal Biomass

Concentrations typically higher in the mid-upper stations

Best environmental parameter model explains approximately 26% of variation algal biomass

Chlorophyll a does not significantly correlate with any measured toxin values

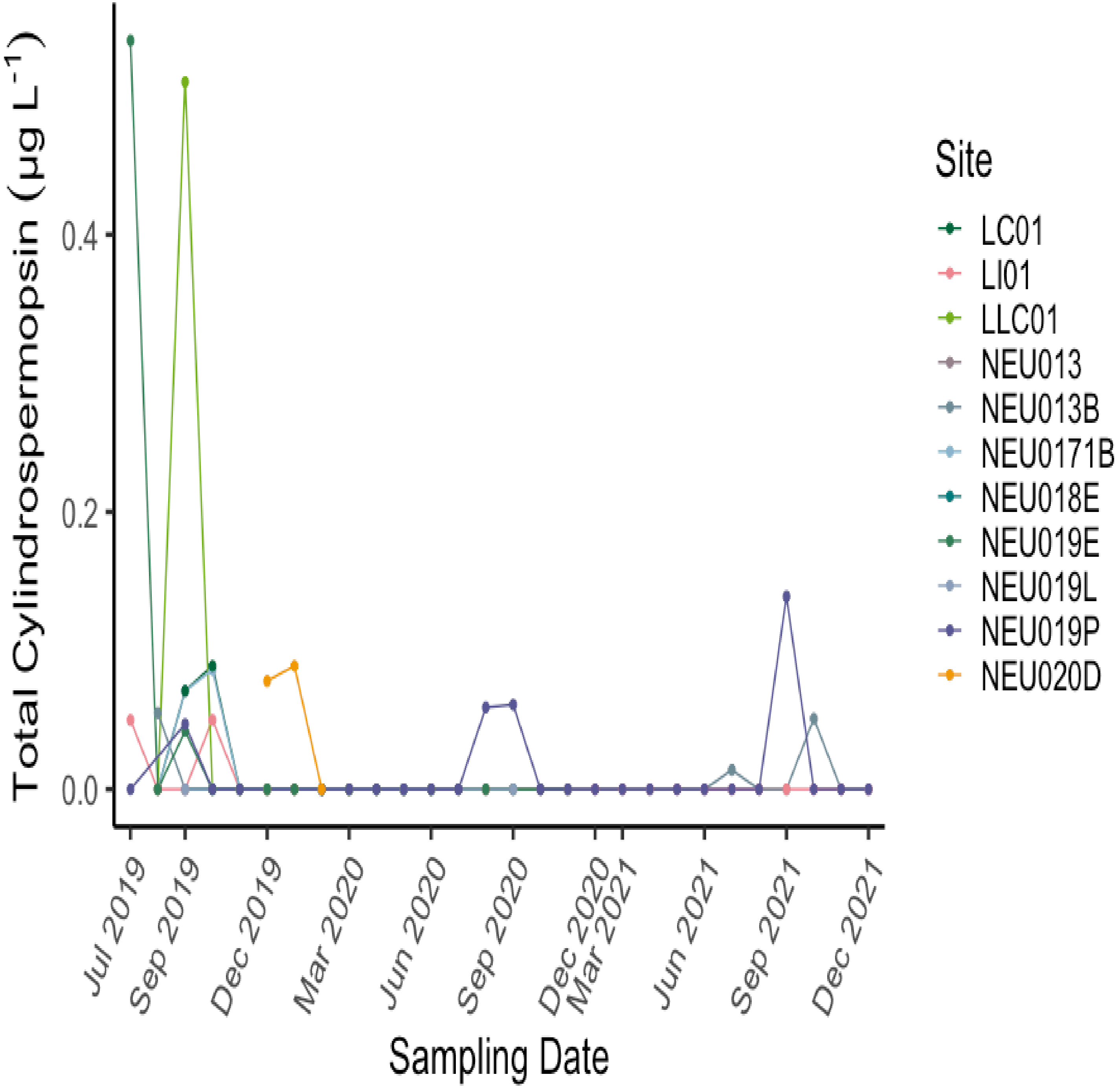


Microcystin

Concentrations v**ary across the lake with higher values typically in the mid-lower stations**

A subset of **environmental parameters correlate with microcystin** concentrations

Parameter	Coefficient	% Variance Explained
Temperature*	0.036	10.84
NH3	0.004	5.55
Turbidity*	-0.003	5.68
Total		**22.07**

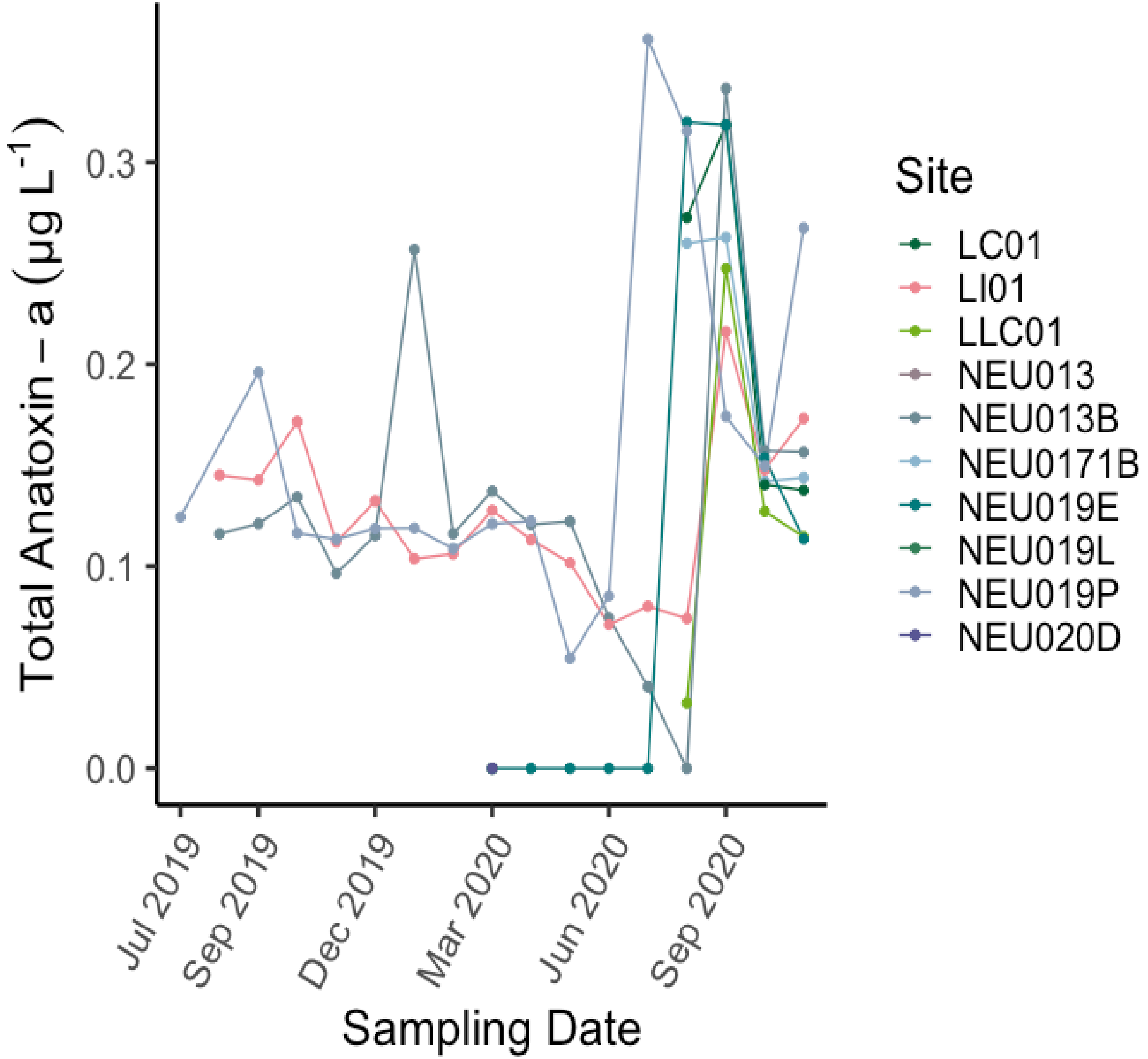


Cylindrospermopsin

Cylindrospermopsin concentrations **rarely rise above 0** and **do not rise above EPA safety thresholds**

Toxin exists **primarily dissolved in the water column**, so accumulation data has more potential to contain high values

Parameter	Coefficient	% Variance Explained
pH	0.02	4.49

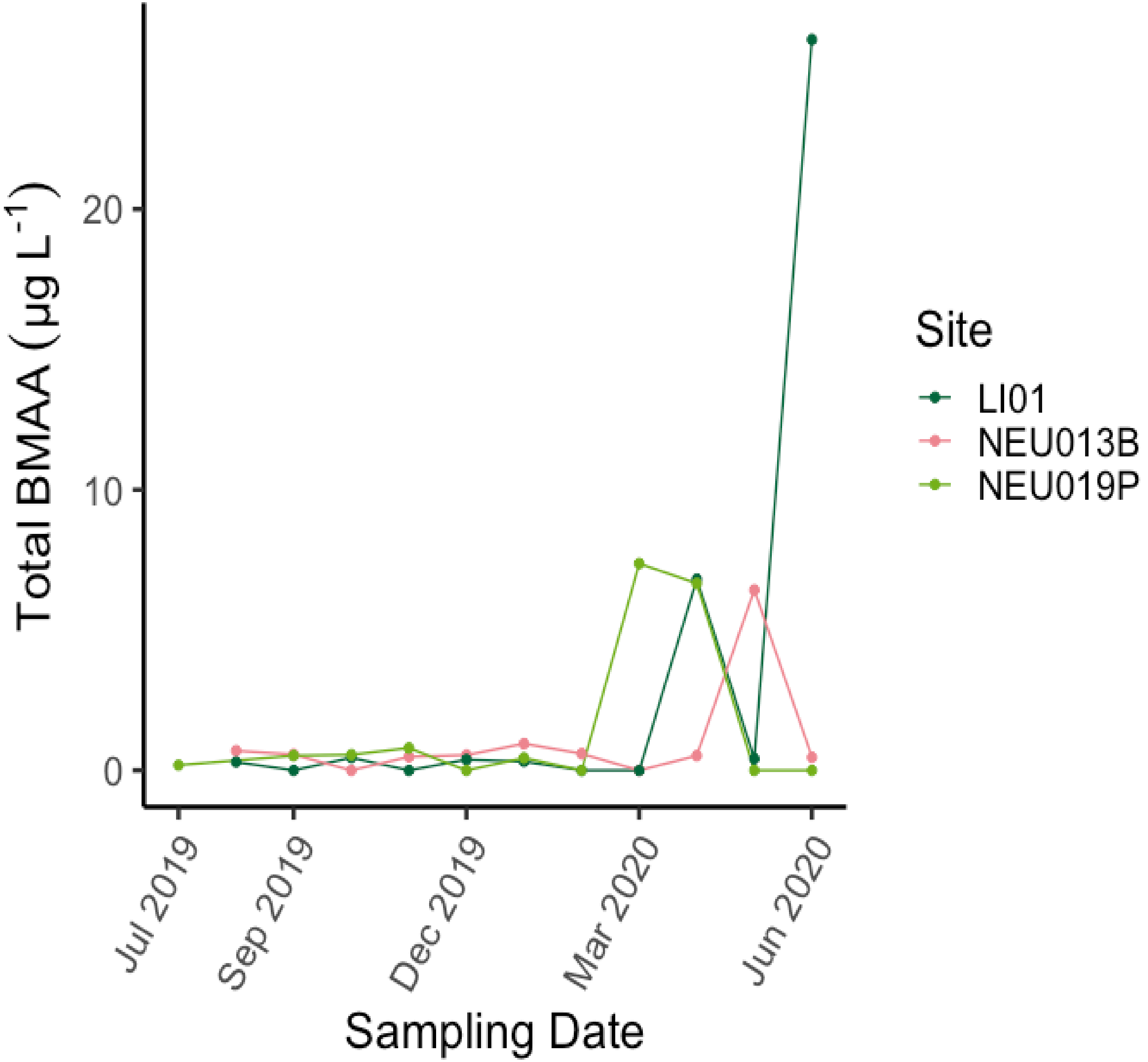


Anatoxin-a

Toxin is **consistently present, but at very low concentrations**

Toxin analysis **will be continued through 2021**

Parameter	Coefficient	% Variance Explained
Turbidity*	0.01	13.03
Temperature*	0.004	3.20
Total Phosphorus	-3.62	0.55
Total		**16.58**



BMAA

Concentrations are **consistently low with a few peaks**

No known safety or recreational standards to compare concentrations to

Toxin analysis will be continued through 2021, potentially **increasing spatial resolution**

Defining the Balance Between N_2 Fixation and Denitrification in Falls Lake

Nathan Hall, Michael Piehler, and Hans Paerl
UNC Chapel Institute of Marine Sciences

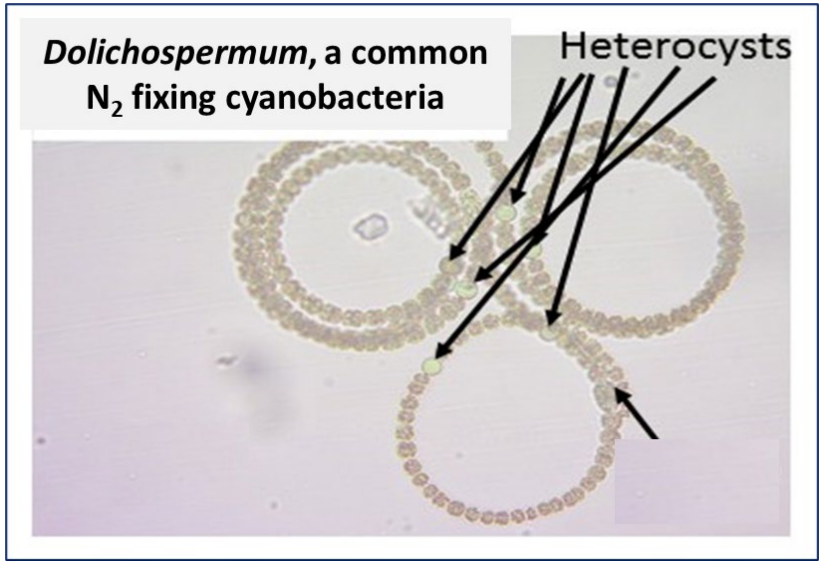
Falls Lake Nutrient Study Research Symposium
7 April 2022

Understanding N_2 fixation & Denitrification in Falls Lake is important

Balance of N_2 fixation and denitrification can determine nutrient limitation-can inform more effective nutrient control strategies

N_2 fixing cyanobacteria are surface bloom and/ or toxin producers

Measuring either helps constrains other parts of the N budget that are difficult to measure

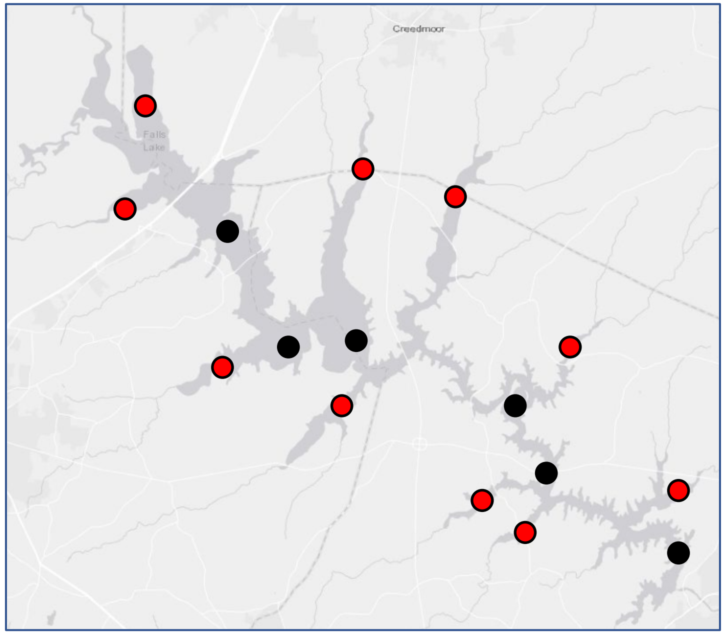


Research Questions

1) Do microbial processes cause a net production (N_2 fixation) or removal (Denitrification) of N from Falls Lake?

2) Is N_2 fixation quantitatively important relative to stream loads and atmospheric deposition? Worth including in models?

3) What factors stimulate N_2 fixation?



Nitrogen Fixation Measurement Methods

1) Collected surface samples

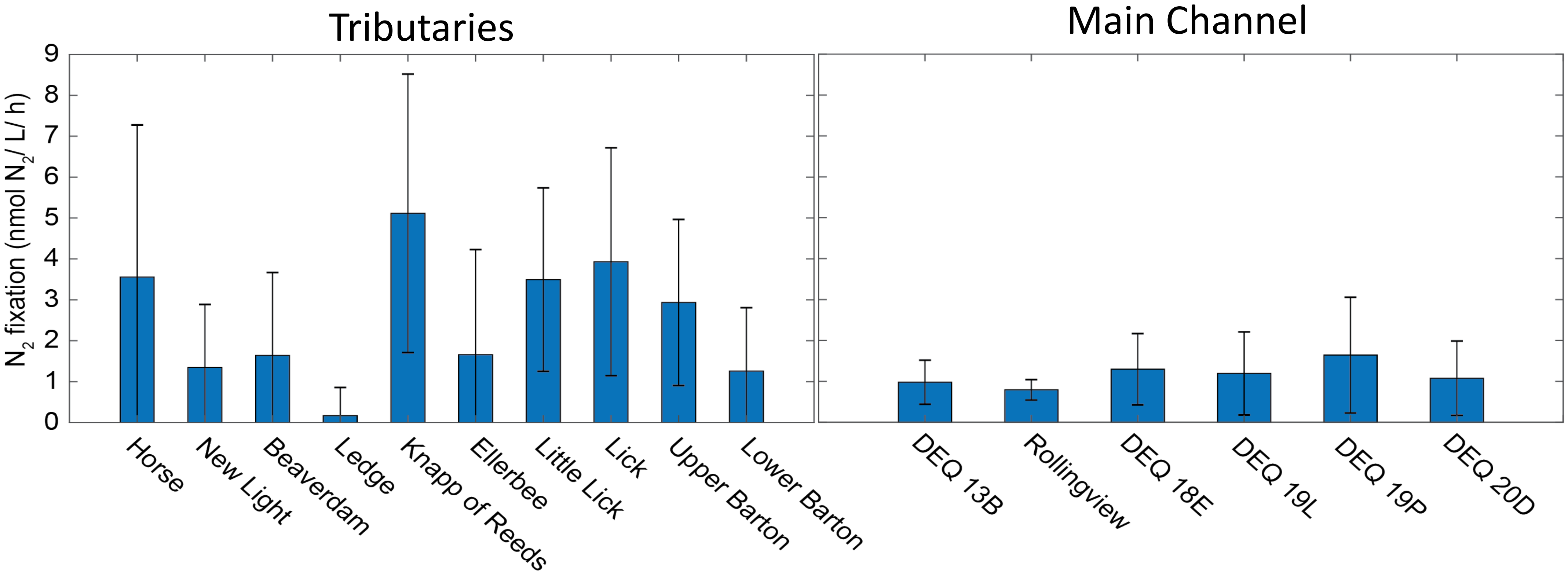
   5 sampling events at 6 main channel (2019-2020)

   5 sampling events at 10 creeks (2021)

2) N_2 fixation measured by acetylene reduction under simulated in situ conditions

3) Ancillary measurements of nutrients, phytoplankton biomass/ composition, hydrographic profiles, and light

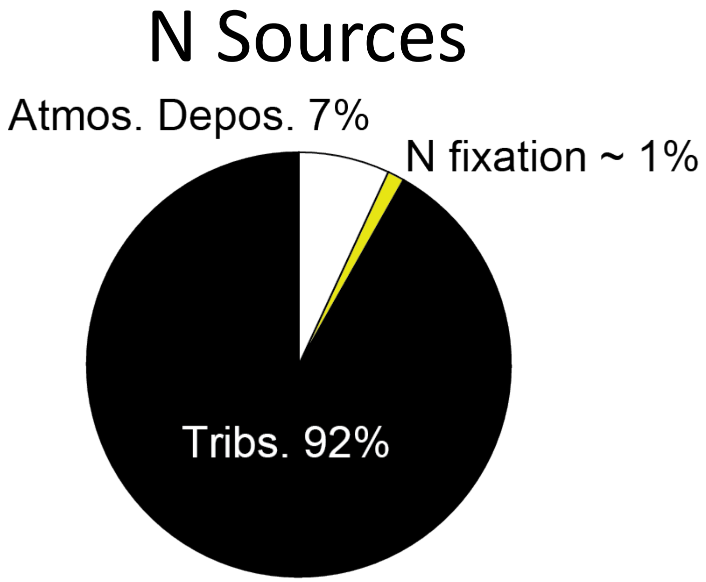
N_2 fixation measurements and scaled-up annual estimates

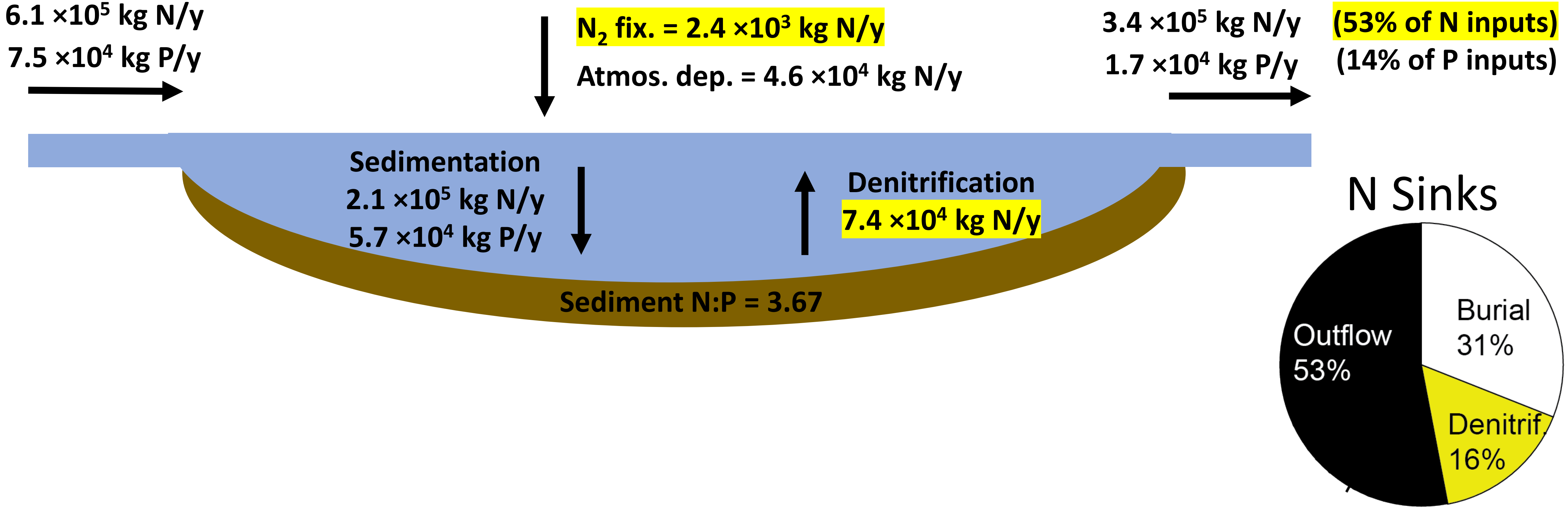


Assumptions: 1-1.5 m photic depth, 12 h photic period, 180 d season

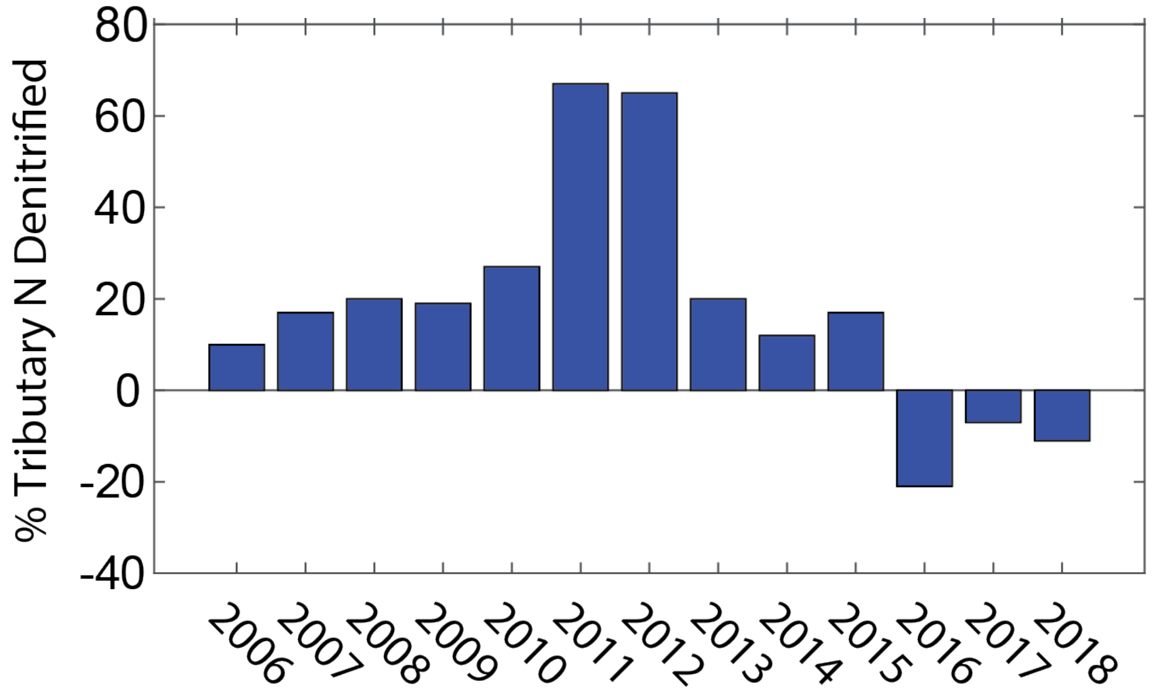
N_2 fixation = 2.4 ×10^3 kg N/y

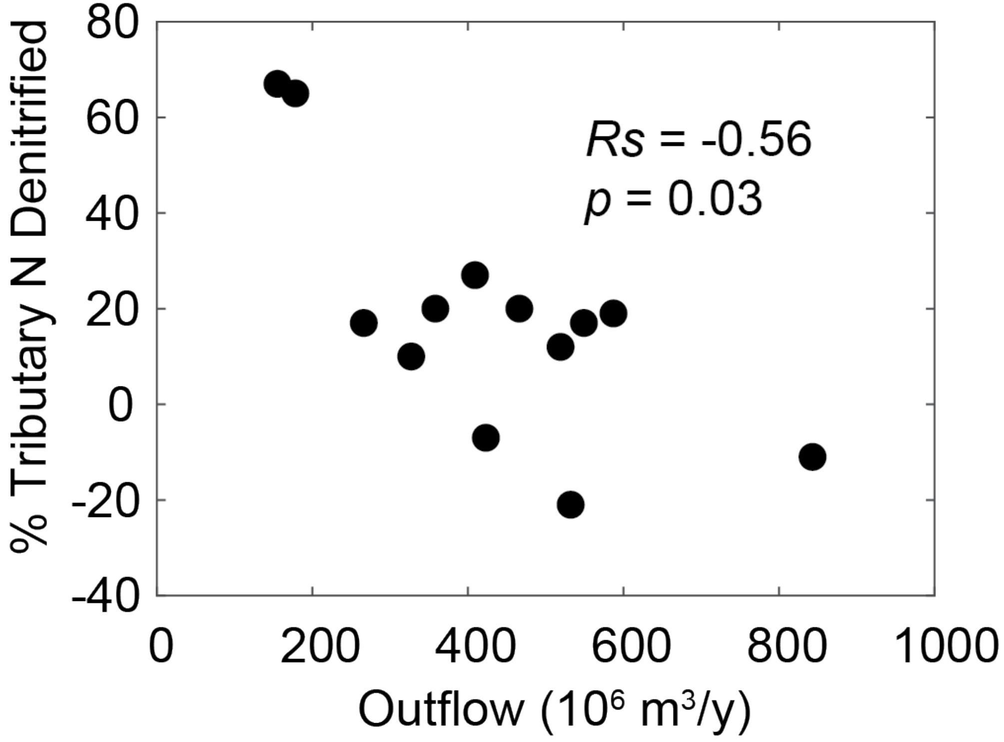
Nutrient Budget for 2006-2019

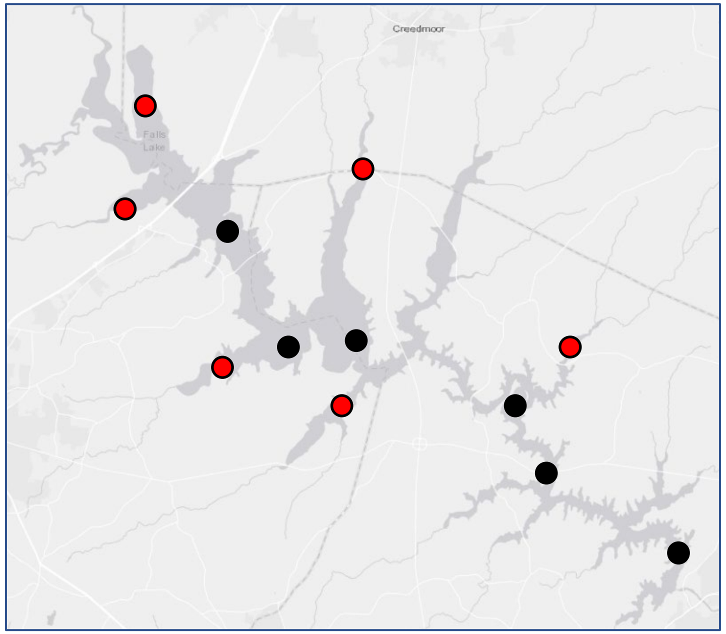




Annual Denitrification Rates by Mass Balance







Direct Denitrification Measurement Methods

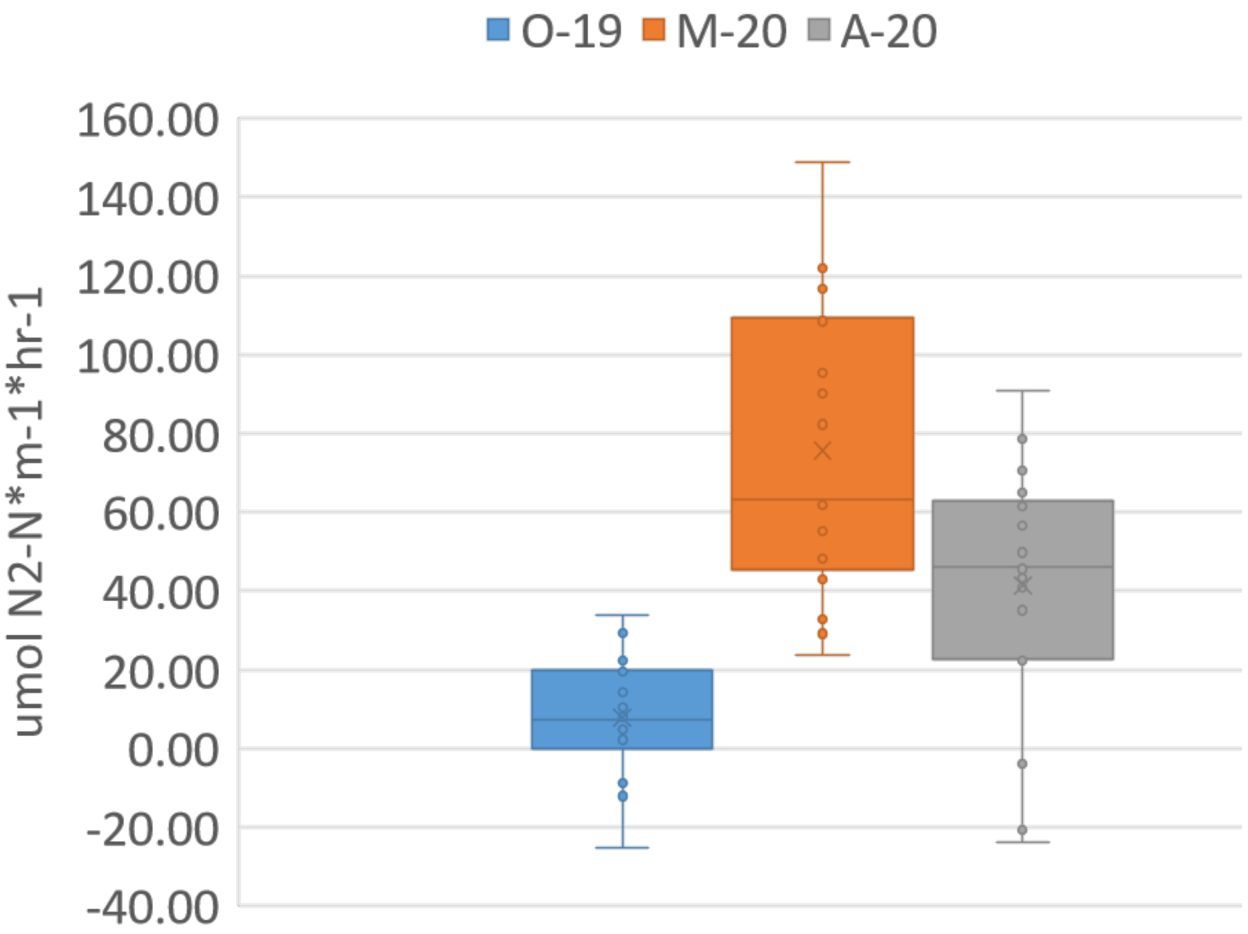
1) Collected sediment cores

   3 samplings at 6 main channel (Oct 2019, May, Aug 2020)

   1 sampling at 6 creeks (Jul 2021)

2) Steady-state, continuous flow incubation- N_2 production measured by membrane inlet mass spectrometry

Average Denitrification Rates Scaled to Lake Sediment Surface

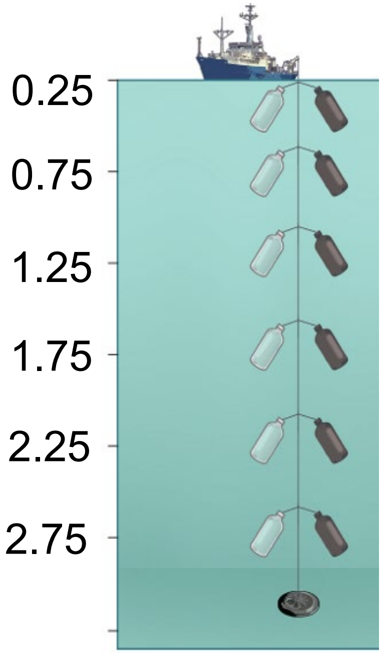


Denitrification as (% Stream Load)	
Oct 2019:	8%
May 2020:	75%
Aug 2020:	41%
Average	42%

Balance of microbial N processes tilts toward N loss by denitrification

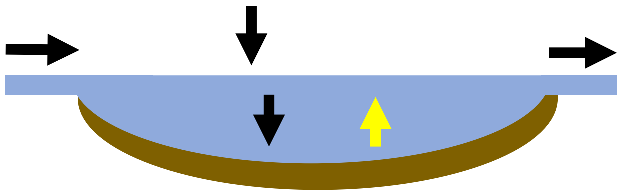
(Rates expressed as % of stream load)

N_2 fixation
Direct measurements
0.5 %



VS

Denitrification
Nutrient budget
16 %



Denitrification
Direct measurements
42 %

Policy Implications

1) Net loss of N by microbial processes may produce N limited conditions for algal growth- supports management of N loads in addition to P

2) Current water quality models appear justified in omitting N_2 fixation

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Researching Alternatives to Bioretention

Bill Hunt, Jackson Tate, Sarah Waickowski
Bio & Ag Engineering, NC State University

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Why Worry About Stormwater?

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What is Required (& Implemented)

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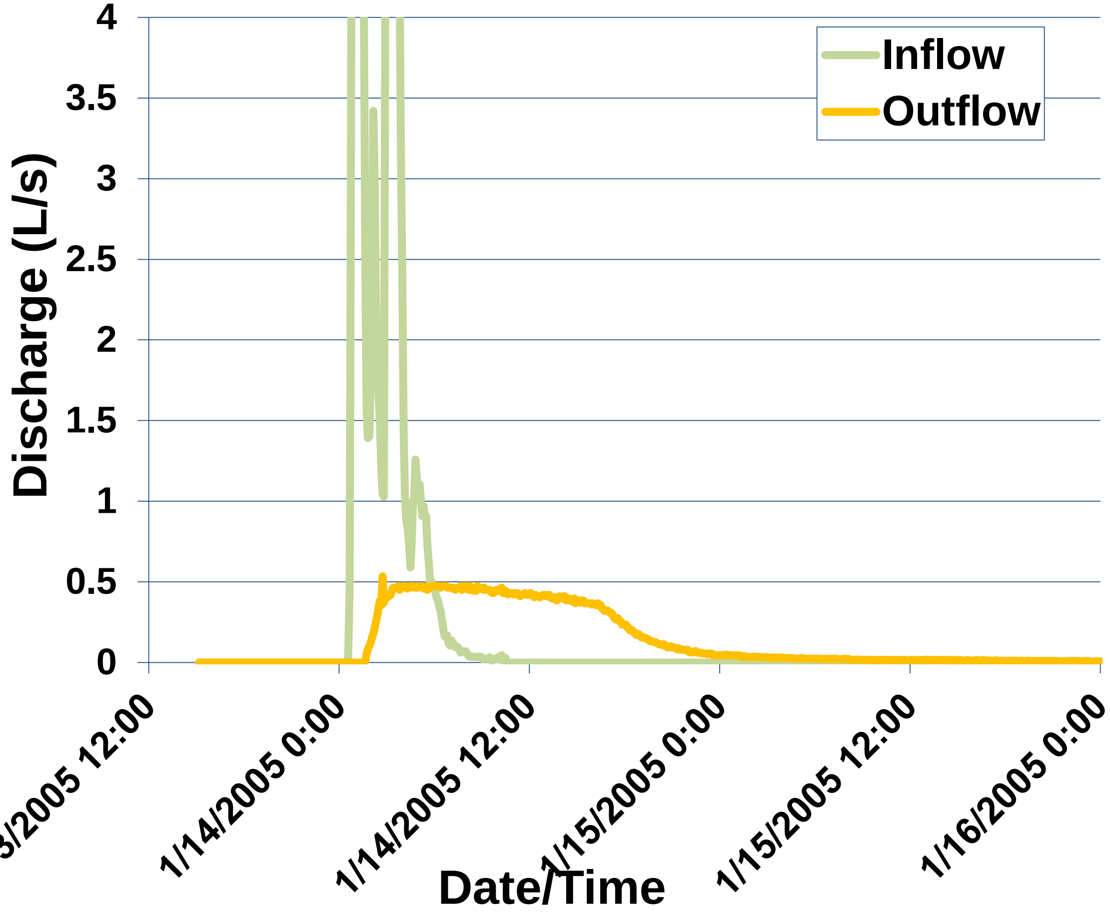
Bioretention!

- Landscape Feature
- Vegetated Sand (Media) Filter
- Employs Most Pollutant Removal Mechanisms
- “Return” to Pre-Dev Hydrology



Why Not Always Use Bioretention?

- Spatial Constraints
  - Ultra-Urban Areas
- Lines-of-sight / Safety
  - Streetside
  - Access for Maintenance
- Sometimes simpler works
- Concern About Proper Maintenance
  - (I Think this is overblown)

Bioretention Alternatives

Sand Filters

Stormwater Treating Street Trees (aka Silva Cells)

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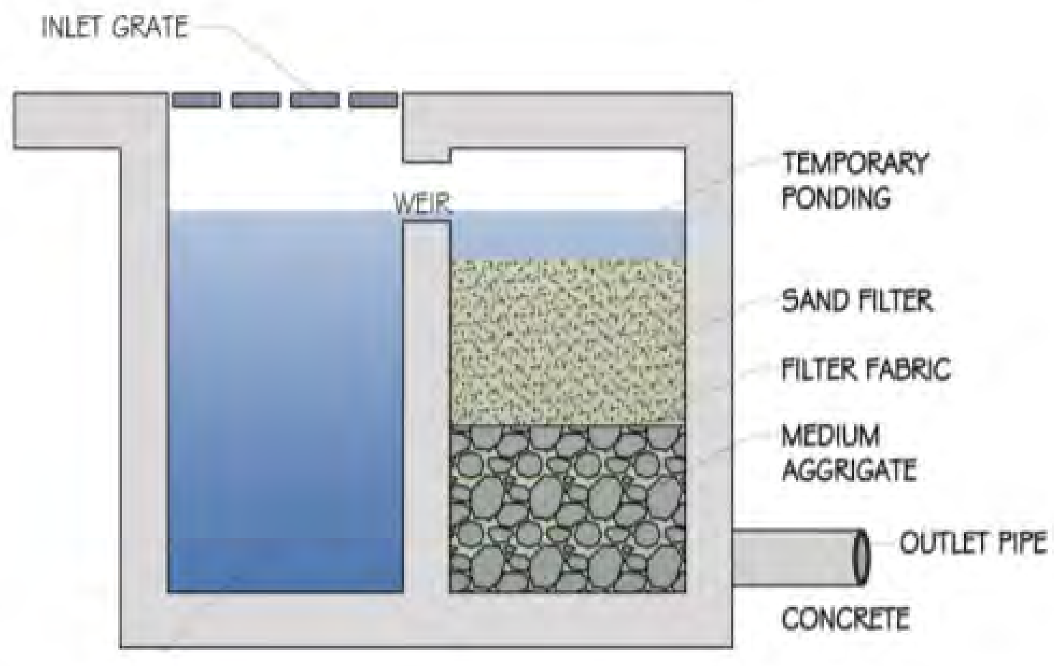
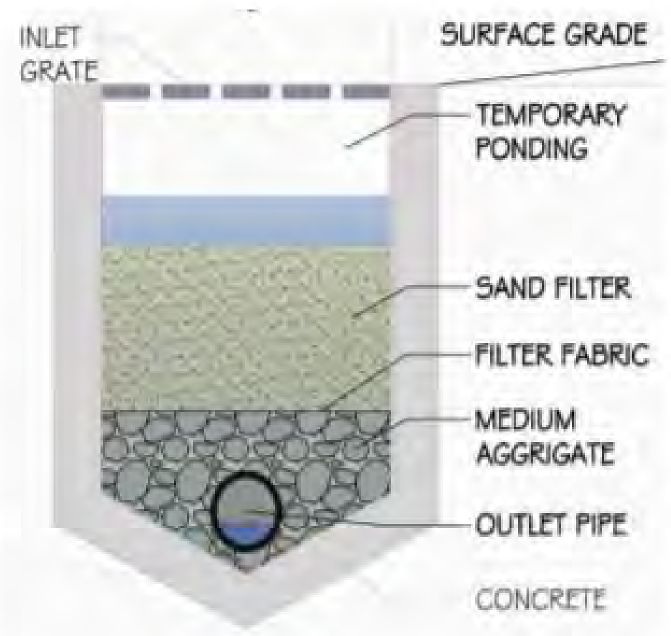
Stormwater Sand Filters





NCDEQ Stormwater Design Manual Section C-6. Sand Filter

- Treatment device that percolates detained water through a sand media
- Removes pollutants via settling, filtering, adsorption
- Effectively removes TSS, BOD, Fecal coliform, Hydrocarbons, & Metals

Why Makes Sand Filters a Potentially Viable Practice?

- Smaller Footprint than Bioretention
- Employs Filtration (like BRCs)
- No/less Vegetation to Maintain
- Studies from other Climate Zones/Soil Types show good performance

Methodology

- 4 sand filters between Fayetteville and Greensboro
- IWS retrofit to one filter in each city (not discussed)
- Lab analysis for TSS, TN (NO_3, NH_3, TKN), TP (OP)

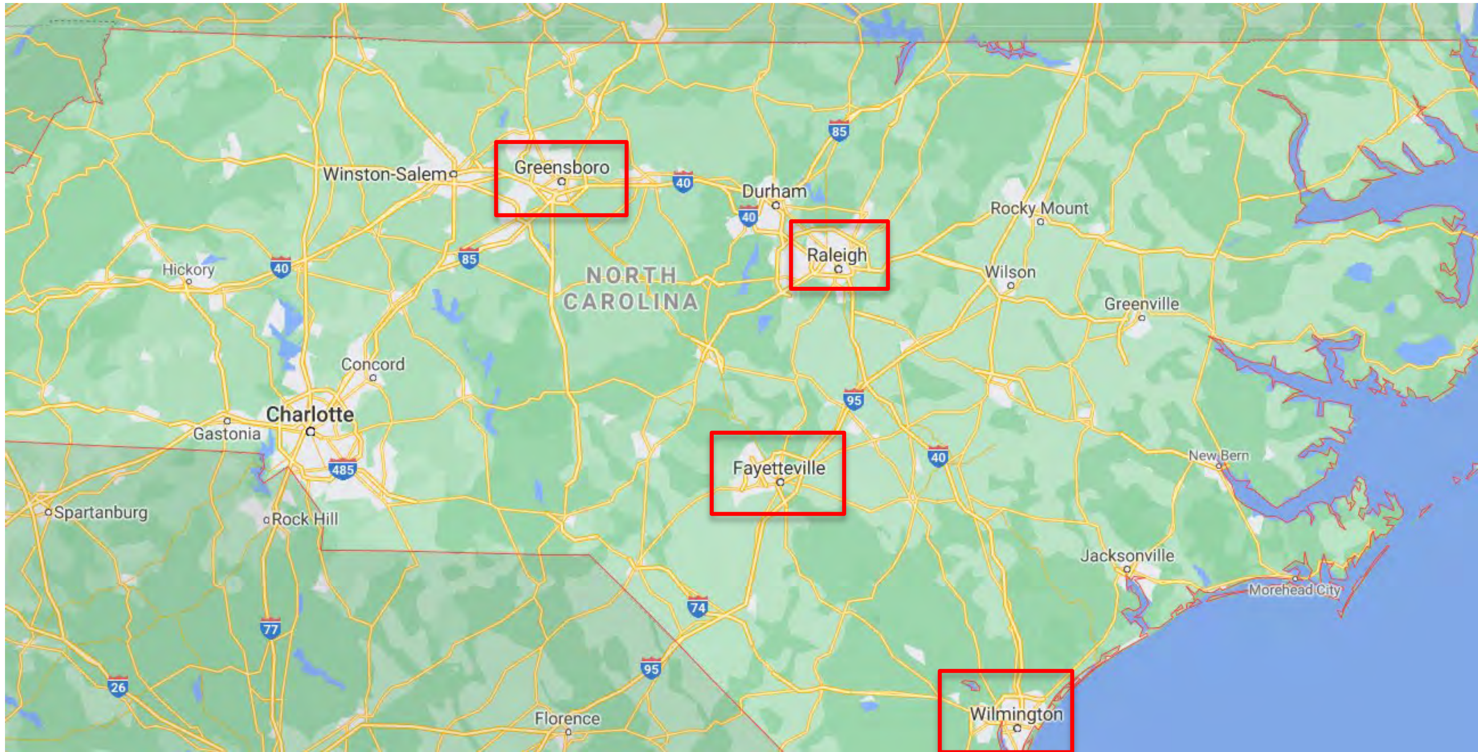


Image of North Carolina from Google Maps

RNR Tire Express

Cape Landing Apartment Complex

Fayetteville, NC

North Greensboro
(Hair Salon)

Sheetz

Greensboro, NC

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Pre-Retrofit Treatment Efficiencies (%)

Site	TKN	NO3-N	NH3	TP	OP	TSS
Sheetz (n = 13)	59.2	-16.1	38.8	22.6	-31.6	74.2
North GSO (n = 12)	-21.0	-104.3	-93.2	21.0	38.3	75.7
Cape Landing (n = 11)	39.0	-49.4	76.5	32.5	11.9	75.6
RNR (n = 12)	65.8	-126.9	73.6	68.9	29.3	94.9
Most Common Range	50-70	20-60		40-60		80-90

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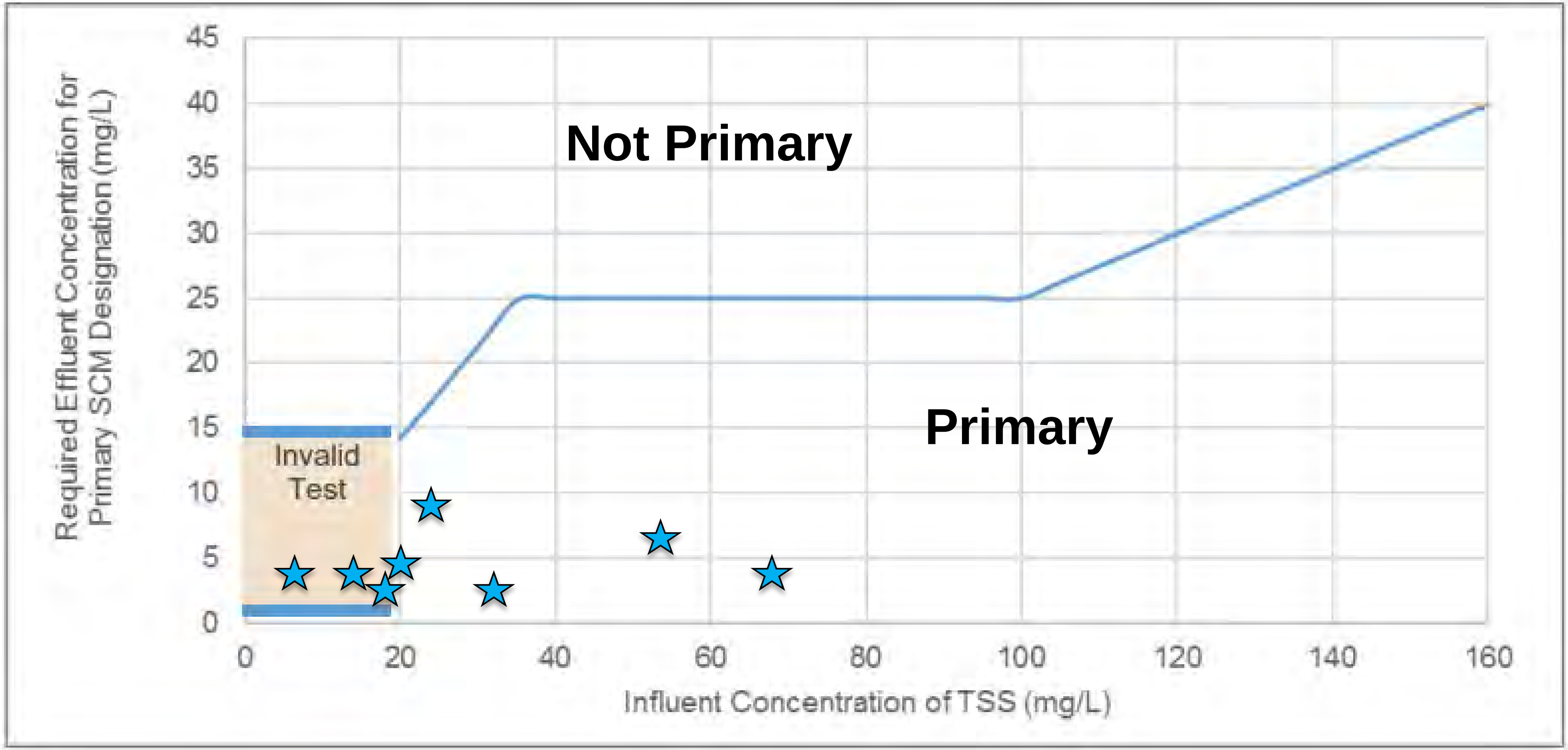
Post-Retrofit Treatment Efficiencies (%)

Site	TKN	NO3-N	NH3	TP	OP	TSS
Sheetz (n = 12)	58.5	-49.8	-9.6	33.6	-26.9	84.1
North GSO (n = 11)	16.1	-67.4	-41.8	23.7	46.5	52.9
Cape Landing (n = 11)	61.2	-156.2	66.8	53.4	-24.4	90.1
RNR (n = 13)	79.9	-48.5	86.2	80.6	71.7	95.8
Most Common Range	50-70	20-60		40-60		80-90

Primary SCM? (Based on TSS)



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Nutrient Crediting

Pollutant	Sand Filter*	Sheetz	North GSO	Cape	RNR
TP (mg/L)	0.12	0.097	0.075	0.059	0.071
TP (%)	45	22.6	21.0	32.5	29.1
TN (mg/L)	1.20	0.471	0.905	0.804	0.572
TN (%)	35	45.2	-53.5	23.2	36.5

** Sand filter EMCs were determined without any NC data, from the guidance on BRCs without IWS*

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(Sand Filter) Summary

- Sand Filters
  - Viable Alternative to: Ponds and (sometimes) Bioretention
  - Issues?: Not particularly attractive
  - Good when: Aesthetics don't matter
  - Great for: Sediment Capture

Typical Urban Trees

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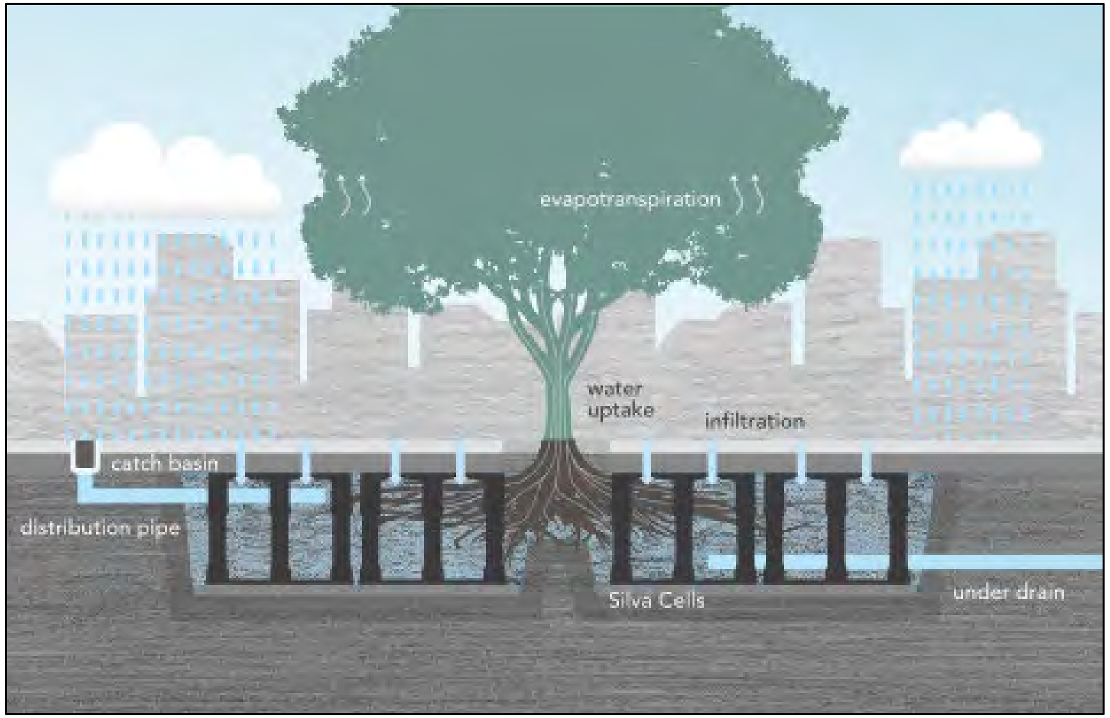
DeepRoot Silva Cells®

- Modular suspended pavement system using soil volume to support **large tree growth** and **stormwater management**



Source: DeepRoot

Why Makes Stormwater-Treating Street Trees a Potentially Viable Practice?

- Smaller Footprint than Bioretention
- Employs Filtration (like BRCs)
- Limited Vegetation to Maintain
- Pose v little safety hazard along street corridors
- Can be combined with other SCMs

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Wilmington Silva Cells®

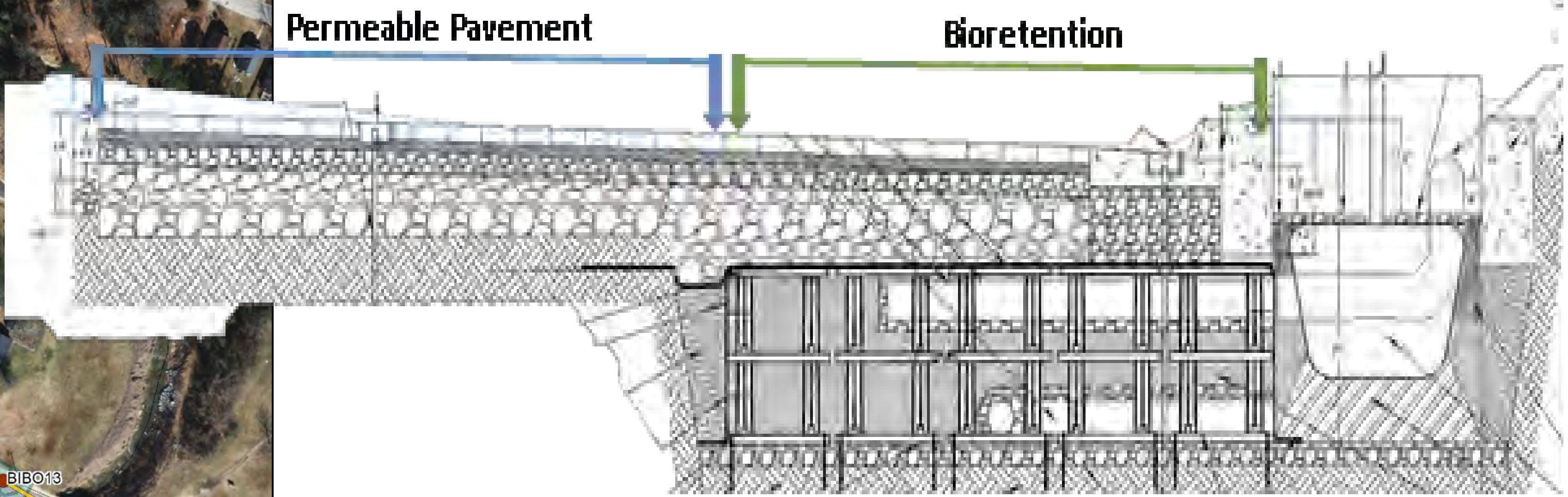
Wilmington Silva Cells® Water Quality- Ann Street

	Pollutant Load Summary (kg/ha/yr)			
Pollutant	Pre-Retrofit	Post-Retrofit	Mass Retained	% Retained
TN	8.47	4.02	4.45	53%
TP	1.43	0.51	0.92	59%
TSS	556	170	416	69%
Cu[a]	0.18	0.04	0.15	70%
Pb[a]	0.14	0.06	0.07	58%
Zn[a]	0.86	0.35	0.51	60%

- No volume reduction
- Recall: 20% of total runoff volume bypassed

Fayetteville Silva Cells®

Fayetteville Silva Cells®



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Fayetteville Silva Cells®-Bypass

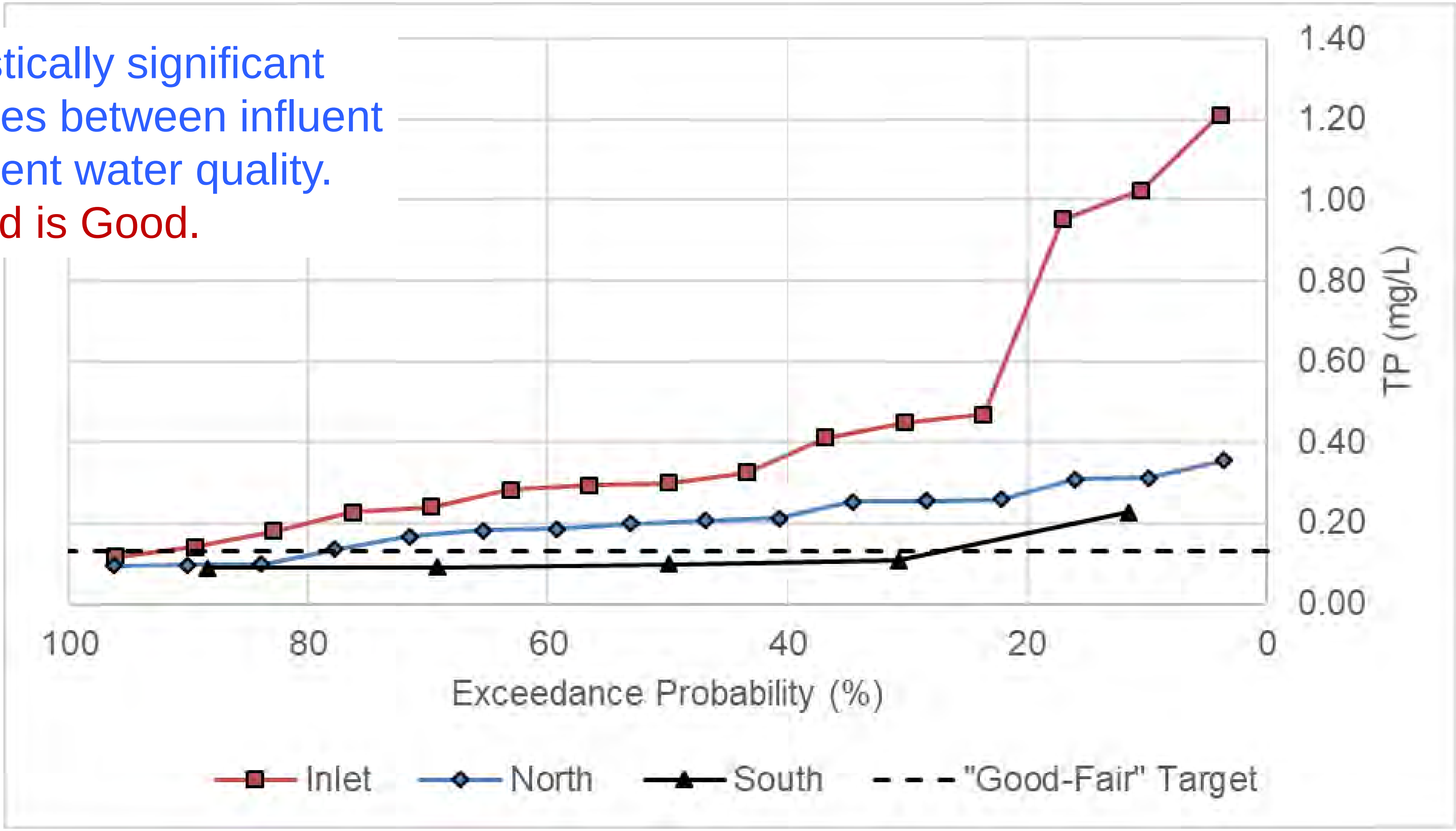
Silva Cells®	Estimated Bypass Volume (cf)				Estimated Percent Bypass (%)			
	Minimum	Mean	Median	Maximum	Minimum	Mean	Median	Maximum
North	12	644	411	7,896	10	80	85	98
South	40	1,231	482	23,816	31	70	70	100

Fayetteville Silva Cells®

Durham Silva Cells®

Durham Silva Cells®

No statistically significant differences between influent and effluent water quality.
But Trend is Good.



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Burlington Silva Cells®

- DeepRoot Silva Cell® paired with Porous Technologies Stormcrete® slabs
- Treatment train designed to treat runoff from 1 in storm event
- Silva Cells® had IWS and backfilled NC bioretention media
- Runoff entered through Stormcrete® slabs into Silva Cells®
  - Tree well with one 4 in distribution pipe

But More than 90% of Runoff Bypassed (mostly) due to Pervious Curb & Gutter Clogging

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Summary

- Sand Filters
  - Viable Alternative to: Ponds and (sometimes) Bioretention
  - Issues?: Not particularly attractive
  - Good when: Aesthetics don't matter
  - Great for: Sediment Capture
- Stormwater-treating Street Trees
  - Viable Alternative: Potentially
  - Issues?: Bypass Volumes can be high
  - Good when: Properly Maintained. Bypass Eliminated
  - Great for: Ultra-Urban areas with reliable Street Sweeping

Thank you!!! Questions?

Evaluating and Managing Nutrient Inputs from Onsite Wastewater Systems in the Falls Lake Watershed: A Multiscale Approach

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

East Carolina University

NORTH CAROLINA Environmental Quality

NC Policy Collaboratory

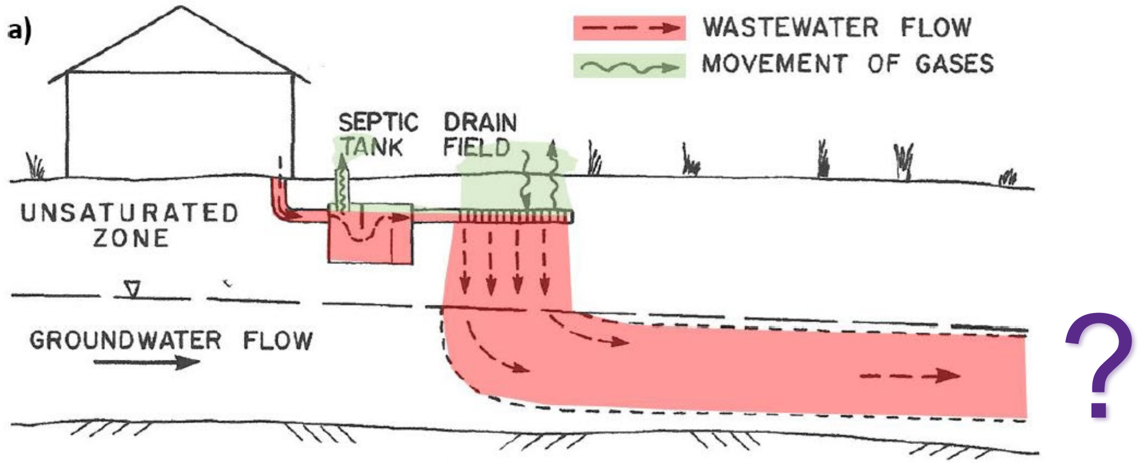
ECU ENVIRONMENTAL HEALTH SCIENCES PROGRAM

Outline

- ❑ Background on onsite wastewater treatment systems (OWTSs)
- ❑ Managing OWTS-derived nutrients using natural and nature-based features
- ❑ Number of OWTSs in the Falls Lake Watershed
- ❑ Research questions
- ❑ Results from the 2 funded Falls Lake studies:
  - ❑ 2020 – 2021 NC DEQ 319 Non-Point Source Program
  - ❑ 2020 – 2021 NC Policy Collaboratory
- ❑ Summary and key takeaways
- ❑ Future steps

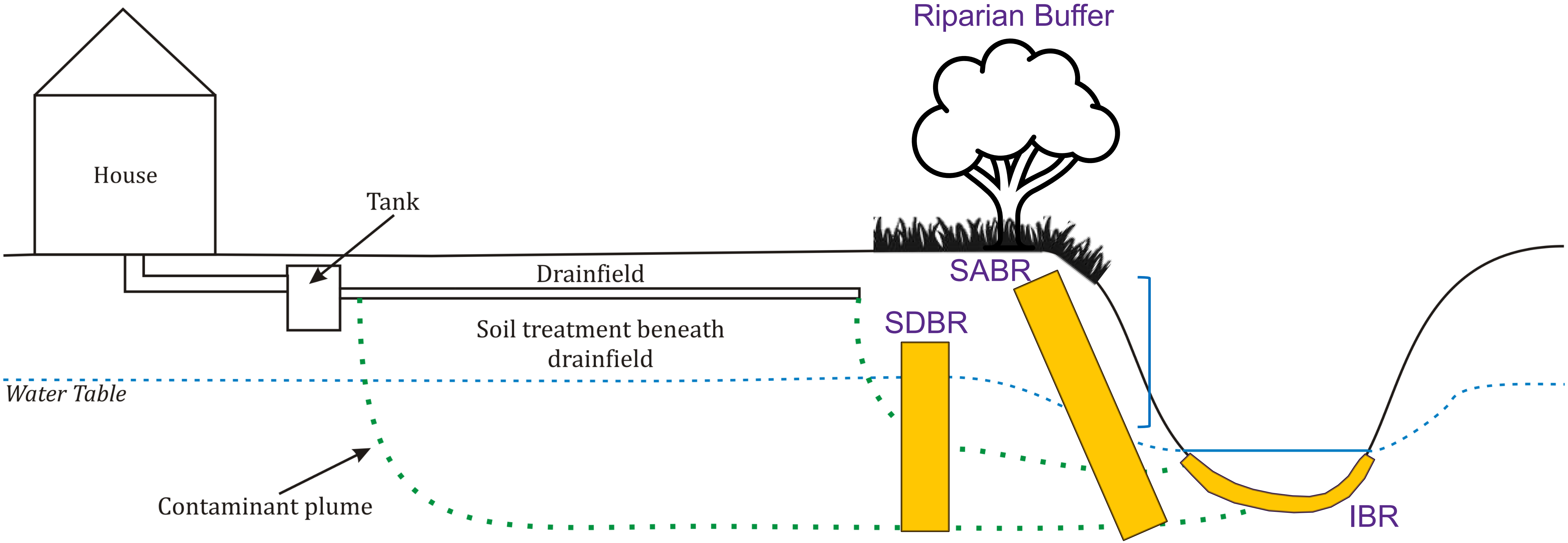
Introduction

- Excess chlorophyll-a and nutrients → among leading causes of lake impairment in NC (US EPA 2021)
- Onsite wastewater treatment systems (OWTSs) commonly cited as an important non-point source of nutrients to surface waters
  - However, there are limited quantitative studies
- Estimating OWTS nutrient inputs at watershed-scale is challenging
  - Discharged effluent is diffuse
  - Lack of OWTS monitoring data
  - Complexity of nutrient transport



(Robertson 2021)

Natural and Nature-based Features

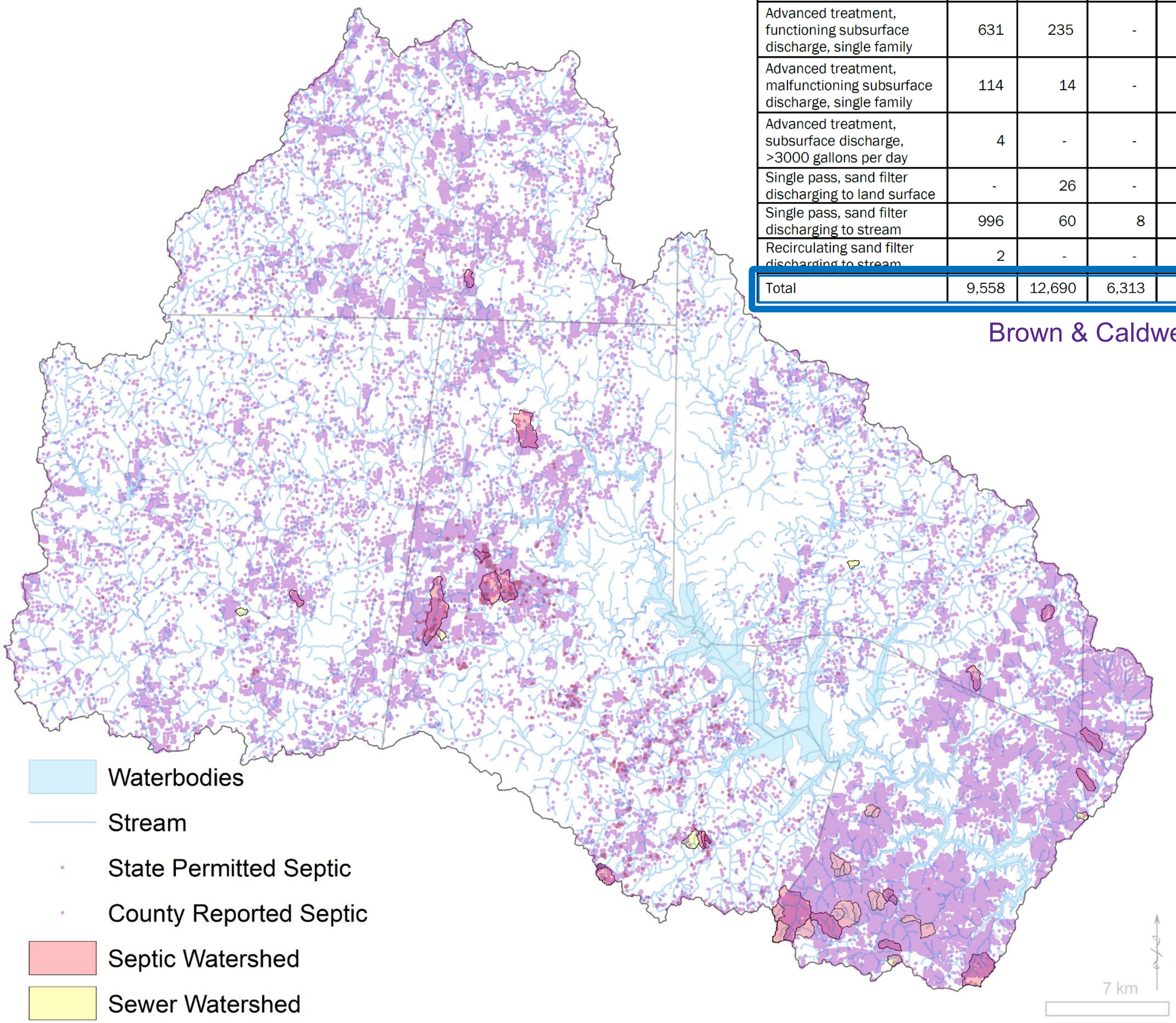


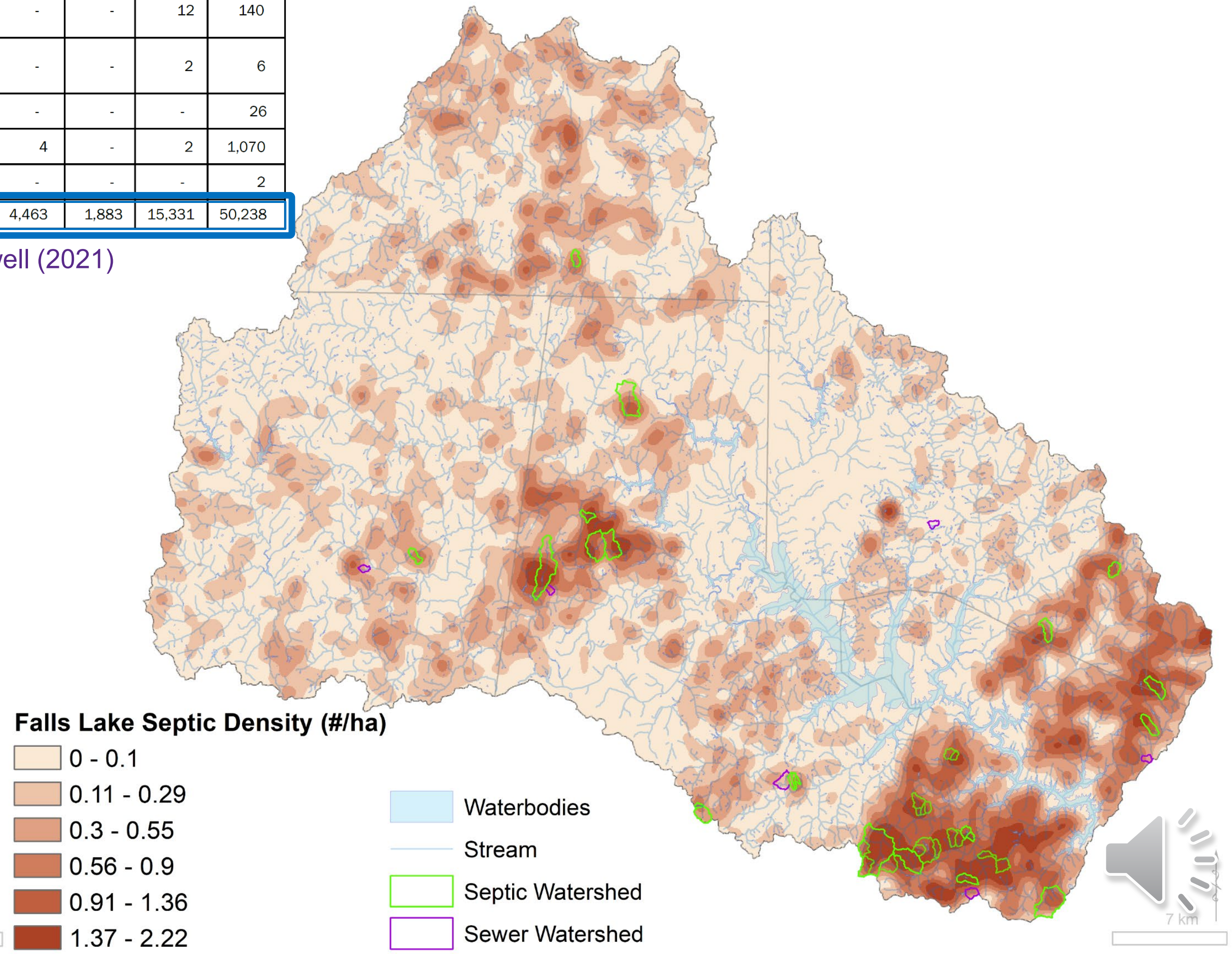
- ❑ Riparian buffers downgradient from OWTS → denitrification (N) and immobilization (if root zones can reach WT)
- ❑ Subsurface denitrifying bioreactors (SDBR), in-stream (IBR), and stream-adjacent bioreactors (SABR) → engineered solutions that facilitate denitrification (N), adsorption/precipitation of P may be plausible

OWTS in the Falls Lake Watershed

Category	Durham	Orange	Person	Granville	Franklin	Wake	Total
Privy	1	7	-	-	-	1	9
Conventional, functioning, subsurface discharge	7,102	11,585	5,671	4,181	1,790	14,094	44,423
Conventional, malfunctioning, subsurface or discharge	708	763	634	278	93	1,057	3,533
Advanced treatment, functioning subsurface discharge, single family	631	235	-	-	-	163	1,029
Advanced treatment, malfunctioning subsurface discharge, single family	114	14	-	-	-	12	140
Advanced treatment, subsurface discharge, >3000 gallons per day	4	-	-	-	-	2	6
Single pass, sand filter discharging to land surface	-	26	-	-	-	-	26
Single pass, sand filter discharging to stream	996	60	8	4	-	2	1,070
Recirculating sand filter discharging to stream	2	-	-	-	-	-	2
Total	9,558	12,690	6,313	4,463	1,883	15,331	50,238

Brown & Caldwell (2021)



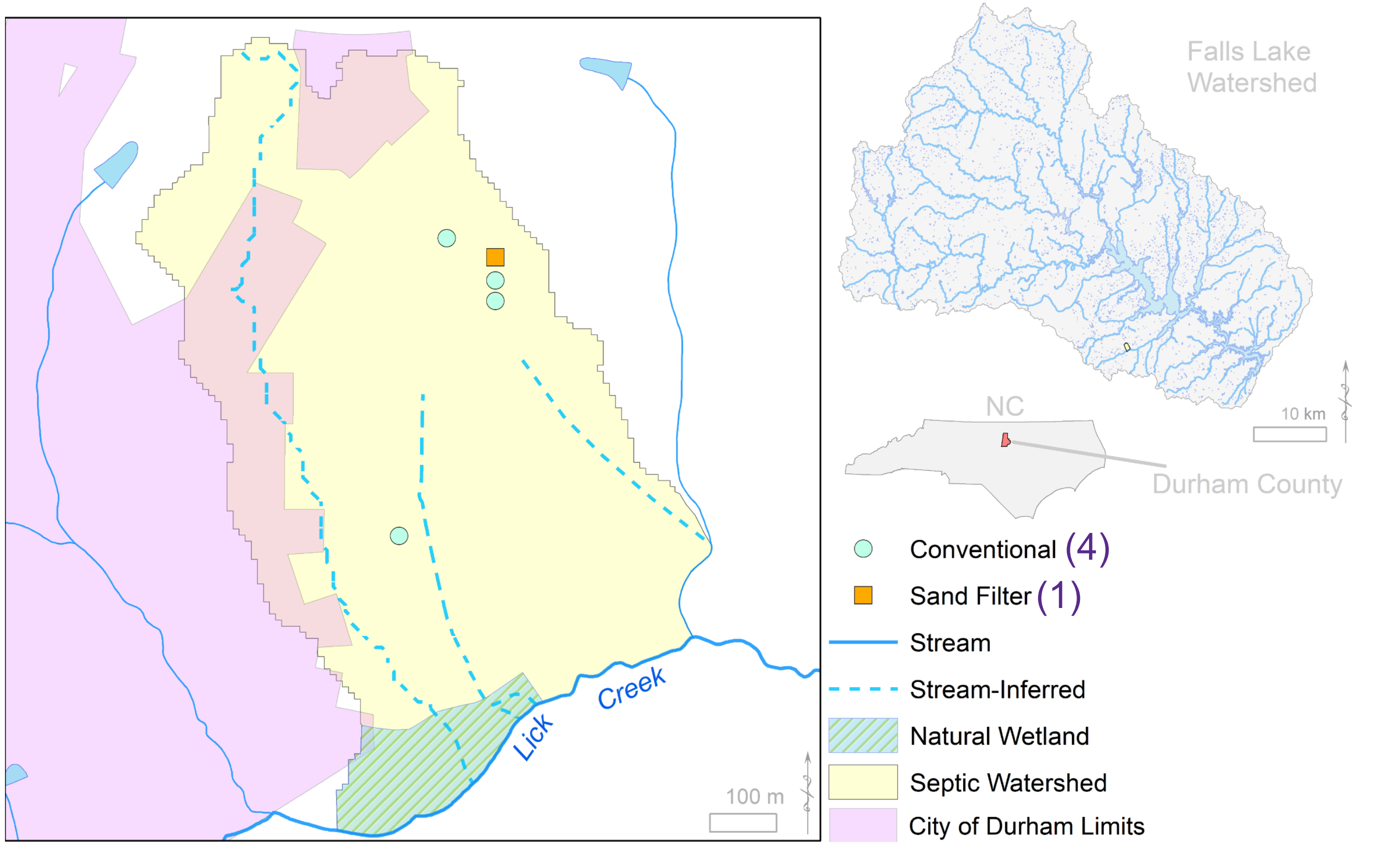


Research Questions

- ❑ How does nutrient attenuation vary at the system and landscape scale?
- ❑ Do OWTS-dominant watersheds contain elevated nutrient exports than sewer-dominant watersheds?
- ❑ Is there a difference in nutrient loading based on geological setting in the Falls Lake Watershed?
- ❑ What bioreactor porous media are most effective at reducing OWTS-derived nutrients?

System and Landscape Scale Monitoring

- GW and WW monitoring at 5 sites (bi-monthly; Sep 2020 – Aug 2021) to quantify nutrient treatment at individual system and lot scale
- Data can be used to calculate wastewater nutrient attenuation at the system and landscape scale
- Efforts led by Charles Humphrey, Guy Iverson, and Jordan Jernigan (DrPH Candidate)



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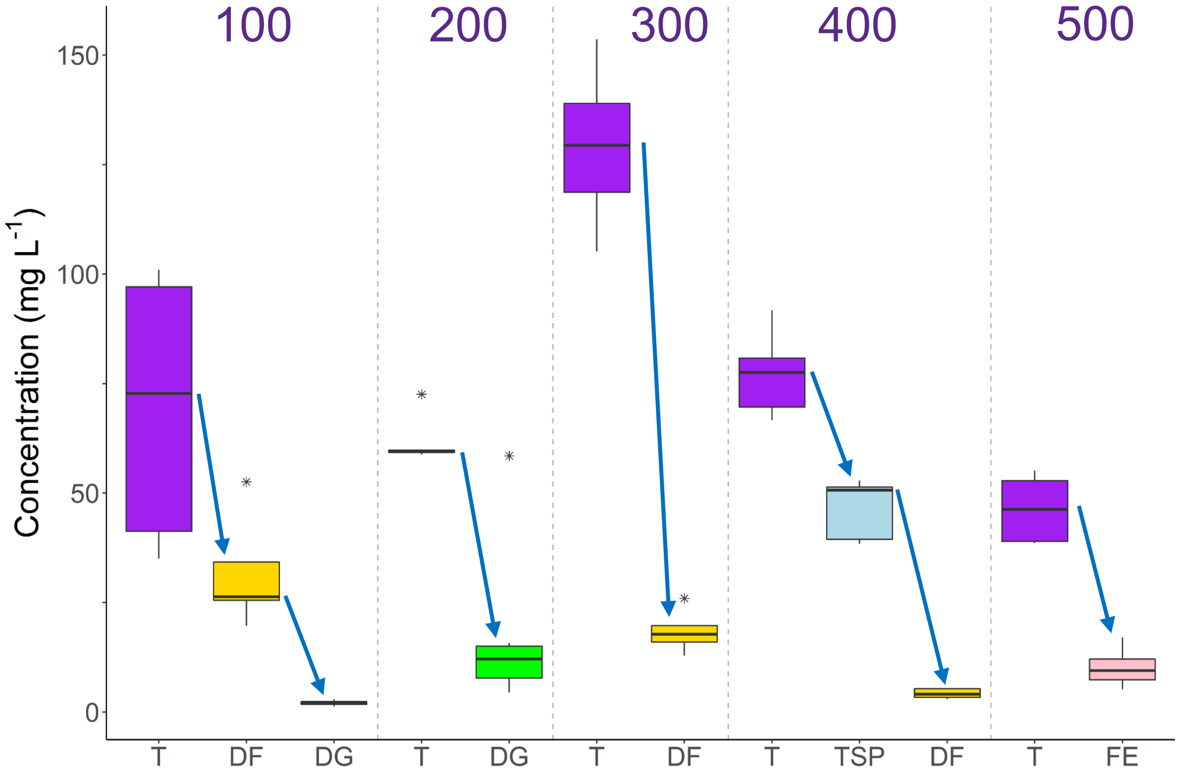
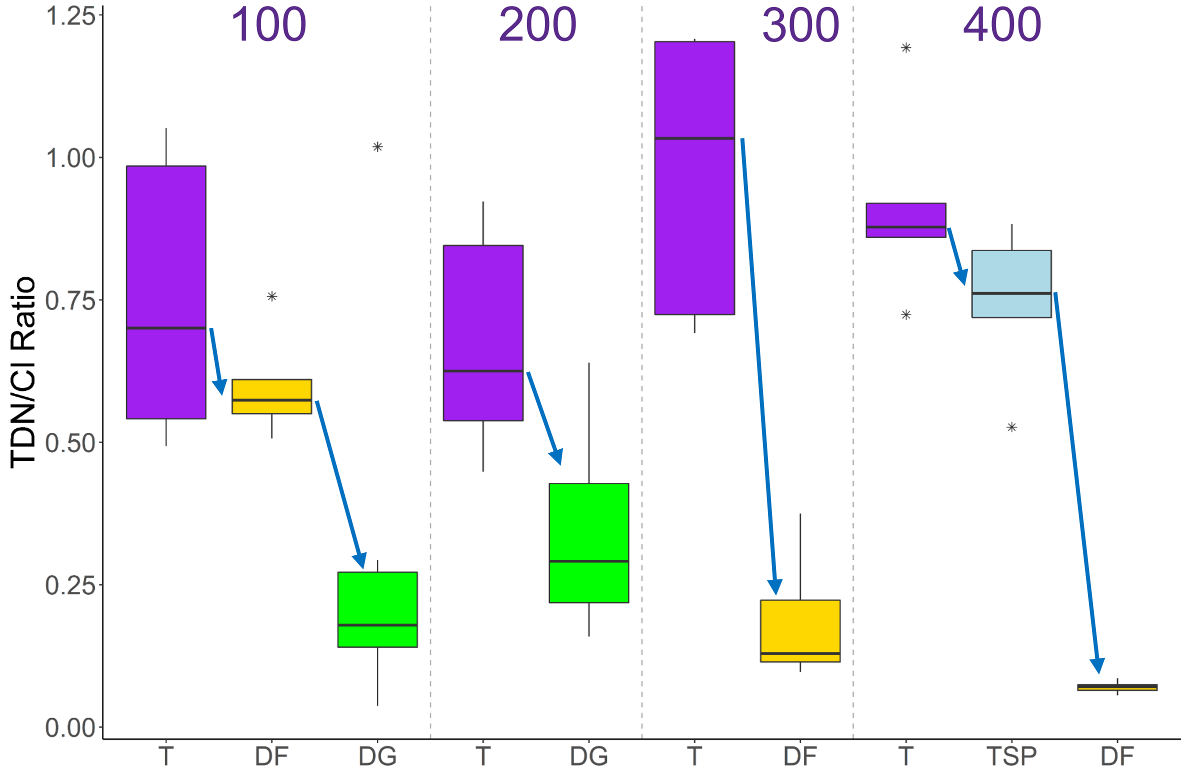
TDN Treatment Efficiency of OWTS





Site	Median Conc (mg L^{-1}) Tank	DF/FE	DG	Conc Reduction (%) Tank-DF/FE	Tank-DG
100	72.75	26.32	1.96	63.8%	97.3%
200	59.40	4.00	12.13	93.3%	79.6%
300	129.40	17.76		86.3%	
400	77.54	4.10		94.7%	
500	46.31	9.49		79.5%	

Site	Median TDN/Cl Ratio Tank	DF/FE	DG	Mass Reduction (%) Tank-DF/FE	Tank-DG
100	0.70	0.57	0.18	18.1%	74.4%
200	0.63	0.21	0.29	66.0%	53.4%
300	0.97	0.13		86.7%	
400	0.91	0.07		92.2%	
500				79.5%	

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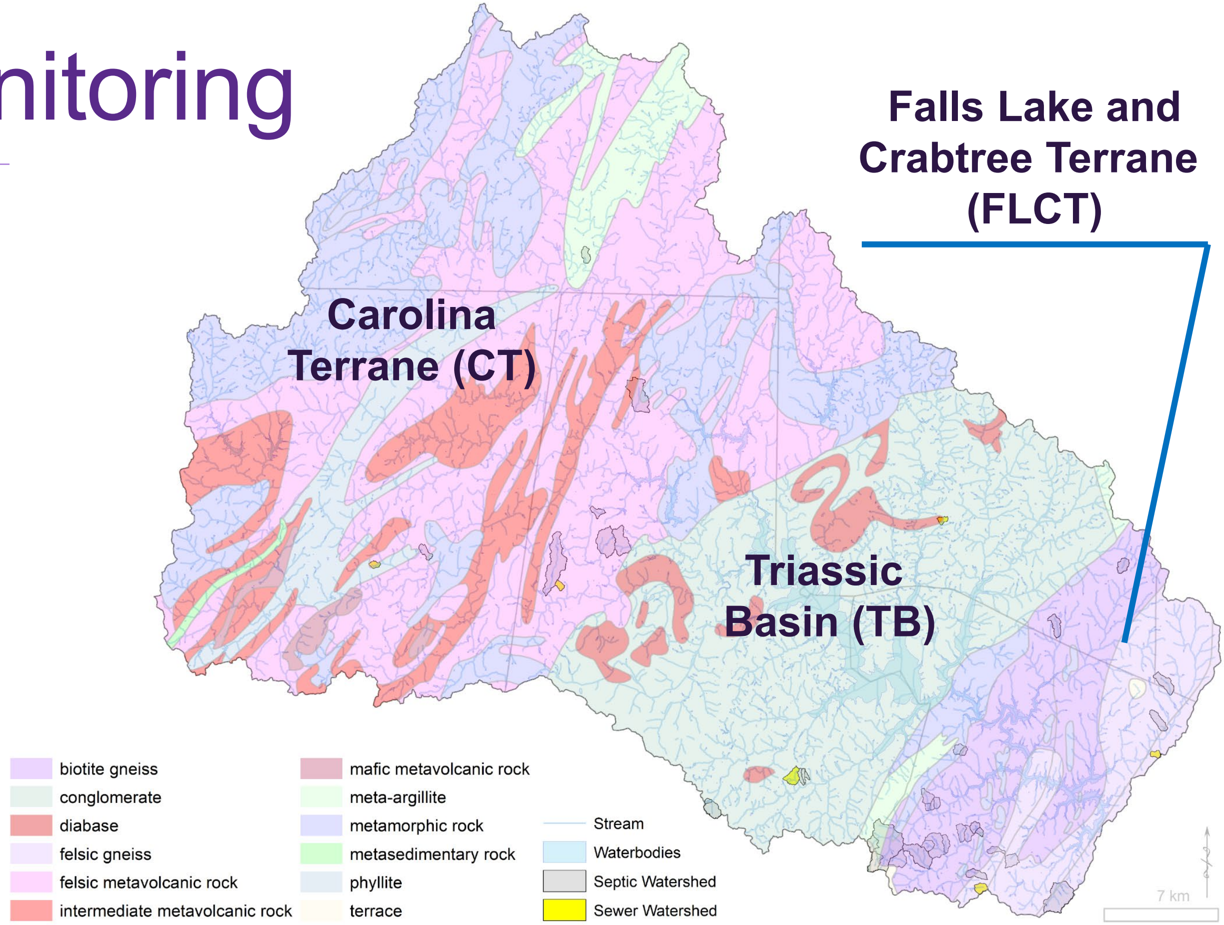
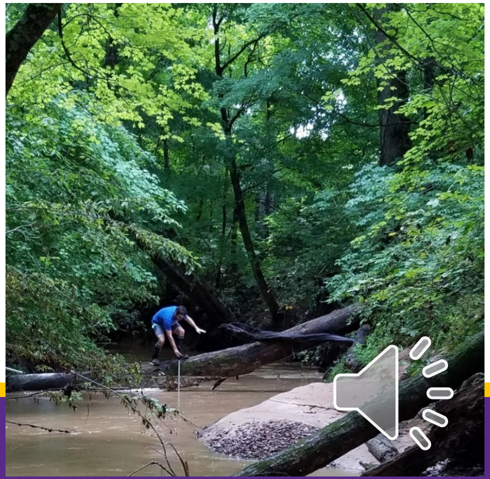
T= tank; DF= drainfield; DG= downgradient; TSP= trench sampling port; FE= filter effluent

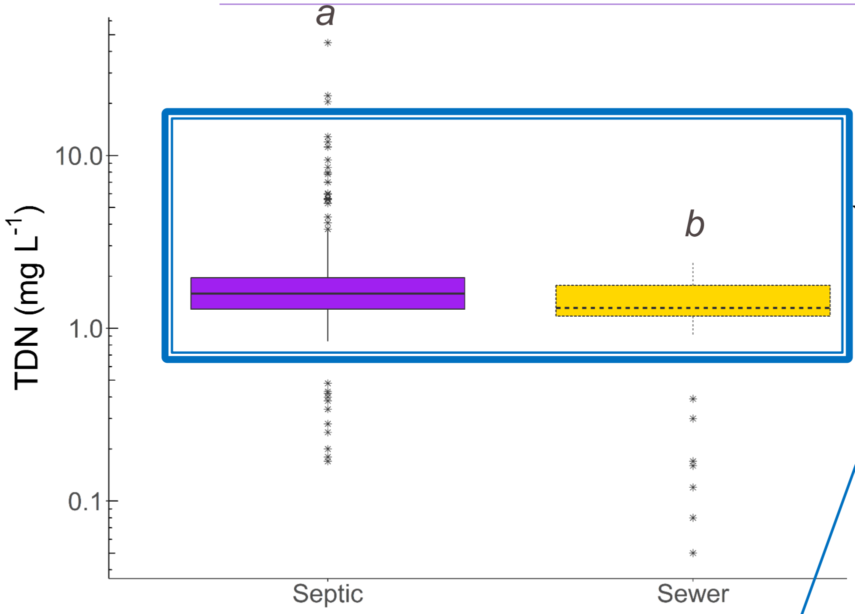
Sub-Watershed Scale Monitoring

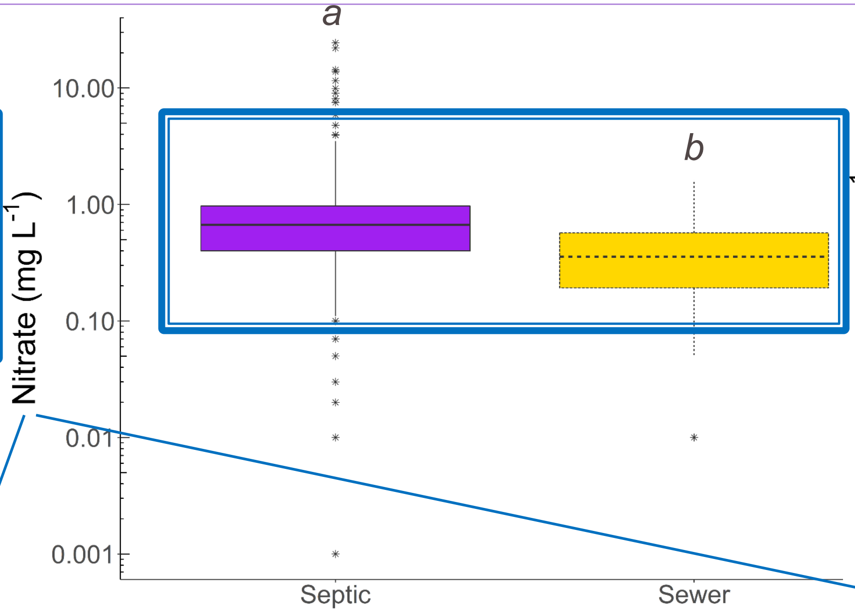
- Sub-watersheds selected based on WW and geological setting
  - 28 total for DEQ (22 OWTS; 6 SEW)
  - Additional 15 for NC-PC (all OWTS)
- OWTS density → up to 2.5 systems/ha
- Focusing on TDN and PO4-P, but other parameters collected too
  - Cl, NO3-N15 isotopes, pH, temperature, DO, turbidity, specific conductance
  - Water level and conductivity logged at 3 OWTS and 3 sewer watersheds
  - Storm sampling at a subset of watersheds

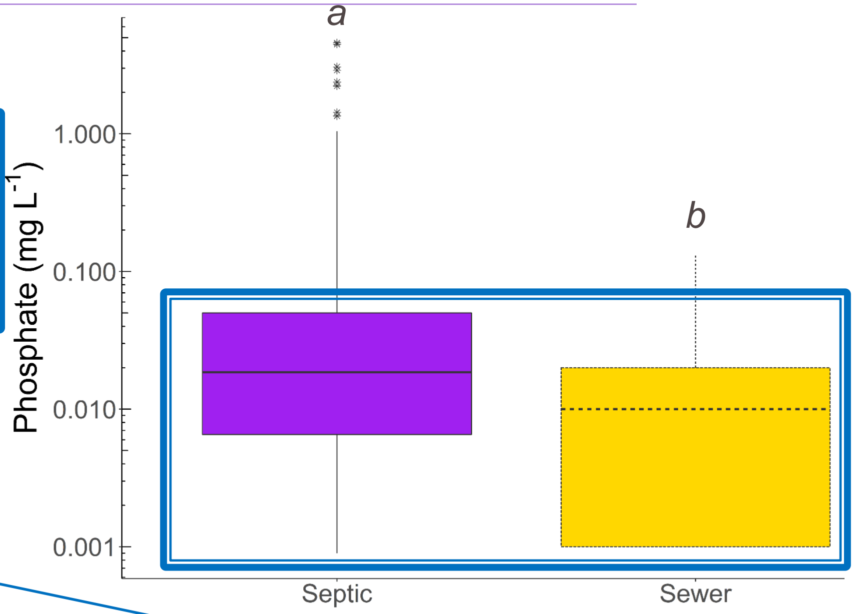




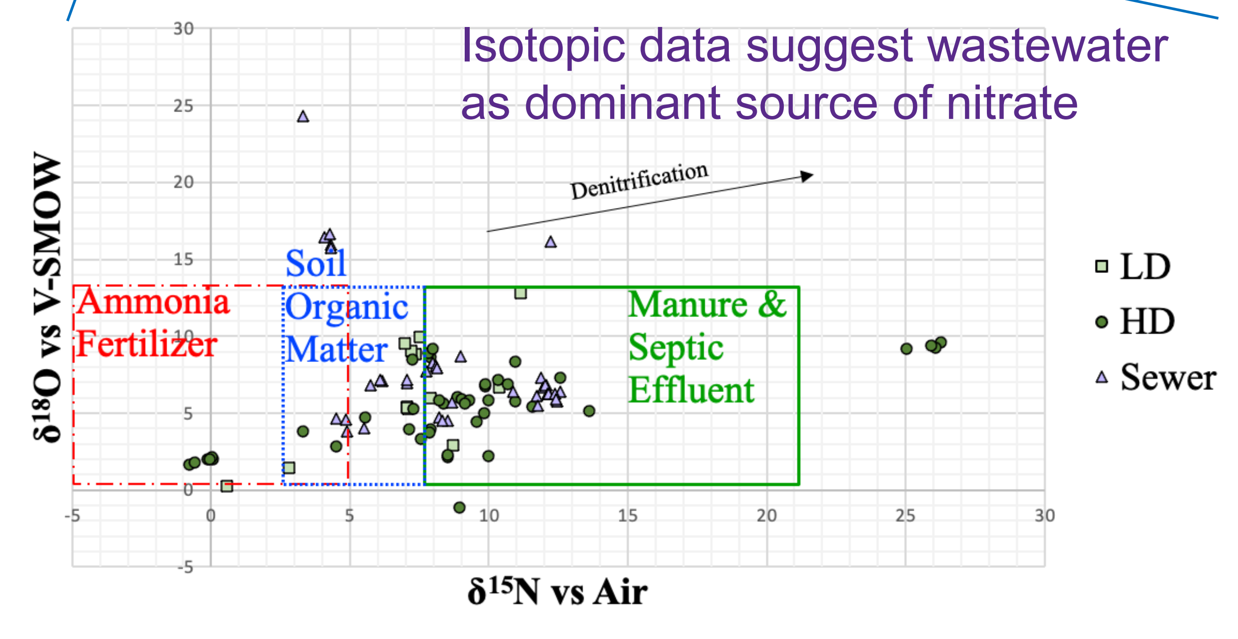
Nutrient Conc – Sub-Watershed Scale





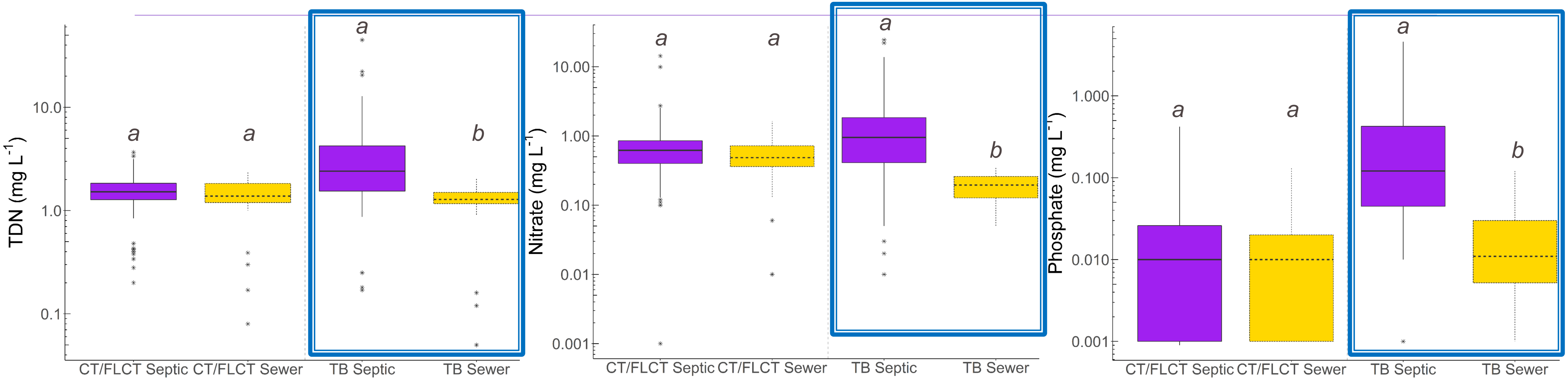


- ❑ TDN concentra
  - ❑ OWTS median: 1 … 3); $p < 0.001$
- ❑ Nitrate concen
  - ❑ OWTS median: 0 … 2); $p < 0.001$
- ❑ Phosphate cor
  - ❑ OWTS median: 0 … 3); $p < 0.001$



differences between median values

Sub-Watershed Conc by Geology



- Nutrient concentration differed between Triassic Basin (TB) geology
  - TDN → OWTS median: 2.41 mg L^{-1} (n= 71); SEW median: 1.28 mg L^{-1} (n= 28); $p < 0.001$
  - NO_3^--N → OWTS median: 0.95 mg L^{-1} (n= 69); SEW median: 0.20 mg L^{-1} (n= 28); $p < 0.001$
  - PO_4^--P → OWTS median: 0.12 mg L^{-1} (n= 71); SEW median: 0.01 mg L^{-1} (n= 28); $p < 0.001$
- OWTS and sewer sub-watersheds contained similar median concentrations of TDN ($p = 0.17$), NO_3^--N ($p = 0.11$), and PO_4^--P ($p = 0.08$) in Carolina Terrane (CT) and Falls Lake and Crabtree Terrane (FLCT) geology

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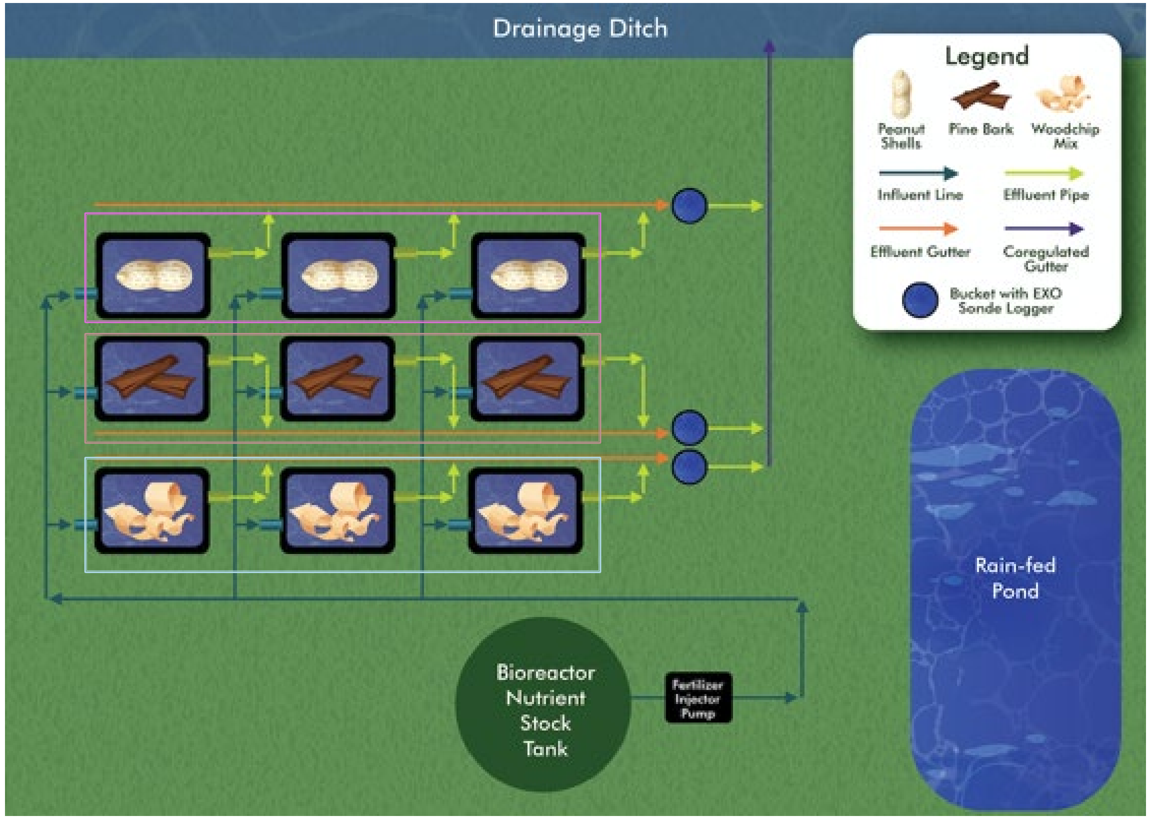
Different letters imply significant differences between median values

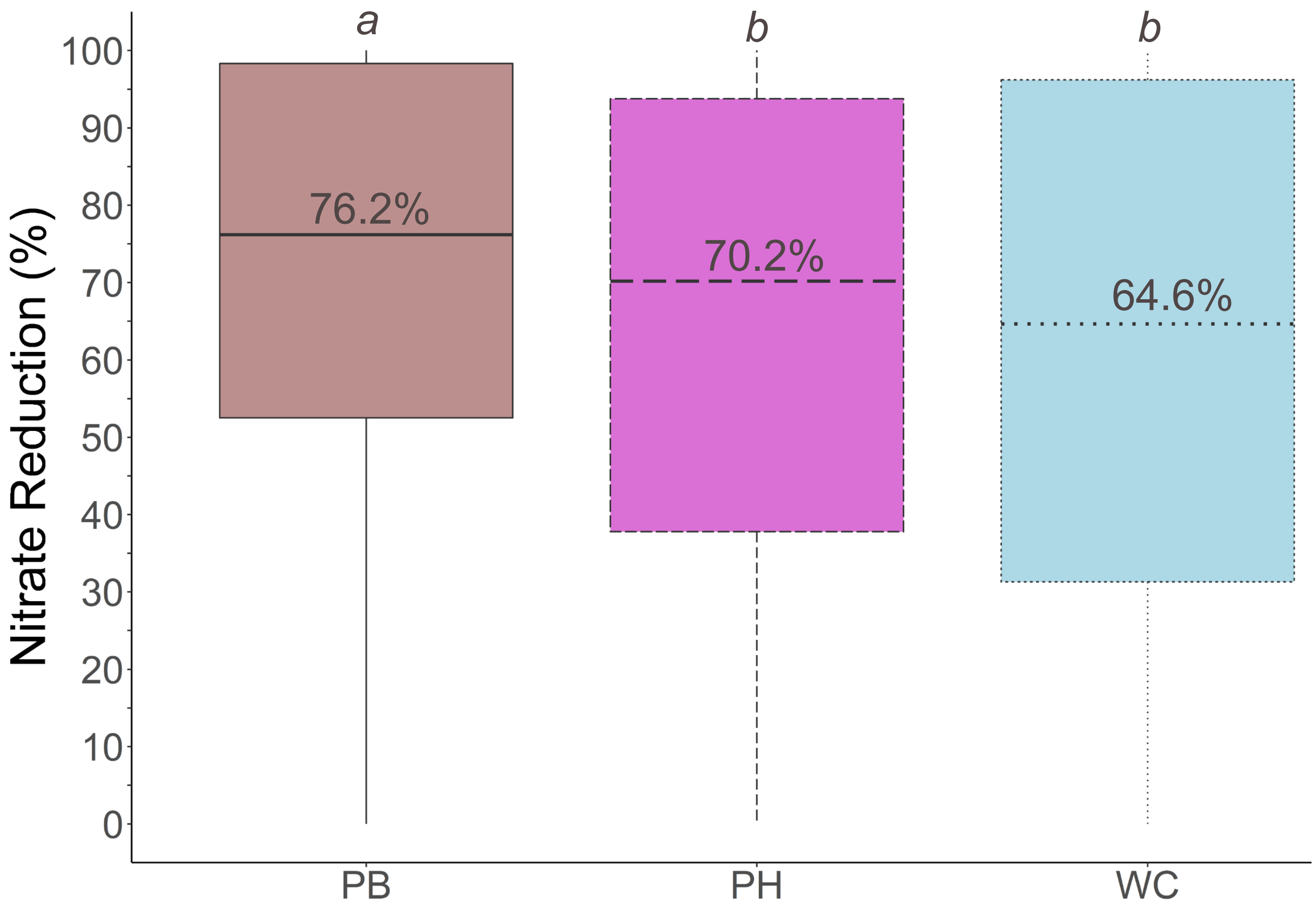
Managing Elevated Nutrient Inputs

- 9 pilot-scale bioreactors (BR)
- 3 using peanut hulls, 3 using pine bark, and 3 using woodchips
- BR dosed with known concentration of nitrate (20 mg L^{-1} NO_3^--N)
- HRT = 0.5, 1, and 2 hr
- Samples collected weekly during 8, 3-week long trials from Jun – Nov 2021



Nitrate Reductions

- Pine bark (PB) most efficient
- Peanut hulls (PH) intermediate efficacy
- Woodchips (WC) least effective, although still good median reduction
- PB significantly different from PH and WC ($p < 0.001$)
- PH and WB not significantly different ($p = 0.37$)



Different letters imply significant differences between median values, which are labeled.

Summary and Key Takeaways

- OWTS can be a significant source of nutrients to impaired and/or nutrient sensitive waters, especially in areas where geologic, soil, weather, or other characteristics negatively affect system or landscape attenuation processes and/or when septic system density is elevated (>1 system/ha).
- Watersheds served by OWTS in Triassic Basin settings contained elevated nutrients relative to all other watersheds, suggesting that other high-density OWTS watersheds in TB-settings may contain elevated nutrients.
- Pine bark, peanut hulls, and woodchips were effective carbon media at facilitating nitrate removal in pilot experiments at HRTs of 0.5, 1, and 2 hr, suggesting that these technologies may improve nutrient attenuation in areas with elevated densities of OWTS.
  - In-stream, stream-adjacent, and subsurface bioreactors could be deployed in areas with high densities of OWTS to enhance nitrate removal.

Future Steps

- System and landscape scale monitoring focused in the Triassic Basin, thus more research in Carolina Terrane and the Falls Terrane and Crabtree Terrane is needed to further constrain nutrient attenuation modeling efforts
  - Current NC Policy Collaboratory grant will help generate some of these data
- Continued efforts to monitor sub-watershed and watershed scale nutrient transport, especially in areas with varying densities of OWTS
- Adoption of best management practices (e.g., denitrifying bioreactors, stream buffer creation/restoration, etc.) designed to enhance natural processing of nutrients before reaching Falls Lake or its major tributaries



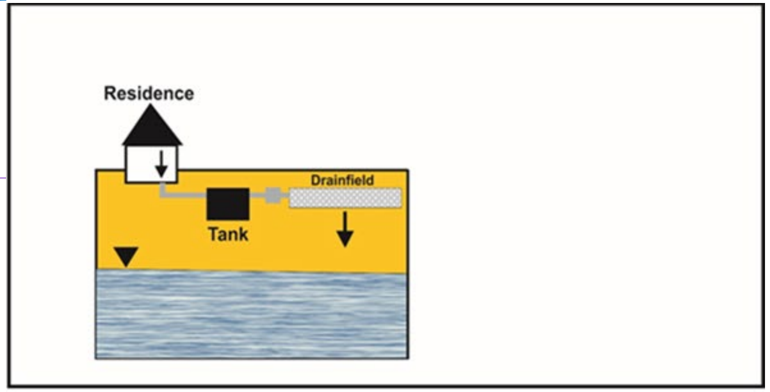
Thank you for your attention!

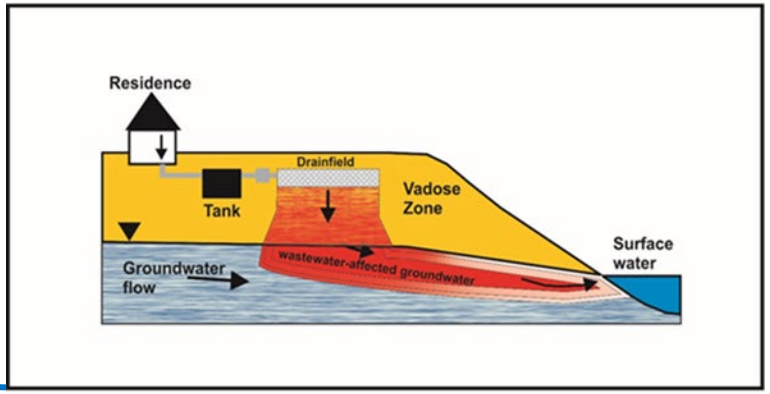


Ancillary Slides

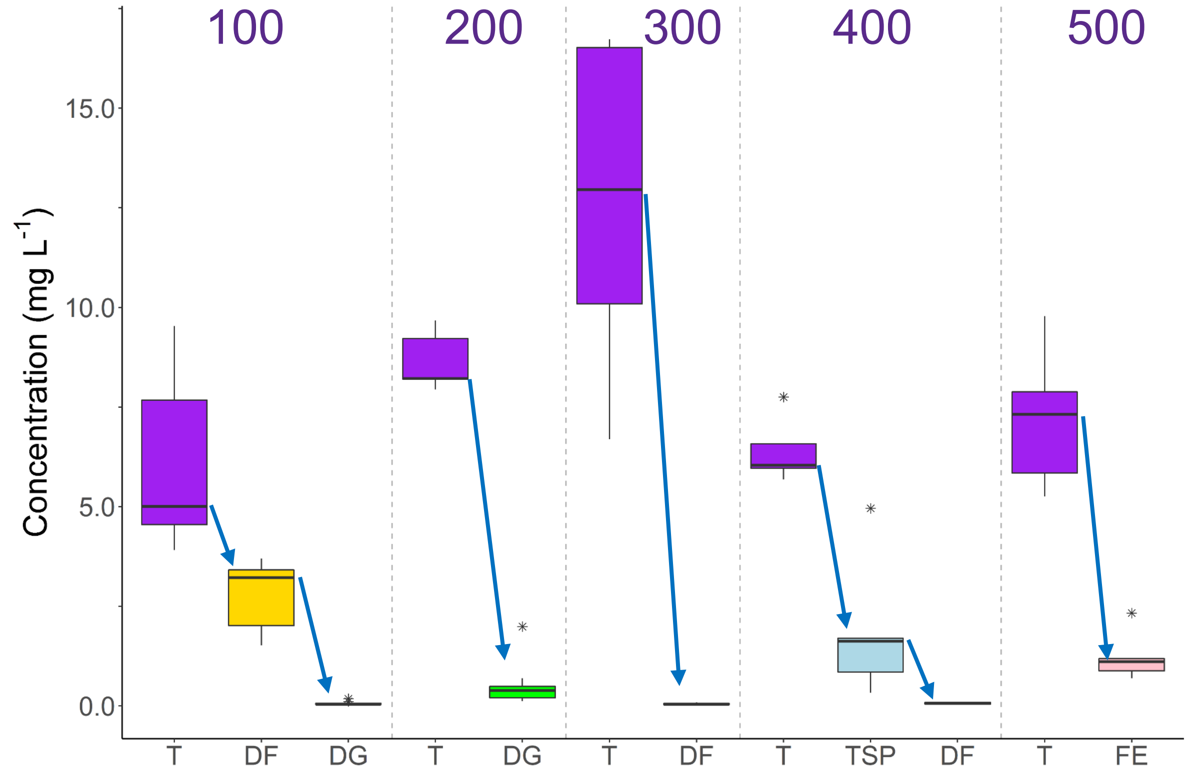
Study Approach

- ❑ Quantify OWTS nutrient loading and attenuation at the site scale (5 sites)
- ❑ Evaluate cumulative nutrient loading to streams and attenuation at the sub-watershed scale
- ❑ Determine which bioreactor substrate was most effective at removing nitrate at the pilot scale

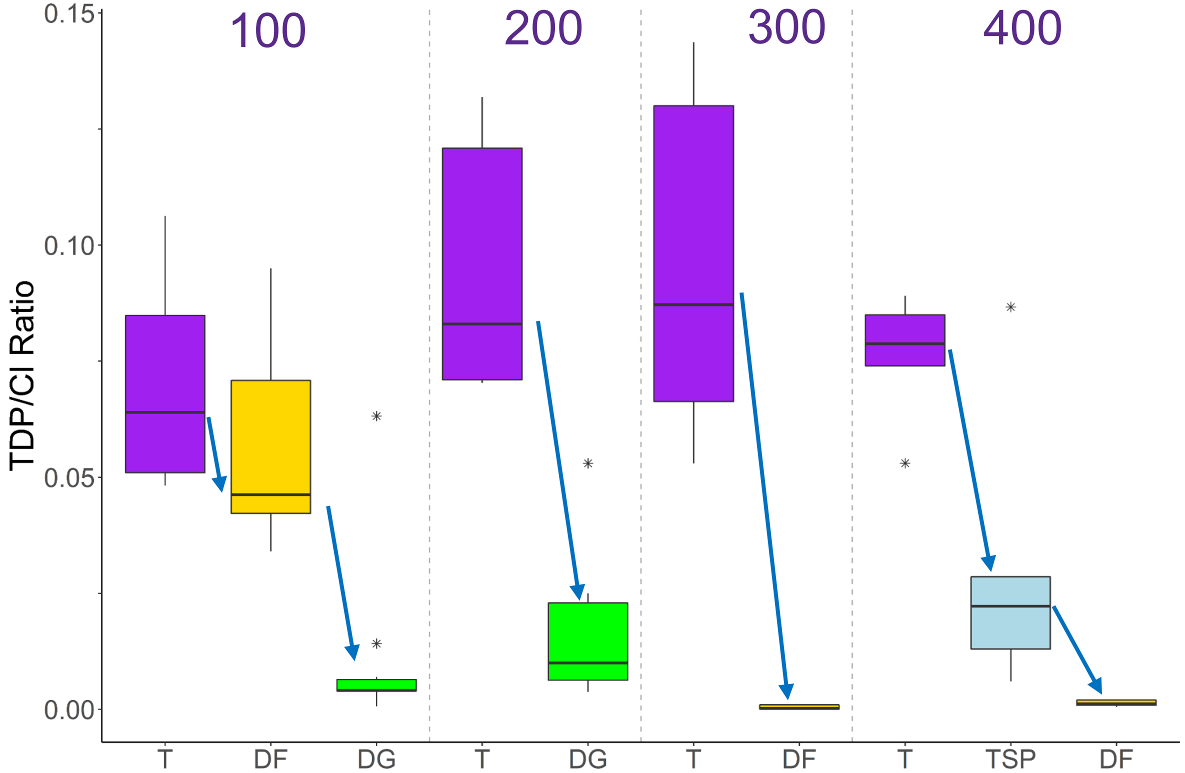




TDP Treatment Efficiency of OWTS



Site	Median Conc (mg L^{-1}) Tank	DF/FE	DG	Conc Reduction (%) Tank-DF/FE	Tank-DG
100	5.006	3.215	0.040	35.8%	99.2%
200	8.214	0.063	0.387	99.2%	95.3%
300	12.958	0.042		99.7%	
400	6.036	0.063		99.0%	
500	7.320	1.109		84.9%	



Site	Median TDP/Cl Ratio Tank	DF/FE	DG	Mass Reduction (%) Tank-DF/FE	Tank-DG
100	0.064	0.046	0.004	27.7%	93.6%
200	0.083	0.004	0.010	95.6%	88.0%
300	0.087	<0.001		99.7%	
400	0.079	0.001		98.5%	
500				84.9%	

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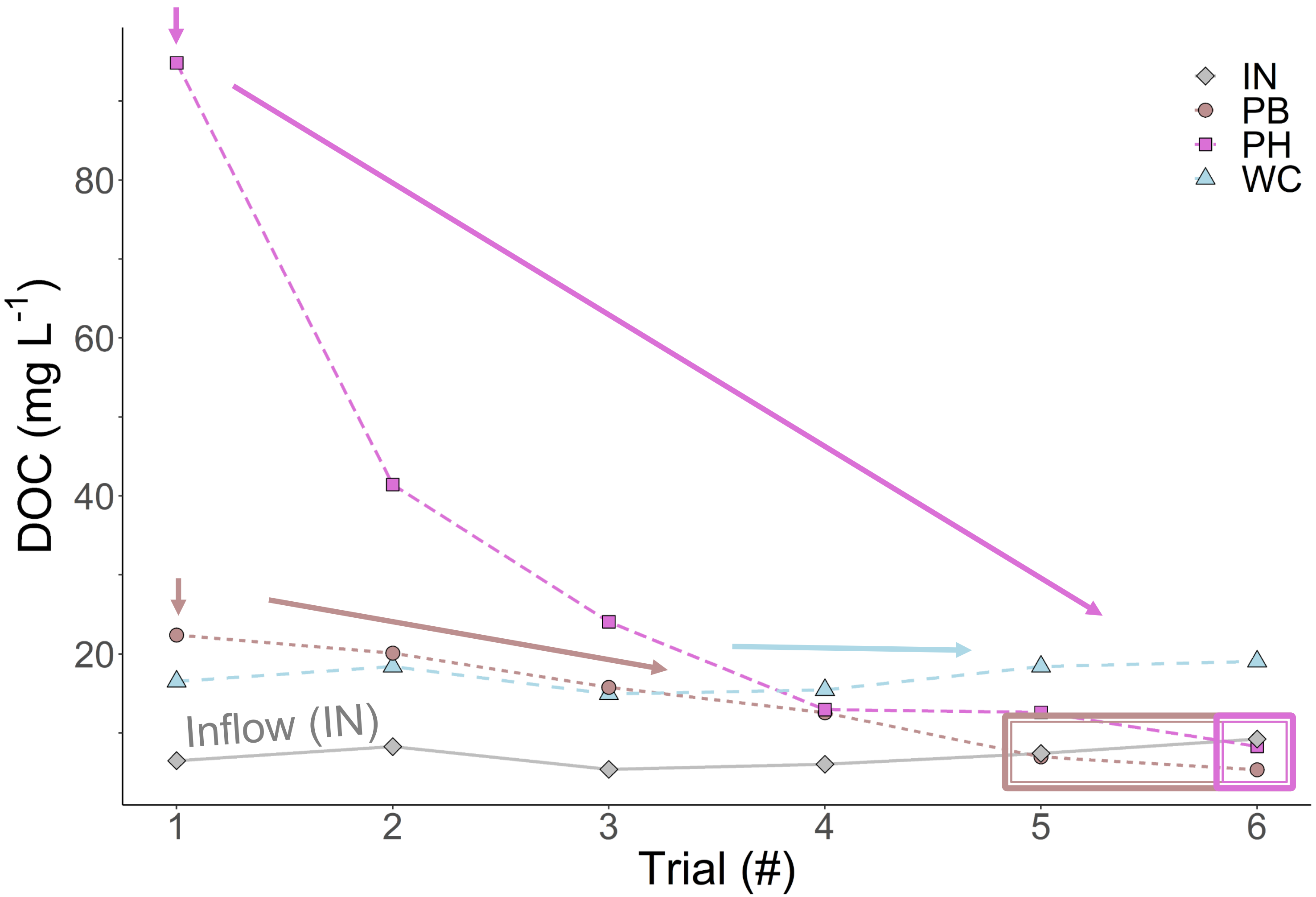
T= tank; DF= drainfield; DG= downgradient; TSP= trench sampling port; FE= filter effluent

Dissolved Organic Carbon (DOC) Emissions

- PH initially emitted elevated DOC through trial 3 (*ca.* 2 months)
  - Gradually reduced and eventually reached inflow mean DOC by trial 6 (*ca.* 4 months)
- PB and WC released *ca.* 20 mg L^{-1} DOC initially
  - PB emissions of DOC steadily decreased through trial 6 and reached inflow mean DOC by trial 5
  - WC emissions remained relatively stable throughout the 6 trials



Sediment and Carbon Accumulation in Falls Lake, NC

Brent McKee, Scott Booth, Sherif Ghobrial, Mackenzie Wise, Alyson Burch
Department of Earth, Marine, and Environmental Sciences
UNC Chapel Hill

Objective:

To quantify rates of sediment and carbon accumulation in Falls Lake

What are Carbon Accumulation Rates (CAR)?

Rates of carbon sequestration into lake sediments from the atmospheric CO_2 over time scales of decades

Why do we care?

CARs in depositional environments
(such as lakes, reservoirs, estuaries, saltmarshes, seagrass and mangroves)
are the major means of naturally removing CO_2 from the atmosphere
over time scales of decades

What drives carbon accumulation in lakes and reservoirs?

Possibilities:

- Sediment type (dry bulk density)
- Organic matter concentrations
- Sedimentation rates
- Organic Carbon Sources

Determining CAR

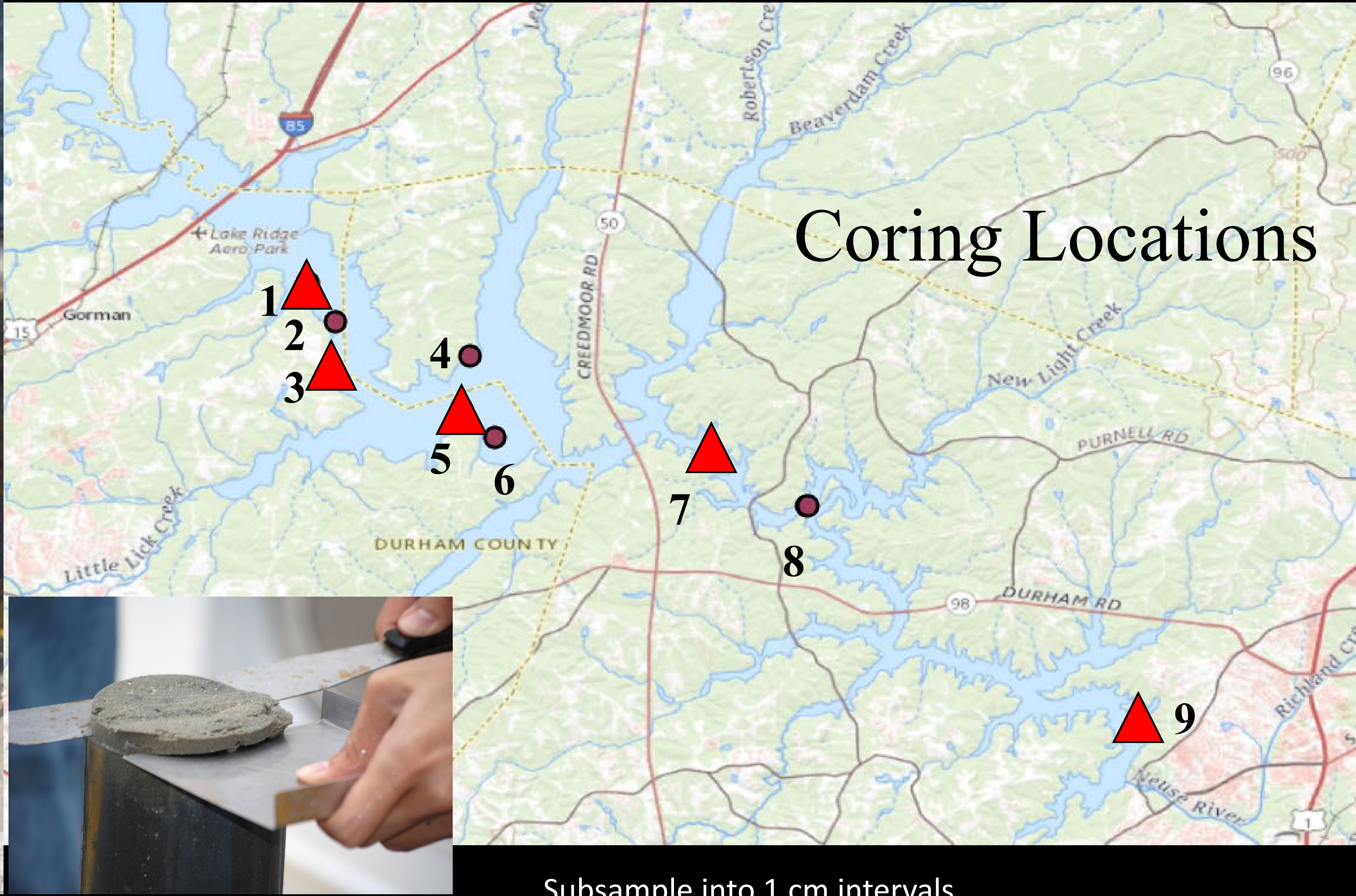
$CAR = DBD * F_{oc} * SAR$

DBD : Dry Bulk Density $g\ cm^{-3}$

F_{oc}: Fraction organic carbon $\%C \div 100$

SAR: Sediment Accumulation Rate $cm\ yr^{-1}$

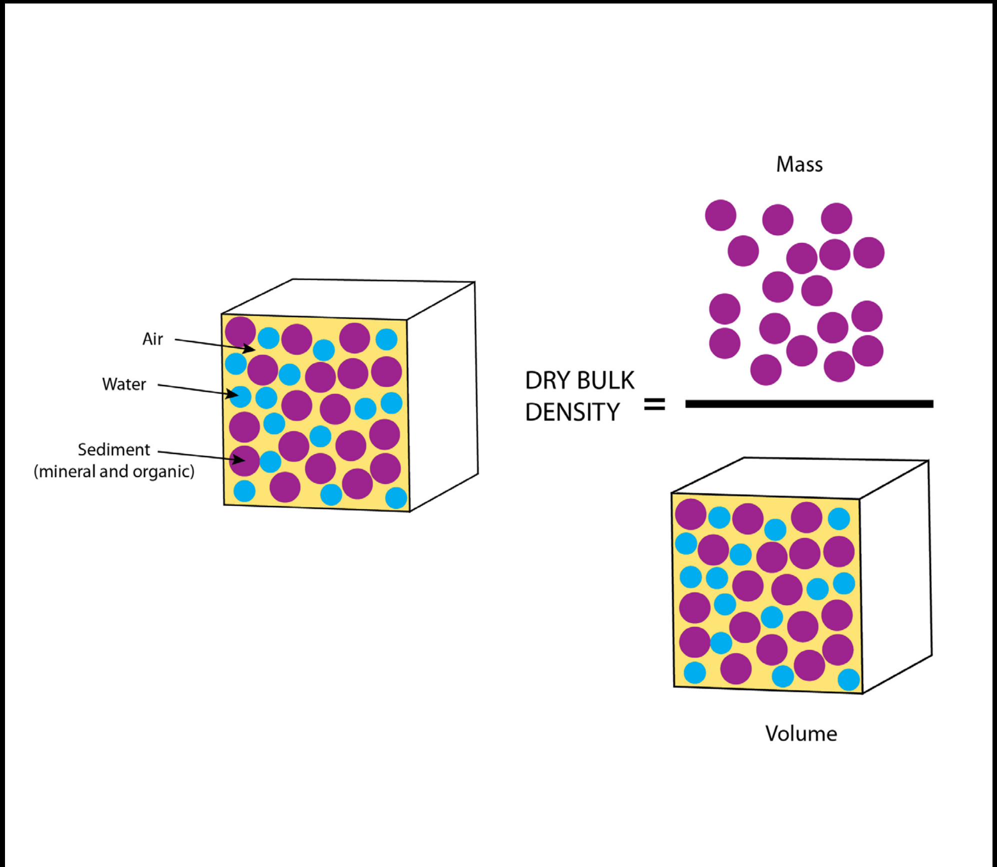
Sampling and subsampling



Subsample into 1 cm intervals

Dry Bulk Density DBD ($g\ cm^{-3}$)

Dry Sediment Mass in a cubic centimeter volume of sediment

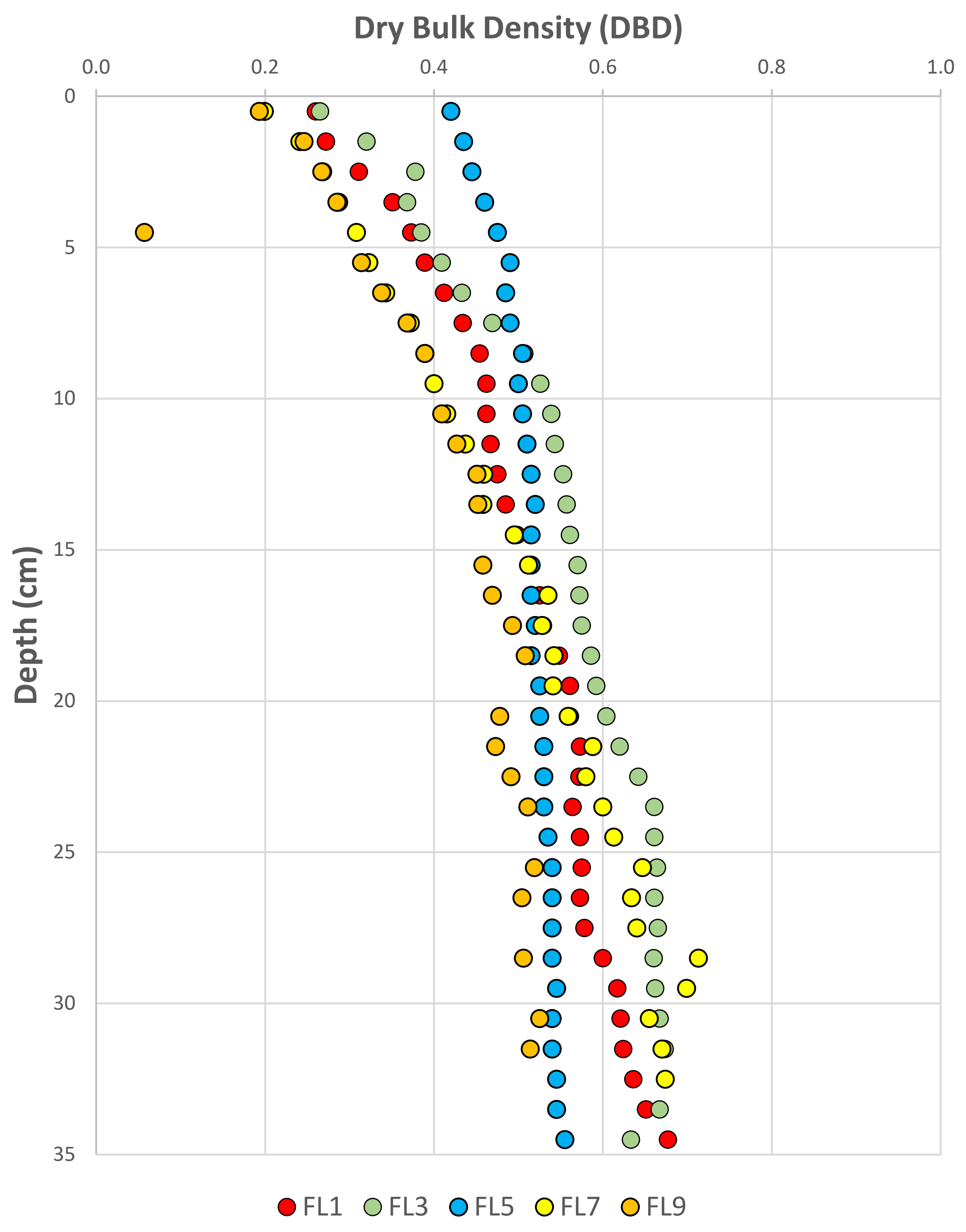


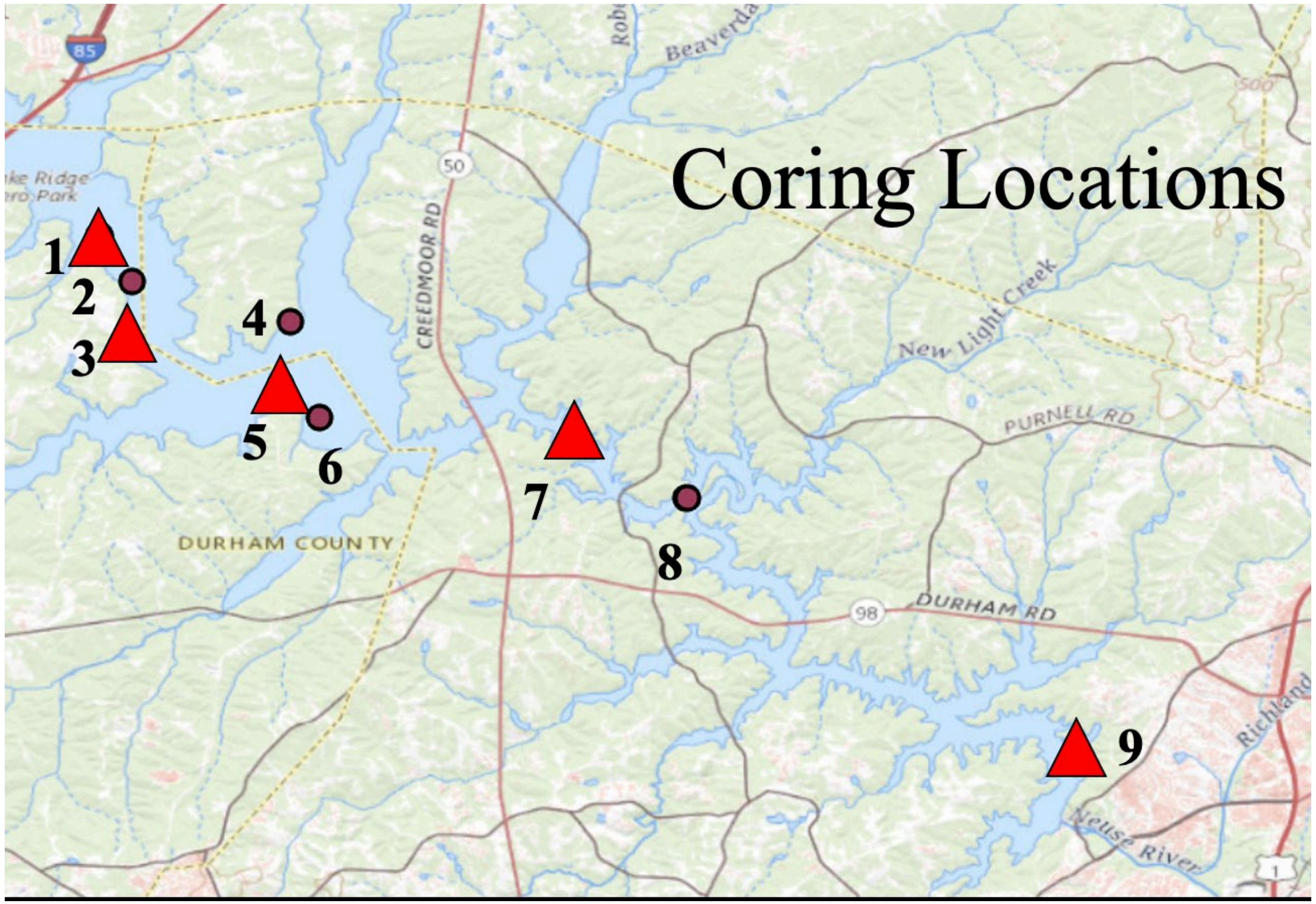
A measure of sediment properties.

Influenced by:

- Grain size
- Organic Matter content
- Compaction

Dry Bulk Density (DBD)



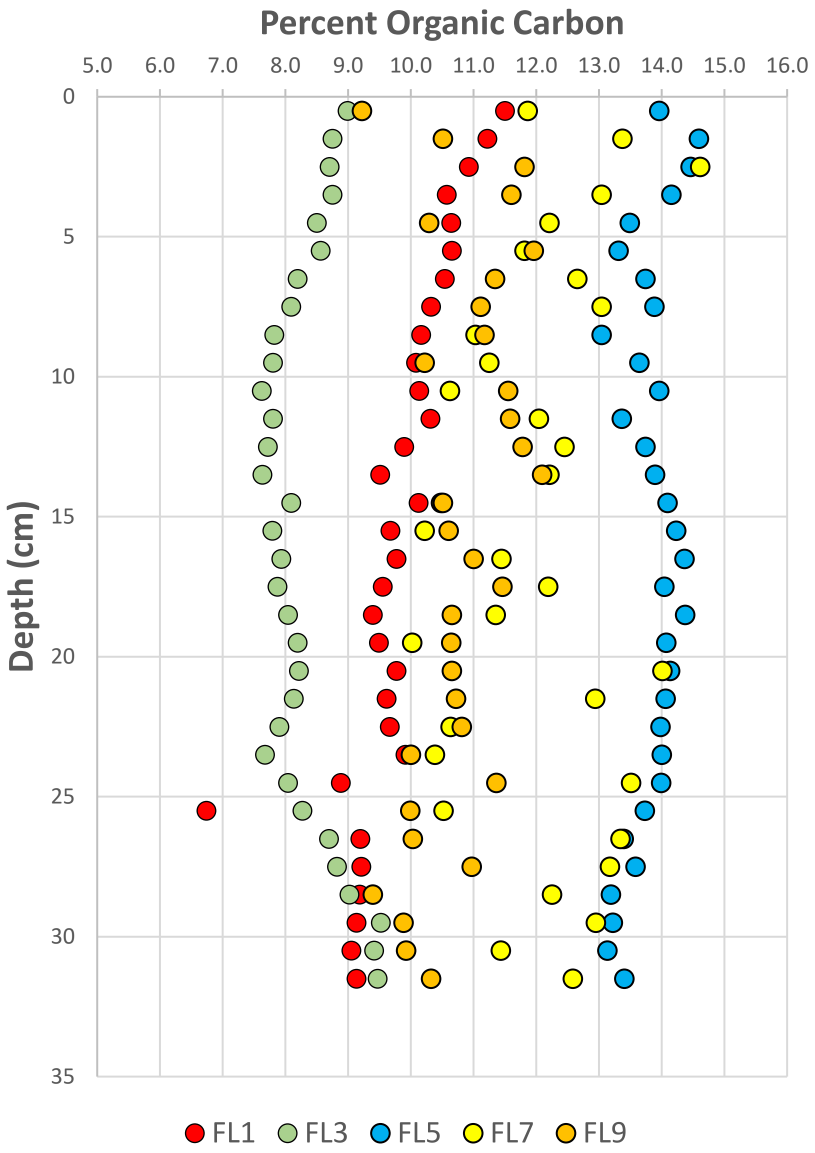


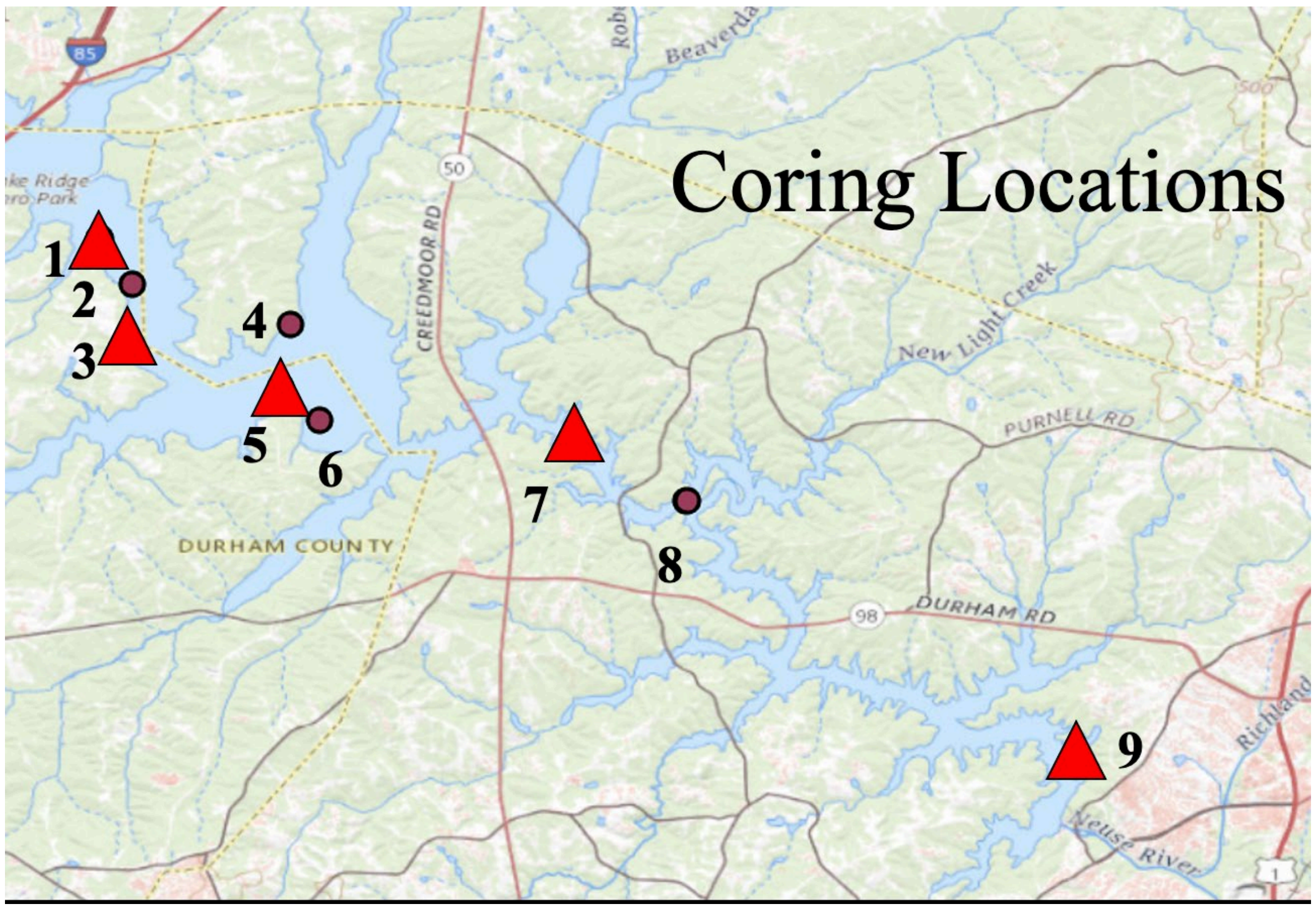
Very similar profiles for all cores

Organic Carbon Fraction F_{oc}

The fraction of sediment that is organic carbon

- Determined by CHN elemental analysis
- From both *in situ* and watershed sources

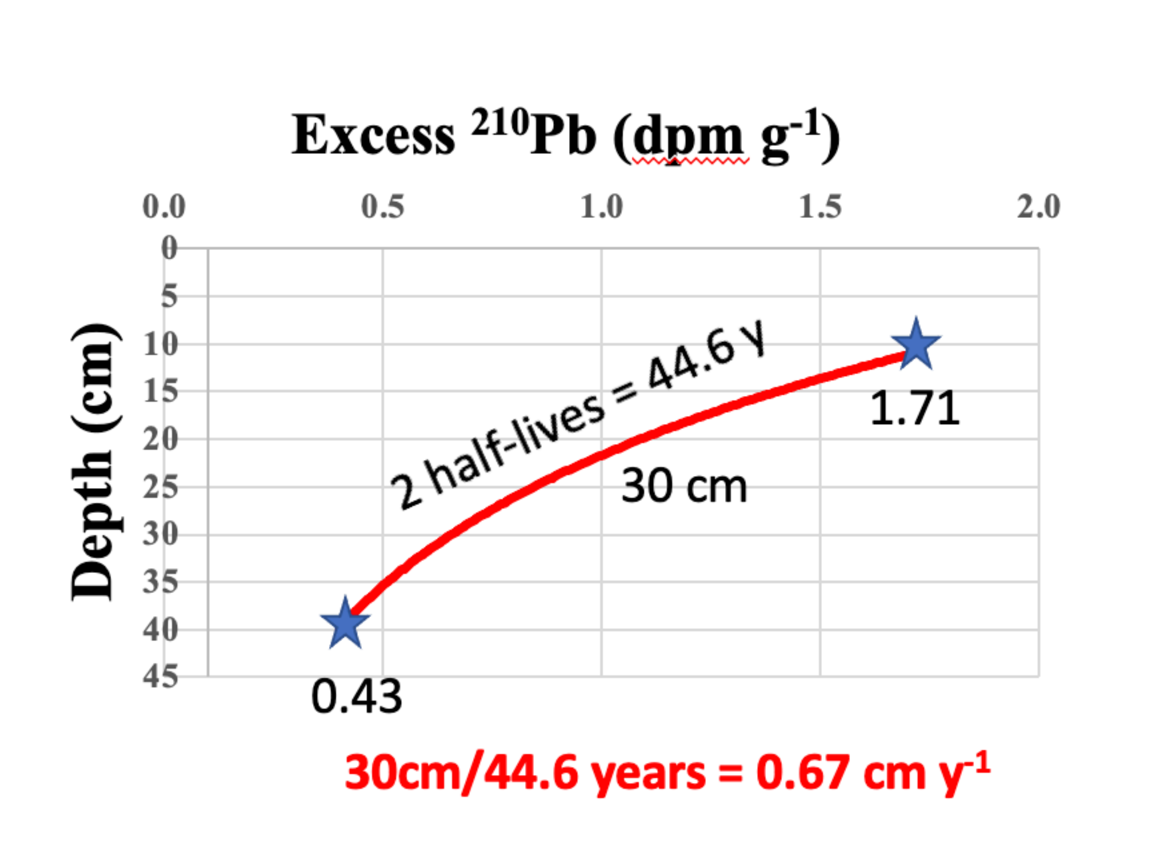




(~ 42% difference from low to high; no spatial pattern)

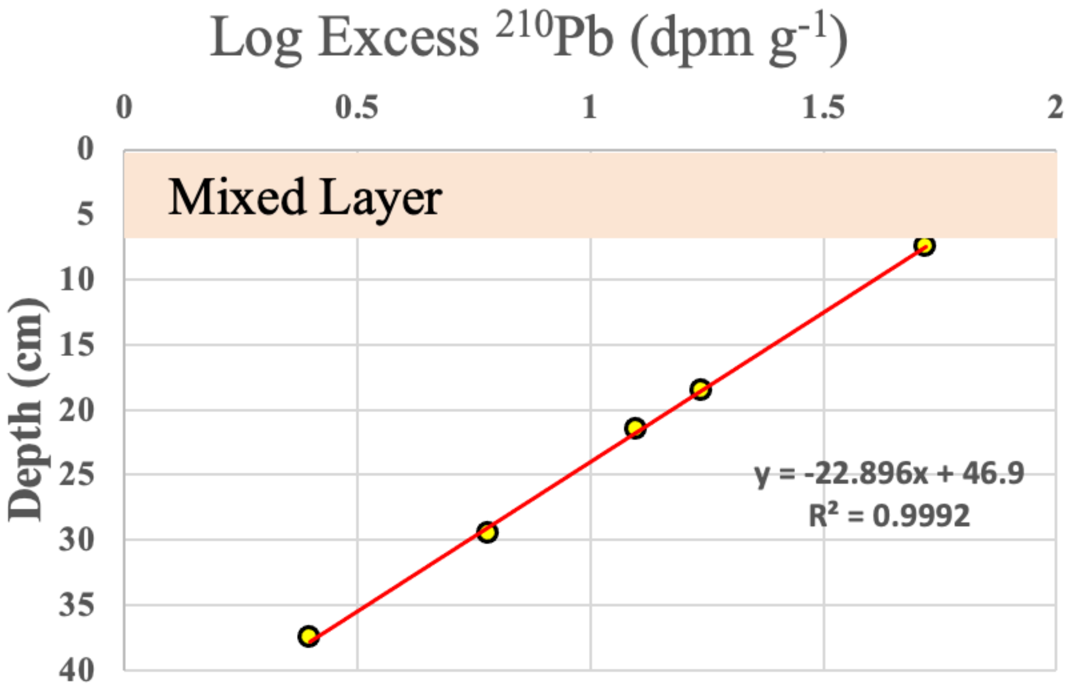
Sedimentation Accumulation Rates SAR (cm yr^{-1})

How Geochronologies (time histories) Work

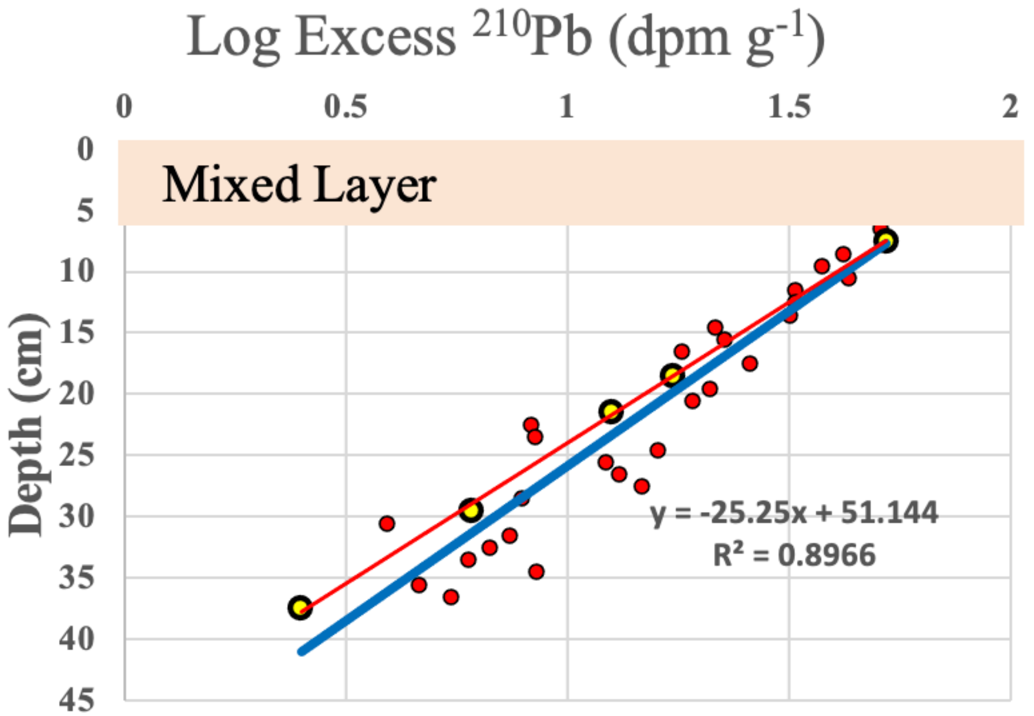


XS ^{210}Pb decays logarithmically with depth as sediment accumulates (Half-life 22.3 years)

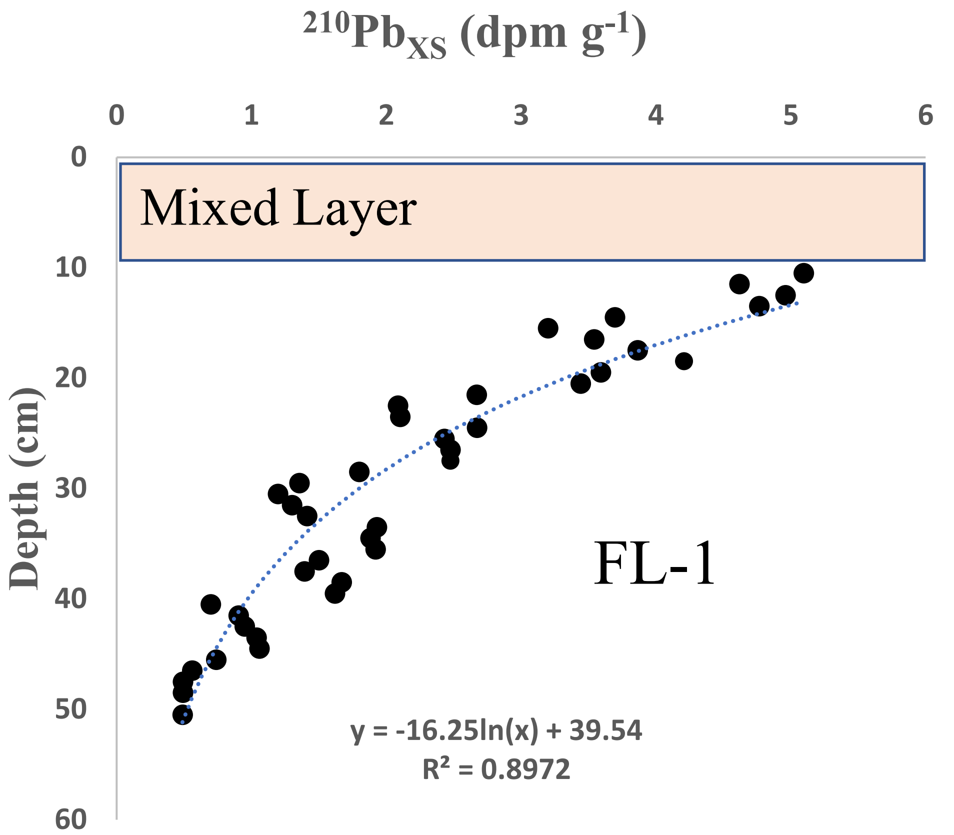
Variable sedimentation model requires analysis of every centimeter down core



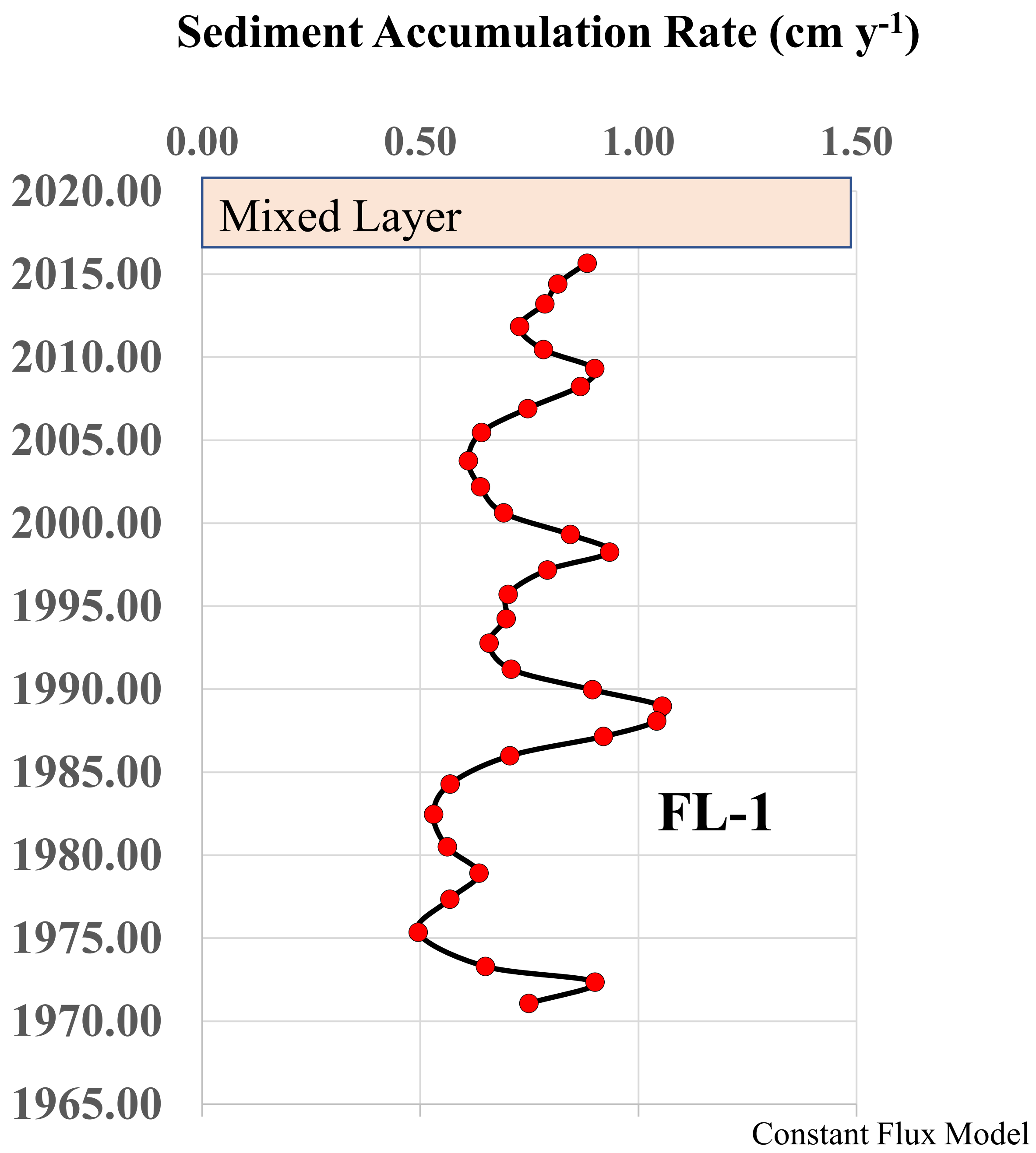
Five (5) intervals measured



Twenty-nine (29) intervals measured (every 1-cm interval)



Mean Sedimentation Rate: 0.56 cm y^{-1}



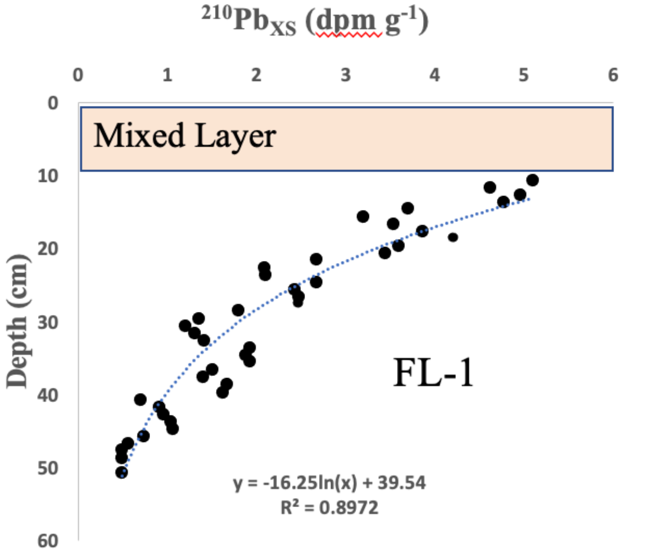
Properties of each 1 cm interval

Other properties whose sediment histories can be quantified:

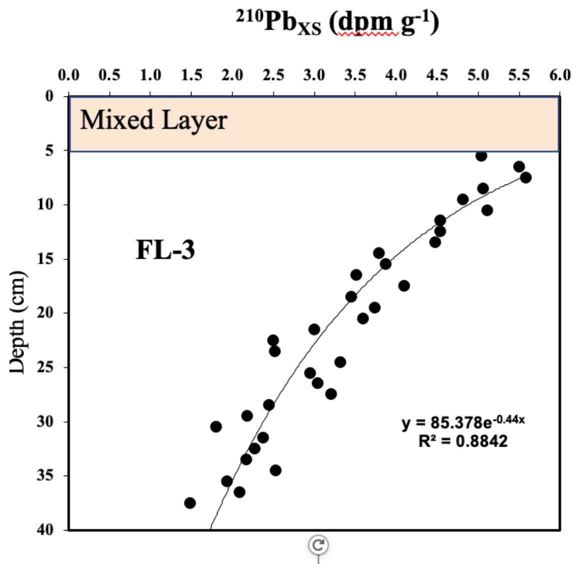
- Nitrogen
- Phosphorus
- Trace Metals and Contaminants
- Microplastics

Depth (cm)	Years	*Measurements per Interval* DBD (g cm-3)	% C	C Burial ($gC\ m^{-2}$)	*Date*
0					2021.3
	0.62	0.24	5.58	196	
1					2020.7
	0.43	0.22	6.34	257	
2					2020.3
	0.74	0.25	6.97	307	
3					2019.5
	0.83	0.28	6.18	219	
4					2018.7
	1.20	0.29	5.75	167	
5					2017.5
	0.90	0.32	5.55	160	
6					2016.5
	0.97	0.33	5.97	211	
7					2015.6
	1.15	0.36	6.18	208	
8					2014.4
	0.88	0.38	5.16	192	
9					2013.5
	1.06	0.39	5.27	215	
10					2012.5
	1.04	0.41	4.95	267	
11					2011.4
	1.22	0.43	5.67	235	
12					2010.2
	0.71	0.43	5.87	171	
13					2009.5
	1.51	0.45	5.63	203	
14					2007.9
	1.17	0.46	4.88	204	
15					2006.8
	1.18	0.48	4.75	247	
16					2005.6
	1.59	0.50	5.37	211	
17					2004.1
	0.86	0.52	5.74	243	
18					2003.2

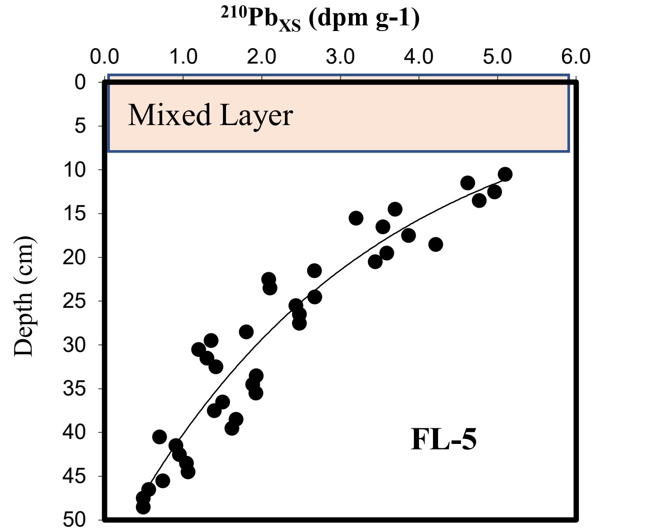
18.1 years



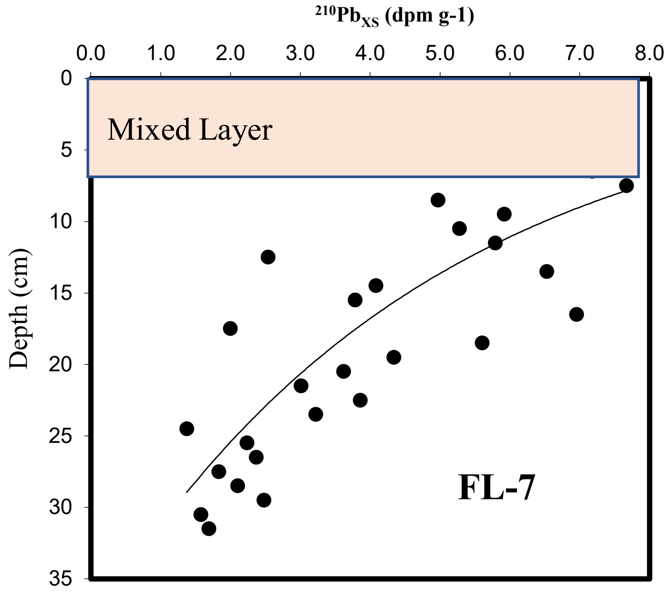
Mean Sedimentation Rate: 0.56 cm y^{-1}



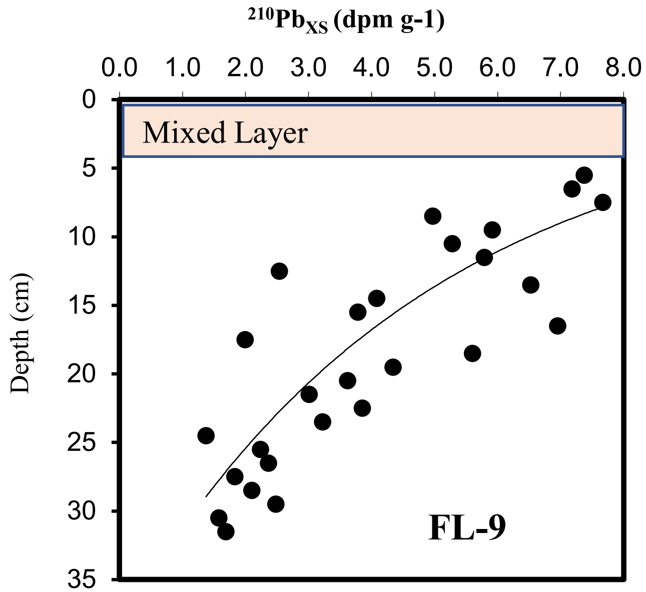
Mean Sedimentation Rate: 0.88 cm y^{-1}



Mean Sedimentation Rate : 0.91 cm y^{-1}



Mean Sedimentation Rate : 0.67 cm y^{-1}

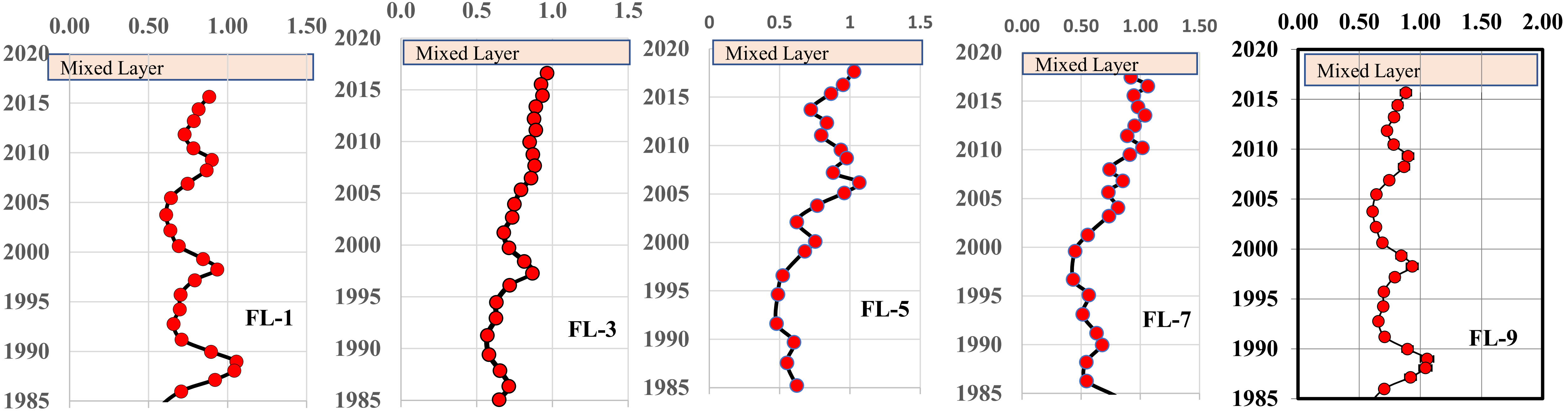


Mean Sedimentation Rate : 0.75 cm y^{-1}

Mean Rates over past 30 years

Range: 0.6 to 0.9 cm y^{-1}

Sediment Accumulation rate (cm y^{-1})



Mean Sedimentation Rate:0.56 cm yr^{-1}

Mean Sedimentation Rate:0.88 cm yr^{-1}

Mean Sedimentation Rate:0.91 cm yr^{-1}

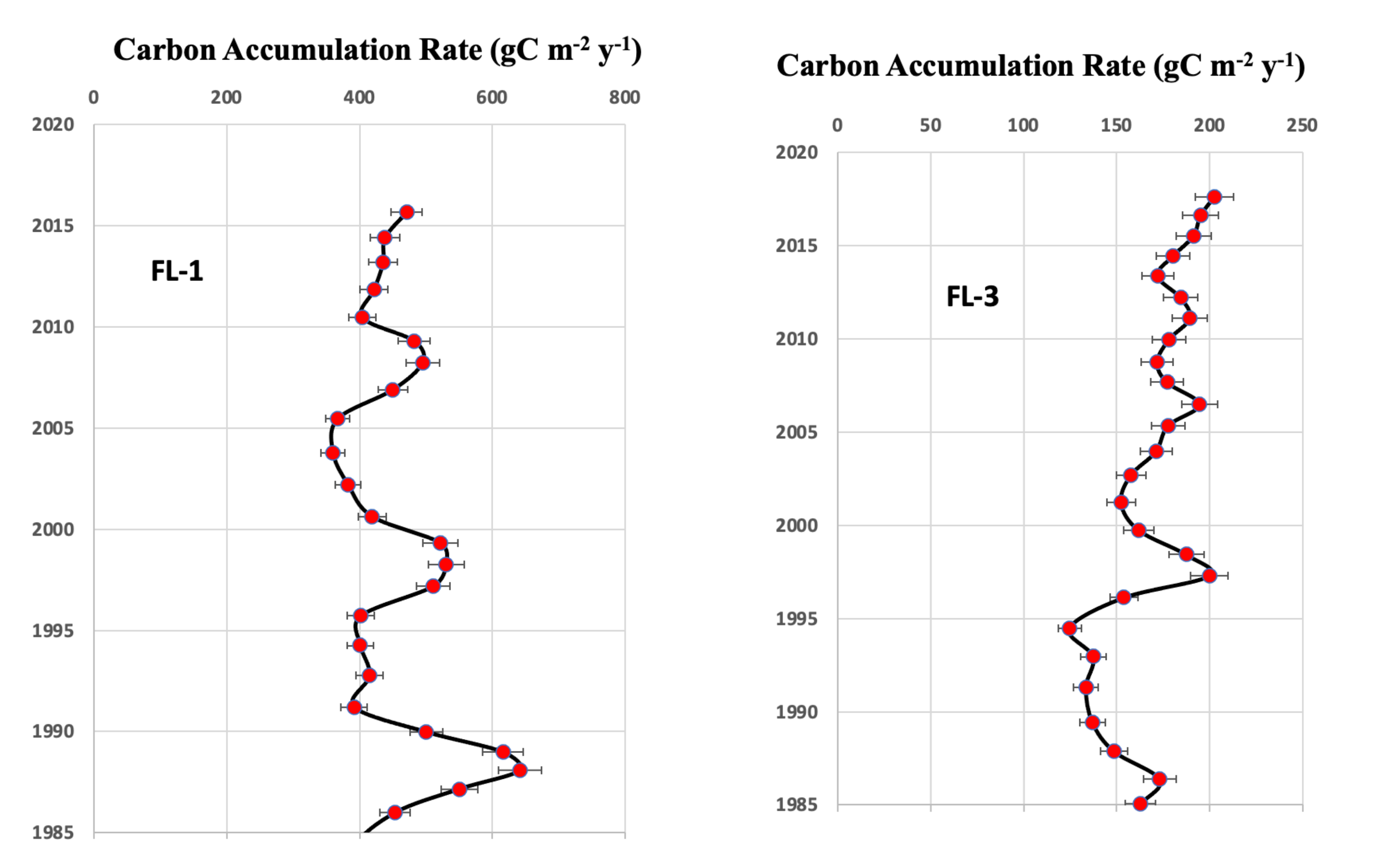
Mean Sedimentation Rate:0.67 cm yr^{-1}

Mean Sedimentation Rate:0.75 cm yr^{-1}

Variable Sedimentation Rates

(constant flux model)

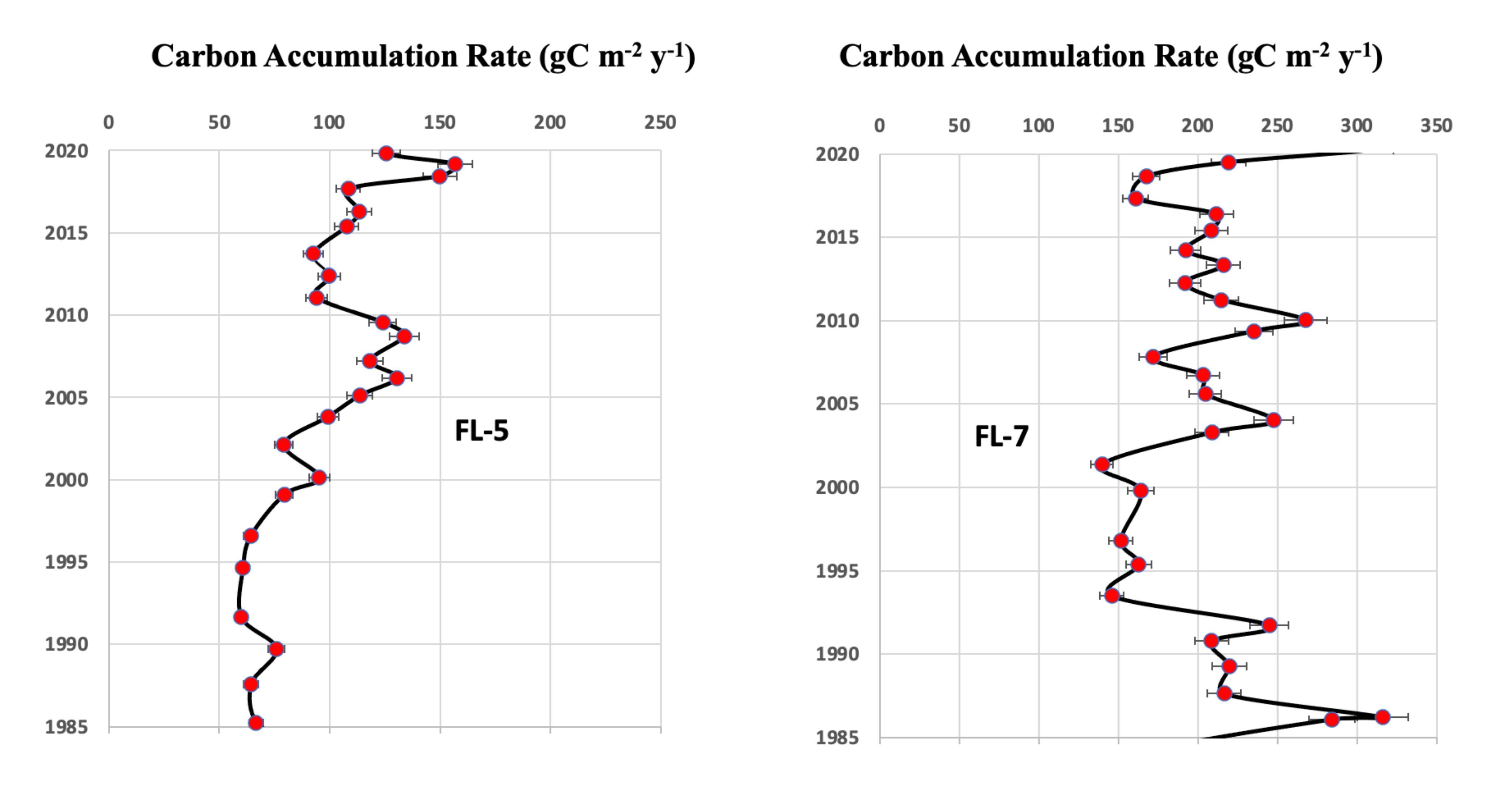
Carbon Accumulation Rates



Mean: 503 g C m^{-2} yr^{-1}
Relatively Constant over 30 years

Mean: 172 g C m^{-2} yr^{-1}
Increasing over 30 years (68%)

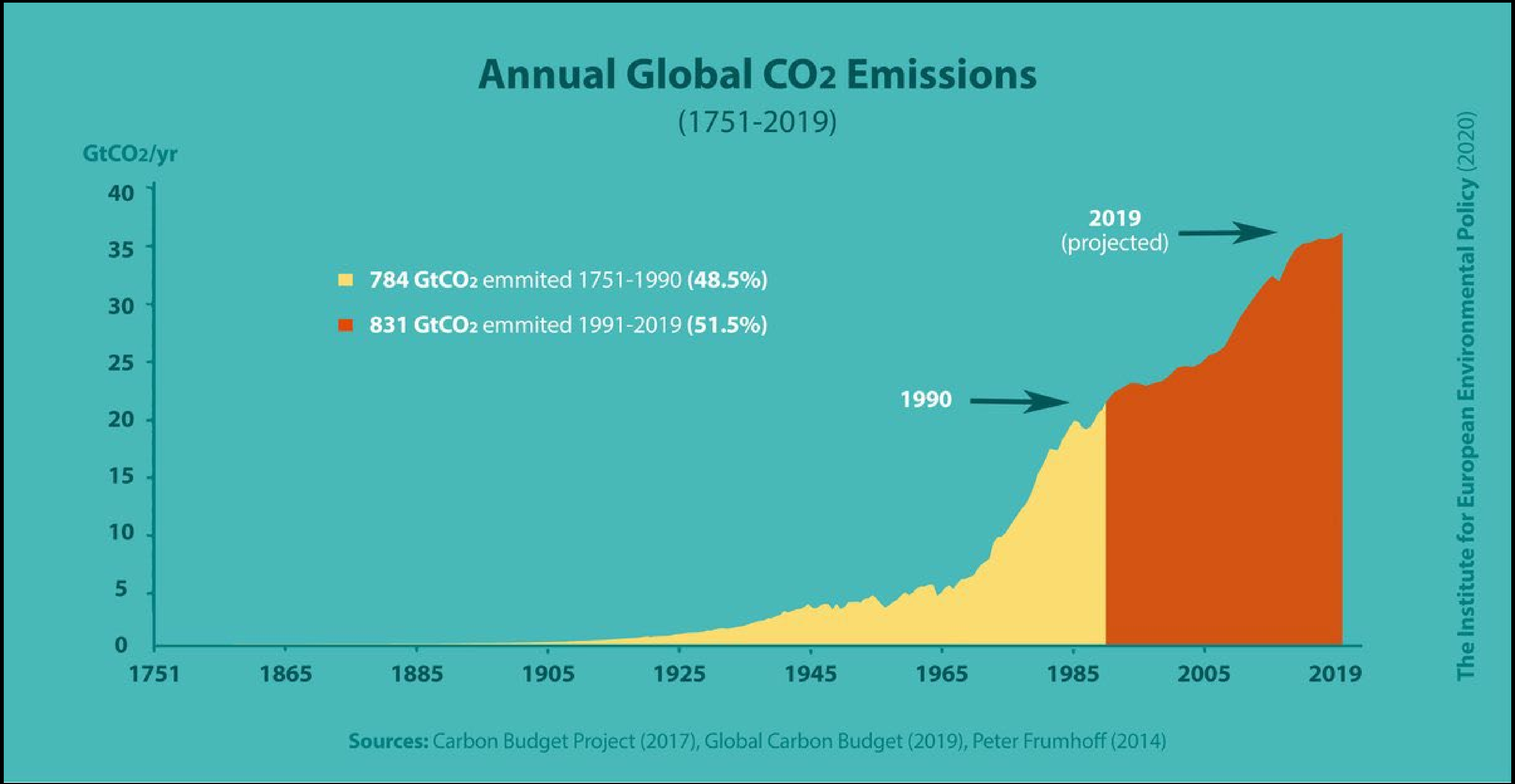
Carbon Accumulation Rates



Mean: 112 g C m^{-2} yr^{-1}
Increasing over 30 years (167%)

Mean: 213 g C m^{-2} yr^{-1}
Relatively Constant over 30 years

More than half of all CO_2 emissions since 1751 emitted in the last 30 years (~ 85% increase)



Conclusions

- Carbon Accumulation Rates in Falls Lake (~250 g C m^{-2} y^{-1}) ≧ to rates in coastal Blue Carbon Environments

- CAR values increase in Falls Lake cores (range from 0 – 167%) over the past 30 years (mean ~20%); global emissions have increased 85% over that period

- Sedimentation rates drive CAR in Falls Lake

Summary Statement

Reservoirs are important sinks for the removal of atmospheric CO_2, with rates of carbon accumulation that are equal to or greater than coastal Blue Carbon environments (saltmarsh, seagrass and mangrove), which have received great attention and interest during the past decade

Determining CAR

$CAR = DBD * F_{oc} * SAR$

also, CAR = Carbon Density * MAR

DBD : Dry Bulk Density $g\ cm^{-3}$
F_{oc}: Fraction organic carbon %C ÷100
SAR: Sediment Accumulation Rate $cm\ yr^{-1}$
MAR: Mass Accumulation Rate $g\ cm^{-2}\ y^{-1}$
Carbon density: DBD* fraction Organic carbon $g\ C\ cm^{-3}$

NC STATE UNIVERSITY

Assessing Controls on Watershed Nutrient Loading through Data-driven Modeling

(and update on Fall Lake model review activities)

7 April 2022

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Dept. of Civil, Constr., and Environmental Eng.
Center for Geospatial Analytics
NC State University

Research Questions:

a) To what extent does **urban nutrient export** exceed background (e.g., forest) export?
b) How responsive are different sources of nutrient loading to **changes in annual precipitation?**
c) How are **vegetated stream buffers and SCMs** influencing export?

Approach:

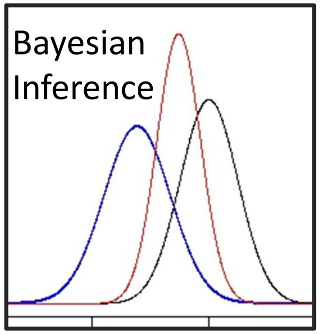
Conventional watershed modeling approach:

Nutrient export and retention process rates → Instream nutrient loads

Data-driven/hybrid modeling approach (this study):

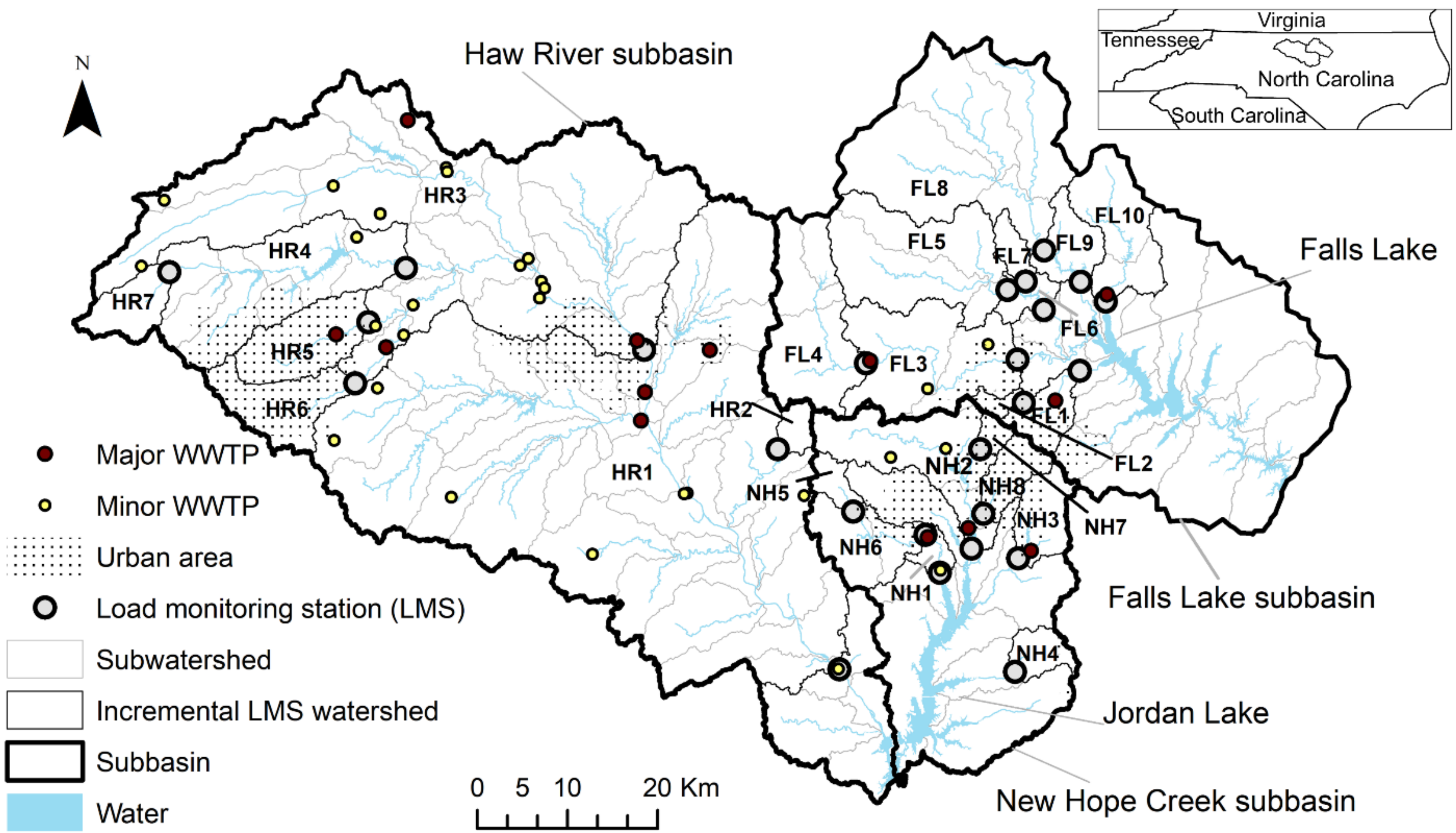
Nutrient export and retention process rates ← Instream nutrient loads

Prior knowledge → Nutrient export and retention process rates



~30 yr of records at
~25 locations
(using USGS WRTDS)

Study area



Haw River subbasin
N
Virginia
Tennessee
North Carolina
South Carolina
Falls Lake
HR1
HR2
HR3
HR4
HR5
HR6
HR7
FL1
FL2
FL3
FL4
FL5
FL6
FL7
FL8
FL9
FL10
NH1
NH2
NH3
NH4
NH5
NH6
NH7
NH8
Falls Lake subbasin
Jordan Lake
New Hope Creek subbasin
Major WWTP
Minor WWTP
Urban area
Load monitoring station (LMS)
Subwatershed
Incremental LMS watershed
Subbasin
Water
0 5 10 20 Km

Incremental loadings

(i = watershed t = year)

$$\hat{y}_{i,t} = L_{i,t,ur1} + L_{i,t,ur2} + L_{i,t,ag} + L_{i,t,und} + L_{i,t,ps} + L_{i,t,ch} + L_{i,t,h} + L_{i,t,cw} - U_{i,t} * r_{i,z} + \varepsilon_{i,t}$$

Land cover-
Pre-1980 Urban (ur1),
Post-1980 Urban (ru2).
Ag, Undeveloped

Dischargers-
Major and minor WWTPs

Livestock-
chickens, hogs, cows

Upstream load retention
(streams and lakes)

$$L_{i,t,x} = \beta_{ec}(p_{i,t}{}^{\gamma_{pic}})^{*}A_{i,t,x} * (1 - r_{i,t,x})$$

β_{ec} = **export** coefficients

Υ_{pic} = **precipitation impact coefficients (PIC)**

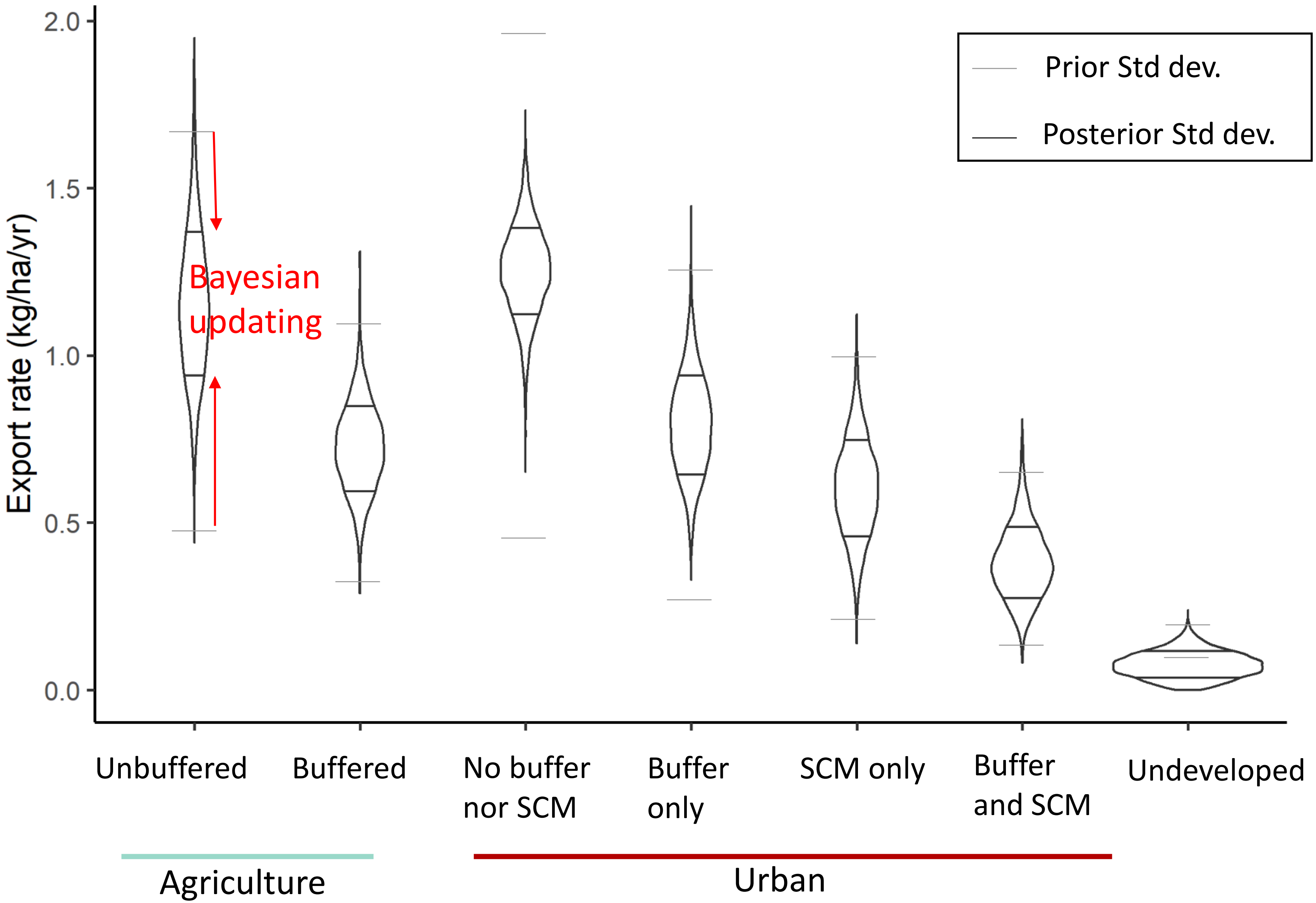
$p_{i,t}$ = scaled precipitation

$A_{i,t,x}$ = **Area** of land cover (ha)

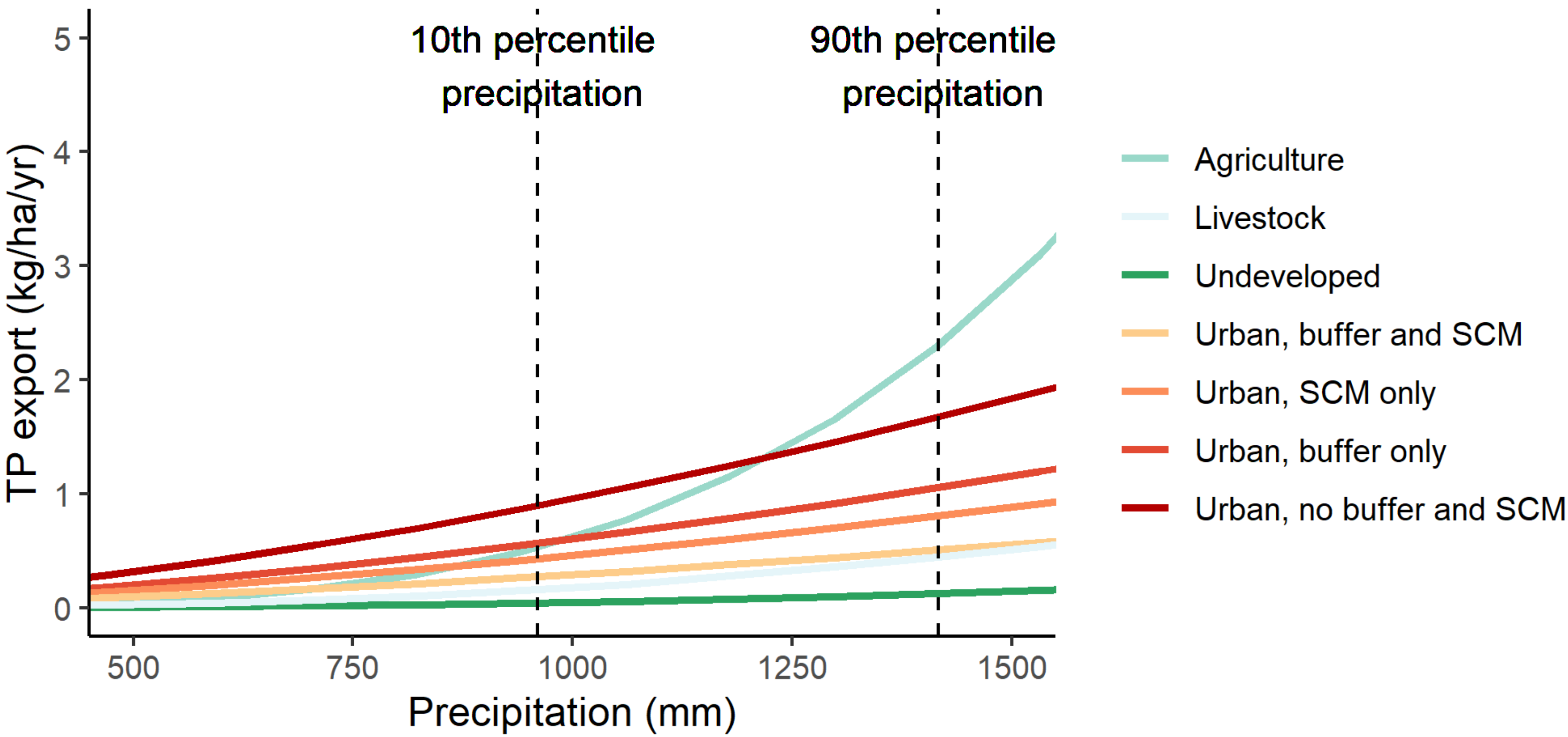
$r_{i,t,x}$ = **retention in streams, lakes, SCMs, buffers**

Results
(focusing on TP)

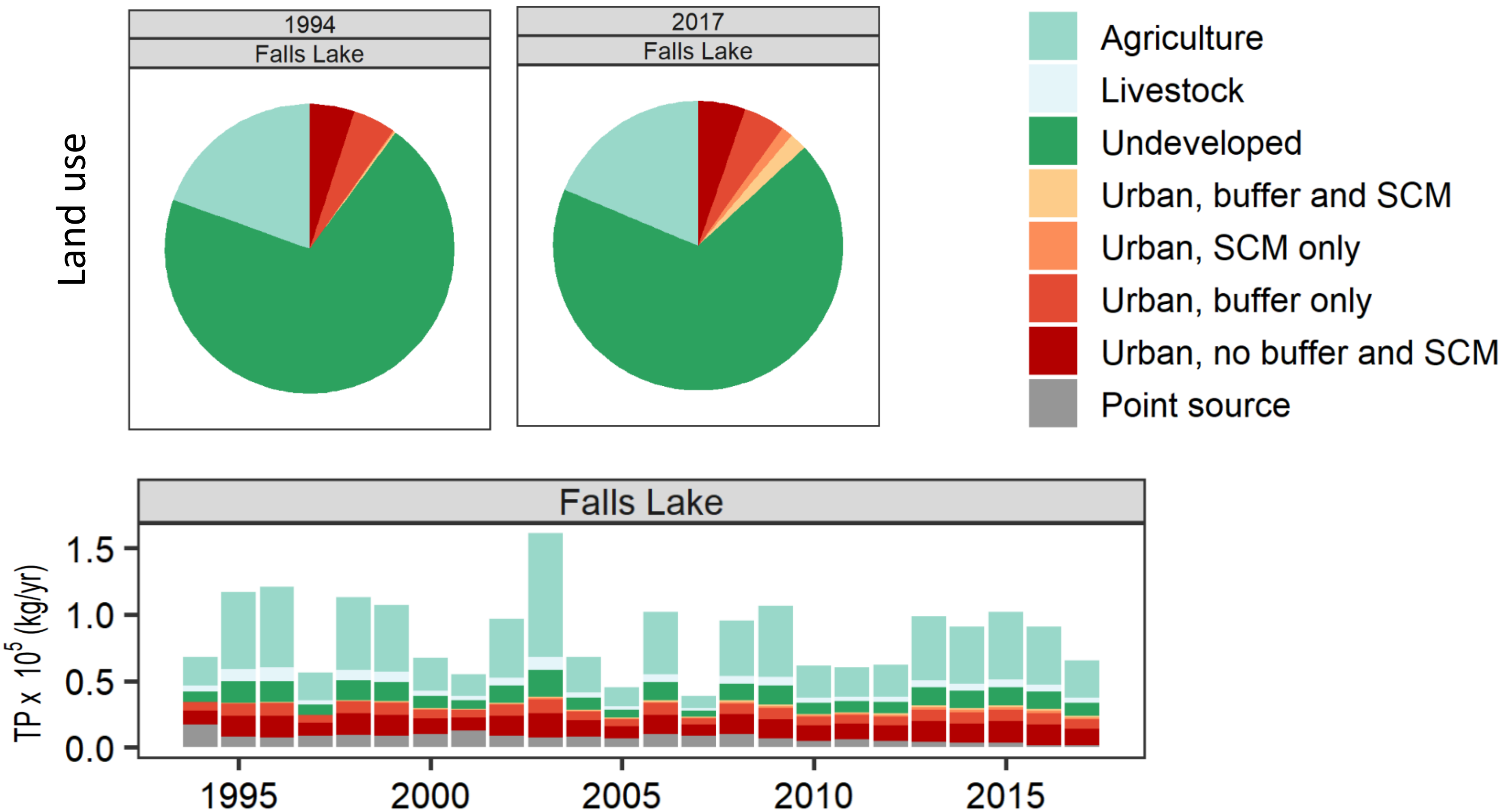
TP parameter estimates



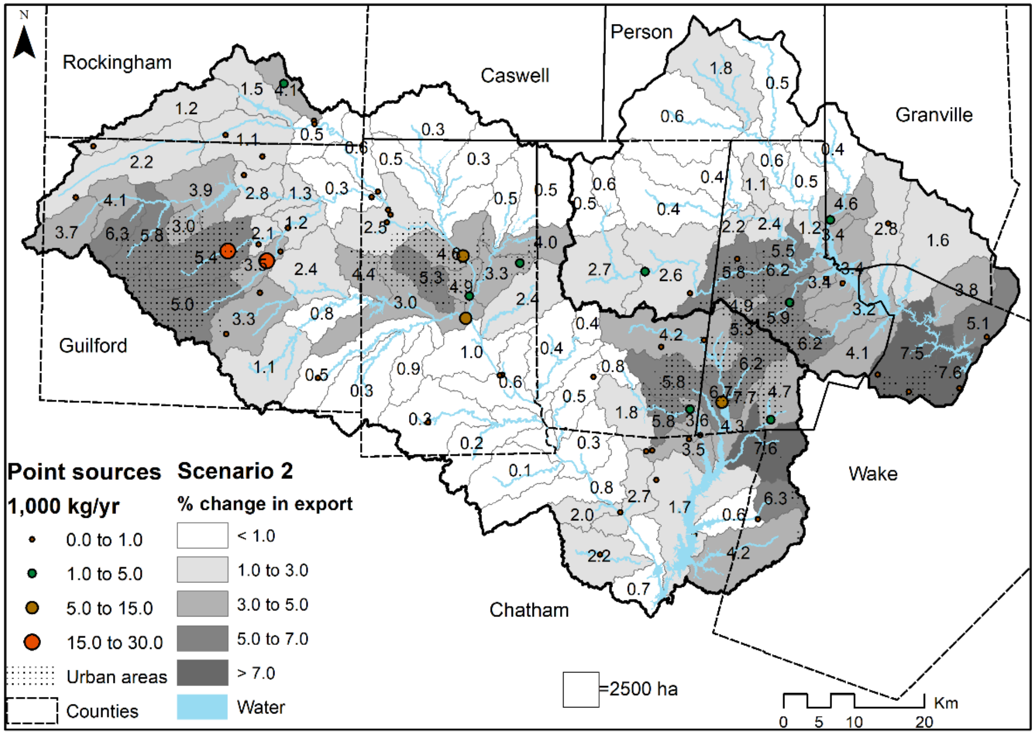
TP export vs. precipitation



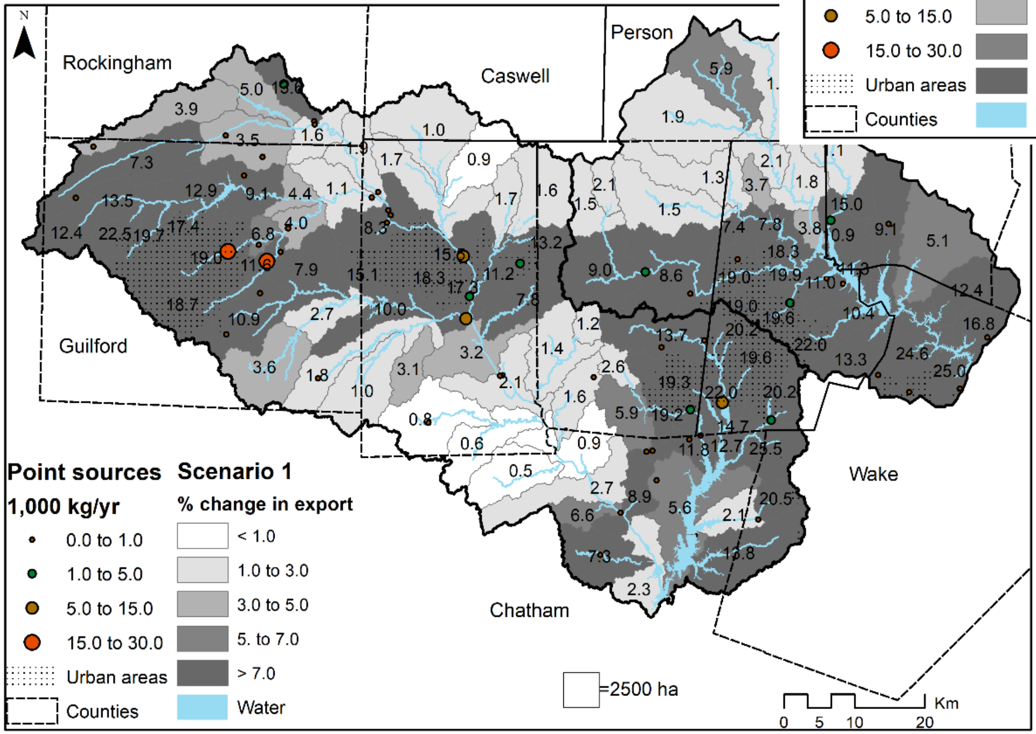
TP Source Apportionment



TP Future Scenarios



20% urban growth
with management
Yields +2.7% export



20% urban growth
no management
Yields +9.3% export

Findings:

a) Undeveloped lands export about an order of magnitude less than unmanaged urban lands (94% less for TP and 91% less for TN).

b) Agricultural lands are most responsive to precipitation (for both TP and TN).

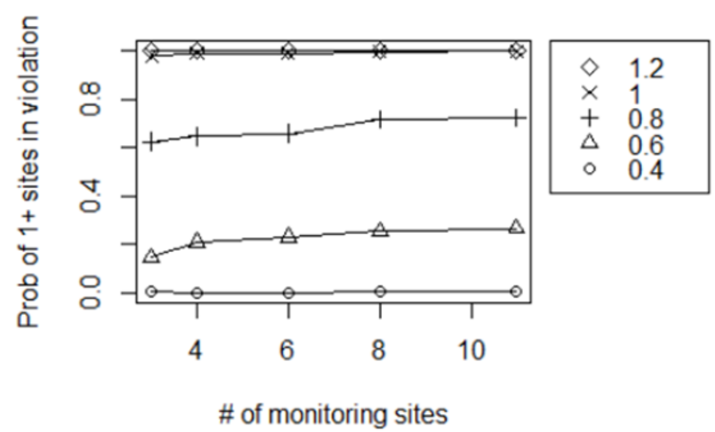
c) Both SCMs and buffers substantially reduce urban loading (70% combined for TP and 64% for TN).

We believe this model provides a unique line of evidence for informing watershed management.

For more details:
Miller et al., 2021, *HESS*
Obenour et al., 2022 WRRI
Karimi et al., *in preparation*

UNRBA Falls Lake modeling review

- Provided review of N and P watershed export rates.
- Provided data on soil P levels and N deposition.
- Provided review of reservoir internal P loading rates.
- Statistically assessed relationship between monitoring network size and probability of standards compliance.



1-sentence summary: Based on our modeling experience in the NC Piedmont and beyond, we provide guidance on the Falls Lake modeling, helping to ensure a robust scientific foundation for informing management.

Acknowledgements:

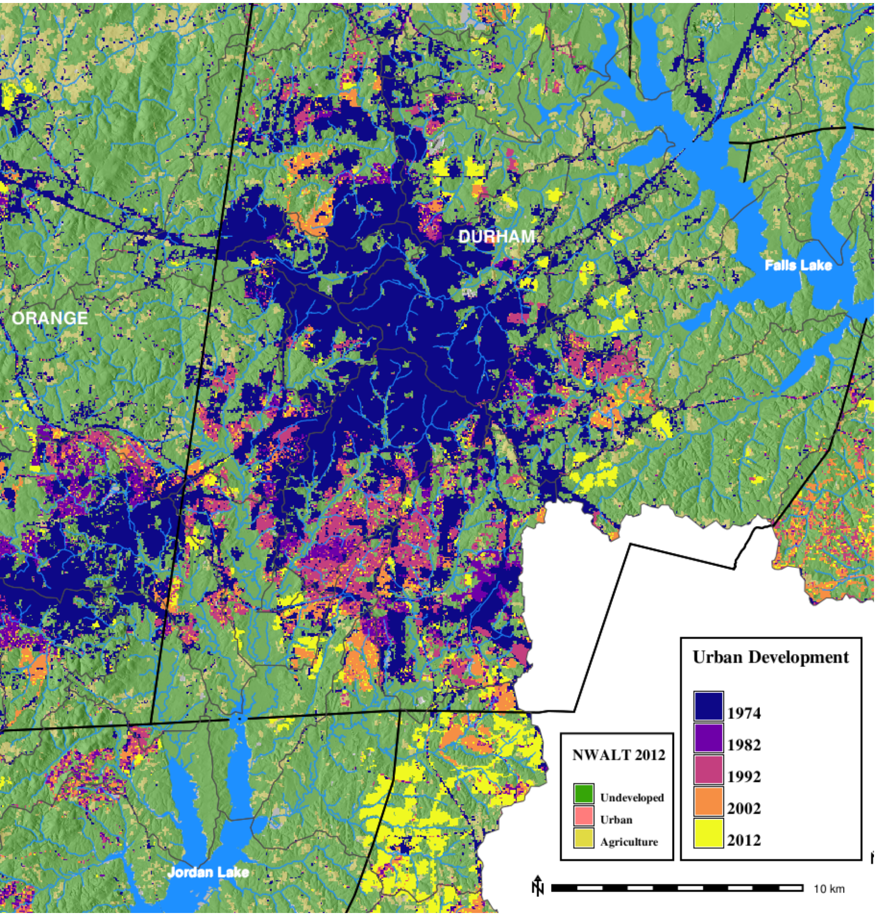
- Smitom Borah (reservoir modeling)
- Kimia Karimi (watershed modeling)
- Helena Mitasova (geospatial data development)
- Corey White (geospatial data development)

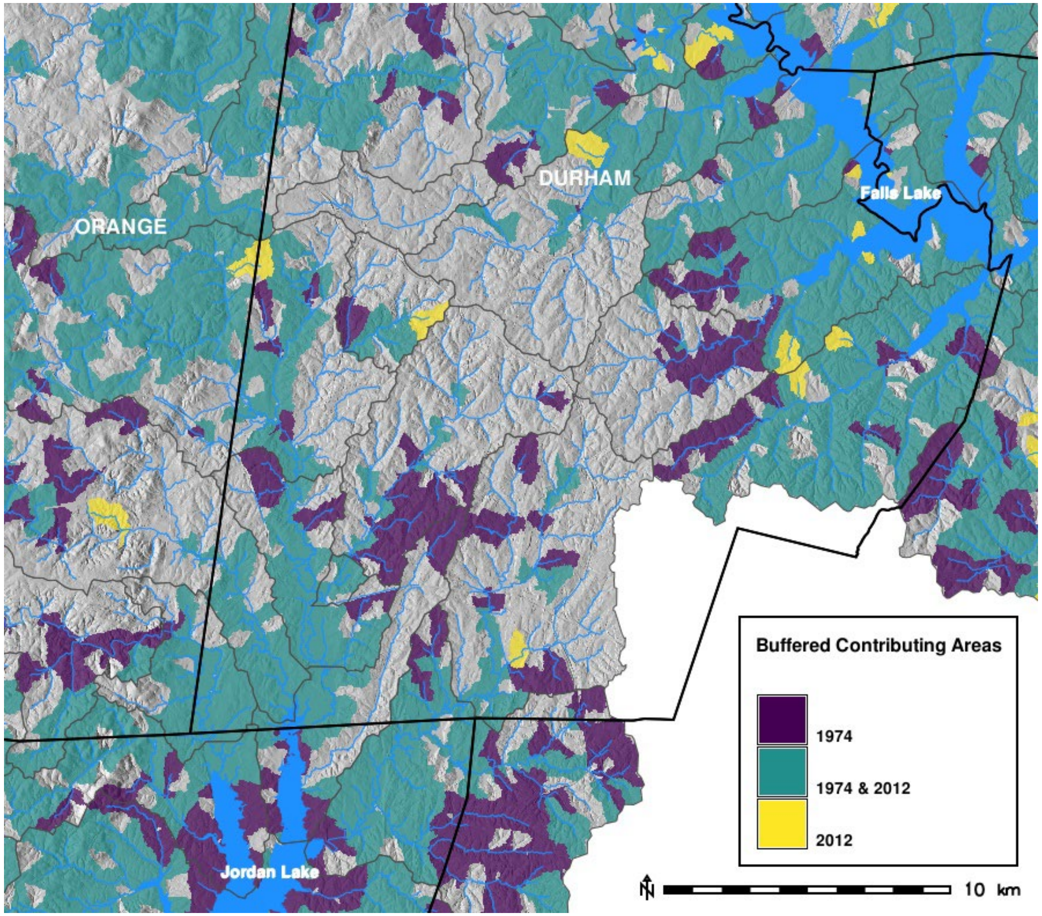
wrri NC WATER RESOURCES RESEARCH INSTITUTE
NC STATE UNIVERSITY COLLEGE OF ENGINEERING
NC Policy Collaboratory
Center for Geospatial Analytics

Additional slides

X

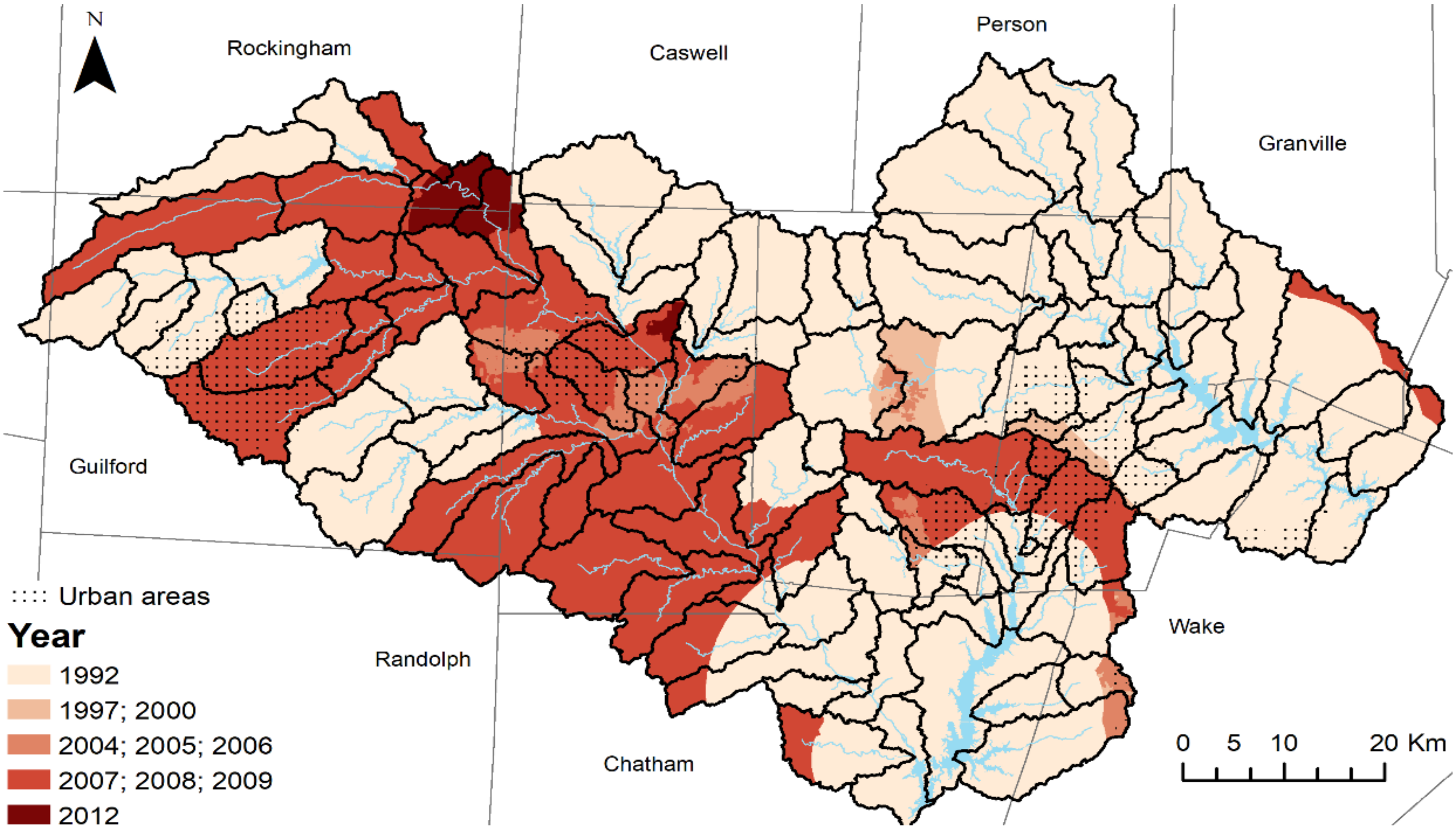
Land use and buffers



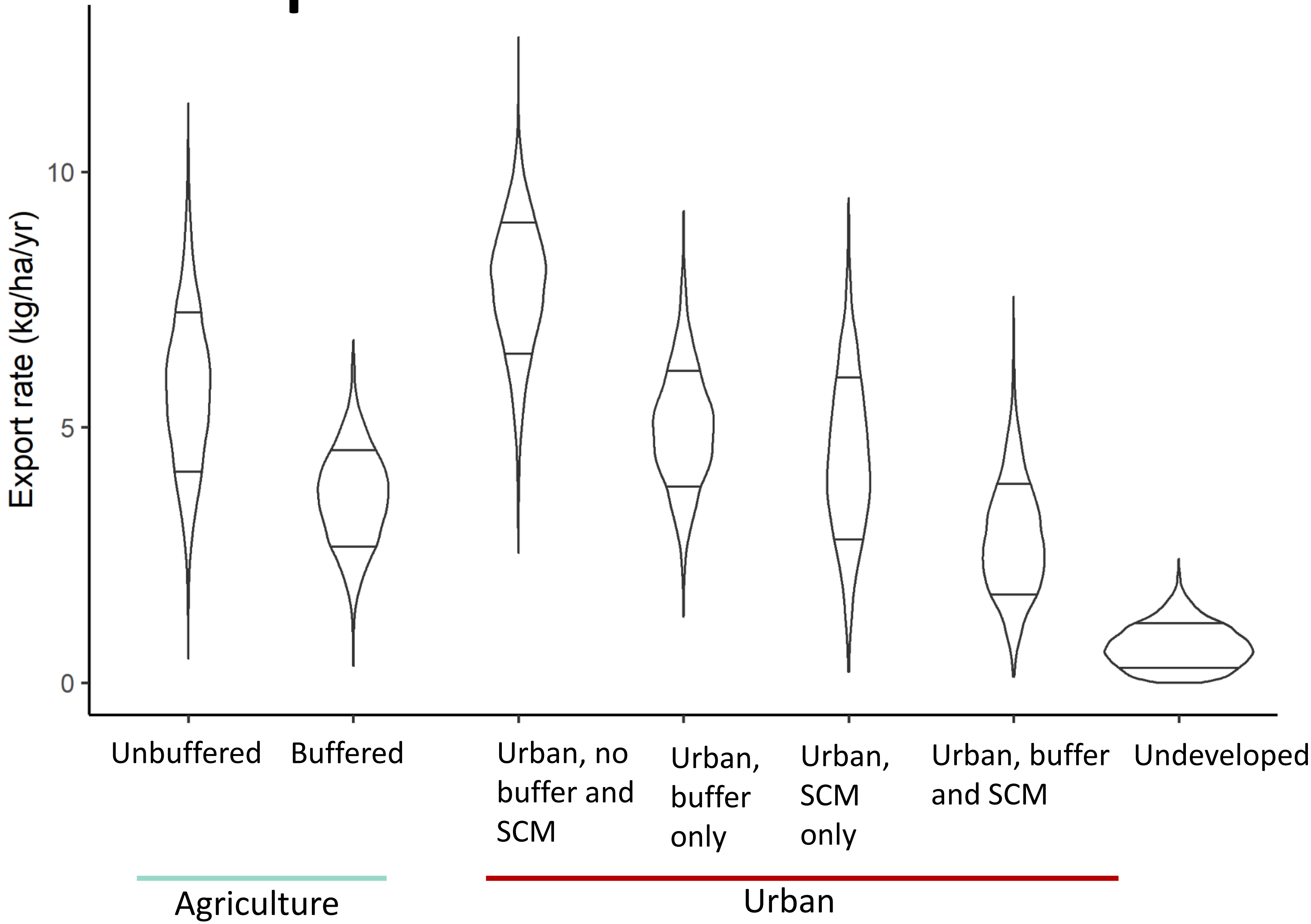


Stream buffer threshold
15 m buffer on both sides
70% undeveloped land

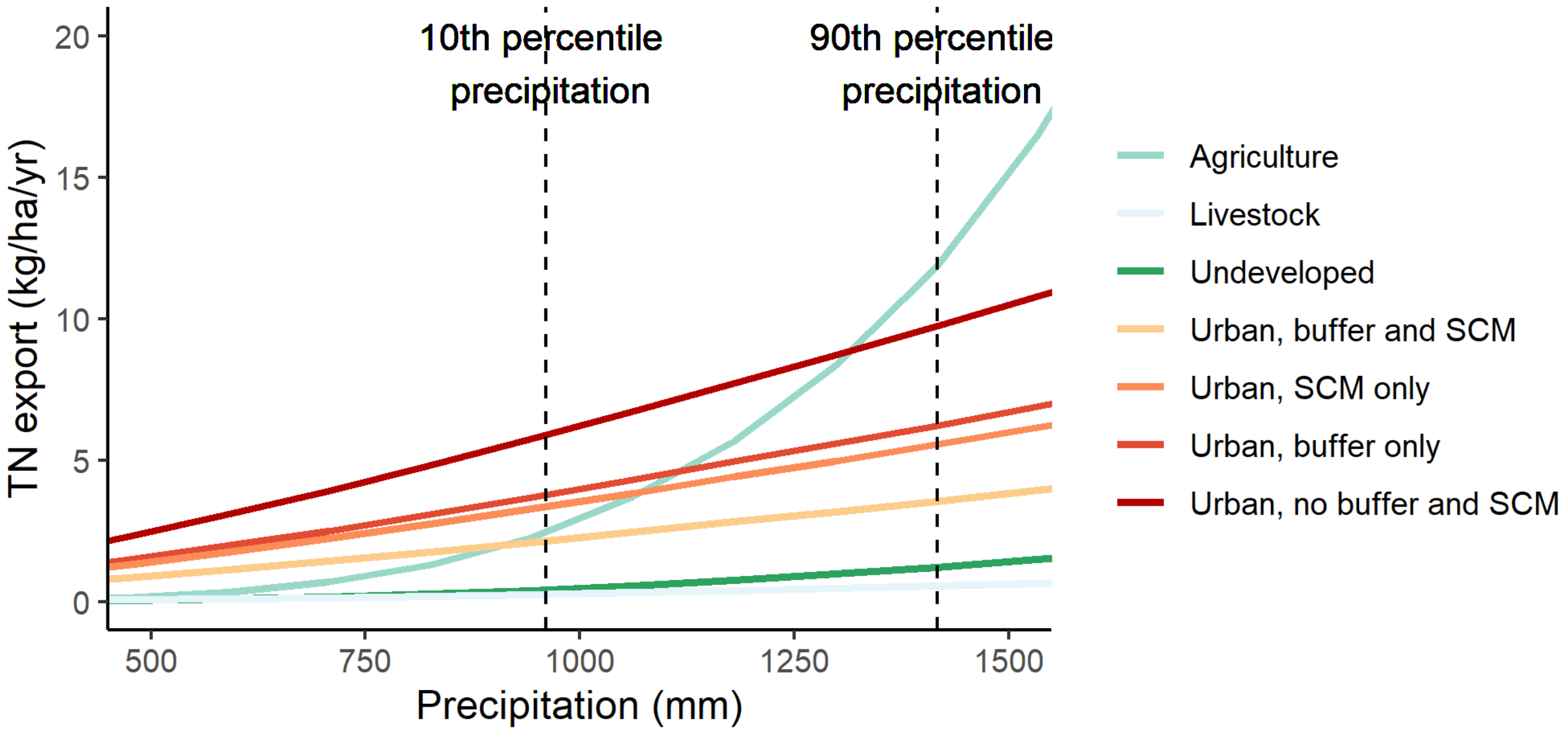
Stormwater control inputs



TN parameter calibration

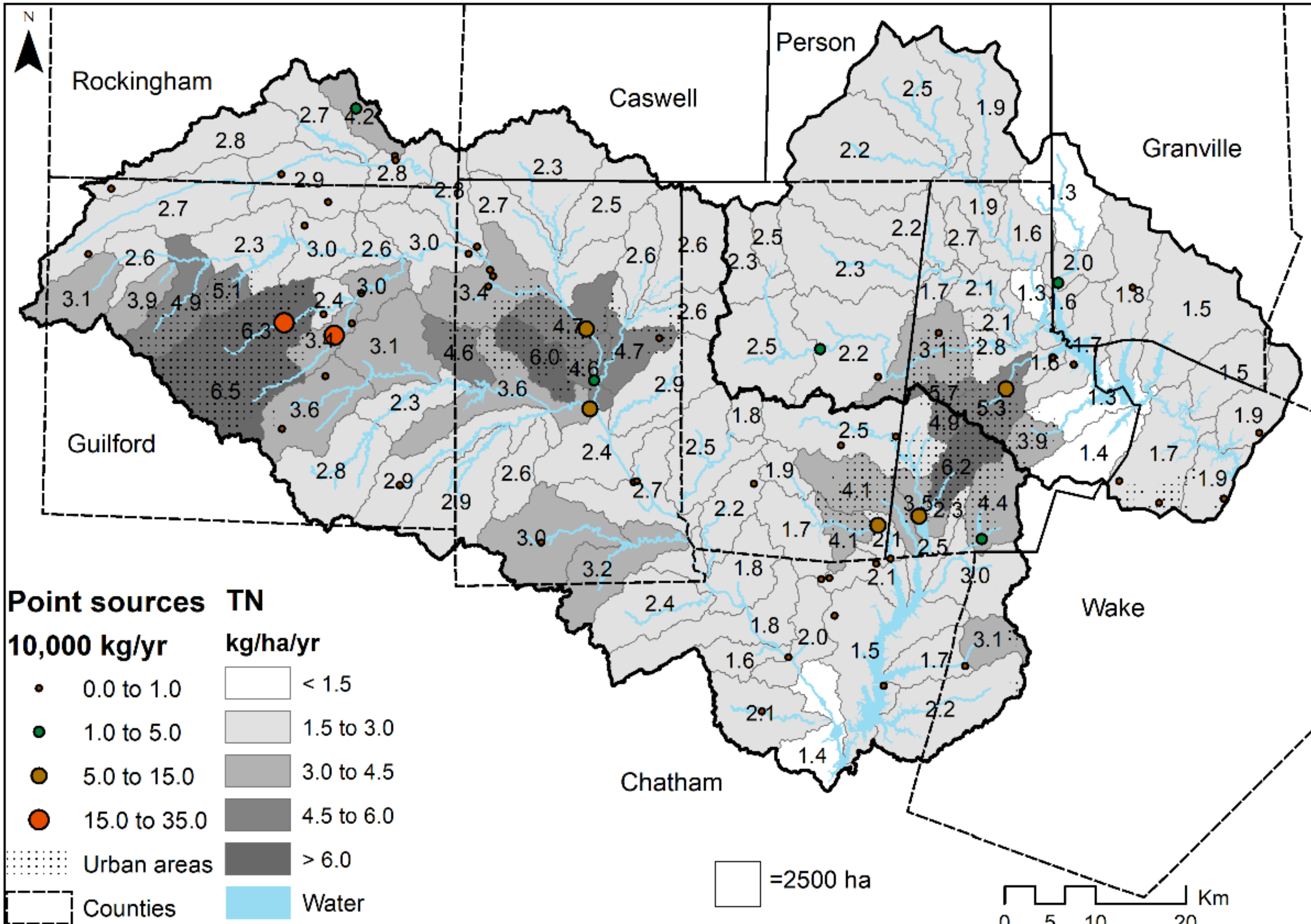


TN export

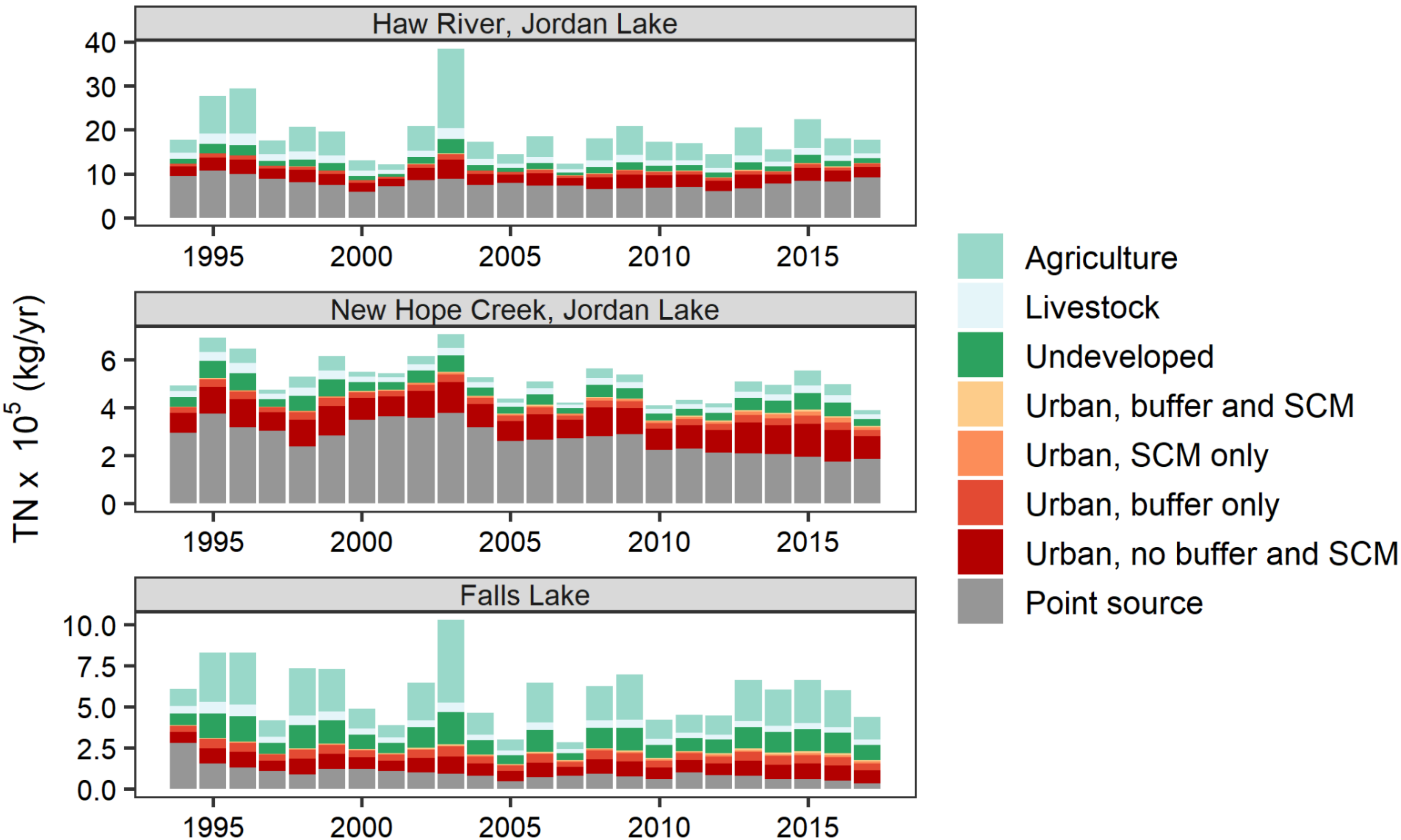


10th percentile precipitation
90th percentile precipitation
TN export (kg/ha/yr)
20
15
10
5
0
500
750
1000
1250
1500
Precipitation (mm)
Agriculture
Livestock
Undeveloped
Urban, buffer and SCM
Urban, SCM only
Urban, buffer only
Urban, no buffer and SCM

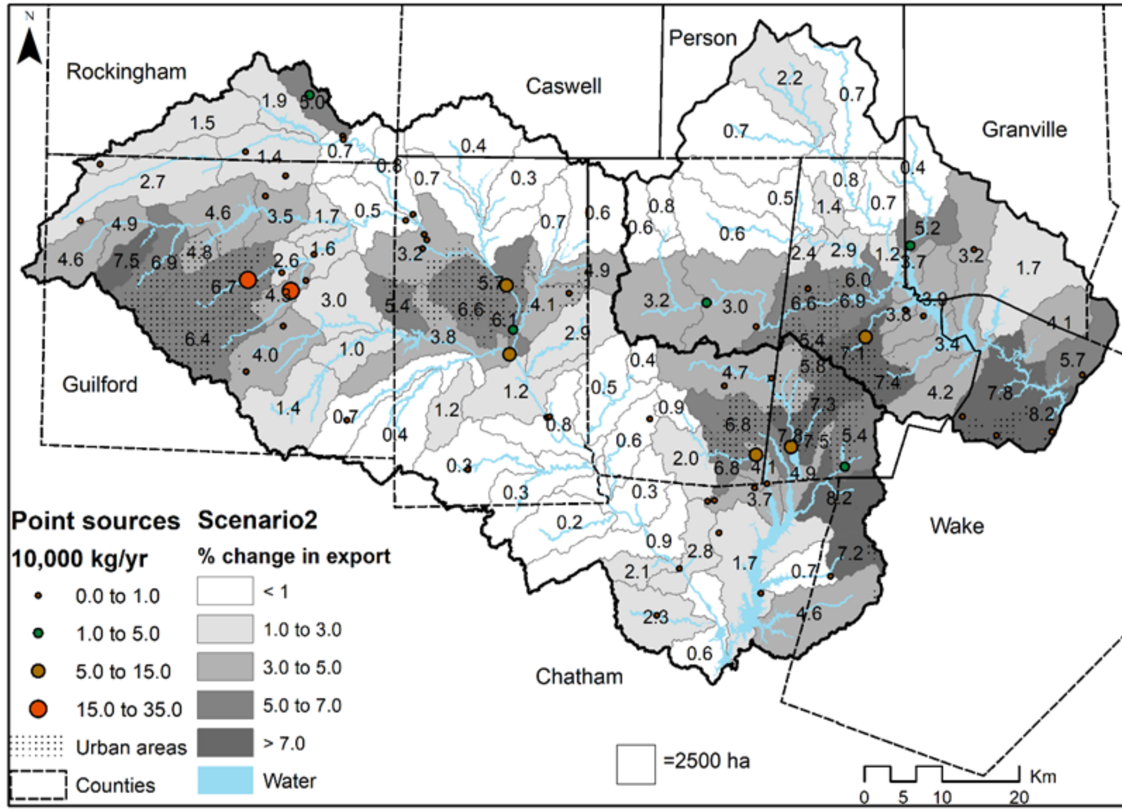
TN export by subwatershed



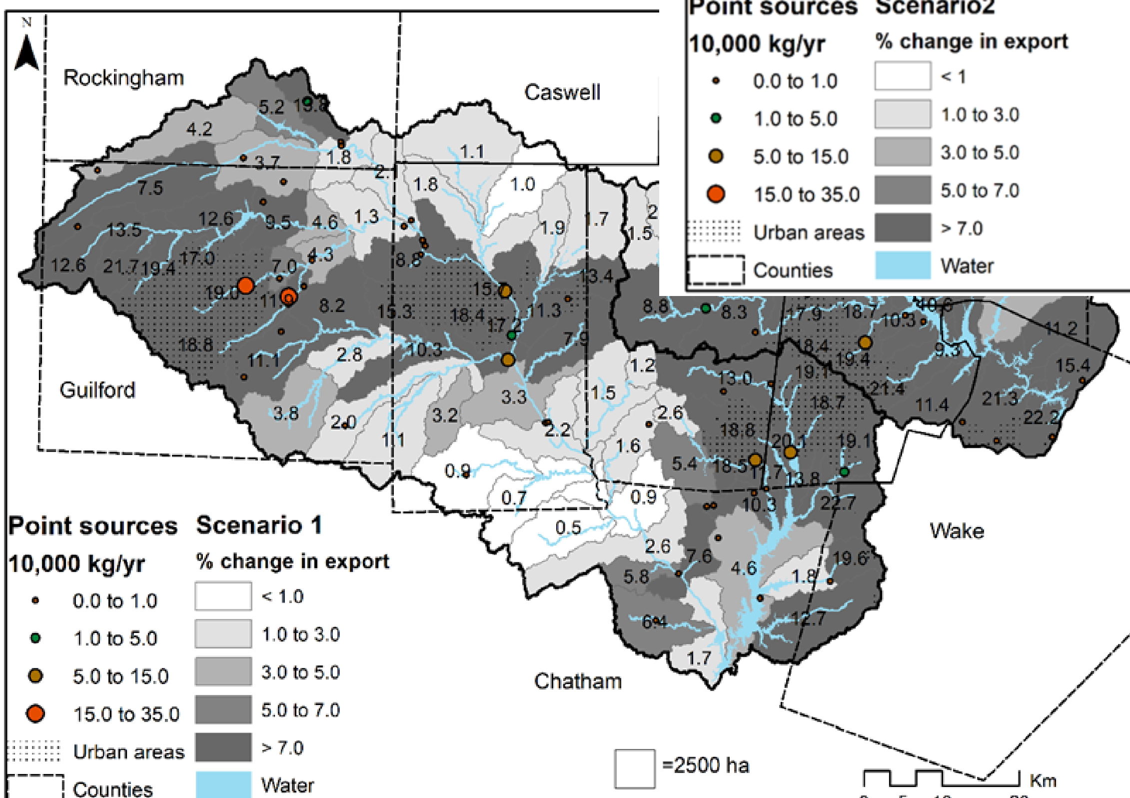
TN Source Apportionment



TN Future Scenarios

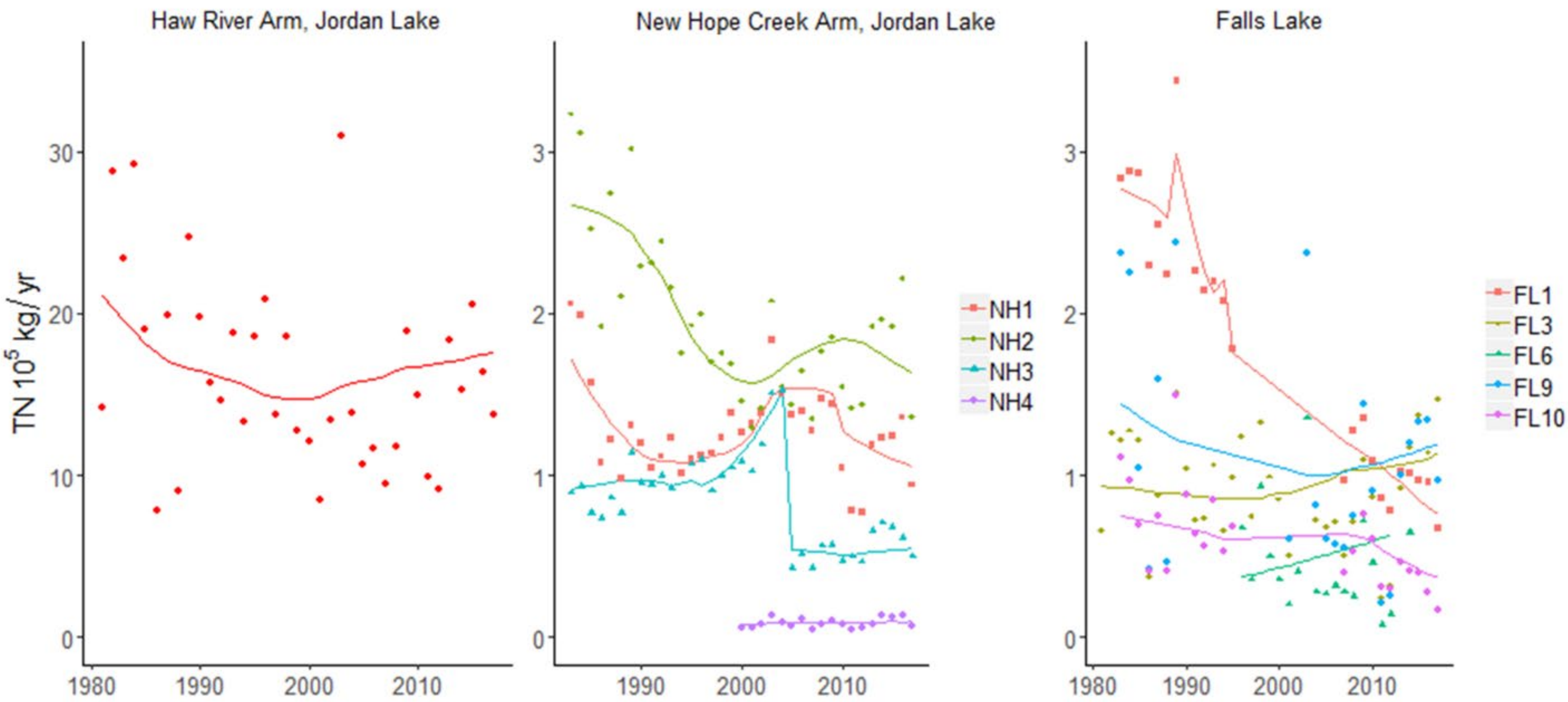


20% urban growth
with management
Yields +3.3% export



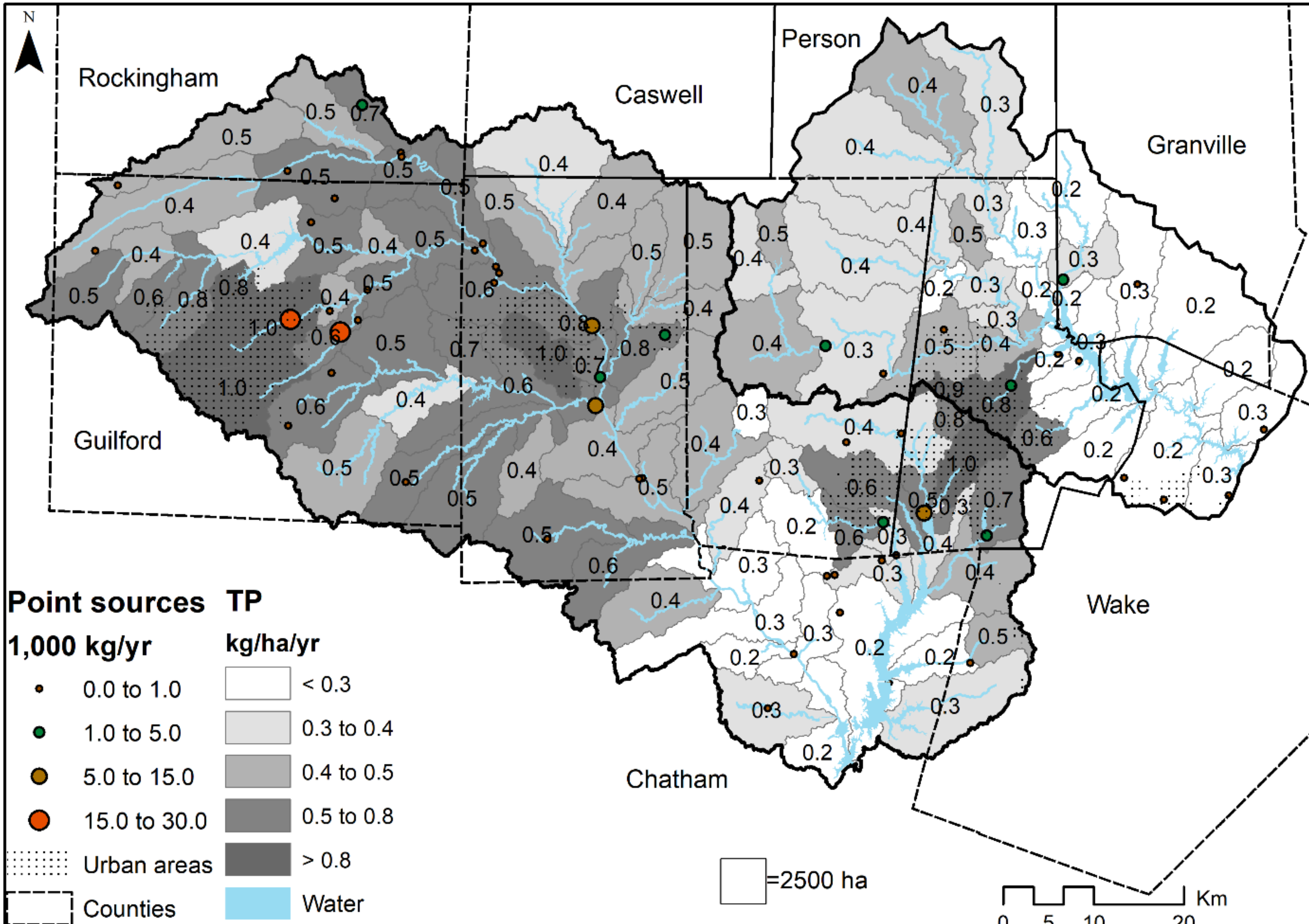
20% urban growth
no management
Yields +9.3% export

N loading estimates at downstream monitoring sites

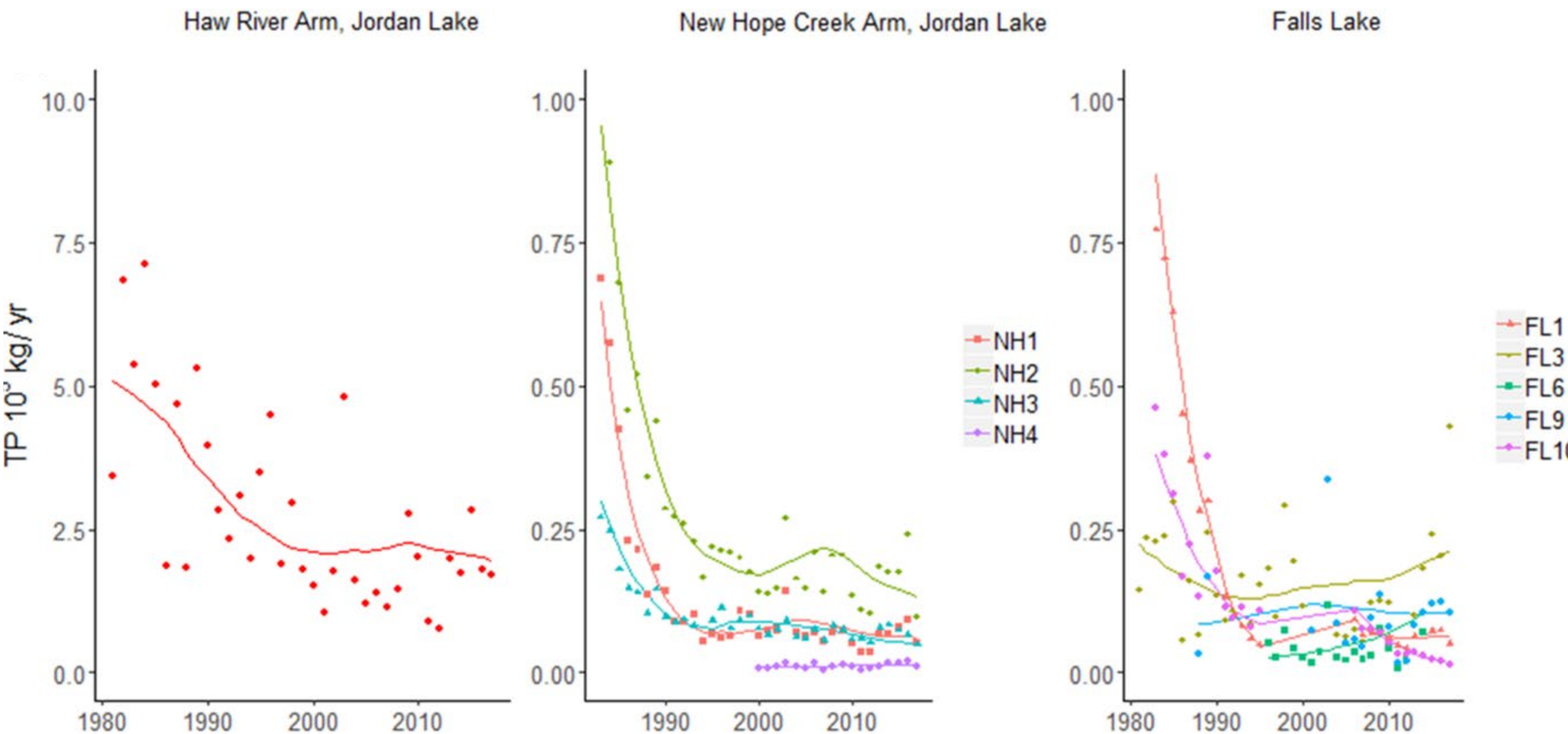


Note: loads estimated using USGS WRTDS

TP export by subwatershed



P loading estimates at downstream monitoring sites



Note: loads estimated using USGS WRTDS

Paying for Nutrient Management in the Falls Lake Watershed

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Research questions

Are there case studies of implementation strategies of site-specific standards in the Southeast?

How might existing tools help Falls Lake stakeholders with financial and policy decision making?

Are there existing or likely future affordability challenges for rate payers? How might they be addressed?

Analyze the IAIA process in the first year of implementation.

Site-specific standard implementation case studies

- Site specific standards do not always result in a reduction in total compliance costs
  - Regulators have often struggled to link designated uses to contaminants and contaminant levels
  - The details of a future site-specific standard for Falls Lake will determine if there is a reduction in total compliance costs
    - A site-specific standard in Falls Lake may not necessarily necessitate a revised management strategy
- We found no case studies for implementation strategies for site-specific standards in the Southeast

Tools

EPA Green Infrastructure Modeling Toolkit

Falls Lake Revenueshed

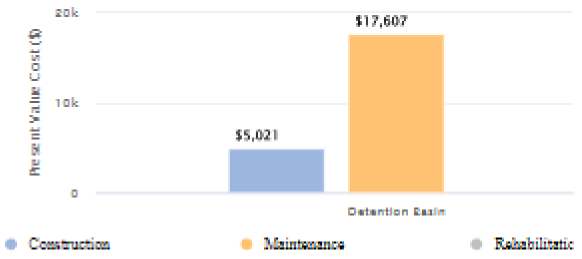
EJ Screen

How might existing tools help Falls Lake stakeholders with financial and policy decision making?

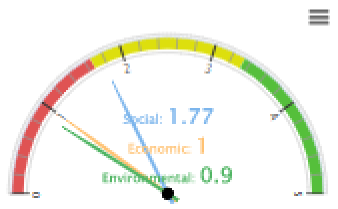
Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) Tool

CLASIC is an online tool that uses a life cycle cost framework to support feasibility and planning of stormwater infrastructure. It helps stormwater professionals, community planners, and local decision makers understand and weigh the estimated costs, reductions in runoff and pollutant loads, and co-benefits of various planning scenarios as they consider stormwater management projects. The tool is fully interfaced with GIS and links with national databases that can be applied at a community level. CLASIC was developed under EPA National Priorities grants by grantees from the Water Research Foundation, Colorado State University, Wichita State University, the University of Maryland, and the University of Utah. (*Note: Not included in video at top of page.*)

Average Annual Cost Over Design Life



Co-Benefit Analysis



Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC)

What is the tool's function?

- Estimate life cycle costs of SCMs
- Quantify co-benefits of SCMs (economy, environment, social)

When to use the tool?

- Deciding on SCMs that will have the greatest ancillary benefits.

How might existing tools help Falls Lake stakeholders with financial and policy decision making?

Introduction | Participants | Water | Wastewater | Stormwater | Property Tax

Falls Lake Revenueshed

What is a Revenueshed?

A revenueshed describes the area within which revenue is generated for protection of the Falls Lake Watershed.

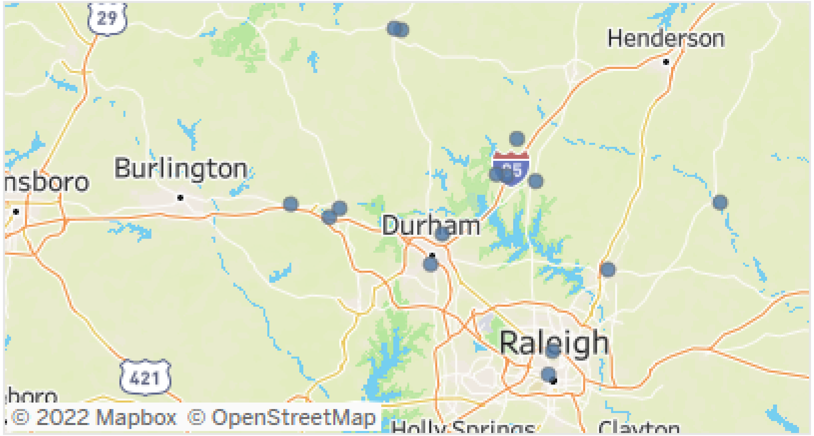
Enter Project Goals:

How would you like to pay for the project?

Enter Cash Amount($):	$0.00
Enter Loan Amount ($):	$0.00
Enter Interest Rate (%):	0.00%
Enter Loan Term (yrs.):	0

Explore Rate and Tax Changes:

1. Choose a project goal by selecting a loan amount, loan term, and interest rate.
2. Investigate the tabs dedicated to different revenue sources.
3. Use sliders to increase revenue supply and acheive target goal.
4. Discover how new revenue for watershed protection may affect customer bill affordability.



The *Water Quality Revenueshed* represents all parcels and environmental service rate payers within the Falls Lake Watershed. Potential revenue from the water quality revenueshed includes wastewater fees for customers whose wastewater is discharged into the watershed, stormwater fees for parcels inside the watershed, and property tax.

The *Water Supply Revenueshed* is made up of 3 municipalities and 1 water authority that currently use Falls Lake water. The revenue source for the water supply revenueshed is drinking water rates.

The *Total Revenueshed* is the combination of the Water Supply and Water Quality Revenuesheds.

https://go.unc.edu/FLRevenueshed

Revenueshed

What is the tool's function?

- Model the impact of small, incremental increases in existing fees to pay for a nutrient management strategy
- Quickly see the potential impact on economically burdened residents
- Explore the impact of full versus partial participation in a nutrient management implementation strategy

When to use the tool?

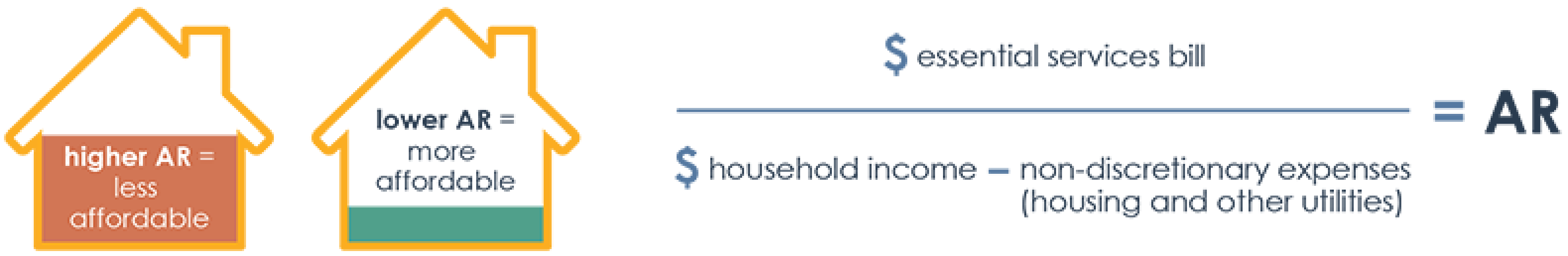
- Financial scenario building for paying for rule compliance both basin-wide and within each individual jurisdiction

Are there existing or likely future affordability challenges for rate payers? How might they be addressed?

- There are residents burdened by paying <u>current</u> water, wastewater, and stormwater bills
- Burden varies heavily by jurisdiction **and** within each jurisdiction
- North Carolina utilities are somewhat limited in what they can do in a Customer Assistance Program (CAP), but there are still options

Are there existing or likely future affordability challenges for rate payers? How might they be addressed?

Affordability Ratio (AR)



where utility services are least affordable for households at a particular point of the income distribution (e.g., AR_{20} is households at the lowest 20th percentile of income)

Butner: AR = 27.3

Durham: AR = 14

Are there existing or likely future affordability challenges for rate payers? How might they be addressed?

North Carolina

Water and wastewater utilities in North Carolina fall under several rate setting regulatory systems.

Commission-Regulated Utilities

The North Carolina Utilities Commission (NCUC) regulates rates set by private water and wastewater companies.[266] The NCUC does not regulate government-owned water or wastewater utilities.[267]

Under N.C. Gen. Stat. § 62-130, the NCUC shall "make, fix, establish, or allow just and reasonable rates" for commission-regulated utilities. Regulation by the NCUC is done on an individual rate case basis.[268] N.C. Gen. Stat. § 62-140 provides that no commission-regulated utility shall "make or grant any unreasonable preference or advantage to any person or subject any person to any unreasonable prejudice or disadvantage" and prohibits commission-regulated utilities from utilizing "any unreasonable difference as to rates or services either as between localities or as between classes of service."

Additionally, commission-regulated utilities are not allowed to charge any person more or less than what the NCUC sets for any service, nor are customers permitted to receive service for a rate greater or less than what the NCUC has set.[269] Under N.C. Gen. Stat. § 62-132, rates set by the NCUC are deemed "just and reasonable," and any rate charged by a commission-regulated utility that differs from the NCUC rates shall be deemed "unjust and unreasonable."

In sum, commission-regulated utilities are not expressly prohibited from implementing low-income customer assistance programs (CAPs) funded by rate revenues; however, any such program would have to be approved by the NCUC. Additionally, the language prohibiting commission-regulated utilities from charging greater or less than commission approve rates, or from granting any preferences or advantages to one customer over another customer, likely holds the greatest potential for legal challenges.

Commission-regulated utilities ⚠

Noncommission-regulated utilities ⚠

State Population (2016):	10,146,788
Median Annual Household Income (2015):	$46,868
Poverty Rate (2015):	17.4%
Typical Annual Household Water and Wastewater Expenditures (2017):	$914

North Carolina has 2,010 community water systems (CWS), of which 1,458 are privately owned and 1,875 serve populations of 10,000 or fewer people.

North Carolina has 318 publicly owned treatment works facilities (POTWs), of which 213 treat 1 MGD or less.

855,740 people are served by privately owned CWS; 7,164,754 are served by government-owned CWS; and 4,409,160 are served by POTWs.

Estimated Long-Term Water and Wastewater Infrastructure Needs:	$15.1 billion

Sources: U.S. Census Bureau, 2016 Population Estimate & 2011–2015 American Community Survey 5-Year Estimates; 2016 EFC Rates Survey; U.S. Environmental Protection Agency, 2016 Safe Drinking Water Information System, 2011 Drinking Water Infrastructure Needs Survey, and 2012 Clean Watersheds Needs Survey. See Appendix C for more details.

Noncommission-Regulated Utilities

Under N.C. Gen. Stat. § 160A-312(a) and § 153A-275, cities and counties are authorized to own and operate "public enterprises," which are defined to include water and wastewater utilities.[270] Further, N.C. Gen. Stat. § 160A-314 and § 153A-277 provide that cities and counties may establish and revise rates for public enterprise services, which "may vary according to

Case Study: Cape Fear Public Utility Authority

- Restructuring rates, lowering costs for about 80% of customers
- Households that use less water pay less per gallon, and those using more pay more per gallon
- Shift financial burden to heavier users- customers that are driving the need for greater capacity
- Achieves affordability and equity?

OASIS UTILITY BILL PROGRAM

Town of Cary- Addressing Financial Hardship

- Assistance is provided by way of donations from other utility customers
- Crisis counselors interview applicants to determine available assistance

BUDGET BILLING PROGRAM

Shelby- Bill Stabilization

- Yearly plan that allows customer to pay the same amount each month based on the last 12 months' billing
- Takes the surprise out of utility bill by stabilizing monthly utility payment throughout the course of the year
- All customers are eligible

Interim Alternative Implementation Approach

Interim Alternative Implementation Approach began July 2021

- Existing projects, planned before the IAIA, may be counted towards the IAIA
- Efforts to expand list of eligible projects
- Template spreadsheet will be/is being used for IAIA tracking

Policy implications:

- Stage II needs are uncertain, pending re-examination of the rules and no implementation strategy case studies exist.
- Existing tools can help with IAIA decision-making.
- Existing strategies exist to lower the burden on economically vulnerable populations.

What research remains for the EFC?

- A broader look at how existing case studies may inform a revised implementation approach in Falls Lake
- Finish in-depth affordability analysis, including identifying burdened census block groups
- Exploration of EPA EJ Screen tool for Falls Lake jurisdictions
- Final analysis of IAIA projects
- Next year: Integrated planning as an approach to nutrient rule compliance

Ongoing support for JLOW

- Development of non-profit
- Evaluation and future implementation of comprehensive governance structure which may necessitate legislative change, but this is a ways out
  - Legislative change could aide UNRBA efforts

Summary

- Some residents may already be economically burdened by their total water bill and addressing these burdens now will decrease the future burden. The outcome of the rule re-examination process may or may not have a major impact on the future implementation strategy and the total cost of compliance.

Acknowledgements

A special thank you to Forrest Westall, Alix Matos, Haywood Phthisic, and Dan McLawhorn for detailed input on our research questions.

Paying for Nutrient Management in the Falls Lake Watershed

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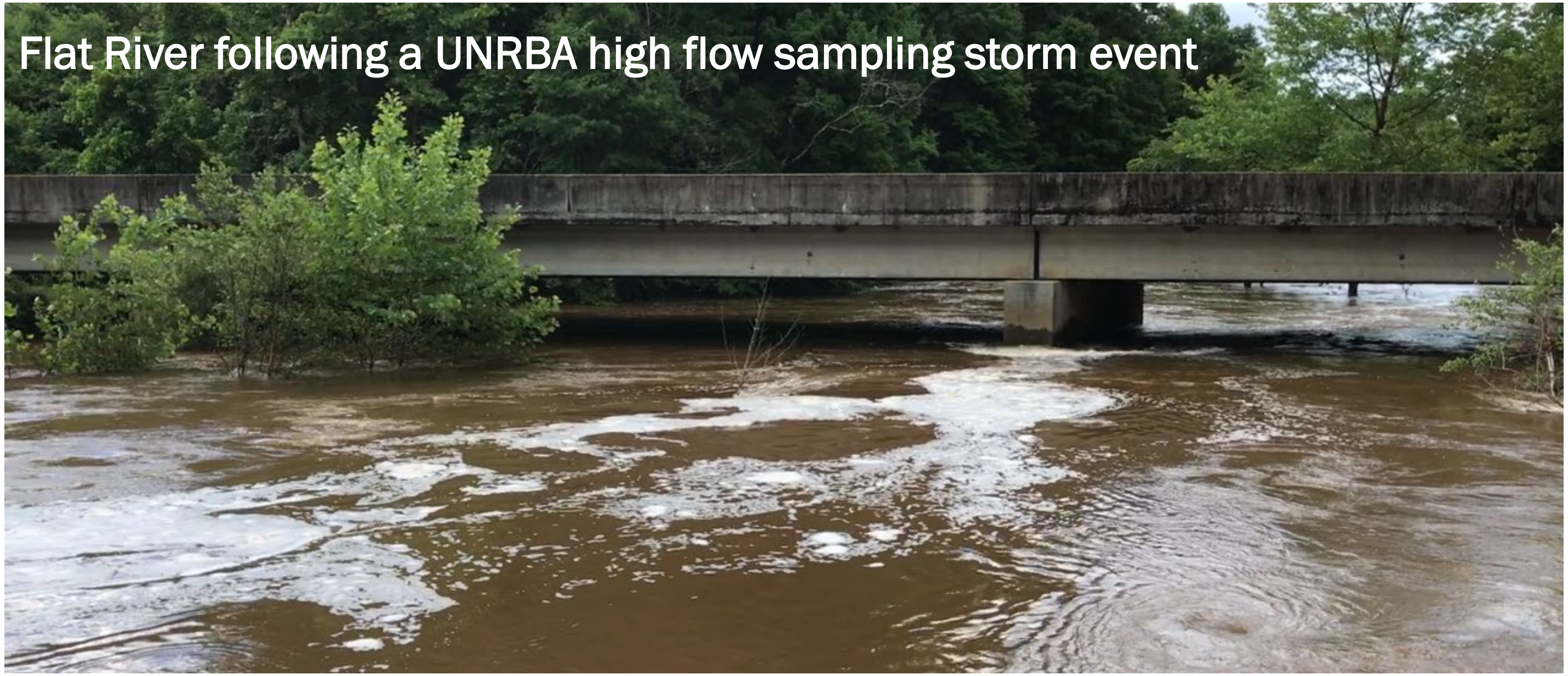
UNC SCHOOL OF GOVERNMENT
Environmental Finance Center

2022 Falls Lake Nutrient Management Study Research Symposium

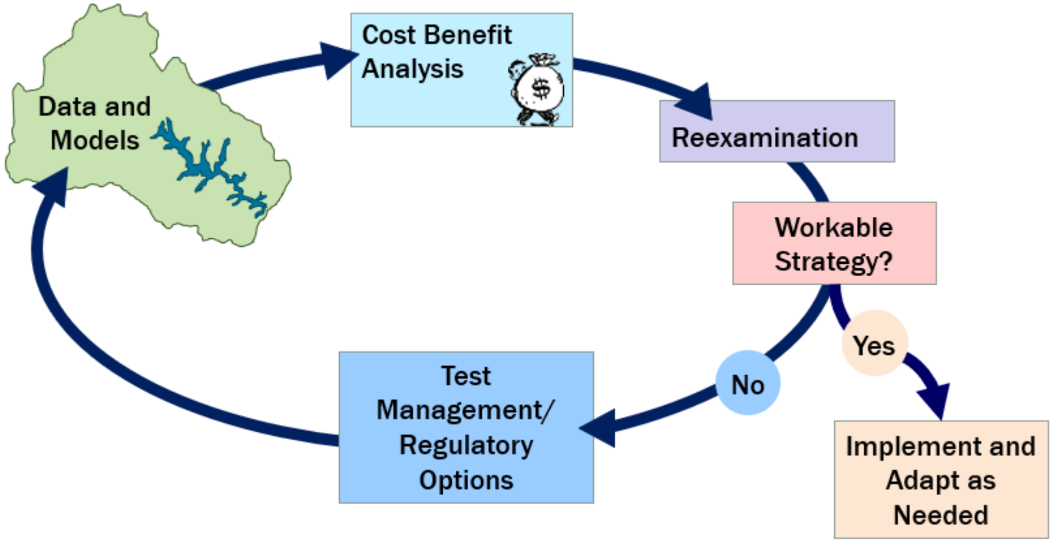
UNRBA's Re-examination - Where We Are, What We've Learned, Moving Forward

April 7, 2022

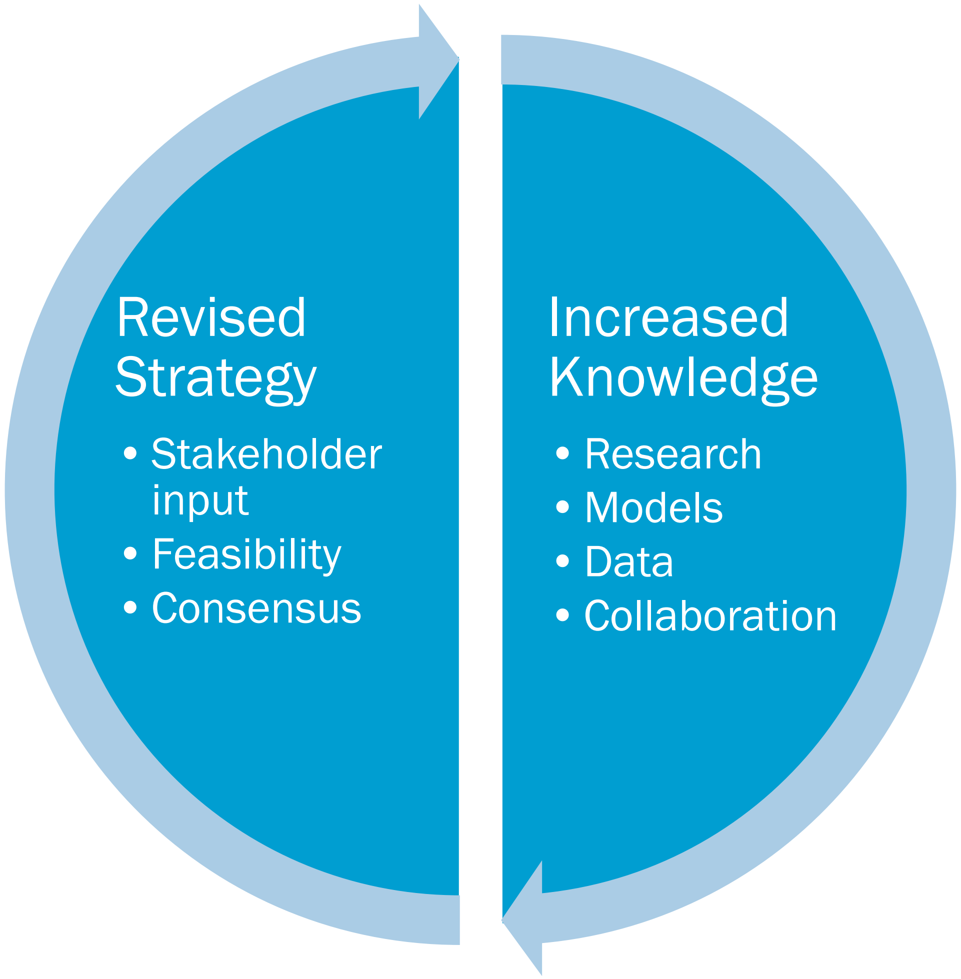


Use Monitoring Studies and Models to Support the Re-examination

- Utilize monitoring studies and subject matter experts to develop and calibrate four models
  - Watershed model using Watershed Analysis Risk Management Framework (WARMF)
  - WARMF Lake model (simpler lake model)
  - Environmental Fluid Hydrodynamic Code (hydrodynamic, water quality, sediment diagenesis)
  - Statistical model to link nutrient loading, lake water quality, and satisfaction with designated uses
- Apply models and run scenarios
  - Understand sources of nutrient loading to the lake
  - Test different management actions and their impact on lake water quality and user satisfaction
  - Factor in cost and technical limitations
- Develop a revised nutrient management strategy
  - Work with stakeholders to hear concerns and ideas
  - Craft a strategy based on consensus

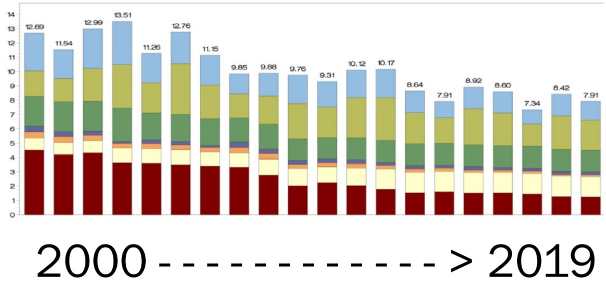


What We've Learned from the Monitoring Studies and the Watershed Model



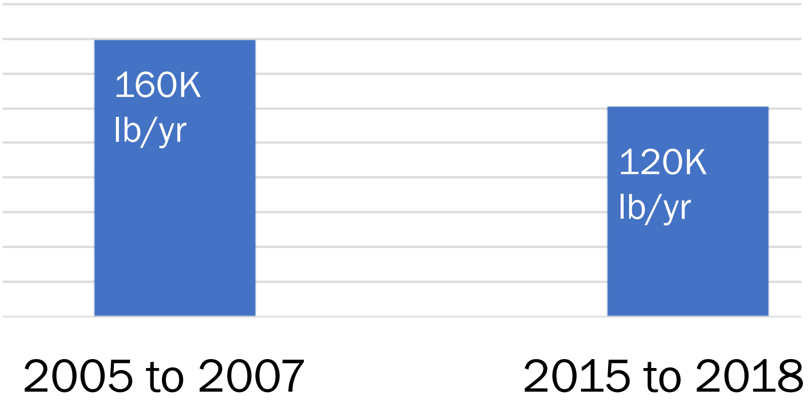
Reductions in Nutrient Loading Since Baseline

- Wet and dry total nitrogen deposition rates have decreased by **26.5 percent.**

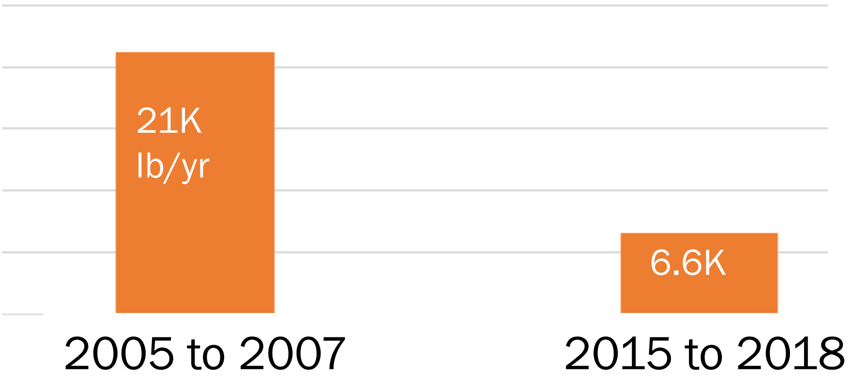


Information on this slide will be summarized in the watershed model report (under review).

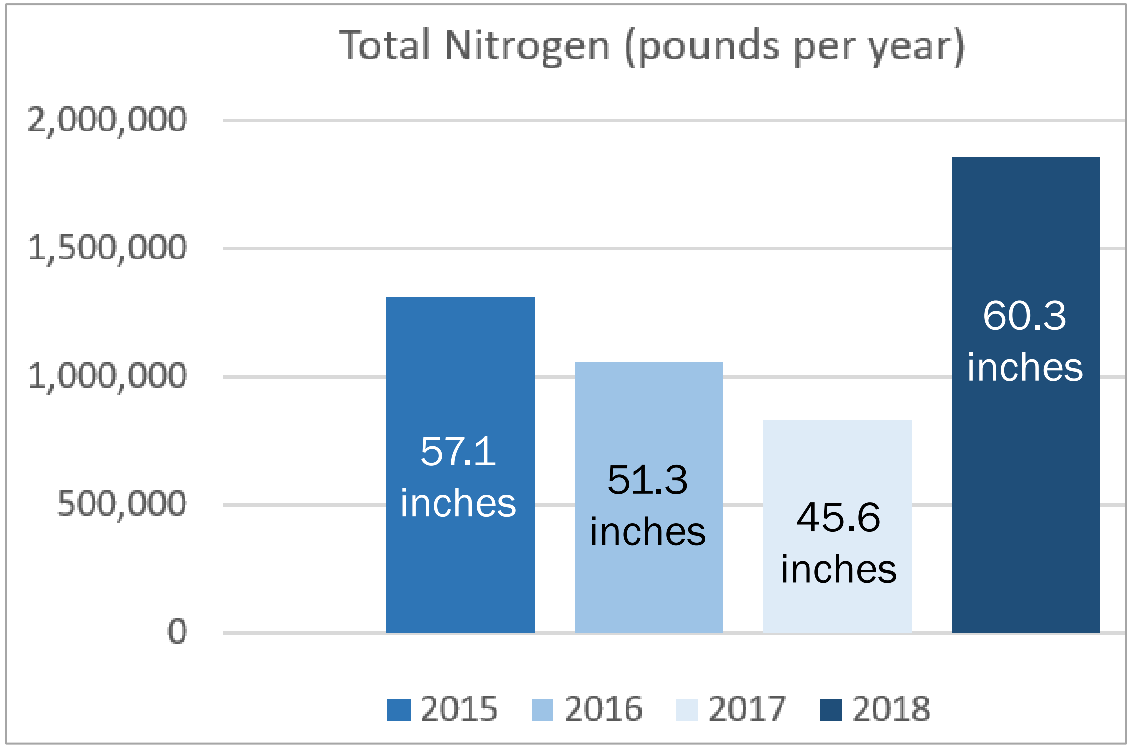
- Total nitrogen loads discharged to streams from wastewater treatment plants have decreased by **24 percent**

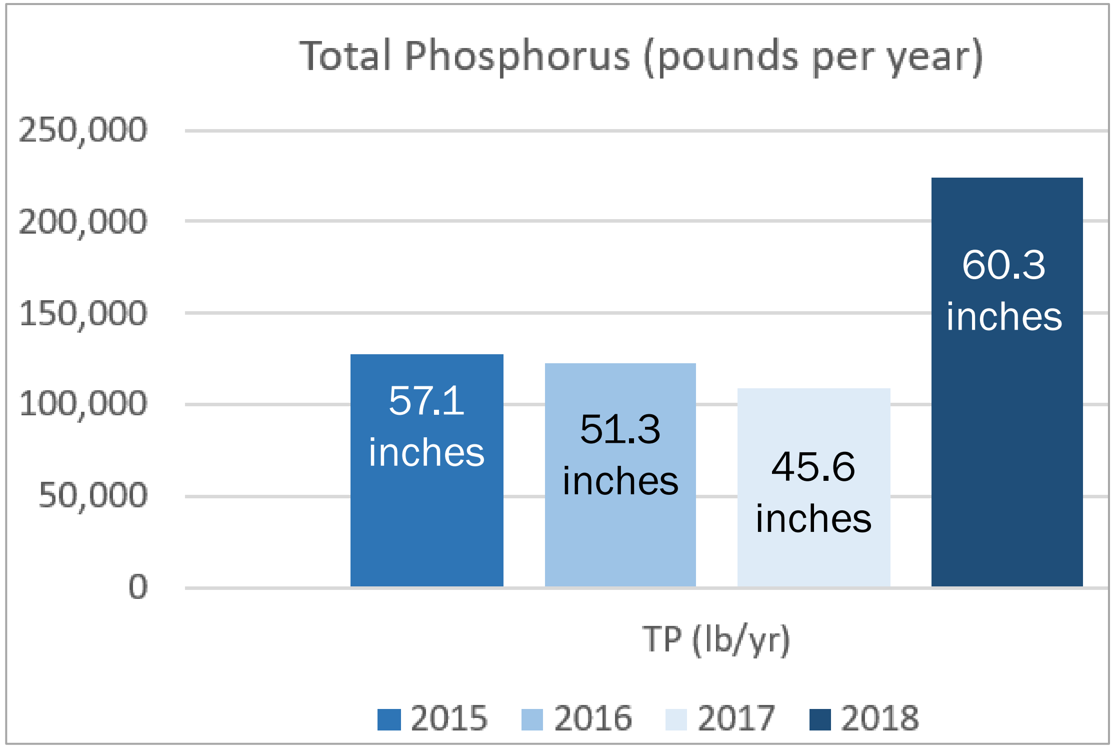


- Total phosphorus loads discharged to streams from wastewater treatment plants have decreased by **69 percent**



Precipitation Drives Variability in Loading (2015 to 2018)



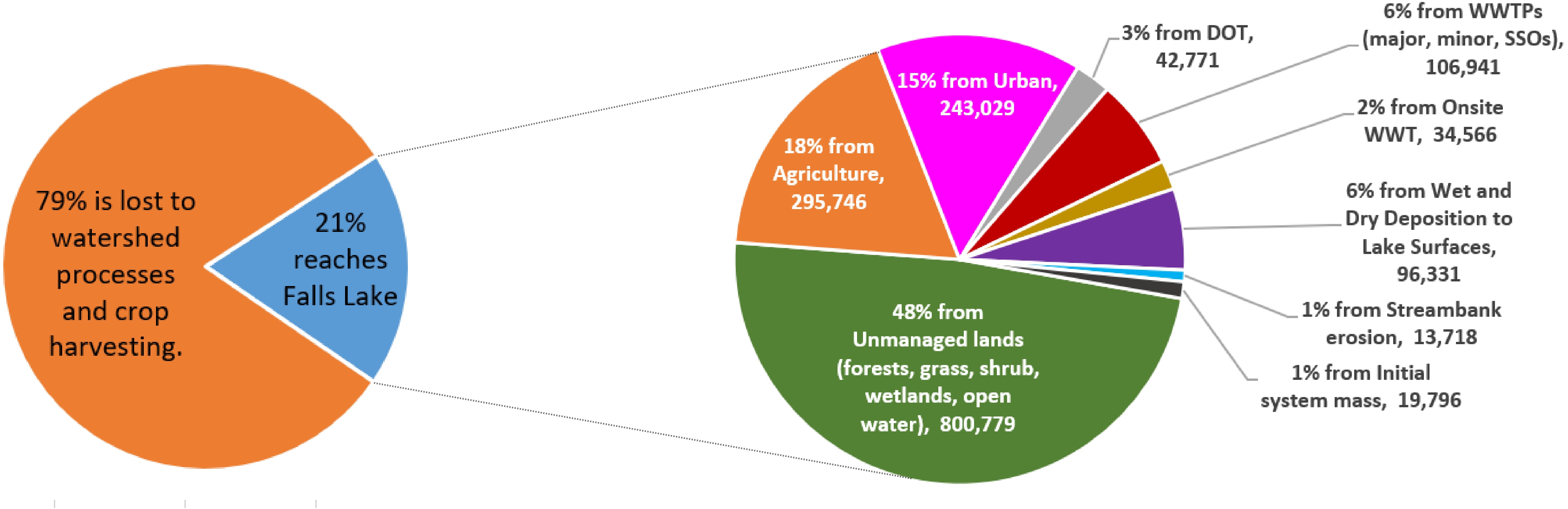


2018 had approximately two times more load passing the UNRBA monitoring stations compared to 2017 but only 30 percent more rain. 2018 included Hurricane Florence which delivered more than 10 inches of rain in some areas.

Annual Average Applied and Delivered Total Nitrogen Loads

Gross inputs:
8.8 million pounds per year

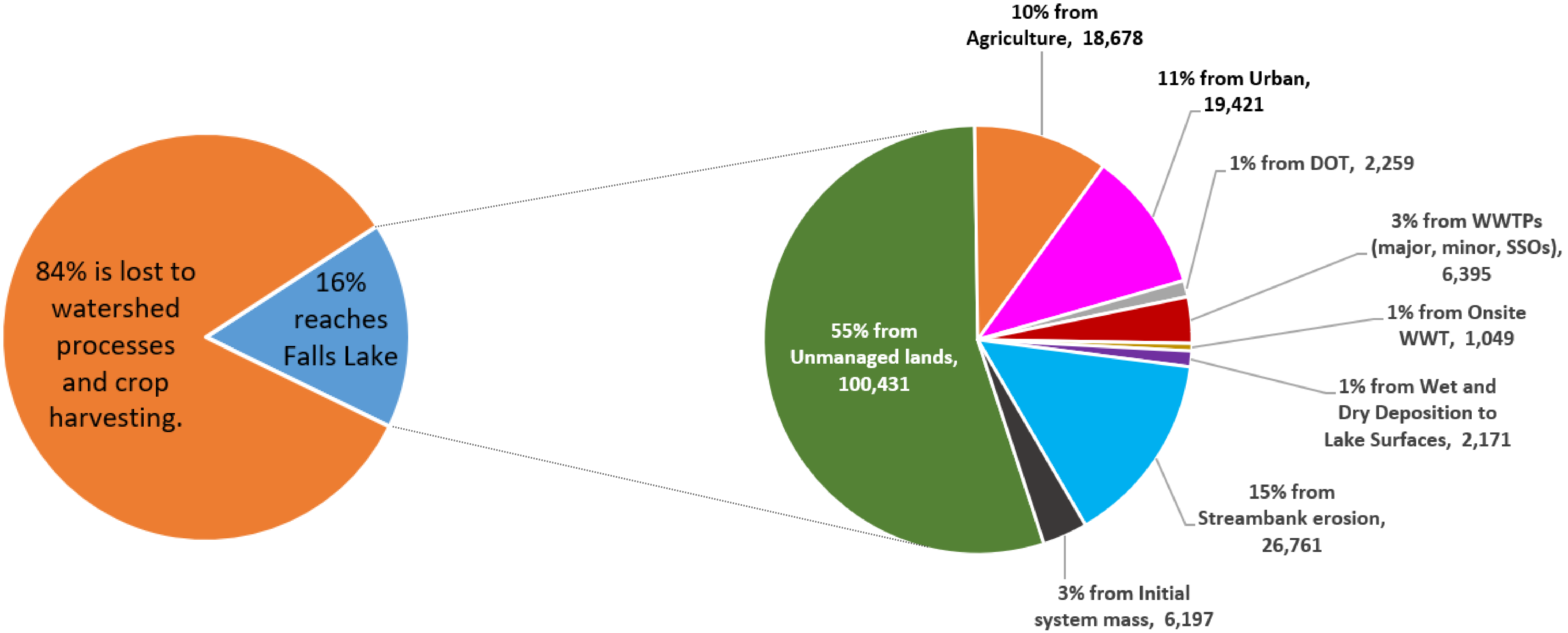
Delivered load:
1.65 million pounds per year



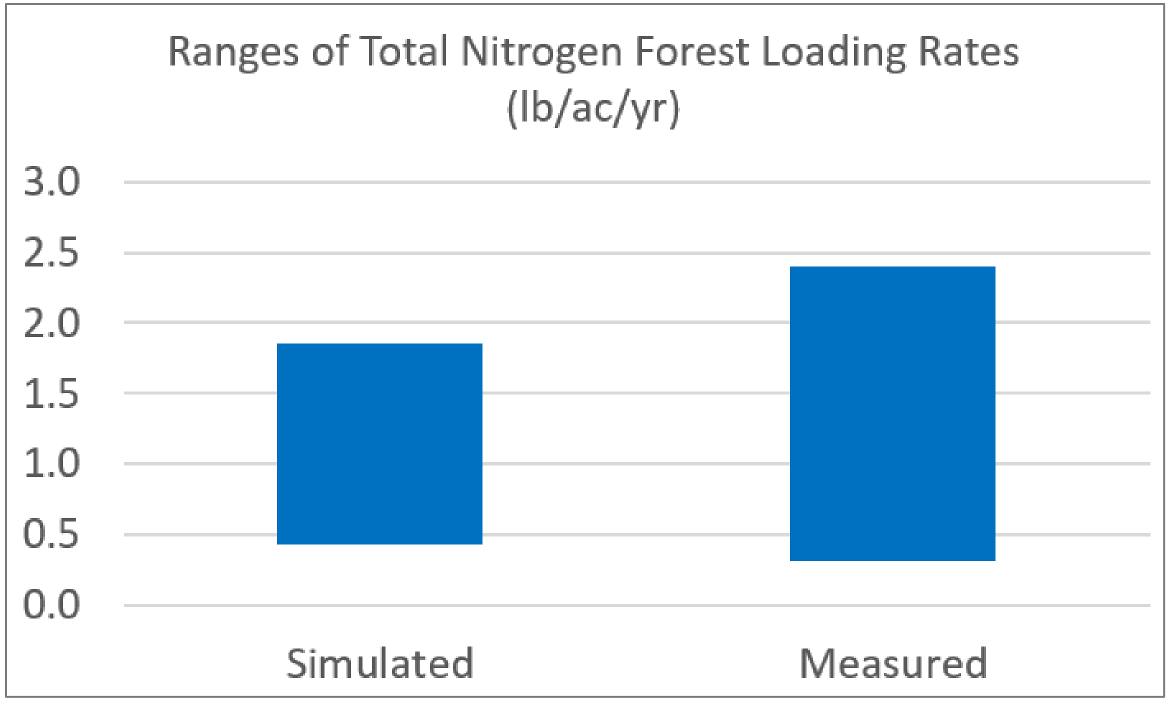
Annual Average Applied and Delivered Total Phosphorus Loads

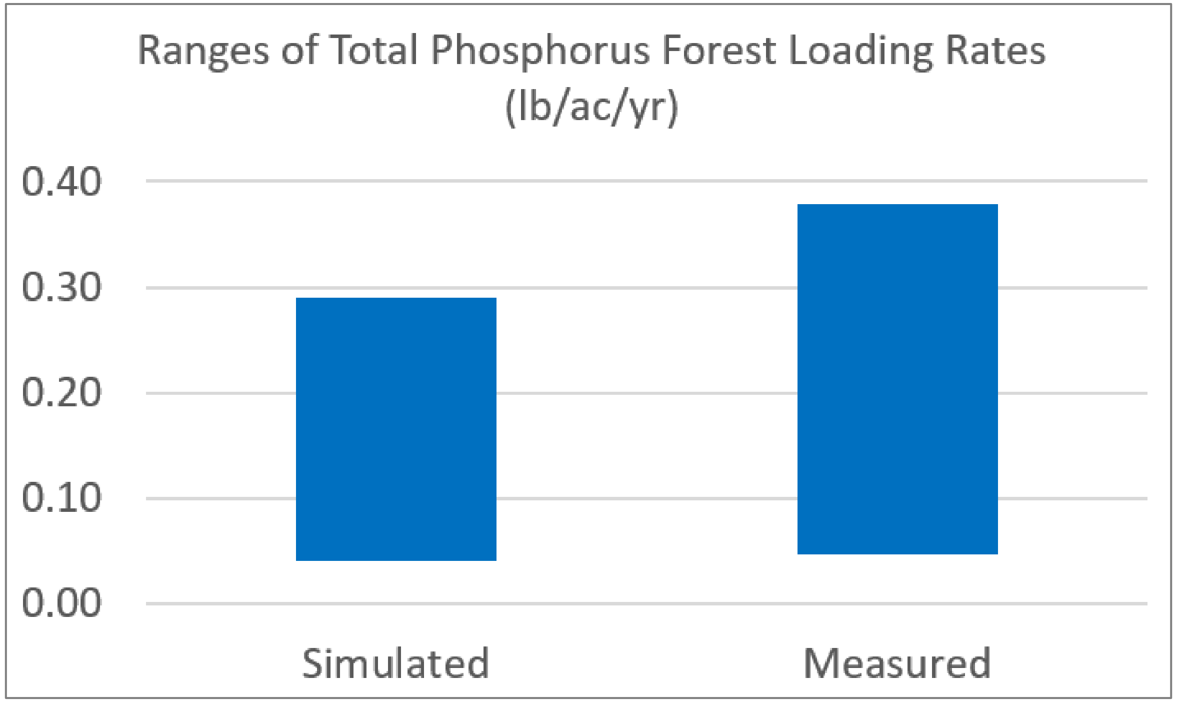
Gross inputs:
1.1 million pounds per year

Delivered load:
180,000 pounds per year



Simulated and Measured Nutrient Loading Rates from Forests





Simulated loading rates from forests are similar to rates measured by the US Forest Service when the hydrologic condition is comparable (dry to average precipitation).

Flow Weighted Nutrient Concentrations are Lower than Baseline

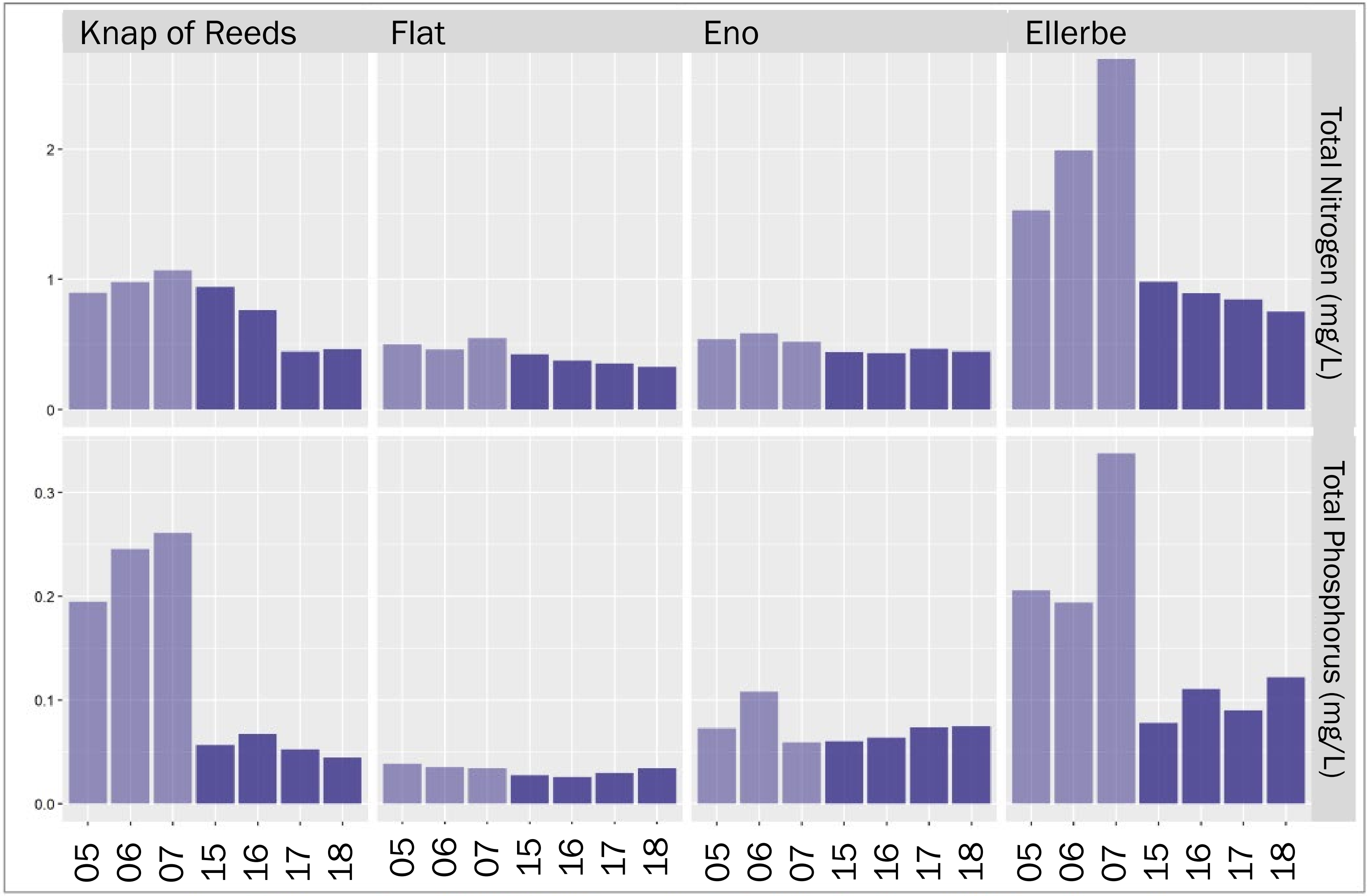


Figure copied from the 2019 UNRBA Monitoring Report

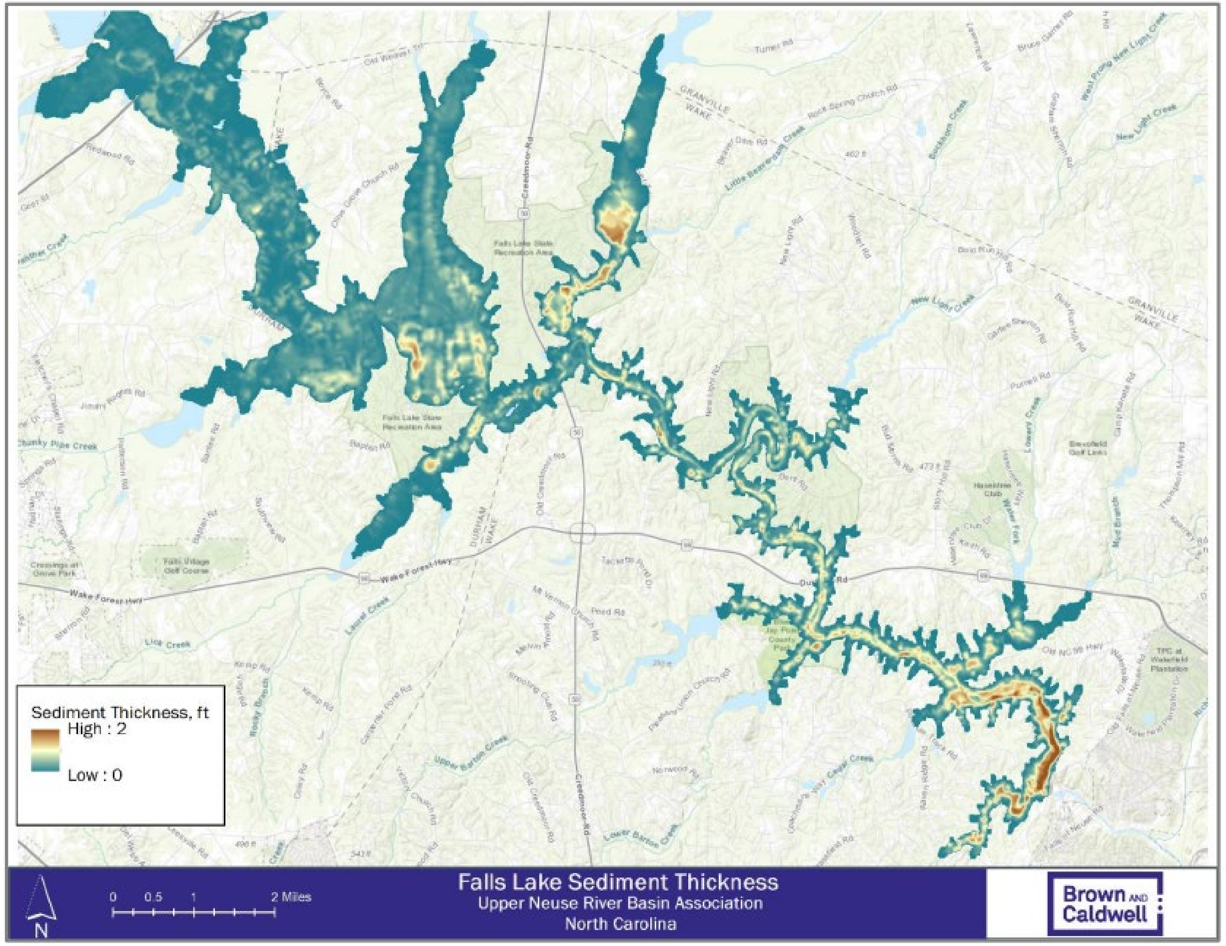
- Lighted shaded bars are baseline years (2005-2007)
- Darker bars are the UNRBA study period (2015-2018)
- Concentrations have declined significantly since baseline

Falls Lake Sediments Release Nitrogen and Phosphorus

- Dr. Marc Alperin (UNC) conducted a study of the sediments in Falls Lake in 2015
  - Total phosphorus releases are limited when oxygen is present
  - Potential ammonium flux is >300 times the potential phosphate flux (concentration gradients)
  - Sediments provide a 20-fold excess of available nitrogen compared to algae requirements for phosphorus
  - Nitrogen fluxes from cores collected within the historic river channel were more than three times higher than cores collected nearby

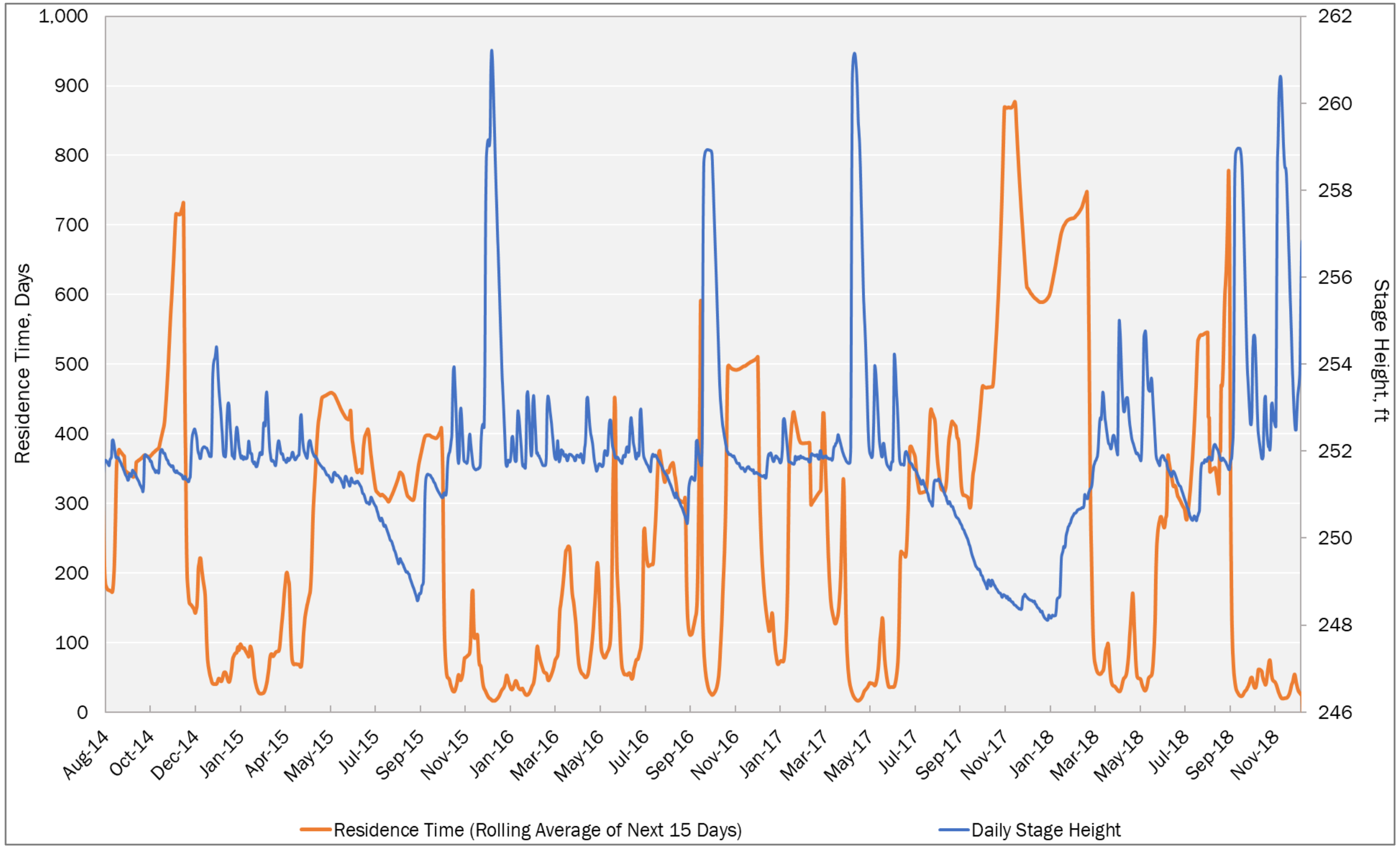
Watershed and Lake Sediments Will Continue to Release Nutrients

- Dr. Alperin estimates continued releases of nitrogen for 10 to 40 years even if all other nutrient inputs are <u>ZERO</u>
- Estimates of annual nutrient releases from sediments
    - 200,000 pounds of total nitrogen; 11% to 24% of the watershed load
    - 14,000 pounds of total phosphorus; 6% to 13% of the watershed load
- The watershed model indicates land-based management changes would take 20 to 25 years to stabilize in terms of delivered load to Falls Lake



Falls Lake Special Study – Sediment Thickness Results

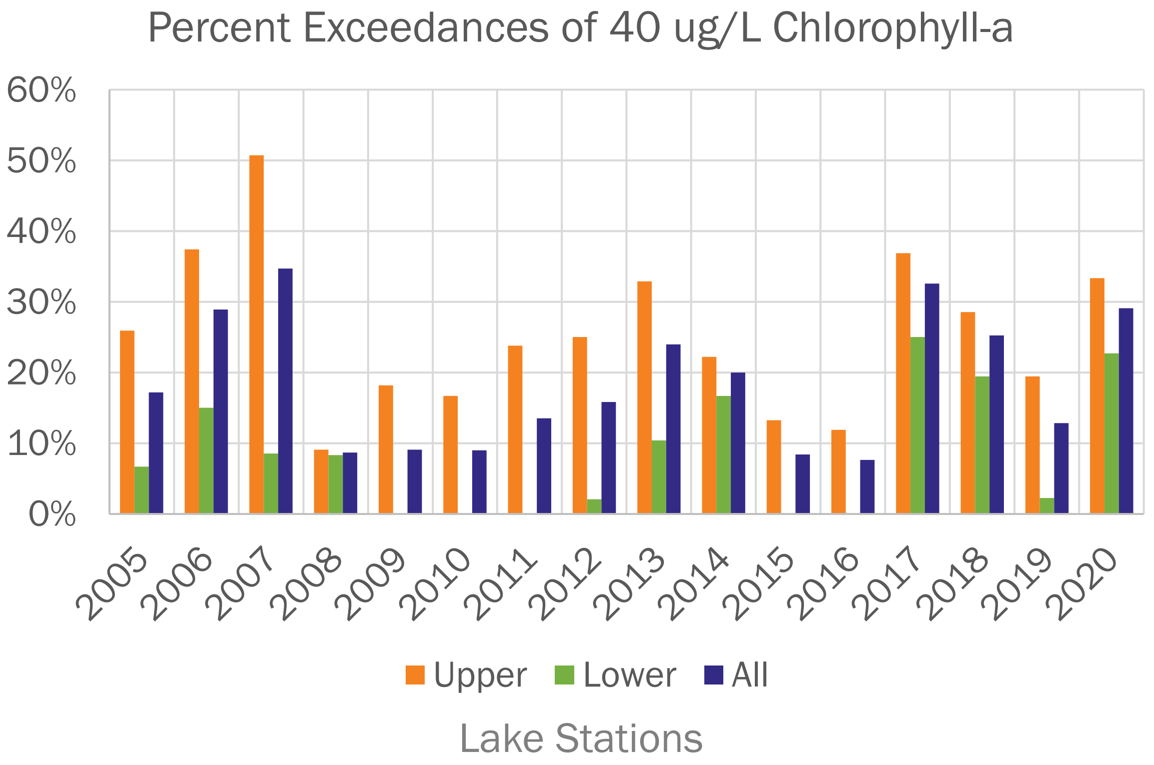
Reservoir Residence Time Evaluation



- Residence time controls the ability of algae to grow
- Longer residence times allow for more growth
- The USACE controls releases from Falls Lake for flood control and minimum releases
- Residence time can change rapidly and can vary from a couple of days to almost 900 days.

Lake Chlorophyll-a Concentrations

- Better than pre-construction predictions
- Improved or similar compared to baseline
- Recent observations are driven by lake operations, residence time, and seasonality rather than nutrient loading
- Concentrations were higher in years that had lower precipitation and nutrient loading
  - Nutrient loads in 2017 were half those in 2018 due to hydrologic condition
  - Chlorophyll-a concentrations in 2017 were the highest within the UNRBA study period

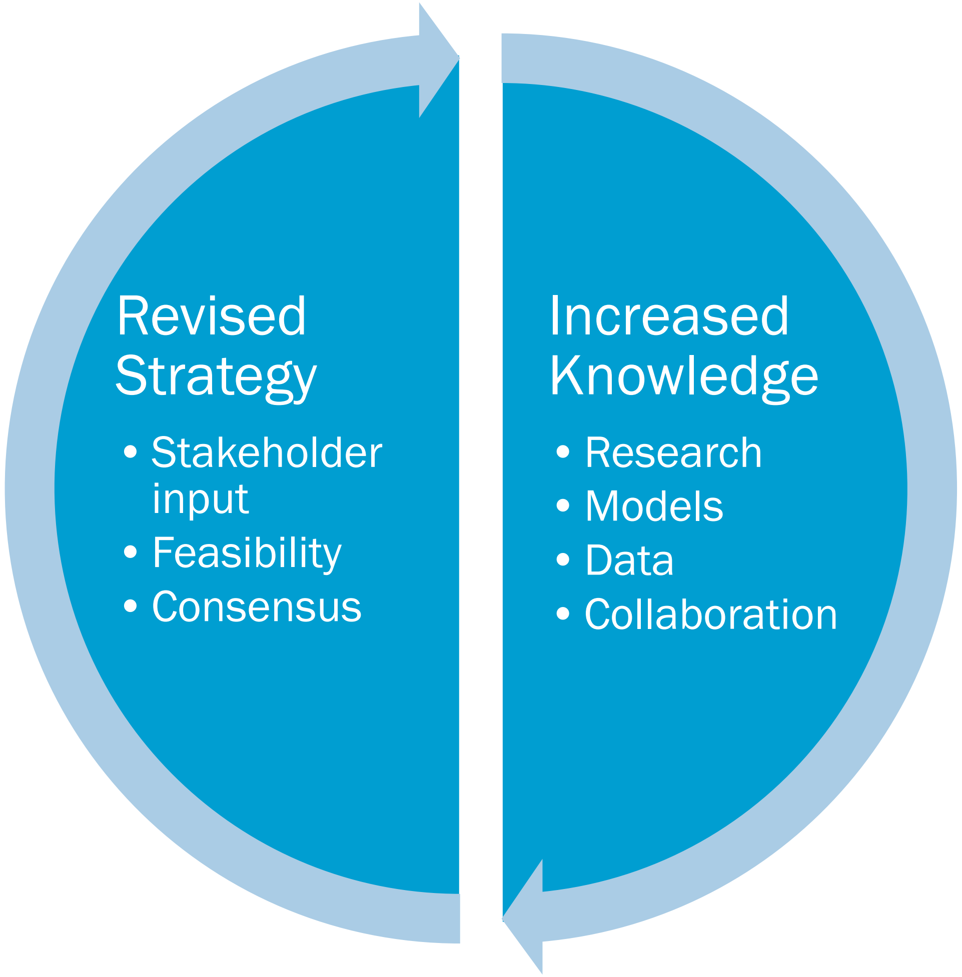


Applying Increased Knowledge from Research and Modeling to Revise the Nutrient Management Strategy

- Watershed loading from uncontrollable sources limits how much nutrients can be reduced
- Significantly reducing nutrients is a very long-term undertaking
  - Soils in this watershed retain nutrients
  - Lake sediment nutrient cycling diminishes the benefits of nutrient management
  - Lake has sufficient supply of nutrients to maintain algal levels for decades to come
- Local governments have limited opportunities to control nutrient loading from existing development (technology, feasibility, logistics, costs)
- Falls Lake is meetings its designated uses, and they must be sustained
- The current chlorophyll-a standard is not related to meeting designated uses
- We must get the standard right for Falls Lake (site-specific standard)

Development of a Revised Nutrient Management Strategy

- Develop and calibrate three lake models
- Propose a site-specific chlorophyll-a standard
- Apply increased knowledge
  - Quantify sources of nutrient loading
  - Evaluate scenarios and management options
  - Consider cost, benefits, and limitations
- Work with stakeholders to develop a revised nutrient management strategy based on consensus



Additional Information (Hyperlinks)

- UNRBA technical reports and data; meeting information - https://www.unrba.org/
- UNRBA general information - https://upperneuse.org/
- Key reference documents:
  - Overview of the Work of the UNRBA
  - UNRBA Infographic
  - UNRBA Fast Facts
- Comprehensive UNRBA Monitoring Data Report
- UNC Collaboratory Falls Lake Study website - https://nutrients.web.unc.edu/resources/

Please send questions or additional feedback to

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Session 3 Stakeholder Questions