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December 20, 2021

To: The Honorable Jimmy Dixon, Co-chair, Environmental Review Commission
The Honorable Chuck Edwards, Co-chair, Environmental Review Commission
The Honorable Edward Goodwin, Co-chair, Environmental Review Commission
The Honorable Brent Jackson, Co-chair, Environmental Review Commission
The Honorable Pat McElraft, Co-chair, Environmental Review Commission
The Honorable Norm Sanderson, Co-chair, Environmental Review Commission

From: Jeffrey Warren, PhD, Executive Director, North Carolina Policy Collaboratory

Re: Collaboratory Falls Lake Study Interim Update

*SENT VIA ELECTRONIC MAIL*

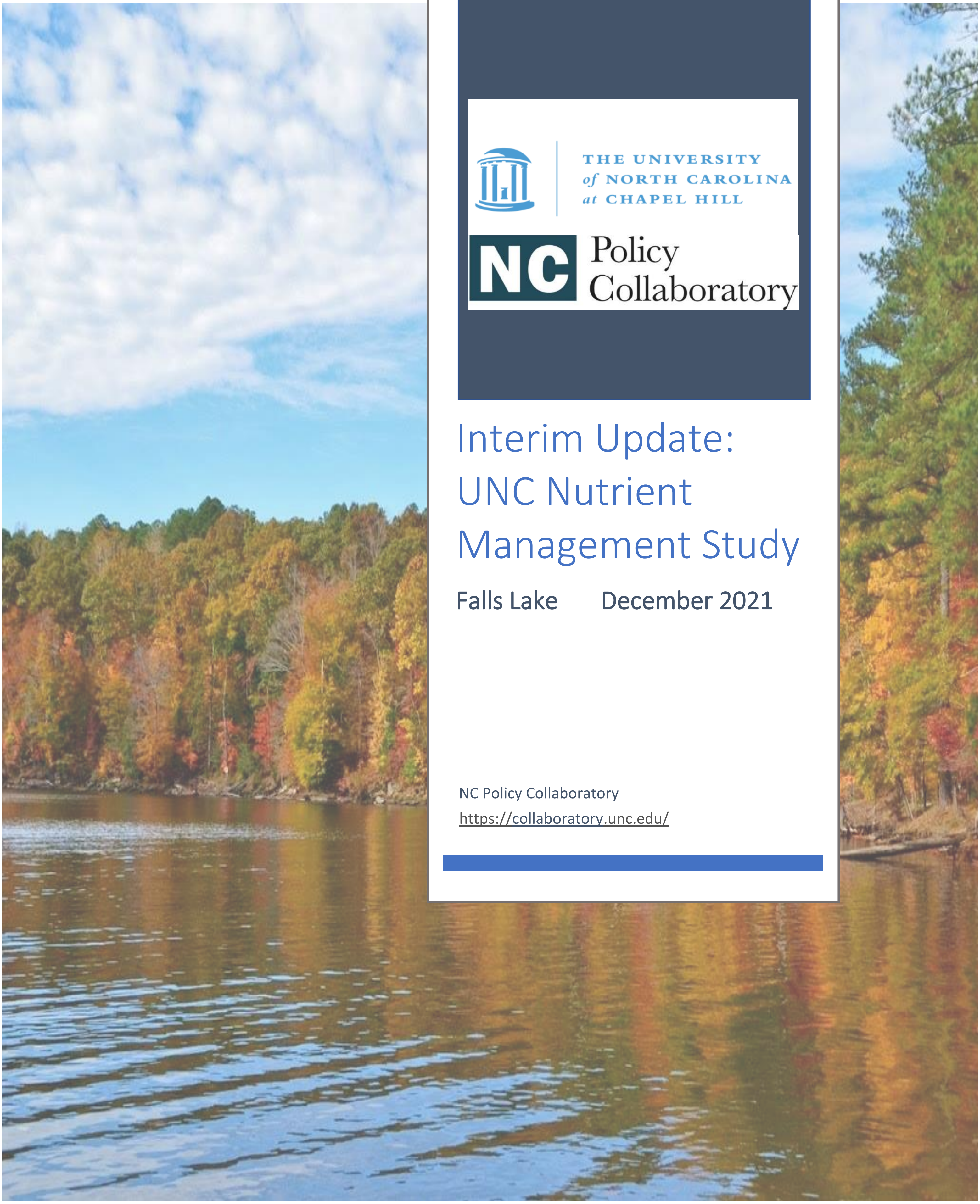
Attached for your consideration is the Interim Update of the Collaboratory's Falls Lake study pursuant to Session Law 2016-94 section 14.13 (c), which directed UNC-Chapel Hill to conduct a multi-year study and analysis of nutrient management strategies and compilation of existing water quality data of Jordan and Falls Lake.

I would note that this year's budget bill (Session Law 2021-180) provided $750,000 for continuation of the study with a final report date of December 31, 2023. We appreciate the General Assembly's support of this important project.

If you have any questions or would like more information about the report, please do not hesitate to contact me (jeff.warren@unc.edu) or Steve Wall, Collaboratory Outreach Director (swall@email.unc.edu).

Dr. Jeffrey Warren, PhD
Executive Director

Attachment



THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

NC Policy Collaboratory

# Interim Update: UNC Nutrient Management Study

Falls Lake December 2021

NC Policy Collaboratory
https://collaboratory.unc.edu/

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## Legislative Charge

During the 2016 legislative short session the North Carolina General Assembly approved a special provision in the annual budget bill, "Development of New Comprehensive Nutrient Management Regulatory Framework." This section directed UNC-Chapel Hill to oversee a study and analysis of nutrient management strategies and synthesis of existing water quality data in the context of Jordan and Falls Lake (*See Appendix I for full legislative text)*.

The legislation provides $500,000 annually over six years beginning in FY 2016 – 2017 with progress reports on the study required every year. The first three years of the study were focused on Jordan Lake, culminating in a final legislative report that was submitted in December 2019. The Jordan Lake report and supporting documents can be found at http://nutrients.web.unc.edu/.

In the summer of 2019, the research team transitioned to focusing on Falls Lake. The original legislation establishing the study mandated a final report for Falls Lake in 2021. The 2018 budget bill extended this deadline, requiring study results to be completed by the end of 2023, with interim updates in advance of the final report.

**In the 2021 budget bill, Session Law 2021-180 (Section 8.5) the legislature appropriated an additional $750,000 for the Falls/Jordan Lake study. The bill provides that any remaining funds at the end of the 2021-22 fiscal year shall not revert but remain available to support the study until December 31, 2023.**

Over the course of 2019-2021 researchers from UNC-Chapel Hill, East Carolina University, and NC State University have been conducting a number of research projects focused on Falls Lake as part of the study, including:

- Evaluating reservoir vulnerability to eutrophication, including harmful algal blooms, relative to nutrient and sediment loads, streamflow patterns, and climate, for both current conditions and future scenarios.
- Identifying major sources of nutrients and sediments to Falls Lake and the timing of loading.
- Examining the potential for toxic algae growth in Falls Lake.
- Evaluating likelihood of nutrient mitigation through the implementation of best management practices, regulatory measures and restoration efforts.
- Evaluating innovative financing mechanisms for stormwater controls and analysis of costs and benefits of water quality improvement.

*Figure 1. Researcher Brent McKee, UNC-Chapel Hill and his research group at Falls Lake*

# Study Framework

## Overview

This collection of research projects synthesizes interdisciplinary analyses of Falls Lake's nutrient content and fluctuation, the factors that affect it, mitigation strategies and their effectiveness, and financial implications of proposed processes. Several distinct research teams are evaluating a number of factors related to the water quality of Falls Lake, including flows in and out of the lake, the potential for development of toxic algae, review of existing modeling efforts, mitigation strategies and financial resources available for those strategies. That research is guided by fundamental research questions that serve as the foundation of the study.  As an example of the topics being considered as part of the study, some of these research questions are listed below.

## Research Questions

How do the lake's nutrient levels change differently during various flow conditions? How does the water movement differ between timescales, and how does this affect nutrient levels in the lake?

How can we better understand sediment fluxes associated with Falls Lake and the rates of sediment input to the fate of particulate materials?

Are year-round patterns of cyanobacterial abundance in Falls Lake associated with toxin presence?

Do onsite wastewater treatment systems increase nutrient concentrations in streams draining to Falls Lake? What are the optimal locations for bioreactors along low-order streams to reduce nutrient inputs?

Is there a clear inflection point in the slope of the relationship between zooplankton and phytoplankton biomass for Falls Lake that may guide development of a site-specific criterion?

# Introduction

## Falls Lake Background

FALLS LAKE WATERSHED

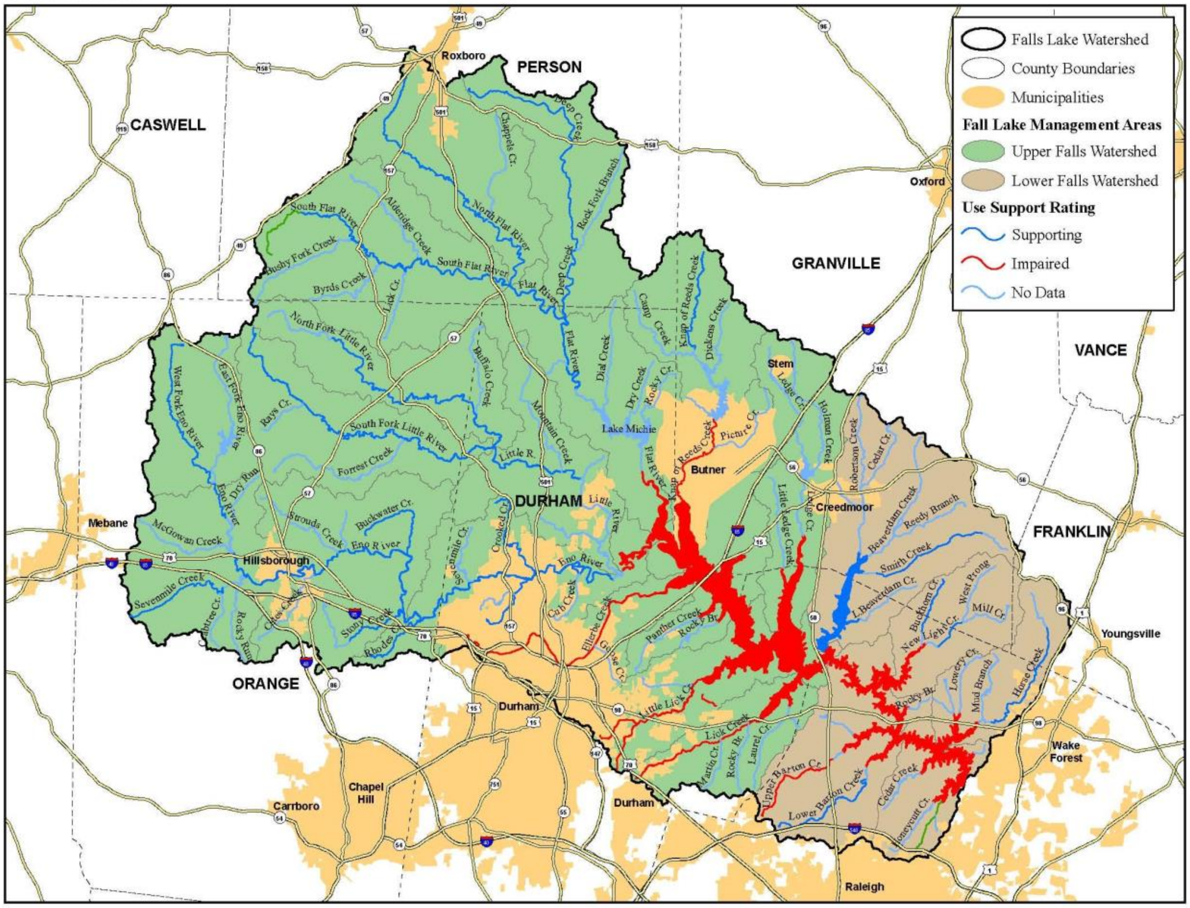



*Figure 2. Falls Lake Map. Source: http://portal.ncdenr.org/web/fallslake*

Falls Lake is a 12,410-acre reservoir in Durham, Wake, and Granville counties of North Carolina. The lake stretches 28 miles up the Neuse River to its source at the junction of Eno, Little, and Flat rivers. Its name comes from the Falls of the Neuse, which describes what used to be a whitewater section of the river between the Piedmont and the Coastal Plain and was submerged during construction of the reservoir.

The Army Corps of Engineers began building the reservoir in 1978 and completed construction in 1981. The lake was built to control damaging floods, serve as a water supply source, and protect downstream water quality during droughts. It provides drinking water for half a million people in Raleigh, Garner, Knightdale, Roseville, Wake Forest, Wendell and Zebulon.

Just two years after construction was finished in 1983, the lake was classified as a Nutrient Sensitive Water because it did not meet state standards for chlorophyll a in reservoirs. Chlorophyll a is a photosynthetic pigment in algae, and high levels indicate excessive amounts of algae, which can lead to reduced light penetration, low oxygen levels, eutrophication and nutrient imbalance in lakes. Nitrogen and phosphorous are two nutrients that algae and plants need to grow, and are often limiting factors. Management of nitrogen and phosphorous limits algal growth and decreases eutrophication.

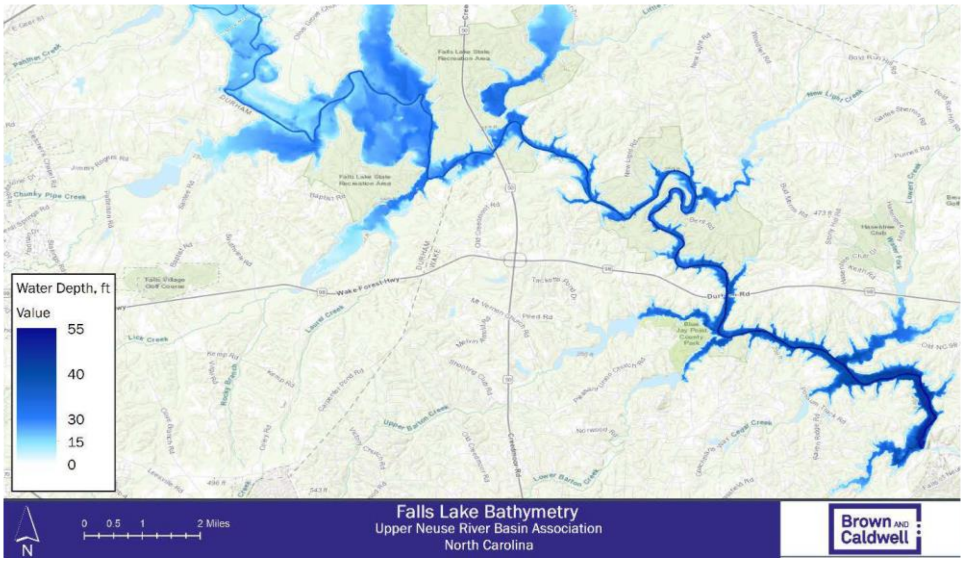



*Figure 3. Falls Lake Bathymetry, data collected 2017 (UNRBA 2019)*

The Falls Lake Nutrient Management Strategy was implemented in 2011 in an effort to improve water quality. The strategy, also known as the Falls Lake Rules, was developed by DWQ and focuses first on the lower, less-polluted portion of the lake, moving upward to the poorest water quality in the upper basin. They target nutrient discharge to the lake from various sources, including stormwater runoff, wastewater treatment plants, and agriculture.

## Study Design

Fall Lake's nutrient content and fluctuation, the factors that affect it, mitigation strategies and their effectiveness, and financial implications of proposed processes are being evaluated by an interdisciplinary team of researchers. Mike Piehler, the Director of the UNC Institute for the Environment is the faculty lead on the project. Researchers from UNC-Chapel Hill's Institute of Marine Sciences, Institute for the Environment, Environmental Finance Center, NCSU's Marine, Earth, and Atmospheric Sciences Department, NCSU's Civil, Construction, and Environmental Engineering Department, and East Carolina University, (*See Appendix II for full roster of study team)* conducted several individual studies which together support a thorough and accurate survey of Falls Lake's characteristics and management options.

## Modeling Support Initiative

Over the last year, the Falls Lake Study has incorporated a critical piece of research that supports the ongoing modeling efforts of the Upper Neuse River Basin Association (UNRBA). The scientific review of watershed and water quality modeling to support nutrient management in the Falls Lake watershed is being led by Professor Dan Obenour at North Carolina State University.

The foundation of this research includes continuous engagement with UNRBA's modeling team and providing technical guidance about model improvement.

Some of the major activities during this period included:

- Providing recommendations on the segmentation of the lake model, such as splitting an existing segment at the Cheek Road Causeway.
- Providing guidance for reconciling flows and closing the flow balance, including making flow adjustments, what level of smoothing is appropriate for these adjustments, and how the smoothing algorithm works.
- Addressing watershed model calibration issues to ensure the model reasonably captures the sources and seasonality of nitrogen loading. Suggestions were made for calibrating nitrogen transformation rates and their associated temperature adjustment factors. This work also included a review of atmospheric nitrogen deposition data.
- Developing a geostatistical algorithm for assessing the probability of compliance with the state's water quality criteria, subject to different spatial monitoring resolutions. This analysis was conducted in response to questions posed by UNRBA regarding how different monitoring strategies will influence compliance with water quality standards.
- Conducting a literature review of sediment phosphorous release rates below U.S. lakes and waterbodies due to the uncertainty of internal loading from sediment.

The modeling team will continue to work closely with the research team and the Falls Lake modeling team to help ensure the most accurate and robust model possible under the circumstances.

## Sharing Research Results

One of the hallmarks of the Falls Lake Study has been the engagement from the research team with local governments and other interested parties about the latest findings from the ongoing research. This continued interaction between stakeholders and researchers has dual purposes. First, the external stakeholders can provide guidance and input to researchers and identify research questions of importance as the study moves forward. Secondly, the researchers are constantly sharing their latest findings and what they might mean for management implications.

Despite the challenges of meeting in person due to the COVID-19 pandemic during 2021, the research team worked closely with partners to identify effective new means to share research results. As such, much of this engagement work has shifted from in person to virtual, including the annual symposium.

On May 19, 2021, the NC Policy Collaboratory, the UNRBA and the UNC Institute for the Environment jointly held the Falls Lake Nutrient Management Study Research Symposium. Mike Piehler, faculty lead for the study, provided an overview of the research taking place and Forrest Westall, Executive Director of the UNRBA, presented comments on the re-examination of the Falls Lake Nutrient Management Strategy.

The symposium highlighted research during three sessions:

- Watershed Processes
- In-Lake Processes
- Stakeholder Engagement, Financing, and Future Work

Throughout the sessions, participants had the opportunity to ask questions and have further discussions with the individual researchers. Similar to the attendance numbers from previous in person symposiums on the Jordan and Falls Lake Study more than 100 participants joined the meeting.

In addition to the symposium, the Falls Lake Study researchers have been actively engaging with UNRBA staff and members to provide the technical and policy implications of their work. Individual researchers have delivered in-depth presentations to the monthly UNRBA meetings and have also been involved in discussions with staff on a regular basis.

Engagement and collaboration are incredibly important for the Falls Lake Study because both the UNRBA and DEQ have been working on identifying solutions for Falls Lake water quality issues for many years. The Collaboratory's Falls Lake Study is intended to complement and support the previous and ongoing work. **Consequently, it is important to outline the latest activity from both to provide the full context and scale of research, sampling and monitoring taking place in Falls Lake and in the watershed.**

## Upper Neuse River Basin Association

The Falls Lake Study team has been working closely with the UNRBA to ensure that the research is not duplicating prior efforts and addressing the most critical issues facing Falls Lake. Below is a summary update from the UNRBA's latest initiatives as part of the re-examination process.

The UNRBA was formed in 1996 "to examine water quality conditions and regulatory controls within the Falls Lake watershed" with goals to develop pollution reduction and management strategies that provide a sustainable water supply for the region. The UNRBA supports the implementation of the N.C. Department of Environmental Quality Division of Water Resources' Falls Lake Rules.

UNRBA has contributed to reducing nutrient loading and thus water quality improvements in Falls Lake. According to DWR, the stage I reduction targets for agriculture, wastewater treatment plants, and the N.C. Department of Transportation have been met. In 2012, new development regulations were adopted by local governments, but existing development regulations have not been set. UNRBA has worked to develop regulations that reduce loading from existing development, which includes the Nutrient Development Project and the Stage I existing development Interim Alternative Implementation Approach.

*Nutrient Credit Development Program*

In 2014, UNRBA invested $310,000 in the Nutrient Credit Development Program "to expand the list of state-approved nutrient-reducing practices in North Carolina." Credits for three practices were developed "for remedying illicit discharges, soil improvement, and cattle exclusion." Two additional practices were submitted for credit; DWR is developing the credit for buffer and restoration in developed areas, while credit development for land conservation has been postponed.

*Stage I Existing Development Interim Alternative Implementation Approach (IAIA)*

This program works "to develop an alternative approach for complying with the Rules that uses financial investment in projects and actions that benefit water quality and encourage water management in the watershed." It "promotes actions that provide 'on-the-ground' benefits to the watershed and lake." The IAIA is only valid until the Falls Lake Rules are readopted and is based on voluntary participation.

*Stage II Re-examination*
The Stage II requirements are large and costly additional reductions in nutrient loading from developed lands in the watershed. The predictive model used to develop the Falls Lake Rules was restricted by limited data causing a lot of uncertainty. Because of these reasons, the rules allow for a re-examination.

*Monitoring*
The UNRBA initiated a monitoring plan in 2014 and continued until October 2018. In addition to routine monitoring, special studies conducted provided an understanding of the functions of Falls Lake's physical, chemical, biological, and geological characteristics. "The UNRBA invested approximately $3.5 million in this effort to fill in gaps and improve understanding of the lake and the watershed." The comprehensive monitoring report found that chlorophyll a concentrations are typically much lower in the streams than in the lake. Another key finding is that nutrient loading is not the only driver of algal growth in the lake -- the hydrology, morphology, retention time, depth, and characteristics of the different areas of the lake are just as important.

*Modeling*
Since the completion of the monitoring efforts, the UNRBA has been providing $800,000 annually to support modeling and regulatory efforts. There are four types of models being developed to support the re-examination that will provide evidence for a revised strategy. "After the predictive models are developed, they will be used to evaluate the impacts of different management options on lake water quality and designated uses."

*Looking ahead*
Since completing the four-year monitoring study, the UNRBA is now focusing on the development of the models, which are to be calibrated in 2021. Using the monitoring and modeling data, the UNRBA will propose a revised strategy in 2023.

The full UNRBA update document can be found at: https://nutrients.web.unc.edu/resources/

## NC Department of Environmental Quality 5 Year Report

The Falls Lake Nutrient Strategy is the NCDEQ's comprehensive set of rules enacted in January 2011 "designed to restore water quality in the lake by reducing the amount of pollution entering upstream." The strategy works to reduce nitrogen and phosphorus inputs to Falls Lake to maintain the state's chlorophyll a standard. The rules help to protect the designated uses of Falls Lake, including its water supply, fish and wildlife, flood control, and recreational uses.

**As part of the Falls Lake Rules the Department of Environmental Quality is required to submit a report to the N.C. Environmental Management Commission every five years, which provides an update on water quality progress in the lake. Below is a brief synopsis of the DEQ report submitted in July 2021.**

Stage I of the rules, which have the objective of meeting the chlorophyll a standard in the lower lake was originally 10 years in length, but the General Assembly extended the end of Stage I until the Falls Lake Rules are readopted. Stage II of the rules requires additional reductions in the upper watershed to achieve nitrogen and phosphorus reductions of 40 and 77 percent, and meeting chlorophyll a standards throughout the lake by 2041. It is likely Stage II requirements and timeframe will be reconsidered through the readoption.

To view the full Falls Lake Nutrient Management Strategy: https://deq.nc.gov/about/divisions/water-resources/water-planning/nonpoint-source-planning/falls-lake-nutrient-strategy

In the past five years, the DEQ Division of Water Resources evaluated nitrogen and phosphorus loading to the lake. Using a method that removes the effects of annual flow variations to observe changes that may be a result of nutrient management actions, DWR's analysis indicated a 20 percent reduction in nitrogen and a 52 percent reduction in phosphorus in the 5-tributary load between baseline and 2019.

In 2020, DWR also initiated a study to assess Falls Lake, which involved monitoring and tracking changes in chlorophyll a concentration with implementation of the rules. The first analysis, using 2008-2018 DWR reports, found that most of the lower lake is meeting the chlorophyll a standard in data time frames that roughly correspond to implementation of the Falls Lake rules (Stage 1). Over the last two reports, there has been little change in the lake's status, with the upper lake exceeding the standard.

The second analysis found that chlorophyll a exceeds standards in the upper lake and gradually decreases moving downstream to the dam over periods 2015-2019 and 2011-2014. The analysis for 2015-2019 shows lower standard exceedances lake-wide relative to the baseline period but shows little change from 2011-2014.

The Falls Lake Rules are in their tenth year of implementation. As originally required, all rules are being implemented and each source is meeting or exceeding its Stage I reduction goals. The implementation will continue until the rules are reexamined and readopted in 2026-2027. Over the past ten years DWR has implemented and/or achieved the following:

- *Wastewater*: facilities have achieved 57 percent reduction in nitrogen and 73 percent in phosphorus, exceeding Stage I requirements and just shy of Stage II requirements.
- *New Development Stormwater*: new development stormwater ordinances require development projects to meet at least 30 percent to 50 percent of their nutrient load reduction requirements onsite, while the rest can be met with offsets. Through December 2020, 114,930 pounds of nitrogen and 16,408 pounds of phosphorus offset credits were purchased as part of meeting new development requirements.
- *Agriculture*: agriculture is required to submit progress reports to DWR annually. The 2019 crop-year report estimates reductions in agricultural nitrogen loss of 77 percent and 36 percent from croplands and pastureland, respectively, relative to baseline estimates
- *Existing development*: a compliance option known as the Interim Alternative Implementation Approach, for Stage I was developed due to the need for additional time to expand the "toolbox" of nutrient reduction practices.
- *Strategy-wide activities*: DWR developed a "Catalog of Nutrient Reduction Practices" as a compilation of all currently approved nutrient reducing practices available for use.

The full 2021 status report can be found here: https://deq.nc.gov/media/19917/download

# *Research Summaries*

*The Collaboratory's Falls Lake Study involves several teams of researchers working on specific aspects of the study. Below are summaries of the second year of research activities and initial findings. The full research reports can be found at:* http://nutrients.web.unc.edu/

## In Situ Observational Study of Falls Lake

### *Background*

Falls Lake is a man-made reservoir that was created by the US Army Corps of Engineers (USACE) in the late 1970's. It is 28 miles long with at least 18 tributaries. Six bridge causeways (railroad, I85, Fish Dam Rd, Hwy 50, New Light Rd, and Hwy 98) segment the main stem of the lake, and Hwy 50 divides the lake's volume approximately in half, with the upper section shallower and wider than the lower section.

Outflow of the lake is controlled by USACE for flood control downstream, maintaining a stable lake level, and ensuring there is enough drinking water supply for the surrounding communities.

Since the opening of Falls Lake, the North Carolina Division of Water Quality has obtained water quality data from the lake. It was found that there were over 40 micrograms per liter of chlorophyll a in portions of the lake. This finding elicited a modeling study in the 2000's to identify nutrient reduction targets, and in 2010 rules to reduce nutrient input to the lake were established. The UNRBA, the City of Durham, and NCSU Center for Applied Aquatic Ecology have collected and analyzed water quality data from the lake and its tributaries to supplement the work of the North Carolina Division of Water Quality.

The movement of water and associated components of water (nutrients, sediment, algae, etc.) impact lake water quality. Residence time is a lake-wide average assessment of water movement, influencing the water quality. UNRBA found that residence times varied from 20 days to 2.5 years, and that long residence times corresponded to when USACE would lessen outflow for flood control downstream. It was also found that the timeline of nutrient uptake, algal growth, and primary productivity were fast compared to average transport timescales. The relationship between the short-term hydrodynamics in Falls Lake and productivity was noted by UNRBA to have implications for the lake's water quality model.

### *Questions addressed*

- How do the lake's nutrient levels change differently during high- and low- flow conditions?
- How does water movement over hourly timescales differ from water movement over seasonal scales, and how does this affect nutrient levels in the lake?

### *Research Methods*

Acoustic Doppler current profilers (ADCPs) were used to measure water velocities through the water column at four locations along the lake. Near the ACDPs, moorings were used to measure temperature, irradiance, conductivity, and water depth to gain more understanding in thermal stratification and light extinction. When In Situ instruments were serviced, additional measurements were collected over the side of the boat. These measurements were vertical profiles of photosynthetically active radiation (PAR), temperature, conductivity, turbidity, Chl-a, dissolved oxygen, and pH.

### *Findings*

Observation from this study successfully showed lake circulation over a range of time scales. Lake circulation was shown to vary spatially and between data collection points, and the strongest flows observed were associated with large lake level variations. This observation reflects how lake levels typically rise abruptly after an inflow event from tributaries. Since water flow over the dam is restricted, a more gradual reduction in lake levels is seen as the flow over the dam is increased at established rates after inflow events.

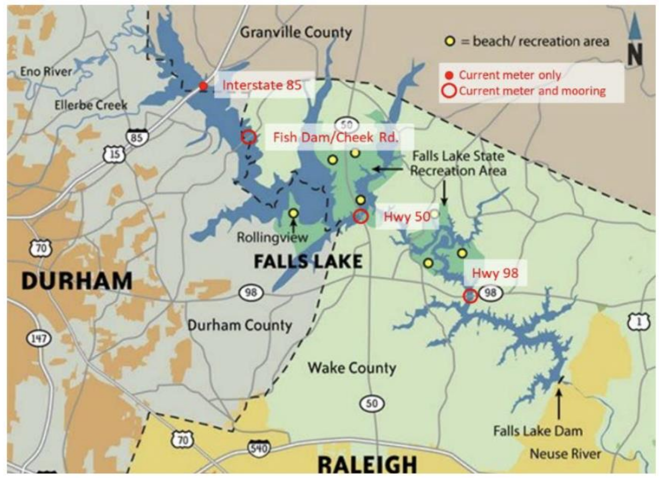



***Figure 2. Locations of in situ ADCPs and water column moorings in Falls Lake***

*Currents*

The currents in the lake show a clear response to the inflow and release cycles, and fast increases in water levels occur with large and brief current pulses in the upper portions of the lake. The magnitude of inflows decreases toward the dam. The release of water at the dam impacts the lower portions of the lake the strongest, but there is still a noticeable impact in the upper portions of the lake. Currents coming from a release of water over the dam are smaller in magnitude than currents associated with inflows but are sustained over a long period of time. Currents during inflow events are uniform with depth and are unidirectional. During periods of limited inflow, when there is little rainfall in the watersheds of the tributaries, the lake level is relatively constant or slowly falling. Currents during these periods were typically <0.1 m/s, but with variations in magnitude and direction with depth. When Falls Lake is thermally stratified, as in the summer, the surface flow usually moves in the direction of the wind and can either be downstream towards the dam or upstream away from the dam. The currents mid-depth may also flow in the opposite direction as the surface water currents. During fall and winter when the lake is less stratified, currents can still have reverse flows with depth, but the magnitude of these currents are less than when the lake is more stratified.

*Oscillation*

There was observed to be a 5.5-hour natural oscillation of Falls Lake. Water levels rise at one end of the lake, then force flow down-gradient along the length of the lake until the lake surface slope is reversed. Then the process is repeated and drives flow in the opposite direction. The nearly constant presence of this oscillation is believed to have a role in mixing of the lake and causing a base level of mixing.

*Thermal Structure of the Lake*

The moorings put in place throughout the lake provided information about its thermal structure. For the year observed, stratified conditions began in March and lasted until late September. The strength of stratification was consistent in the various sites throughout the lake.

*Light Penetration*
The In Situ sensors and shipboard PAR sensors indicated that light penetration increases significantly along the axis of the lake moving towards the dam. Since the majority of freshwater inputs are upriver of the dam, the majority of sediment influx from runoff and high river flow enters the lake system upriver of the dam. The upriver region of the lake is also wider and shallower and historically has had higher chlorophyll a levels. The combination of these factors is expected to contribute to higher turbidity, and therefore lower light penetration toward the upper end of the lake and along the lake gradient as observed.

*Residence Times and Lake Turnovers*
Residence times are a commonly used measure of flushing and is defined as lake volume over the inflow or outflow rate. Residence times are highly variable, and the median value over the last 30 years is 4.75 months. During the sampling period the value was found to be 3.3 months.

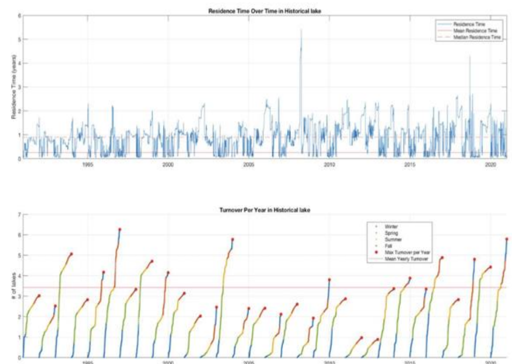


*Figure 15. (top) daily estimate of residence time for Falls Lake, with mean and median values shown as horizontal lines; (bottom) turnovers in a year, shown as a cumulative curve for each year.*

Lake turnovers are also used to measure flushing, which is the number of lake volumes that leave the lake in a given time frame. The long-term lake turnovers in a year are approximately 3.3 months, but for the sampling period it was 5.85 months suggesting that the year sampled was a "wet" year-where there is higher-than-normal inflow to the lake.

## Management Implications
This study continuation has provided much needed data about water cycling within Falls Lake to fill a knowledge gap. With a better understanding of physical factors other than inflow and outflow events that influence water movements, more accurate models can be produced.

The knowledge gained can also aid in creating policy to address nutrient concentration within Falls Lake. With more information about what drives water flow, nutrient reduction targets and strategies can be implemented.

## Researchers

Rick Luettich, Tony Whipple, Harvey Seim, and Ollie Gilchrest
UNC-CH Institute of Marine Sciences, UNC-CH Department of Earth, Marine & Environmental Sciences

## Defining the Balance Between Cyanobacterial $N_2$ Fixation and Denitrification in Falls Lake

### *Background*

The current nutrient response model for Falls Lake was developed by the NC Department of Environmental Quality - Division of Water Resources (DWR) and was used to support Stage II of the Falls Lake Nutrient Management Strategy to reduce nitrogen (N) and phosphorous (P) loads by 40% and 77%, respectively. At the time the model was developed, there was considerable uncertainty in several of the model components-including tributary inputs and sediment nutrient fluxes.

Phytoplankton nutrient limitation in lakes and reservoirs is critically driven by the balance between $N_2$ fixation by cyanobacteria and N removal via denitrification. Denitrification in reservoirs can remove significant quantities of N and can lead to strong N limitation in combination with efficient trapping of P. N limitation has the potential to favor cyanobacteria groups capable of $N_2$ fixation. DWR's current water quality model does not contain $N_2$ fixing cyanobacteria, despite cyanobacteria capable of $N_2$ fixation regularly comprising 25% or more of phytoplankton biomass during the summer. This prevents the ability to simulate these N inputs into the reservoirs, which can lead to serious errors in model estimation. Identifying N inputs by $N_2$ fixation will significantly enhance the understanding of phytoplankton nutrient responses in Falls Lake and fill a significant data gap in the N mass balance for Falls Lake. As this gap in the mass balance is filled, lake-wide N losses through denitrification can be calculated through a mass balance approach.

### *Research Methods*

Water samples were collected between late July 2019 and early July 2020 along a transect of 6 main channel stations. Samples at ten stations within major creek arms were conducted between May and September 2021.

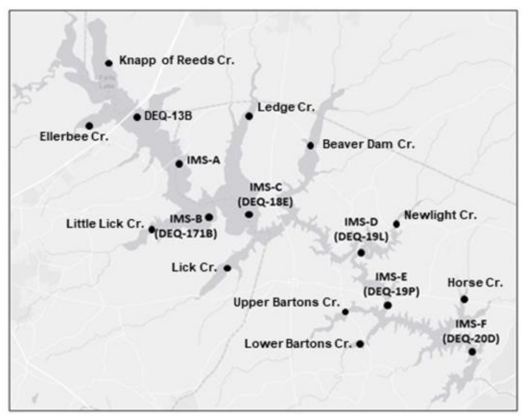



Figure 1. Map of main channel and creek sampling stations for measurements of N fixation rate. Five of the six main channel stations coincided with stations sampled monthly by NC Dept. of Environmental Quality (NCDEQ).

$N_2$ fixation measurements were found using an acetylene reduction technique for the mid-channel locations and creek arm samples.

Samples of each photic zone underwent a dissolved nutrient analysis. Biomass of dominant phytoplankton classes was calculated from accessory photopigment concentrations using the matrix factorization program. Biomass of potentially $N_2$ fixing, heterocystous cyanobacteria was found through microscopical enumeration. Examining the relationship between directly measured rates of $N_2$ fixation by biomass of heterocystous cyanobacteria allowed an estimate of the biomass-specific rate of $N_2$ fixation. This biomass-specific rate of $N_2$ fixation was used with a time series of heterocystous cyanobacteria biomass collected by NCDEQ to estimate an approximate monthly time series of $N_2$ fixation from 2011 to 2020.

Lake-wide annual N input due to $N_2$ fixation was calculated in two ways. The first relied solely on direct measurements of $N_2$ fixation from the water samples collected. The second scaled up and averaged the monthly time series of $N_2$ fixation that was estimated from the biomass-specific rate of $N_2$ fixation by heterocystous cyanobacteria.

A set of nutrient addition bioassay experiments was conducted at three creek stations during spring and summer 2021 to determine the limiting nutrient in the creek arms and to determine the extent to which P availability impacts $N_2$ fixation.

Annual stream loads of total N and total P into and out of Falls Lake were calculated using the weighted regressions on time, discharge and seasonal model based on gaged stream flows, and monthly concentration data. Inputs of N were calculated as the sum of tributary loads, atmospheric deposition and $N_2$ fixation, and the retention of N and P were found as the difference between inputs and outputs. The whole lake denitrification rate was estimated based on the ratio of N:P retention and mass ratio of surface sediments that were determined by a previous study (Alperin 2019).

*Findings*

Rates of $N_2$ fixation generally ranged from 0-5 nmol N/L/h with an average of 1.3 nmol N/L/h. A general but weak trend showed that higher rates of $N_2$ fixation occurred in samples incubating closer to the surface, indicating that light availability is likely a constraint on $N_2$ fixation in Falls Lake.

In the main channel stations, there was a statistically significant, negative relationship observed between $N_2$ fixation and ammonium, which is expected as ammonium is known to inhibit the synthesis of the enzyme complex required for $N_2$ fixation. Phosphate exhibited a statistically significant positive relationship to $N_2$ fixation. These results support the current paradigm that $N_2$ fixation is promoted under conditions of low N and high P availability.

There was observed to be a strong and statistically significant relationship between biomass and $N_2$ fixation. Estimates of $N_2$ fixation rates based on heterocystous cyanobacteria biomass varied seasonally from about 0.1 nmol N/L/h during the winter to above 10 nmol N/L/h during the summer.

There was variation in the calculated annual N input due to $N_2$ fixation to Falls Lake depending on the method used. The annual N input due to $N_2$ fixation derived from direct measurements from $N_2$ fixation from water samples was ~6600 kg N/year, supplying an average of ~1% of the tributary N loads. Estimation of lake wide annual $N_2$ fixation rates based on heterocystous cyanobacteria biomass averaged 23,000 kg N/y, contributing ~5% of the tributary N load. Annual estimates of $N_2$ fixation derived from both methods were added to annual estimates of tributary N loads and atmospheric deposition to develop a mass balance for N for each method for the years 2006-2019. Rates of denitrification differed depending on the mass balance for each method used. Denitrification rates derived via direct measurements from $N_2$ fixation from water samples averaged $3.8 \times 10^4$ kg N/year, while rates from heterocystous cyanobacterial biomass averaged $4.1 \times 10^4$ kg N/year.

*Management Implications*

This study fills a knowledge gap about nutrient fluxes in Falls Lake. By reducing uncertainty about the balance between $N_2$ fixation and N removal through denitrification, a more accurate nutrient response model can be created to provide precise target N and P reduction goals to lower phytoplankton biomass to meet water quality standards.

*Researchers* Nathan Hall and Hans Paerl, UNC-CH Institute of Marine Sciences

## Cyanotoxin Presence and Year-round Dynamics in Falls Lake

### *Background*

Cyanobacterial Harmful Algal Blooms (CyanoHABs) in North Carolina freshwater systems can negatively impact drinking water, fisheries, tourism, and food web resilience. The goal of this research is to examine the spatiotemporal dynamics of CyanHABs in relation to cyanotoxins in Falls Lake. Algal growth and cyanotoxin presence were observed at multiple sampling sites throughout Falls Lake to identify the environmental conditions that seem to favor algal growth and/or toxin productions ("hot spots"). Additionally, this study aimed to identify the cyanobacterial taxa that are dominating the system and associated with toxin presence and determine if the data collected indicates the accumulation of cyanobacterial biomass and/or toxins in certain regions of the lake.

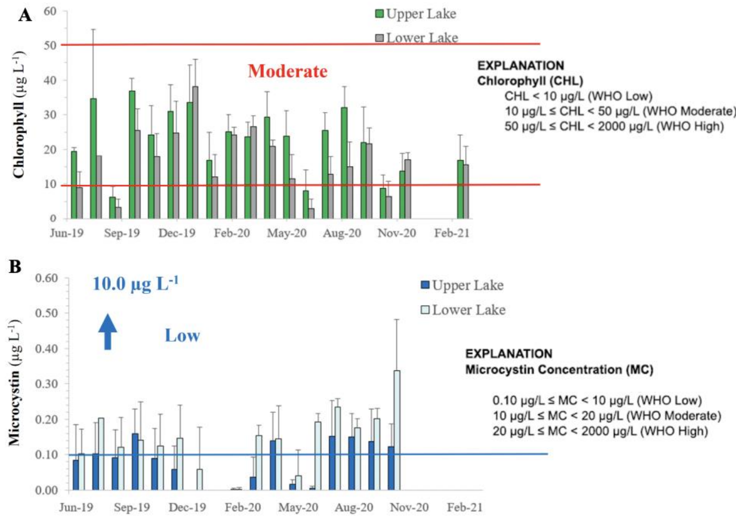
### *Research Methods*

Monthly surveys were conducted in collaboration with the North Carolina Department of Environmental Quality (NC DEQ) through the NC DEQ's Ambient Water Monitoring Program. Whole lake water was collected at 11 stations to determine particulate and dissolved toxins levels, as well as chlorophyll a concentrations. Additionally, 4 out of 11 sampling stations had Solid Phase Adsorption Toxin Tracking (SPATT) units deployed to screen for MCY, ANA, and CYL. SPATT units are a screening tool that allow for the detection of specific toxins when traditional monitoring approaches cannot resolve toxin presence. All toxins' samples and chlorophyll a were analyzed following previously established protocols, and dissolved oxygen, temperature, conductivity, and pH were measured using a YSI sonde with support from the NC DEQ.

### *Findings*

Overall algal biomass (chlorophyll a) averaged slightly higher within the upper, wider portion of the lake (26.65 $\mu g\ L^{-1}$) compared to the more restricted, narrower, lower part of the lake (19.45 $\mu g\ L^{-1}$). Chlorophyll a level remained relatively high throughout the late fall and early winter months, with concentrations of chlorophyll a exceeding 40 $\mu g\ L^{-1}$ in 11% of the measurements. This value of chlorophyll a showed the lake to be impaired, and overall observed the chlorophyll a range aligns Falls Lake with water bodies characterized to hold moderate exposure risk for MCY (microcystin) based on the World Health Organization guidelines. However, when refining categorization based on the collected MCY measurements from this study, Falls Lake can be re-categorized as low exposure risk for MCY. Overall, MCY concentrations tended to be slightly higher for the lower part of Falls Lake, supporting that chlorophyll a often does not spatially follow trends for toxins.

**Figure 1:** (A) Chlorophyll a and (B) total MCY concentrations (both in µg L$^{-1}$) shown as average across the upper and lower Falls Lake stations from June 2019 to February 2021 and November 2020, respectively. Red lines indicate the WHO-recommended thresholds for MCY exposure risk levels based on each of the parameters (see legend). Sampling for December 2020 and January 2021 was cancelled due to COVID19 concerns.




Over two years of observation, it was found that MCY and ANA are the most prevalent toxins found across the lake with CYL also being present at times. Through cyanotoxin analyses for whole water samples, it was found that the total MCY averaged 0.11 µg L$^{-1}$. CYL concentrations averaged 0.04 µg L$^{-1}$. MCY was detected both intracellularly and dissolved, ANA was detected mostly in the particulate phase, and CYL was only measured in the dissolved fraction.

**Table 1**: Summary of analyses for 5 cyanotoxins using discrete samples (grab samples) and *in-situ* toxin tracking (n = 879; see further in text). MCY = microcystin, CYL = cylindrospermopsin, ANA = anatoxin, STX = saxitoxin and BMMA = beta-Methylamino-L-alanine.

| | Particulate | | Dissolved | | SPATTs | |
|---|---|---|---|---|---|---|
| | % pos | n | % pos | n | % pos | n |
| MCY | 61 | 175 | 56 | 163 | 88 | 50 |
| CYL | 0 | 82 | 16 | 80 | 31 | 51 |
| ANA | 97 | 64 | 4 | 48 | 0 | 21 |
| STX | 0 | 30 | 0 | 36 | | |
| BMAA | 67 | 30 | 10 | 49 | | |

Currently there is limited data available on how quickly various toxins are released from cyanobacterial cells throughout the early phases of a bloom. However, several studies suggest that the release of toxins may be quick as a bloom reaches its peak, and then starts to decline. Data from this study also indicate that certain areas within the lake showed relatively high dissolved concentrations where toxin residence times may be prolonged.

*Management Implications*
Data from this study show that maximal toxin concentrations did not exceed regulatory thresholds set through the World Health Organization. However, there may be potential risks from continual low-level exposure to multiple toxins with a year-round presence. The prevalence of MCY and simultaneous presence of multiple cyanotoxins may call for future examination of toxin transfer to higher trophic levels (ex. fish) which could pose a risk for human consumption.

This was the first comprehensive study that focuses on cyanotoxin dynamics in Falls Lake, and this information is valuable for local residents, monitoring agencies, and recreational users of the lake. Based on the preliminary data, regular toxin monitoring seems warranted for several toxins to more accurately assess the water quality and ecosystem health for Falls Lake. This study can serve as a baseline for cyanotoxin dynamics in Falls Lake, and help future studies evaluate potential food web impacts and public health exposure risks for recreational users of the lake.

*Continuation of Study*
For the continuation of this study, it is intended to continue toxin measurements for MCY at all 11 stations, for CYL at 7, for ANA, BMMA, and STX at 3 priority stations. The focus of the upcoming project will be to characterize cyanobacterial communities throughout Falls Lake, identify how species composition is related to toxin patterns, and establish whether toxin populations are connected throughout the lake-indicating areas that are primarily bloom and/or toxin production sites.

*Researcher*
Astrid Schnetzer, North Carolina State University

## The Importance of Impoundment Ecosystems to Global Organic Cycling and Climate Change in Falls Lake

### *Background*

This study is a two-part research project examining sediment and carbon cycling in Falls Lake with an overall aim to better understand the sediment fluxes associated with Falls Lake, from rates of sediment input to the fate of particulate materials within the lake from seasonal to decadal timescales.

### *Research Objectives*

1. To quantify the temporal and spatial inputs of suspended sediments and associated organic carbon to Falls Lake.
2. To collect cores within Falls Lake to quantify rates of bottom sediment accumulation, which will help quantify carbon and nutrient fluxes in bottom sediments.

### *Research Methods*

Collectively, the Flat River, Eno River, Little River, and Ellerbe Creek contribute approximately 70% of the water discharge into Falls Lake. Water discharge was monitored, and water samples were collected from these four major inputs. Water discharge was monitored over the course of the year to fill in gaps in online and easily accessible 2019-2020 water discharge data from the US Geological Survey (USGS). Water samples were analyzed to determine total suspended matter (TSM) and particulate organic carbon (POC) concentrations. A sediment rating curve (plotting TSM concentrations vs. water discharge) was constructed for each of the four water inputs to assist in predicting sediment inputs to Falls Lake. A relationship for TSM vs. POC concentration was established for each of the inputs to give insight into how the organic carbon fraction of suspended matter varies over space and time. A water discharge vs. POC concentration rating curve was also created for each of the inputs to predict POC concentrations and flux based on water discharge.

To quantify sediment and carbon accumulation rates, 30-50 cm sediment cores were collected by boat from 9 stations throughout Falls Lake. The cores were analyzed for the natural radiotracer $^{210}Pb$, which is used to quantify sediment and carbon accumulation rates on the lakebed over decadal time scales. Analysis of the cores is ongoing. Sediment accumulation rates were plotted as a function of depth in the core to observe changes in sedimentation rate over the past approximately 60 years since Falls Lake reservoir was established. A time history within the sediments of Falls Lake was created, which can be used to examine other contaminant and nutrient inputs to Falls Lake over time. Sediment cores were also analyzed for organic carbon concentrations to determine organic carbon accumulation rates.

*Findings*

*Quantifying the temporal and spatial inputs of suspended sediments and associated organic carbon to Falls Lake*

During the study period the water discharge had a large range for all four inputs, ranging from 1-6000 cubic meters per second (CMS). None of the sample collections were near a high flow stage, rather they represented medium-low discharge flows. The TSM vs. water discharge rating curve for Ellerbe Creek and Little River were best represented by linear regressions with $R^2$ values above 0.95, indicating that discharge rarely results in water levels high up on the banks or in water levels that overbank. The Eno River and Flat River display a more typical rating curve that was best represented through a logarithmic relationship, with an initial steep increase in TSM at lower water discharge values and reaching an asymptote in TSM values as water discharge reaches maximum values. In all four water inputs rating curves were created to adequately predict TSM values at a given location and discharge, showing that TSM can be predicted using water discharge data readily available online from the USGS. POC values appear to be strongly correlated with TSM values, which means POC values of Falls Lake inputs are also able to be predicted based on water discharge values.

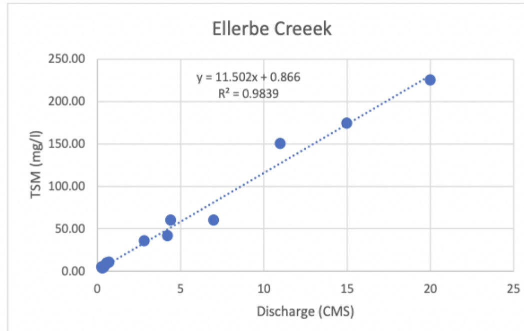



**Figure 1** shows the relationship between water discharge (CMS cubic meters per second) and TSM (total suspended matter; mg/l) for Ellerbe Creek

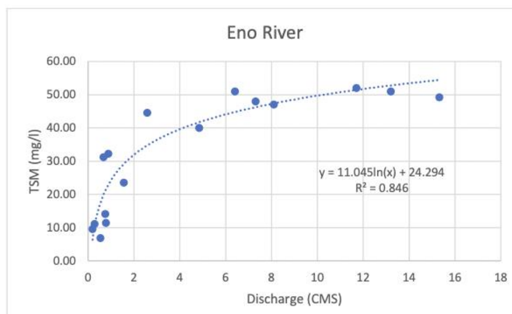



**Figure 3** shows the relationship between water discharge (CMS cubic meters per second) and TSM (total suspended matter; mg/l) for Eno River

*Using sediment cores within Falls Lake to quantify rates of bottom sediment accumulation*

Sediment accumulation rates for cores that have been quantified and modeled so far range from 0.7 to 1.0 cm y-1. These rates are higher than most estuaries and provide insight into potential total sediment that is accumulating in Falls Lake. The sediment accumulation rate was found to have increased 3-4 times over the past 45 years at two sampling stations in Falls Lake. Carbon accumulation rates observed have also increased 3-4-fold over the past 45 years, which demonstrates that carbon storage has dramatically increased alongside $CO_2$ emissions in some parts of Falls Lake.

*Management Implications*

This study fills a knowledge gap of sediment and carbon accumulation rates to provide crucial insight into particulate matter fluxes, which is important for nutrient management of Falls Lake. Past literature has suggested that lakes and impoundments may bury four times as much carbon as the world's oceans, which has significant impacts on global carbon sequestration and climate. This study deepens understanding of the role of reservoirs like Falls Lake into carbon sequestration, which is becoming increasingly important as $CO_2$ emissions continue to rise.

*Researchers*


Brent McKee, Sherif Ghobrial, and Scott Booth
UNC-CH Department of Earth, Marine, and Environmental Sciences

## Nutrient Loading from Onsite Wastewater Systems in the Falls Lake Watershed: Evaluating the Potential for Nutrient Load Reductions via Bioreactors

### *Background*

Onsite wastewater treatment systems (also known as septic systems) are commonly used wastewater treatment systems for people living in suburban or rural areas in North Carolina, and it is estimated there are 50,000 septic systems in the Falls Lake Watershed. Septic systems have the potential to discharge elevated levels of pollutants and nutrients to groundwater and/or surface waters downgradient from disposal fields, which may reach Falls Lake and contribute to eutrophication in the lake. The goal of this research was to use an integrated approach to identify tributaries of the Falls Lake Watershed with elevated system nutrient loads and evaluate the potential for in-stream bioreactors to reduce nutrient loads to Falls Lake.

### *Questions Addressed*

- Which stream reaches in the Falls Lake watershed are most vulnerable to excess nutrient loading from onsite wastewater treatment system inputs?
- Which sub-watersheds in the Falls Lake watershed that have elevated septic system densities (> 1.5 systems/ha) have elevated baseflow nutrient concentrations?
- Does the published literature suggest that in-stream bioreactors can reduce nutrient inputs to Falls Lake, and if so what types of systems are most likely to be effective and what are the potential reductions?
- What bioreactor porous media are most effective at reducing onsite nutrient transport?
- What are the optimal locations for bioreactors along low-order streams to reduce nutrient inputs to Falls Lake?

### *Research Methods*

Geographic Information System (GIS) analysis was used to evaluate septic system density and identify potential sub-watersheds with elevated septic system densities (> 1 system $ha^{-1}$). Land cover data was also used to estimate the potential locations for in-stream bioreactors, riparian buffer restoration, or other best management practices (BMPs) designed to enhance nutrient reduction.

Water quality was assessed through sampling sub-watersheds with elevated septic system densities in December 2020 and February 2021. A multiprobe sonde was used to measure water temperature, pH, dissolved oxygen, conductivity, and oxidation-reduction potential. Samples were analyzed for nitrate, ammonium, total Kjeldahl nitrogen (TKN), particulate nitrogen (PN), total phosphorus (TP), total dissolved phosphorus (TDP), phosphate, particulate phosphorus (PP), dissolved organic carbon, and total dissolved nitrogen (TDN). Dissolved organic nitrogen (DON), total nitrogen (TN), and total phosphorus (TP) were calculated from sample analysis.

A pilot-scale experiment was designed to gather information on the use of denitrifying bioreactors paired with phosphate sorbents. In this experiment, the efficacy of 3 different substrates as bioreactors (roasted peanut shells, pine bark, wood chips of mixed species) were compared, and the efficacy of 3 different hydraulic retention times (HRT) (30 minutes, 1 hour, and 2 hours) were also compared. Water with a concentration of $NO_3$-N and 1 mg/L $PO_4$-P was pumped through the bioreactors at a constant rate depending on the hydraulic retention time being tested. Samples were collected at different pore volumes to capture the reduction in nitrate-N at steady state.

### *Findings*

*Which stream reaches in the Falls Lake watershed are most vulnerable to excess nutrient loading from onsite wastewater treatment system inputs?*

Previous research shows that septic system density is an important factor impacting nutrient loading from septic systems to streams. Numerous clusters of high septic system densities were found in the southeastern portion of the Falls Lake watershed, primarily in Wake County. Similar clusters of high septic system densities were also observed in the central portion of Durham County. The high septic system density in these areas suggests that the stream reaches in these sub-watersheds are vulnerable to nutrients from septic systems. Previous research also suggests that the Triassic Basin is vulnerable to elevated nutrient levels from septic systems due to elevated septic system density and soil properties.

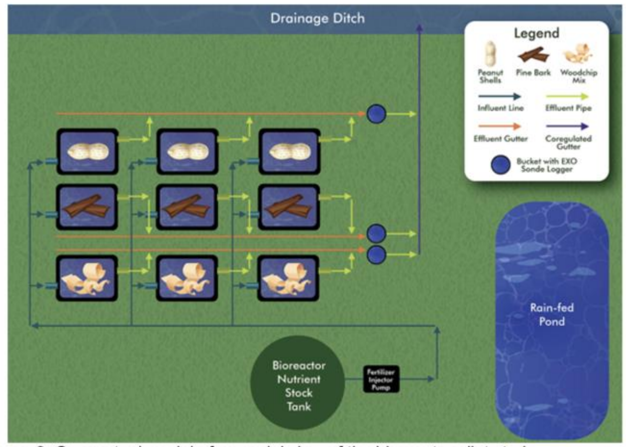


**Figure 3.** Conceptual model of an aerial view of the bioreactor pilot study.

*Which sub-watersheds in the Falls Lake watershed that have elevated septic system densities (> 1.5 systems/ha) have elevated baseflow nutrient concentrations?*

Most of the studied sub-watersheds showed elevated concentrations of total nitrogen (TN) and total dissolved nitrogen (TDN), with concentrations of TN and TDN ranging from 1.5 to 10 mg $L^{-1}$. Previous research suggests that eutrophication can occur at TN values above 1.5 mg $L^{-1}$, and 25 of the studied sub-watersheds had TN values above this. Eight of these sub-watersheds had a median T concentration > 2 mg $L^{-1}$, and septic system density in these sub-watersheds mostly exceeded 1.5 systems $ha^{-1}$. Isotopic analysis suggested that watersheds with a higher density of septic systems (2-2.25 systems $ha^{-1}$) were more likely to contain nitrate originating from a human and/or animal waste signature.

A past study devised target thresholds for total phosphorus (TP) in agricultural watersheds ranging from 0.013-0.036 mg $L^{-1}$. Based on this range, 23 of the studied sub-watersheds contained elevated TP concentrations, with median concentrations of TP and TDP in the sampled sub-watersheds being 0.05 and 0.03 mg $L^{-1}$, respectively. These results show that septic systems can be a source of nitrate in sub-watersheds, and other nutrients may be reaching sub-watershed outlets and increasing nutrient loads to Falls Lake.

*Does the published literature suggest that in-stream bioreactors can reduce nutrient inputs to Falls Lake, and if so what types of systems are most likely to be effective, and what are the potential reductions?*

In-stream bioreactors are designed similarly to denitrifying bioreactors. Denitrifying bioreactors contain carbon-rich media that reduces nitrate compounds into dinitrogen gas. These bioreactors have been adopted to treat elevated nutrients from human and animal waste, and past studies have found that denitrifying bioreactors can reduce nitrate-N concentrations by 14 – 98%. Phosphate sorbents can be paired with denitrifying bioreactors to attenuate nitrates and phosphates from the water. A past study reported that a phosphate sorbent paired with a denitrifying bioreactor had an average dissolved phosphorus reduction of 45%. In-stream bioreactors are installed in the streambed of small drainage ways, tile drains, or shallow, low-order streams for denitrification through a carbon-rich media (usually woodchips). At the time of this study, in-stream bioreactors have not been widely used. Past studies suggest that in-stream bioreactors or other denitrifying bioreactors can be effective in reducing nonpoint sources of nitrate and phosphate in shallow, low-order streams in the Falls Lake watershed. However, additional research is needed to evaluate the efficacy of denitrifying bioreactors.

*What bioreactor porous media are most effective at reducing onsite nutrient transport?*
Preliminary results indicate that pine bark is the most effective media for promoting denitrification and the HRT of 2 hours appears to have the most potential for nitrate reduction (between 15-100%). This data suggests that pine bark can reduce annual nitrate masses by up to 15.6 pounds per cubic feet of bioreactor at an HRT of 2 hours.

*What are the optimal locations for bioreactors along low-order streams to reduce nutrient inputs to Falls Lake?*
Optimal locations for bioreactors are influenced by many factors, including septic system densities, soil type, and geology. Based on these factors, the Triassic Basin region of the Falls Lake watershed would be a good area to focus bioreactor efforts due to its propensity for elevated nutrients in stream reaches. Also, important considerations in determining optimal location for bioreactors are nutrient concentration and speciation. The most optimal location would be a stream reach containing elevated nutrients, mainly nitrate and phosphate. Park Ridge, Kinsdale 1 and 2, Woody, Barclay, and Asbury would be excellent candidates for in-stream bioreactors since nitrate was the dominant species in TN. Additionally, Greens Down 1 and 3, Appaloosa Run East, Tacketts Pond 1, Jenkins, Leslie 1, and Brookfield could also be considered since nitrate comprised > 30% of TN. The Asbury, Green Bay, Harold, Woody, and Donlin sub-watersheds are excellent candidates for a bioreactor with sorbent reactive media designed to immobilize phosphate, as phosphate is prominent in the TP of these sub-watersheds.

### *Management Implications*

This study shows that most sub-watersheds contained elevated nitrogen and phosphorus concentrations compared to reference conditions. Using an integrated approach is useful in identifying sub-watersheds with elevated nutrients and to consider practices to remediate elevated nutrients. Previous research shows that in-stream bioreactors can reduce nitrate and phosphate concentrations by approximately 78% and 74%, respectively, indicating these bioreactors can be a useful tool in managing nutrient levels in sub-watersheds. Results from the bioreactor pilot study suggest that pine bark was an effective media for denitrification and its nitrate reduction efficiency was similar to recent studies on in-stream bioreactors. Additional research is recommended to evaluate the efficacy of in-stream or stream adjacent bioreactors in nutrient management strategies, especially in sub-watersheds with elevated nutrient concentrations and septic system densities.

*Researchers* Guy Iverson, Michael O'Driscoll, Charles Humphrey, Natasha Bell, Ann Marie Lindley, John Hoben, and Jennifer Richardson East Carolina University

## Paying for Nutrient Management in the Falls Lake Watershed

In year two of the Falls Lake Nutrient Management Study, the Environmental Finance Center (EFC) engaged with stakeholders in the Falls Lake watershed to understand their nutrient management spending and strategy and the impact of the Falls Lake Rules on stakeholders' spending. The EFC also developed a revenueshed tool in Tableau to explore the implications of raising funds for nutrient management projects and track the progress of the Interim Alternative Implementation Approach (IAIA) as written by the UNRBA.

The UNRBA includes 13 of the 15 jurisdictions governed by the Falls Lake Rules and involves members of the agricultural and environmental advocacy communities. It has advocated for a re-examination of Stage II of the Rules, which is the more intensive and costlier stage. The Falls Lake Rules necessitated specific measures to comply and increased the timing and amount of nutrient management strategies within jurisdictions as well as regional cooperation to comply with the Falls Lake Rules. However, if the rest of the rules are implemented as currently written, there would be a significant financial burden on local governments. As such, UNRBA supports the re-examination of the rules and the possible adoption of a site-specific standard for Falls Lake. UNRBA has also created and advocated for the IAIA, which began July 1, 2021, and aims to help jurisdictions comply with Stage 1, existing development, of the rules.

The IAIA expands the list of allowable nutrient reduction options, allows jurisdictions to collaborate on strategy implementation for nutrient reduction, and tracks financial investment rather than nutrient reductions. The general view of the IAIA among interviewees was positive or neutral, with many noting that it would be less expensive than compliance with the Falls Lake Rules as originally written. Given the flexibility and the opportunity to receive credit for already completed projects under the IAIA, the EFC expects to see a broad range of effort and accomplishments, which it will track alongside UNRBA in year three. Overall, UNRBA is viewed positively by members because it facilitates monitoring, modeling, and advocacy, while promoting communication and collaboration across organizations.

### *Revenueshed Analysis*

A revenueshed is an area within which revenue is generated for watershed protection and it expands the traditional impactor pays model to include those that benefit from watershed protection without directly impacting water quality. UNRBA established its own revenueshed via the membership fee schedule with a flat fee dues model, area in the watershed (impact), and water demands (benefit). The Falls Lake revenueshed provides a baseline revenue generation and the revenueshed tool can show how small increases in existing fees and taxes can result in significant revenue generation.

#### *Revenueshed Analysis for Falls Lake*

The Falls Lake watershed spans six counties and includes all or part of eight municipalities. These counties and municipalities have over $35 billion in taxable value within the watershed. Four drinking water utilities get water from Falls Lake or reservoirs within the watershed, three wastewater utilities have NPDES wastewater permits for discharging effluent into the watershed, and 10 stormwater utilities have systems completely or partially within the watershed.

To protect Falls Lake, Raleigh instituted a watershed protection fee in 2011 of $0.15 per 1,000 gallons for all water users, generating about $2.25 million annually. Additionally, Durham introduced a "penny per tier" watershed protection fund with $0.01 per CCF charged to Durham water customers, raising around $100,00 a year.

### *Innovative Fees for Financing Water Quality Projects*

Finding alternate sources of financing within the revenueshed can help generate the dollars needed for nutrient reduction projects for Falls Lake. The EFC searched for case study examples of programs that leverage creative revenue sources for watershed protection. One example is a usage fee, which refers to charges imposed on persons that use the benefits or services that a state, local, or federally protected area offers. These can include boating fees, hunting/fishing licenses, or park entry fees. Yet, overall, this is an unexplored area of environmental finance. The following programs are used to generate revenue for water and aquatic habitat restoration efforts.

In Maryland, the Chesapeake Bay trust fund collects money from vehicle license plates, donations through the state income tax form, other private donations, and partnerships with other foundations and agencies. Additionally, the Maryland Waterway Improvement fund uses funds collected from a water vessel excise tax to support water quality improvements. Maryland also has the state-run Program Open Space which uses property taxes to protect land and reduce runoff into waterways. Finally, the Pennsylvania Fish and Boat Commission runs a voluntary habitat/conservation permit program that collects voluntary contributions from anglers and non-anglers across the state for fish habitat work, research, and stream habitat restoration.

### *Researchers*

Erin Riggs, Evan Kirk, and Elsemarie Mullins, UNC Environmental Finance Center

## Assessment of Zooplankton-phytoplankton Relationships in Falls Lake to Guide Development of Site Specific Numeric Nutrient Criteria

### *Background*

Increasing nutrient enrichment in lakes and reservoirs changes the palatability and nutritional value of primary producers and causes other structural changes in the food web. This leads to a decrease in efficiency of trophic transfer from primary producers to zooplankton, causing many of the classic symptoms of eutrophication. Trophic transfer has an important role in determining the expression of eutrophication, and there is considerable interest in using trophic transfer efficiency as a metric for establishing regulatory criterion for acceptable levels of phytoplankton biomass in U.S. lakes and reservoirs. This project examines the trophic relationship between zooplankton and phytoplankton within Falls Lake to provide guidance for developing site-specific nutrient criteria that is protective of aquatic life uses.

### *Questions Addressed*

- Does the spatial temporal distribution of zooplankton and phytoplankton within Falls Lake indicate significant coupling or decoupling between phytoplankton and zooplankton production?
- How does the trophic transfer efficiency in Falls Lake compare to similar water bodies in the southeastern US?
- Is there a clear inflection point in the slope of the relationship between zooplankton and phytoplankton biomass for Falls Lake that may guide development of a site-specific criterion?
- Is there a clear inflection point in the slope of the relationship between zooplankton and phytoplankton biomass for southeastern reservoirs that may help guide development of a region-specific criterion for phytoplankton biomass that could be adopted for use in Falls Lake?

### *Research Methods*

Zooplankton data from Falls Lake was provided by Dr. Sandra Cooke, Assistant Professor at Greensboro College, who conducted a study of zooplankton in Falls Lake in collaboration with water quality sampling conducted by North Carolina State University's Center for Applied Aquatic Ecology (CAAE). Zooplankton samples were collected at 10 CAAE monitoring stations in Falls Lake with approximate monthly frequency from 2009-2012. Stations were grouped into 3 clusters-upper main arm of the lake, a mid-lake region, and a lower lake region.

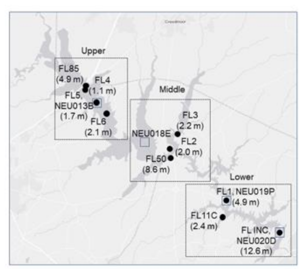



**Figure 1. Map of zooplankton sampling stations (stations beginning FL), average net tow depths at those station, and NC DEQ stations where phytoplankton community composition is monitored in Falls Lake (stations beginning NEU0).**

At each station, duplicate zooplankton samples were collected using a vertical net tow from the bottom to the surface using a zooplankton net and zooplankton were identified to the lowest possible taxonomic level. Biomass of each zooplankton taxa was found by multiplying measured organism density by estimates of dry body weights for each taxa. Average organism abundance (animals/L) at each site visit was calculated as the mean of the duplicate net tow. Hydrographic profiles were conducted, and water samples were collected at the sites to calculate phytoplankton biomass, measured as chlorophyll a. The EPA National Lakes Assessment dataset of southeastern (EPA region 4) reservoirs at elevations less than 500 m was used to compare relationships between zooplankton and phytoplankton biomass in Falls Lake against similar reservoirs, and to investigate the possibility of deriving a region-specific chlorophyll a criteria that might be adopted for use in Falls Lake.

### *Findings*

*Does the spatial temporal distribution of zooplankton and phytoplankton within Falls Lake indicate significant coupling or decoupling between phytoplankton and zooplankton production?*
The relationship between zooplankton biomass and phytoplankton (measured as chlorophyll a) was consistently negative across the observed range of chlorophyll a values. This negative relationship is explained by both zooplankton and phytoplankton exhibiting strong seasonality with largely opposite seasonal patterns, which is likely caused by zooplankton consumption of phytoplankton in the spring and fish consumption of zooplankton during the summer. In Falls Lake, there was observed to be a low zooplankton biomass to chlorophyll a biomass ratio. However, Zooplankton and phytoplankton biomass significantly increased from the lower to upper regions in Falls Lake, showing a positive spatial relationship indicating a strong coupling along the downstream to upstream trophic gradient. The positive spatial relationship indicates that the negative relationship observed at the scale of individual observations must be driven by temporal variability in the plankton. The spatial temporal distribution of zooplankton and phytoplankton provides evidence for a strong trophic linkage between zooplankton and chlorophyll a biomass in Falls Lake.

*How does the trophic transfer efficiency in Falls Lake compare to similar water bodies in the southeastern US?*
Compared to other similar water bodies in the southeastern US, the average zooplankton to phytoplankton biomass ratio of Falls Lake is indicative of a poor trophic transfer efficiency from phytoplankton to zooplankton. The zooplankton to phytoplankton biomass ratio averaged nearly an order of magnitude lower for Falls Lake than other similar reservoirs.

*Is there a clear inflection point in the slope of the relationship between zooplankton and phytoplankton biomass for Falls Lake that may guide development of a site-specific criterion?*
Historically, the inflection point in the slope between zooplankton and phytoplankton biomass has been used as the threshold level of P where coupling zooplankton and phytoplankton production begins to deteriorate. The negative relationship between zooplankton and phytoplankton does not provide an inflection point to develop site-specific criterion for chlorophyll a.

*Is there a clear inflection point in the slope of the relationship between zooplankton and phytoplankton biomass for southeastern reservoirs that may help guide development of a region-specific criterion for phytoplankton biomass that could be adopted for use in Falls Lake?*
In southeastern reservoirs, the best-fit, piece-wise model of zooplankton biomass increased gradually from a low of about 20 μg L-1 zooplankton at 1 μg L-1 chlorophyll a to a maximum of about 100 μg L-1 zooplankton at 51 μg L-1 chlorophyll a, and then declined with further increases in chlorophyll a. The chlorophyll a inflection point where the slope of the zooplankton and phytoplankton relationship is zero should be considered as the upper acceptable limit of chlorophyll a, in this case 51 μg L-1. However, this model only explained less than 7% of the variability in zooplankton biomass, which casts doubt on the underlying assumption that all types of water bodies will demonstrate strong bimodal (increase then decrease) responses of zooplankton biomass to increases in phytoplankton biomass.

### *Management Implications*

Water quality in Falls Lake is currently managed under the Falls Lake reservoir nutrient management strategy-which has established a target of reducing N and P loads by 40% and 77% respectively by 2040 at the cost of approximately 1 billion dollars. Since nutrient reduction efforts have a high cost, this research provides scientific evidentiary support to develop understanding of the relationship between phytoplankton biomass and its impact on aquatic life and usage in Falls Lake.

### *Researchers*

Nathan Hall and Michael Piehler
UNC Institute of Marine Sciences and UNC Institute for the Environment

# Appendix I

## Legislative Text of Session Law 2016-94, Section 14.13. (c)

*Of the funds appropriated to the Board of Governors of The University of North Carolina, the sum of five hundred thousand dollars ($500,000) for each of the fiscal years from 2016 – 2017 through 2021 – 2022 is allocated to the Chief Sustainability Officer at the University of North Carolina at Chapel Hill to designate an entity to oversee a continuing study and analysis of nutrient management strategies (including in situ strategies) and compilation of existing water quality data specifically in the context of Jordan Lake and Falls Lake.*

*As part of this study, the entity shall*

- *(i) review data collected by the Department of Environmental Quality and by other stakeholders from water sampling in areas subject to the Falls Lake or Jordan Lake Water Supply Nutrient Strategies and compare trends in water quality to the implementation of the various elements of each of the Strategies and;*
- *(ii) Examine the costs and benefits of basin wide nutrient strategies in other states and the impact (or lack of impact) those strategies have had on water quality.*

*The entity shall report to the Environmental Review Commission, the Environmental Management Commission, and the Department of Environmental Quality as set forth below:*

- *(1) With respect to Jordan Lake, the final results of its study and recommendations for further action (including any statutory or regulatory changes necessary to implement the recommendations) no later than December 31, 2018, with interim updates no later than December 31, 2016, and December 31, 2017.*

- *(2) With respect to Falls Lake, the final results of its study and recommendations for further action (including any statutory or regulatory changes necessary to implement the recommendations) no later than December 31, 2021, with interim updates no later than December 31, 2019, and December 31, 2020. No indirect or facilities and administrative costs shall be charged by the University against the funds allocated by this section. The Department of Environmental Quality shall provide all necessary data and staff assistance as requested by the entity for the duration of the study required by this subsection. The Department shall also designate from existing positions an employee to serve as liaison between the Department and the entity to facilitate communication and handle data requests for the duration of the project.*

# Appendix II

## Roster of Study Team Members

| Name | Affiliation |
|---|---|
| Piehler, Mike (Study Lead) | UNC-CH Institute for the Environment |
| Bell, Natasha | East Carolina University |
| Booth, Scott | UNC-CH Department of Marine Sciences |
| Borah, Smitom | NCSU Department of Civil, Construction and Environmental Engineering |
| Burch, Alyson | UNC-CH Department of Marine Sciences |
| Fensin, Elizabeth | NCDEQ Water Sciences |
| Ghobrial, Sherif | UNC-CH Department of Marine Sciences |
| Gilchrist, Ollie | UNC-CH Institute of Marine Sciences |
| Gray, Kathleen | UNC-CH Institute for the Environment |
| Hall, Nathan | UNC-CH Institute of Marine Sciences |
| Hoben, John | East Carolina University |
| Humphrey Jr., Charles | East Carolina University |
| Hunt, William F. | NCSU Department of Biological and Agricultural Engineering |
| Iverson Guy | East Carolina University |
| Kimia Karimi | NCSU Department of Civil, Construction and Environmental Engineering |
| Kirk, Evan | UNC Environmental Finance Center |
| Lindley, Anne Marie | East Carolina University |
| Luettich, Rick | UNC-CH Institute of Marine Sciences |
| McKee, Brent | UNC-CH Department of Marine Sciences |
| Mullins, Elsemarie | UNC Environmental Finance Center |
| Obenour, Dan | NCSU Department of Civil, Construction, and Environmental Engineering |
| O'Driscoll, Michael | East Carolina University |
| Paerl, Hans | UNC-CH Institute of Marine Sciences |
| Parkins, Grant | UNC-CH Institute for the Environment |
| Richardson, Jennifer | East Carolina University |
| Riggs, Erin | UNC Environmental Finance Center |
| Schnetzer, Astrid | NCSU Marine, Earth, and Atmospheric Sciences |
| Seim, Harvey | UNC-CH Institute of Marine Sciences |
| Spurlock, Danielle | UNC Department of City and Regional Planning |
| Triana, Victoria | UNC-CH Institute for the Environment |
| Valera, Marco | NCSU Marine, Earth, and Atmospheric Sciences |
| Vander Borgh, Mark | NCDEQ Water Sciences |
| Waickowski, Sarah | NCSU Department of Biological and Agricultural Engineering |
| Whipple, Tony | UNC-CH Institute of Marine Sciences |

## NC Policy Collaboratory Staff

**Jeff Warren**, Executive Director
**Laurie Farrar**, Financial Analyst
**Steve Wall**, Outreach Director
**Rebecca Rice,** Graduate Research Intern
**Gabbi Schust**, Graduate Research Assistant

## NC Policy Collaboratory Advisory Board

**Al Segars**, Chair, PNC Distinguished Professor of Strategy and Entrepreneurship, Kenan-Flagler Business School
**Anita Brown-Graham**, Professor of Public Law and Government, School of Government
**Jaye Cable**, Senior Associate Dean for Natural Sciences, Professor, Department of Marine Sciences
**Greg Characklis**, Philip S. Singer Distinguished Professor, Department of Environment Sciences and Engineering
**Don Hobart**, UNC Associate Vice Chancellor for Research
**Mark Little**, Executive Director of CREATE, UNC Kenan Institute of Private Enterprise
**Rick Luettich**, Professor and Director, UNC Institute of Marine Sciences
**Mike Piehler**, Director, UNC Institute for the Environment

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*Janis Arrojado, an Environmental Policy Intern with the Collaboratory, Sascha Medina and Taylor Fitzgerald, Graduate Communications Interns with the Collaboratory, made significant contributions to the drafting of this report.*