Falls Lake Nutrient Management Study

https://collaboratory.unc.edu/

Interim Update to the North Carolina General Assembly

December 2022

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Executive Summary

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.

Importantly, those funds have allowed for the continuation of research topics and additional data gathering to reach fuller and more robust findings. In addition, as outlined below the additional funds provided support for new research areas that will strongly supplement previous work.

Over the course of 2019-2022 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.

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?

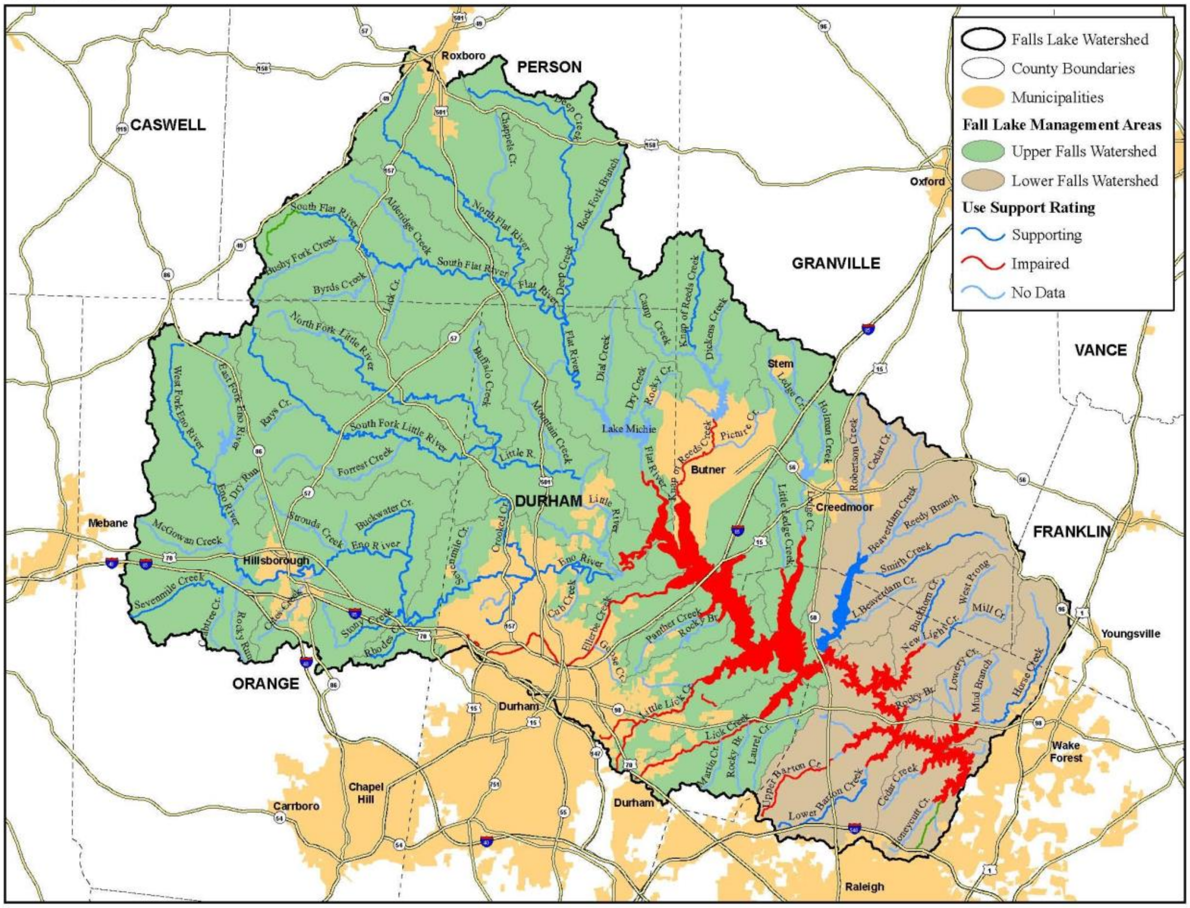
Do onsite wastewater treatment systems increase nutrient concentrations in streams draining to Falls Lake? What are the optimal locations for bioreactors along low-order streams to reduce nutrient inputs?

Can the ratio of zooplankton to phytoplankton biomass be used as an indicator of food web of health that could guide a site-specific criterion for Falls Lake phytoplankton biomass.

Introduction

Falls Lake Background

FALLS LAKE WATERSHED



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.

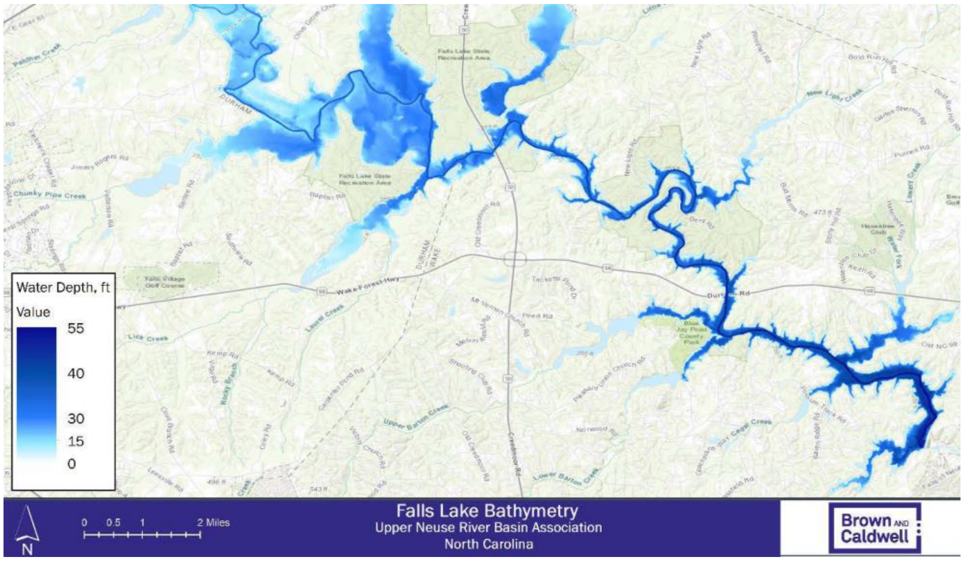


Figure 1. Falls Lake Bathymetry, data collected 2017 (UNRBA 2019)

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.

New Research Topics

While much of the research in the final year of the Falls Lake Study will build on previous work, a couple of new topics will see increased focused. These new issues will help round out the study to ensure that findings and recommendations are taking a comprehensive approach to identifying solutions.

Estimating Nutrient Loads to Falls Lake from Streambank Erosion

This study will investigate how streambank erosion of Falls Lake tributaries contributes to sediment inputs. As well as harming habitats and decreasing reservoir capacity, sediment can carry nutrients like phosphorus into water sources, exacerbating issues associated with eutrophication like algal growth. The goal of the study is to determine the relationship between Falls Lake's high nutrient levels and sediment from streambank erosion. The results from this study can contribute to watershed modeling that will project long term impacts and needs of the reservoir. These models can inform policymaking for stakeholders that rely on Falls Lake for drinking water, recreation, and fishing.

Researcher: Barbara Doll, NC State University

Examination of Nutrient Policies and Powers Available for Readoption of Falls Lake Rules

The State has a significant number of nutrient impaired waterbodies that are the source of drinking water supplies for metropolitan areas. The regulatory scheme to address those impairments imposes huge financial burdens on local governments and can limit or bar the recruitment of industry which discharges regulated nutrients in its treated waste water. See N.C. Gen. Stat. §143-215.3(a)(8). The statutory and regulatory controls for addressing nutrient excess loading of lakes and streams have been in place for decades without substantial change or re-examination by the policy makers of the State. The controls arise from the federal Clean Water Act (hereafter "CWA"), the statutory provisions adopted by North Carolina in response to federal mandates, and rules adopted by the NC Environmental Management Commission.

The implementation efforts by local governments confirm that the control of nutrients in any waterbody will be an ongoing process for decades at significant cost to local governments in particular. As in North Carolina, other states have seldom met with complete success in the control of excess nutrient; however, several states have pursued solutions or policy methods that may provide a long-term strategy without the threat of litigation to enforce multiple regulatory requirements at the same time. The report will examine statutory amendments that can provide opportunities for a more structured relationship between the regulated local governments and the State to allow for long term strategies that will provide local governments an opportunity to more carefully tailor nutrient responses in the Falls Lake basin.

Researcher: Dan McLawhorn, Legal and Policy Consultant

Sharing Research Results: Falls Lake Study Symposium, April 7, 2022

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.

After a virtual symposium in 2021, the 2022 symposium returned to an in person gathering with more than 100 attendees. On April 7, 2022, the Collaboratory, the UNRBA and the UNC Institute for the Environment jointly held the Falls Lake Nutrient Management Study Research Symposium. The symposium was organized by the Institute's Grant Parkins and other staff from the Center for Public Engagement with Science.

Mike Piehler presenting at the 2022 Falls Lake 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. *A full agenda for the symposium can be found in Appendix II.*

Upper Neuse River Basin Association: Interim Alternative Implementation Approach

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 UNRBA to provide the full context and scale of research, sampling and monitoring taking place in Falls Lake and in the watershed.**

The UNRBA has been working since 2018 to develop alternative options for achieving Stage I existing development nutrient reductions required by the Falls Lake Nutrient Management Strategy Rules. The three major wastewater treatment plants in the watershed have been able to reach their required nutrient reduction goals, achieving reductions that are more than required for both point sources and existing development combined. Agriculture has also met their Stage I reduction requirements, and the new development rules have been implemented since 2012. However, existing development rules have faced obstacles to interpretation and implementation.

As a result, the UNRBA developed, over its three-year effort, an alternative approach to meet the Stage I Rules for Existing Development. Because Stage I Existing Development is being implemented ahead of the readoption of the Falls Lake rules, the UNRBA called this approach the Interim Alternative Implementation Approach (IAIA). The IAIA allows for joint compliance among participating jurisdictions in the watershed subject to the existing development rule. This approach is also a pilot program to demonstrate if an investment-based approach can be used for compliance under future stages of implementation that will be described in the readopted Falls Lake Rules. The full IAIA program document and other materials are available at https://unrba.org/content/interim-alternative-implementation-approach

The IAIA focuses on improving water quality, water quantity, watershed health, and nutrient reduction. The program moves away from quantifying progress by counting pounds of nutrient reduction as the only measure of compliance. It requires local governments in the Falls Lake watershed to fund projects and actions that improve water quality and water quantity.

This approach allows for more cooperation through joint ventures between the UNRBA, its members, and stakeholders. It is a voluntary program, but jurisdictions declining to participate must comply with the original Stage I Existing Development Rule requirements. Meeting the annual minimum investment requirements prescribed by the IAIA allows participating jurisdictions to achieve full Stage I Existing Development compliance during the next five years and lays the foundation for development of the updated Falls Lake Rules.

The Stage I IAIA uses investment-based compliance which allows jurisdictions to meet their requirements through the commitment of funding for eligible projects and actions. The original Falls Lake Rules used a nutrient load reduction-based compliance framework. Under the Rules, jurisdictions would have faced nutrient load reduction requirements based on the amount of existing development in the watershed. Evaluations performed by the UNRBA projected that these reductions would have required jurisdictions to spend substantial amounts and, in many cases, were not technically or logistically feasible.

The investment-based system under the IAIA ensures that if a jurisdiction is meeting committed funding levels for eligible projects and activities and showing compliance with these commitments in annual reports, then they are demonstrating compliance. The IAIA allows participants and stakeholders to come to an agreement on appropriate, fair, and equitable funding levels for Stage I and, where quantification methods exist, estimate the nutrient loading reductions from each program investment. The funding levels are based on reasonable interim commitments and willingness to pay. These commitment levels are determined cooperatively by the participating jurisdictions and agreed to by the NC Division of Water Resources (DWR). Additionally, a reporting tool has been developed to track compliance with required investment levels.

The IAIA also allows for additional implementation of projects as it expands eligible practices and actions to meet requirements. These projects include all state-approved practices with established nutrient credits, land conservation in high-priority areas, green infrastructure and best management practices, illicit discharge detection and elimination, and any other practices that DWR approves. This expansion encourages a broad use of watershed improvement and protection actions and has resulted in more jurisdictions investing in watershed health.

Along with the approval of the program by DWR, the NC Environmental Management Commission (EMC) unanimously approved the IAIA. Every local government in the UNRBA has voluntarily joined the IAIA, and year one of the program is complete.

Based on the IAIA annual commitments, the minimum required investment is $1.5 million. Year one reporting shows that IAIA participants have already committed more than $5.5 million for projects under development now and in future years. Members of both the UNRBA and DWR have praised implementation of the IAIA as positive momentum for the Rules and as an example of the commitments of local governments to improving water quality.

Research Summaries for FY 2021-22

Falls Lake In Situ Observation

Background

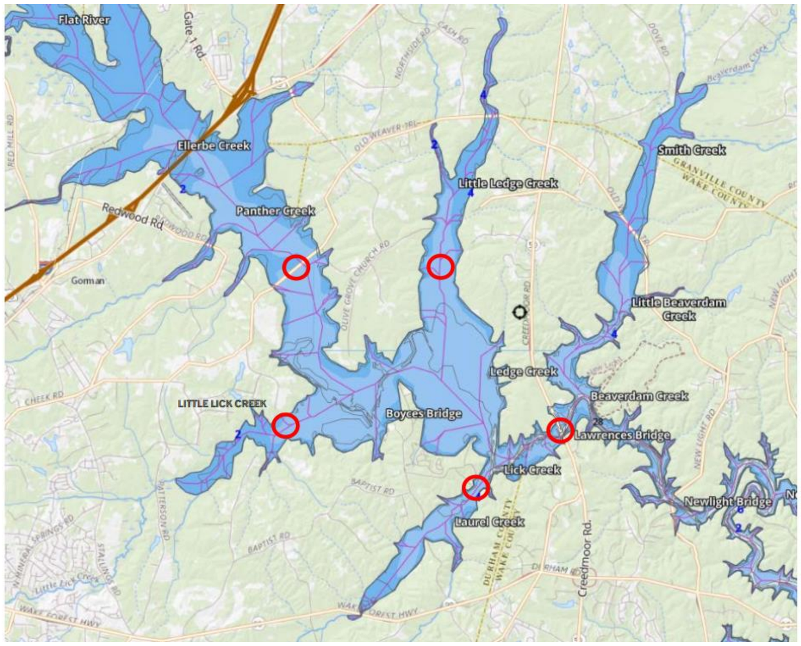
Year 1-2 studies in Falls Lake have delineated principal features of the transport and physical structure along the main stem of the lake. In addition to the aforementioned main stem, there are also several "side arms" of the lake which possess substantial surface area and low inflow volumes. For the Year 3 performance period, the research team designed and are currently continuing a 15-month field study in the mid to upper, nutrient sensitive, portion of Falls Lake and three sidearms that adjoin the lake in this area. The study objectives are to determine how the side-arms impact transport in this portion of the lake and to evaluate spatial variability in key water quality properties in these areas.

Research Methods

The two primary research methods employed to collect data were through the deployment of acoustic doppler current meters and hydrographic moorings and through data collection over the side of the boat.

Acoustic Doppler current meters and hydrographic moorings were deployed on August 31, 2021 to continuously measure water flow, water depth, and temperature through the water column at two locations along the main stem (Fish Dam Road and Hwy 50) and in three significant sidearms that join with this portion of the lake. These locations were picked in order to provide simultaneous observations of water motion and physical properties along the main stem and the intersecting sidearms. The instruments were successfully recovered, data downloaded and the instruments re-deployed in March 2022. The instruments remain in place and are planned for final recovery in the fall 2022.

In addition to the collection of *in situ* data, additional measurements are collected over the side of the boat on approximately monthly trips. These additional measurements consisted of vertical profiles of photosynthetically active radiation (PAR), (Li-Cor model LI-193 spherical sensor) and temperature, conductivity, turbidity, Chl-a, dissolved oxygen and pH (Endeco-YSI multi-parameter probes models 6600 or EX02). Data collected through these trips was used to assist and correct data from the *in situ* sensors, as well as provide a more comprehensive understanding of the lake. High spatial resolution water quality data was also collected on these trips through a flow through system which pumps surface water from the lake into a small chamber on the boat, which possessed a multi-sensor water quality sonde, and provides a high-resolution spatial picture of the water quality variables and their gradients across this portion of the lake.



Results

Only a portion of the data collected during Year 3 has been downloaded from the *in situ* instrumentation. The remainder will be retrieved when the instruments are recovered in the fall. At a lake-wide scale, the first four months of the deployment (September – December) had low inflows and outflow. During this period lake levels dropped by approximately 2 ft as outflows exceeded inflows. Conductivity data showed a persistent pattern where values at Fish Dam Rd, the upstream most site along the lake, were highest throughout the month and decreased moving downstream. A similar pattern existed through the fall, suggesting that high conductivity water may be diluted with lower conductivity inflows as it moves downstream. Data collected via shipboard measurements suggests that turbidity and conductivity both appear to be higher towards the upstream portion of the sample area and decrease in the downstream direction. This trend in conductivity is consistent with that identified at the mooring sites.

Surface conductivity data collected in January prior to a large inflow event again showed the pattern of high values at Fish Dam Rd and subsequent decreasing levels in the downstream direction. However, the large inflow event and ensuing January events significantly decreased the conductivity at Fish Dam Rd and to a much smaller extent at the other sites, eventually bringing all five sites to similar conductivity values. Shipboard measurements in early February showed a similar pattern of conductivity and turbidity as in September, albeit with a larger range on turbidity and a narrower range on conductivity.

Researchers: Rick Luettich, Tony Whipple, Harvey Seim, Crystal Fulcher, UNC-CH Institute of Marine Sciences, UNC-CH Department of Earth, Marine & Environmental Sciences

Scientific Review of Watershed and Water Quality Modeling

Background

Historically, atmospheric phosphorus (P) deposition has been considered a minor contributor to overall phosphorous loading, relative to other sources like fertilizers. However, some studies suggest that it can be important for particular lakes and urban areas. Primary sources of atmospheric P deposition are marine aerosols, dust from agricultural activities and deserts, biomass burning, soil erosion, and coal and oil combustion. Atmospheric P transport is different from nitrogen (N) transport in that it does not have a stable gaseous phase in the Earth's atmosphere and is mainly restricted to aerosols. Also, unlike N, P deposition data is not generally available through the National Atmospheric Deposition Program (NADP). Thus, atmospheric P deposition data is relatively scarce, and it must often be estimated from small-scale measurement studies or models.

In addition, excessive nutrient input is one of the major reasons for water quality impairment in lakes and reservoirs across the world. Nutrients, such as nitrogen and phosphorus, increase the productivity in these water bodies (eutrophication), leading to a plethora of subsequent problems such as algal blooms, reduced DO levels, fish kills, and odor and taste problems in drinking water. While phosphorus is the limiting nutrient for eutrophication in many freshwater systems, studies have shown that nitrogen too can be the limiting or co-limiting nutrient. Nitrogen can enter water bodies through groundwater inflow, run-off from the watershed, atmospheric deposition, and upward flux from the sediments (internal loading). Internal nitrogen loading occurs mostly in the form of ammonia, which can be subsequently transformed into other forms, such as nitrate or organic nitrogen. In addition to eutrophication, an abundance of ammonia under high pH levels can cause ammonia toxicity that could be lethal to fish.

Research Methods and Results

In this memorandum, the researchers conducted four studies to tackle the issues listed above: 1) a review of atmospheric phosphorous deposition data, 2) a literature review of urban vs. rural nutrient export rates, 3) a review of sediment nitrogen release for U.S. lakes and reservoirs, and 4) an overview of the WARMF-watershed model calibration in conjunction with the UNRBA.

First, researchers conducted a review of atmospheric phosphorus deposition data. They looked at several studies that explored P depositions on a global, national, and local scale. Estimates of atmospheric TP deposition vary widely across different studies. In the U.S., estimates typically range from 0.05 to 0.5 kg/ha/yr. In the most recent study, atmospheric TP deposition for the Falls Lake Basin was approximately at 0.08 kg/ha/yr in 2012, but with notable uncertainty. Most sampling occurred over limited time intervals and may underestimate P deposition in some cases. In addition to global and national studies on P deposition, regional studies may provide more insights into spatial and seasonal patterns. In another study, P deposition samples were collected from 1988-1991 on the campus of UNC Wilmington. Wet and dry P deposition was small compared to N. The N:P molar ratio of atmospheric deposition was 51 (mass ratio of 23). The wet and dry P deposition values were reported as <0.19 and <0.01 kg/ha/yr, respectively, indicating higher contributions of wet deposition. The dry deposition was greatest in spring and declined through the summer. Both dry and wet P deposition declined in winter. The seasonal variation in P deposition may be related to tillage and fertilization schedules in agricultural areas since they are usually tilled and fertilized before planting in spring.

Next, researchers conducted a literature review of urban vs. rural nutrient export rates. Some notable findings include studies that look at Falls-Jordan watersheds. Particularly, in the two watersheds the urban TP export rates were set about 10x higher than forest/undeveloped land export rates. In addition, monitoring results in the Falls-Jordan watersheds show higher dissolved P and N concentrations and load as impervious cover increased. Continuous monitoring of nitrate suggested an order of magnitude higher export from developed lands relative to forested lands. Under base flow, dissolved N and P loads from urban lands are around 3-4 times higher than from forested lands.

Third, researchers conducted a review of sediment nitrogen release for U.S. lakes and reservoirs. As discussed above, excess nitrogen can impair waterbodies. Internal nitrogen loading occurs mostly in the form of ammonia. Their discussions largely centered around sediment ammonia flux but also reported the sediment nitrate flux observed in different water bodies. The sediment ammonia and nitrate fluxes vary widely in the United States. Researchers found sediment ammonia flux to typically range between ~0.5 to 150 mg N/m^2/day across different lakes and reservoirs. Fluxes were summarized as <5 mg N/m^2/day for oligo/mesotrophic water bodies, 5-10 mg N/m^2/day for meso/eutrophic water bodies, and >15 mg N/m^2/day for eutrophic/hypereutrophic water bodies under anoxic conditions.

There are many factors responsible for such a wide variation in sediment ammonia and nitrate fluxes in US lakes and reservoirs. For one, as water bodies become more eutrophic, the organic loading to the sediments increases, and the mineralization of this organic matter produces a diffusive ammonia flux. Thus, eutrophic and hypereutrophic water bodies have much higher sediment ammonia flux compared to oligotrophic and mesotrophic water bodies. Next, the photic (or light) conditions of a water body can also affect the sediment nitrogen flux. Finally, an increase in temperature generally increases the sediment nitrogen flux. As the bottom water warms up, the mineralization rate of organic nitrogen in the sediments increases, leading to greater sediment nitrogen release.

A study reported that the sediment ammonia flux in Jordan Lake ranged between about -20 to 50 mg N/m^2/day and 0 to 50 mg N/m^2/day under oxic and anoxic conditions, respectively, at dark, room-temperature (~20°C) conditions. The highest sediment TN fluxes were predicted in the summer season when the bottom water temperature is around 25°C in Jordan Lake. In Falls Lake, two separate studies were carried out: one study supported by UNRBA in 2015 and another by EPA in 2018. In the UNRBA study, the summer sediment ammonia flux, estimated through diagenetic modeling, ranged from about 30 to 90 mg N/m^2/day along the main stem of the Neuse River. In the EPA study, carried out using benthic chambers, the summer sediment ammonia flux ranged from 16 mg N/m^2/day to 161 mg N/m^2/day. In both of these studies, the sediment ammonia fluxes generally increase as one moves from the upstream toward the dam. Shallower regions are less susceptible to anoxic conditions and thereby less ammonia might be released from the sediments in these regions. The UNRBA study indicated that ammonia flux in the river channel is reported to be about three times higher than that in the historic river floodplain. In general, high ammonia fluxes are expected in deeper areas where hypoxic conditions are likely to prevail.

Finally, researchers also provided an overview of the WARMF-watershed model calibration used to look at the Falls Lake watershed. The researchers engaged with Falls Lake modeling team, led by the UNRBA. Together, they address the model calibration issues and set goals to better represent the atmospheric nitrogen and phosphorous deposition. They also used the model to compare nutrient loading rates from urban and undeveloped lands based on other studies in the region. In general, this review suggests that urban areas export 4-12 and 2-8 times more TP and TN, respectively, than undeveloped lands. Motivated in part by this review, the model calibration was updated by extending the model warmup period so that soil processes and nutrient export could better equilibrate with nutrient inputs, resulting in greater differences between urban and undeveloped land export.

Future Work

The researchers will continue to have conversations with UNRBA staff/modelers to discuss simulations of nutrients and algae in the two lake models. Staff and modeling consultants have been responsive to inputs about the WARMF-lake model along with the literature review of sediment phosphorous/nitrogen fluxes. They will continue to have discussions into the next fiscal year and make improvements as needed.

Researcher: Daniel R. Obenour, NC State University

Defining the Balance Between Cyanobacterial N2 Fixation and Denitrification

Background

Constraining N inputs by N2 fixations will significantly enhance our understanding of phytoplantkton nutrient responses in Falls Lake and will fill a significant data gap in the N mass balance for Falls Lake.

Research Methods

Sampling: Between late July 2019 and early July 2020, a series of five N_2 fixation assessment campaigns were conducted along a transect of 6 main-channel stations (Figure 1). Between May and October 2021, a series of five N_2 fixation assessments were conducted at ten stations located with major creek arms. During mid-channel sampling, integrated surface water from the surface to twice Secchi depth was collected from up two six stations that spanned the reservoir from just downstream of the I-85 bridge at Fish Dam Rd. (station A) to near the dam (station F) (Figure 1). During 2021, creek arms stations were sampled from ~0.2 m deep by holding an open bottle just below the surface. N_2 fixation measurements were made using the acetylene reduction assay method assuming a 4:1 ratio of N_2 to acetylene reduction.

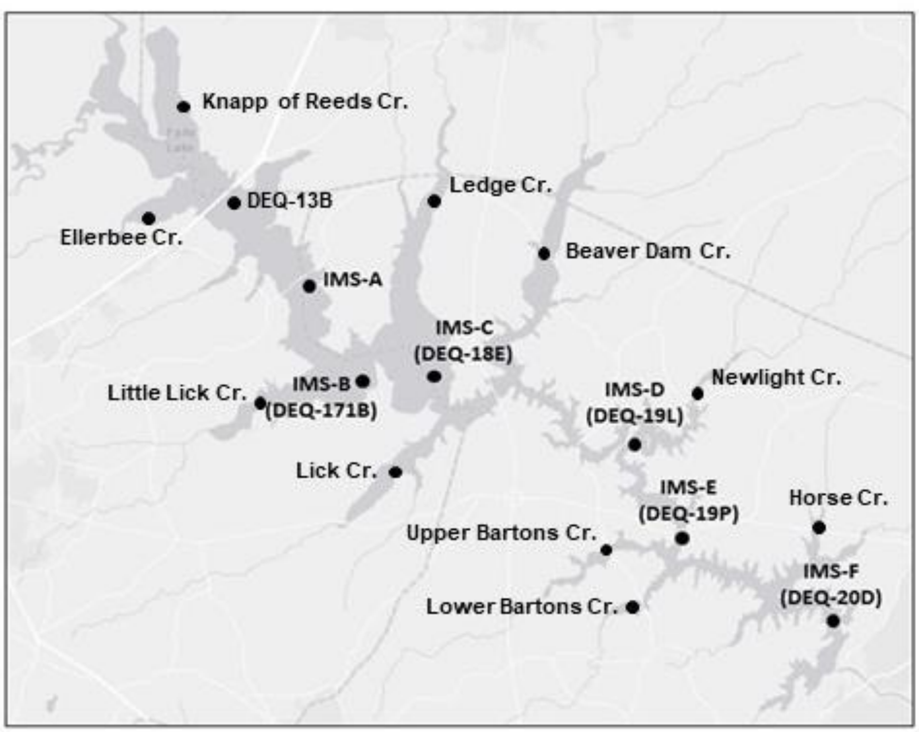


Figure 1. Map of main channel and creek sampling stations for measurements of N fixation rate. Five of the six main channel stations coincided with stations sampled monthly by NC Dept. of Environmental Quality (NCDEQ).

Findings and Management Implications

Our measurements indicate that N_2 fixation supplies a small fraction (< 5 %) of the total N inputs to Falls Lake. Low availability of bioavailable phosphorus and light appear to be key constraints on cyanobacterial N_2 fixation. Analysis of long-term cyanobacteria abundance data collected by NC DEQ-DWR revealed higher abundances of cyanobacteria capable of N_2 fixation during drought years. This suggests that N_2 fixation may become a more important part of the N budget when external N supplies are low. Nutrient addition experiments indicated N limitation of phytoplankton production during summer. During summer, Falls Lake is likely N limited but low bioavailable P constrains the ability of N_2 fixing cyanobacteria to alleviate the N deficit. This suggests that both N and P should be targeted to control phytoplankton biomass levels.

Comparison of mass balance estimates vs. direct measurements of denitrification

N_2 fixation measurements were added to a N budget for Falls Lake to calculate the lake-wide N loss due to denitrification. Based on the budget, we estimated N losses due to denitrification between 34,000 and 46,000 kg N/y or about 15% of tributary inputs. Dr. Piehler's laboratory conducted four campaigns to directly measure rates of sediment denitrification in Falls Lake from sediment cores collected at main channel and creek arm locations. Denitrification rates from the sediment cores were scaled up spatially and temporally based on the sediment area represented by each station and the hydrological conditions represented by each campaign (e.g. measurements during seasonal summer hypoxia vs. after fall mixing, see Piehler et al. 2020-2021 annual report for more detail). The scaled-up rates from these direct measurements ranged from 50,000 to nearly 500,000 kg N/y (Figure 19). The average across the three campaigns was 237,000 kg N/y or approximately 47% of the average tributary load of N from 2006 to 2019. This estimate of lake-wide denitrification was ~2-3 fold higher than our best estimates based on the nitrogen budget. Potential reasons for this discrepancy include overestimation of denitrification rates by a small number of core incubation measurements and potential underestimates of N inputs from tributaries. **Collectively, however, both methods indicate that denitrification is an important microbially-mediated N removal mechanism for Falls Lake.**

Cyanotoxin Presence and Year-round Dynamics

Background

The main goals of the study are to understand the characteristics of Falls Lake's Cyanotoxin Harmful Algal Blooms (CyanoHABs) and determine what environmental factors contribute to their presence. Algal blooms harm water sources when they contain cyanobacteria: a type of bacteria that creates, holds, and releases toxins like microcystins (MCY), anatoxin (ANA), cylindrospermopsin (CYL), saxitoxin (STX) and beta-Methylamino-L-alanine (BMAA). Adverse impacts on human health form cyanotoxins can be associated with oral consumption of cyanotoxins in drinking water, consumption of contaminated fish and seafood, inhalation of aerosolized toxins, and dermal exposure, with varying degrees of dermatological, gastrointestinal or respiratory issues depending on the cyanobacteria and toxin mixtures and levels present. Thereby, affected several identified uses for Falls Lake.

Research Objectives

1. Characterize spatiotemporal patterns for MC, CYL, ANA, SXT, and BMAA in Falls Lake across a three-year sampling period and identify potential toxin hotspots.
2. Compare Falls Lake toxin profiles with chl a concentrations and algal cell counts to assess the efficacy of these metrics to estimate toxin exposure risks.
3. Relate physicochemical conditions with toxin concentrations and profiles as well as cyanobacterial species composition to identify patterns associated with community structure and/or toxin production across Falls Lake.

Coordinating sampling efforts with the Department of Water Quality (NC DEQ)'s sampling stations for their Ambient Water Monitoring Program, water samples were taken from 11 locations on the lake to establish a baseline on which toxins would be present at which regions within the lake and correlate with pertinent environmental factors including nutrients, temperature, dissolved oxygen, pH and conductivity. At 4 stations Solid Phase Adsorption Toxin Tracking (SPATT) was implemented which is a method that returns an accumulated, time-integrative toxin signal for MC, ANA, CYL and STX. In highly dynamic systems this method is highly complementary to water grabs which may not allow to capture toxin dynamics due to the episodic nature of bloom events and where only a finite volume of water is collected at one specific timepoint. To characterize cyanobacterial community composition on the species level samples for molecular (DNA) analyses were also collected which are currently processed and their analyses a major focal point of the final year of the project. Molecular analyses of cyanobacterial composition will allow to decipher between potential toxin producers or non-toxin producing taxa.

Findings

The most prevalent toxins in Falls Lake are MCY and ANA, followed by CYL and BMAA. Saxitoxin could not be detected in a subset of tested samples. In the upper watershed, chl a levels were higher than in the lower watershed. According to guidelines from the World Health Organization, the level of chl a would classify that region of the lake as one of moderate exposure risk to MCY; however, the sample data shows that the actual levels of MCY in the upper watershed are within the “low-risk” exposure range.

Despite the higher nutrient concentration in the upper watershed, MCY had its highest concentrations in the lower watershed during fall 2020. MCY and CYL were detected in the water (dissolved) rather than inside bacterial cells (particulate).The toxin profiles for the SPATT data showed that 83 percent of samples had more than 2 toxins bound to cells and 19 percent had 2 of the 4 toxins in dissolved form. This indicates that multiple toxins are present year-round and exist within cells and freely in water. In-depth statistical analyses to identify potential environmental drivers for the varying toxins are underway.

Management Implications

While the toxin levels indicated by monthly grab samples do not indicate that regulatory guidelines for recreation are reached, Falls Lake’s nonattainment status for nutrients (chl a) could lead to increased cyanotoxin activity and subsequent exposure in the future. The project findings will be used to set forth recommendation on where higher temporal resolution for sampling and toxin monitoring should be attempted to make sure bloom peak periods are properly documented and with it the full range of toxin concentrations for the lake. In other words, leverage water sampling more frequently than once a month to increase the likelihood of capturing bloom dynamics at all their stages, from initiation to peak and demise. A continuation of the NC DEQ’s Ambient Water Monitoring Program will allow for researchers to continue water sampling as part of the Nutrient Management Study.

Future Actions

Based on the presence of multiple toxins year-round, further study of low-level cyanotoxin exposure is warranted. Determining how chronic low-level exposure impacts food webs and water can inform public policy surrounding fishing, recreation, and drinking water to ensure that the uses of Falls Lake are protected.

Researchers: Astrid Schnetzer and Emily Pierce, NC State University

Sediment and Carbon Accumulation

Background

Carbon dioxide concentrations are rapidly rising in the atmosphere due to emissions from burning fossil fuels. Natural "sinks" – processes that remove carbon from the atmosphere – on land and in the ocean absorbed the equivalent of about half of the carbon dioxide emitted each year in the 2011-2020 decade. However, with more rising emissions to the atmosphere than natural processes can remove, the amount of carbon dioxide in the atmosphere increases every year. The buildup of gases in the atmosphere warms the climate and leads to several changes around the world.

Research Methods

In this study, researchers at UNC-Chapel Hill's Department of Earth, Marine, and Environmental Sciences quantified rates of sediment and carbon accumulation in Falls Lake, NC. Carbon accumulation rates (CAR) are the rates of atmospheric carbon dioxide removal and burial in sediment deposits over time scales of decades. CARs are natural "sinks" in depositional environments (such as lakes, reservoirs, estuaries, saltmarshes, seagrass, and mangroves). They are the major means of naturally removing carbon dioxide from the atmosphere over the time scale of decades and help offset human carbon emission buildups.

To quantify CAR values in Falls Lake, researchers looked at factors that influence the rate of carbon accumulation: 1) sediment characteristics (mainly grain size); 2) dry bulk density (the mass of particulate material in a volume of sediment); 3) the organic matter content of the sediments accumulated; 4) rates of sedimentation; and 5) source of the organic carbon accumulated. More specifically, CAR can be determined and calculated using a fraction of organic carbon, dry bulk density, and sedimentation rate.

Sediment cores were collected at 8 locations from a Carolina Skiff using a handheld push core with a 10-inch diameter acrylic core tube. After retrieval, each core was dissected at 1 cm intervals down the length of the core. The dry bulk density (DBD) is the dry sediment mass in a cubic centimeter volume of sediment (g cm^{-3}) and is an important measure of sediment properties. Wet samples from each core interval (1 cm) were weighed, freeze-dried, and reweighed to determine the loss of water and to calculate water content and dry bulk density. Next, the organic carbon Fraction F_{OC} was measured. Aliquots of dried samples from each 1 cm interval were weighed and then combusted in a muffle furnace at 450° C for 12 hours. After cooling in a desiccator, samples were reweighed to determine the loss of percent organic matter. A calibration algorithm was used to convert percent organic matter (%OM) to percent organic carbon (%C). Finally, sedimentation rates were determined using naturally occurring radioisotope Pb-210 which is continuously delivered from the atmosphere and rapidly attaches irreversibly to particulates on land and is suspended in aqueous environments. After attaching to particulates, Pb-210 follows the pathways of the particulates and in our environment, it is used to determine the rate at which particulates accumulate on the bed of Falls Lake.

Results

The researchers found the mean values for carbon accumulation rates in Falls Lake range from 53 – 1220 g C m^{-2} y^{-1} with an overall mean of 347 g C m^{-2} y^{-1}. This study is one of the most complete and comprehensive evaluations of CARs in reservoirs that exists in the literature.

The rate of carbon dioxide emission to the atmosphere continues to accelerate with more than half of all carbon dioxide emissions since 1751 emitted in the last 30 years. This is approximately an 85% increase in emissions since the construction of the Falls Lake dam and the formation of Falls Lake.

For natural carbon sequestration sites to keep up with the increase in atmospheric carbon dioxide, the rates of carbon accumulation rates within these natural reservoirs must increase. None of the CAR profiles in Falls Lake display a noticeable increase from the time of Falls Lake formation to the present, except for the past 2-3 years. These results suggest that carbon accumulation in reservoirs such as Fall Lake is an important sink of atmospheric carbon but has not kept up with the dramatic increase in carbon dioxide concentrations in the atmosphere.

Next, it was found that sedimentation rates drive CAR in Falls Lake and are much more important than variability and trends in DBD or percent carbon.

Finally, within the regions examined in Falls Lake, carbon accumulation rates have a mean value of ~350 g C m^{-2} y^{-1}. This is equal to or much greater than rates in coastal Blue Carbon Environments (50- 150 g C m^{-2} y^{-1}), such as marsh, mangroves, and seagrass, which have been considered the most important natural global sinks for atmospheric carbon. This calls for a more large-scale examination of reservoirs in which carbon accumulation rates are determined by the quantitative methods used in this study.

Future Work

In the future, the researchers want to examine other potential factors that drive CAR in Falls Lake, such as sediment characteristics and the source of organic carbon accumulated. In addition, during this project, researchers focused on the upper and central basins of Falls Lake. However, the cores collected from the lower lake (stations 7 and 8) appear to have distinctly different concentrations and profiles of DBD, and %C. They would like to increase coverage of the lower lake region to explore the differences.

Researchers: Brent Mckee, Scott Booth, Sherif Ghobrial, Department of Earth, Marine, and Environmental Sciences at UNC-Chapel Hill

Assessing Nutrient Transport from Onsite Wastewater Systems and Efficacy of a Subsurface Bioreactor to Remediate Nutrients in Surficial Aquifers

Background

Septic systems are an important wastewater management strategy for North Carolina's citizens, especially for people living in rural and suburban areas where municipal sewer is unavailable or cost prohibitive. Conventional style septic systems are designed to collect, treat, and dispose of wastewater via infiltration of effluent into soil. Domestic wastewater contains elevated concentrations of nitrogen, phosphorus, pathogens, emerging contaminants, and other pollutants.

In North Carolina, conventional septic systems require a minimum of 45 cm of separation distance between the trench bottom and any soil wetness condition for sandy soils (Group I soils). Soils that are coarse and finer (Group II – IV soils) require a minimum of 30 cm of separation distance. Failure to meet this minimum separation distance results in a septic system malfunction and may result in hydraulic failure potentially resulting in surfaced effluent or backed-up wastewater into the tank or household. Septic system failure rate is highly variable depending on numerous factors like soil characteristics, household wastewater loading rates, frequency of maintenance, septic system design or installation, landscaping practices. Malfunctioning septic systems can "short-circuit" treatment mechanisms that reduce and remove pollutants that may pose a risk to the environment or public.

Research Methods

The goal of this study was to quantify pollutant treatment by septic systems within the Carolina Slate Belt or Raleigh Belt geologic settings. The objectives were to: 1) compare nitrogen, phosphorus, and *E. coli* concentrations in groundwater and surface waters downgradient of septic systems; 2) quantify nutrient mass exports and *E. coli* loadings in streams downgradient of studied septic systems; 3) evaluate septic system performance based on concentration reductions of nutrients and *E. coli*; and 4) quantify mass reductions of nutrients and estimate pollutant removal mechanisms.

This study assessed nutrient and bacteria transport from septic systems to nearby groundwater and streams within Raleigh Belt geologic settings. After collaboration between researchers from Eastern Carolina University and the Wake County Environmental Services, a landowner of a mobile home community was identified as a study site. This community is approximately 5 miles upstream of the Lake Benson Park, an important recreational resource for the region. The Lake is known to have eutrophication issues, making it an ideal candidate to improve understanding of nutrient and pathogen delivery to its tributaries. Three septic systems were identified in this community and a total of 9 piezometers (an instrument for measuring the pressure of a liquid or gas) were installed downgradient of septic drain fields. Each of the mobile home sites were adjacent to a stream. Sites were sampled four times in February, April, May, and June 2022. At Sites 100 and 300, the septic tanks, piezometers, and streams were sampled for nitrogen, phosphorus, and *Escherichia coli* (*E. coli*) concentrations.

For wastewater and groundwater samples, ammonium, nitrate, dissolved organic nitrogen (DON), total dissolved nitrogen (TDN), phosphate, total dissolved phosphorus (TDP), dissolved organic carbon (DOC), and chloride (Cl) was analyzed. For surface water samples, the same analytes were measured in addition to particulate nitrogen (PN), particulate phosphorus (PP), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS). Analysis of nutrients and bacteria occurred at the Environmental Research Laboratory and Water Research Laboratory, respectively, at East Carolina University. Pollutant concentration in groundwater and surface water downgradient of septic drain fields was compared to reference conditions to assess system influence. Concentration reductions, nutrient mass removal, and bacterial load reduction was estimated using percent difference (concentrations) and mixing model estimates (nutrient mass and bacteria loads). Stream exports of TN and TP were also estimated.

Results

Based on the research conducted, concentrations of TDN were highest in septic tanks relative to other sampling locations. The median TDN concentration in groundwater beneath the drain field was 10.28 mg L^{-1}, which was more than double that of the median concentration of TDN in the stream (3.82 mg L^{-1}). Septic tanks, drain field groundwater, and streams contained median TDN concentrations that were approximately 143, 26, and 10, respectively, times greater than reference concentrations of TN for these ecoregions. These results suggest that septic systems can be a significant source of nitrogen to receiving groundwater and surface waters, potentially containing median values that are several factors larger than reference conditions.

In addition, nutrient and *E. coli* treatment was higher at Site 100 than Site 300 due a persistent malfunction at Site 300. PN and PP were also more mobile at Site 300 relative to Site 100, which was likely attributed to the system malfunction. These results suggest that septic systems affected the nutrient and *E. coli* concentrations in water resources downgradient from drain fields, especially during malfunctions. Additional data are recommended to assess long-term nutrient transport.

Concentration reduction data show that both sites were highly effective (> 98%) at reducing TDP and *E. coli*, whereas TDN reductions were not as high. When pooling data, median concentration of TDN, TDP, and *E. coli* reduced 82.7%, 98.2%, and 99.1%, respectively, between septic tank and drain field concentrations. These reduction estimates increased when comparing wastewater concentrations to stream concentrations. The median concentrations of TDN, TDP, and *E. coli* in streams were 93.6%, 99.2%, and 99.7%, respectively, lower than septic tanks.

Future Work

Future work could include isotopic fractionation of nitrate and bacterial source tracking to better assess potential sources of nutrient and *E. coli* in these streams. Additionally, surface water transports were only measured during baseflow conditions from late winter through early summer. Thus, future work should assess seasonal variability in baseflow pollutant transport and how storms affect fate and transport of nutrients and *E. coli* of the studied streams. Another aspect that warrants continued investigation pertains to the longitudinal pollutant transport in streams. This would allow for additional data to evaluate in-stream processing of these streams, which are especially important at Site 300 where the malfunction contributes elevated nutrients and *E. coli* to the stream.

While the current study found elevated nutrients and *E. coli* in water resources downgradient of septic systems, it is possible that other sources contributed. Animal waste (pets and wildlife), lawn fertilizers, agriculture, and stormwater are common nutrient and bacteria sources. In the current study, it is unlikely that agriculture contributed to nutrient and *E. coli* inputs based on land cover data. However, other sources may not be ruled out. Thus, more information regarding the isotopic fractionation of nitrate and bacterial source tracking is needed to improve understanding of possible nutrient and *E. coli* sources. These data are important to further understanding of lot-scale treatment of common pollutants in septic systems, which can help constrain model estimates of nutrient loading to important water resources, such as Falls Lake, Jordan Lake, and other surface waters with similar geological, soil, and weather characteristics.

Researchers: Guy Iverson, Michael O'Driscoll, Charles P. Humphrey Jr., Natasha Bell, and John Hoben, East Carolina University

Paying for Nutrient Management in the Falls Lake Watershed

In year three of the Falls Lake Nutrient Management Study, the Environmental Finance Center (EFC) continued its year two research of the Upper Neuse River Basin Association (UNRBA)'s financing of the Interim Alternative Implementation Approach (IAIA). Using neighboring systems as a guide, researchers analyzed the economic impacts of a site-specific standard for nutrient management.

The study included new research on the affordability of water utilities in UNRBA municipalities, as well as how environmental justice (EJ) community identification can impact decision-making and funding. The EJ community research is based on the Biden administration's Justice40 initiative, which ensures 40 percent of returns on federal investments in climate and clean energy go to back to disadvantaged communities.

How has the IAIA process evolved since the 2021 study?

Methods

The study of IAIA financing was based on year two interviews with members of the UNRBA. To get updated information for year three, researchers analyzed funding data publicized by the UNRBA and identified newly approved methods by the Department of Water Quality (DWR).

Findings

There have been no major changes to UNRBA's funding sources for the IAIA. Just as in year two, most of the fund comes from members' stormwater utility revenues. An additional $11,605 was added to the fund after the Town of Stem joined the UNRBA in January 2022. The only update to methods qualifying for IAIA credit was in Orange County, where there was approved use of pesticides to control invasive plants at the Eno River.

Management Implications

Revenue from stormwater and wastewater charges in UNRBA's municipalities is performing well as an income stream for the IAIA fund.

How affordable are water, wastewater, and stormwater bills and what policies can be implemented to mitigate financial burdens?

Methods

To measure affordability of water, wastewater, and stormwater utility bills, researchers analyzed data from two metrics: 1) percent of 20th percentile household income and 2) affordability ratio of 20th percentile household income (AR20). These methods show the burden of water utilities on the total and disposable income of lower-income households. To find solutions to affordability concerns, researchers used a case study approach and looked at successful assistance programs and public policies from around the country.

Findings

The affordability metric calculations suggest that water sector bills are unaffordable for most municipalities in the UNRBA. Water sector bills are considered affordable if they account for less than 10 percent of total discretionary income (measured using the AR20 metric). Of the municipalities that have water, wastewater, and stormwater fees, the Town of Stem is the only one that has an AR20 metric below this threshold, at 9 percent. The Town of Roxboro has a negative AR20 value, meaning that the average low-income household has a water sector bill that costs more than its total discretionary income.

Management Implications

Affordability metrics like the AR20 and the Clean Water Act Financial Capability Assessment can be used to identify where cost-reduction measures should be implemented. These measures include utility block rates, budget billing programs and customer assistance programs (CAPs). Block rates charge higher rates for households that use more water, giving families more control over their bills; however, this system could disproportionately impact large, multigenerational families who could already face cost barriers. A budget billing program charges the same rate every month regardless of variability in monthly use, allowing households to better plan for their utility costs. To alleviate the cost-burden of qualifying customers, utilities can implement consumer assistance programs that are funded by customer and corporate donations.

What regions of the watershed qualify as environmental justice (EJ) communities? How does this designation impact watershed decision-making?

Methods

To investigate the role of environmental justice (EJ) communities on watershed management, researchers first identified what regions of Falls Lake qualify as EJ communities based on census data and the criteria listed in the federal Justice40 initiative. After identification, the regions were mapped using the Department of Environmental Quality (NC DEQ)'s Community mapping tool and compared with disadvantaged communities previously identified by the NC DEQ using its own criteria.

Findings

There was overlap in the EJ communities identified by Justice40 and NC DEQ, with most of them in Durham, Person, and Granville counties. The NC DEQ-identified areas were smaller, more precise, and more spread throughout the watershed.

Management Implications

Identifying EJ communities using the DEQ Community Mapping Tool and the Justice40 census tracks allows for municipalities to apply for state and federal funding for nutrient management projects. This outside funding will reduce reliance on revenue from utility rates and the general tax fund.

Researchers: Erin Riggs, Evan Kirk, UNC Environmental Finance Center

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

Falls Lake Nutrient Management Study
Research Symposium

Thursday, April 7, 2022
North Carolina Botanical Garden
Chapel Hill, NC

The purpose of this symposium is to **share the breadth of research** happening as part of the Falls Lake Nutrient Management Study and the Upper Neuse River Basin Association's efforts to re-examine the Falls Lake Nutrient Management Strategy.

10:00 Welcome and NC Policy Collaboratory Overview – Greer Arthur

Nutrient Management Study Background - Mike Piehler

The UNRBA Pathway to a Re-Examination of the Falls Lake Nutrient Management Strategy – Forrest Westall

10:30 **Session 1 In-Lake Processes**

In Situ Observational Study of Falls Lake – Rick Luettich, Tony Whipple, Harvey Seim, and Ollie Gilchrest

Assessment of Zooplankton-Phytoplankton Relationships in Falls Lake – Nathan Hall and Mike Piehler

Monitoring for Algal Toxins in Falls Lake – Emily Pierce, Will McClure, Marco Valera, Joseph Mohn and Astrid Schnetzer

Defining the Balance Between N_2 Fixation and Denitrification – Nathan Hall, Mike Piehler and Hans Paerl

Stakeholder Questions

Table Discussion

11:35 **Session 2 Watershed Processes**

Sand Filters and Silva Cells – Bill Hunt, Caleb Mitchell

Evaluating and Managing Nutrient Inputs From Onsite Wastewater Systems in the Falls Lake Watershed: A Multiscale Approach - Guy Iverson, Michael O'Driscoll, Charles Humphrey Jr., John Hoben, Natasha Bell, Jennifer Richardson, Ann Marie Lindley and Jordan Jernigan

	Sediment and Carbon Accumulation in Falls Lake – Brent McKee, Sherif Ghobrial, Mackenzie Wise, and Alyson Burch
	Stakeholder Questions
	Table Discussion
12:30	Break for Lunch
1:15	**Session 3 Stakeholder Engagement, Financing, and Future Work** *Assessing Controls on Watershed Nutrient Loading Through Data-Driven Modeling* – Dan Obenour
	Paying For Nutrient Management in Falls Lake **-** Evan Kirk, Elsemarie Mullins, and Erin Riggs
	UNRBA's Re-Examination: Where We Are, What We've Learned, Moving Forward – Forrest Westall
	Stakeholder Questions
	Table Discussion
	Closing Remarks - Mike Piehler
2:30	Adjourn

Appendix III

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
Doll, Barbara	NCSU Department of Biological and Agricultural Engineering
Jack Kurki-Fox	NCSU Department of Biological and Agricultural Engineering
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
Daniel Line	NCSU Department of Biological and Agricultural Engineering
Luettich, Rick	UNC-CH Institute of Marine Sciences
McKee, Brent	UNC-CH Department of Marine Sciences
McLawhorn, Dan	Legal and Policy Consultant
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
Waickowski, Sarah	NCSU Department of Biological and Agricultural Engineering
Whipple, Tony	UNC-CH Institute of Marine Sciences

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Greer Arthur, Research Director
Laurie Farrar, Financial Director
Steve Wall, Outreach Director
Sarah Fitzgerald, Communications Specialist
Tara Tyson, Grants Manager

NC Collaboratory Advisory Board

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Rick Luettich, Professor and Director, UNC Institute of Marine Sciences
Mike Piehler, Director, UNC Institute for the Environment

Acknowledgments

The Falls Lake Study team and Collaboratory staff would like to recognize the assistance and cooperation from staff at the N.C. Department of Environmental Quality as part of the research process.

The leadership and staff at the Upper Neuse River Basin Association is continuing to provide valuable guidance and background information during the course of the study.

The following UNC students and Collaboratory interns made significant contributions to the drafting of the 2022 Interim Update:

- *Adithi Reddy*
- *Alyssa Coleman*
- *Auburn Robertson*
- *Jenna Rupp*
- *Reiley Baker*