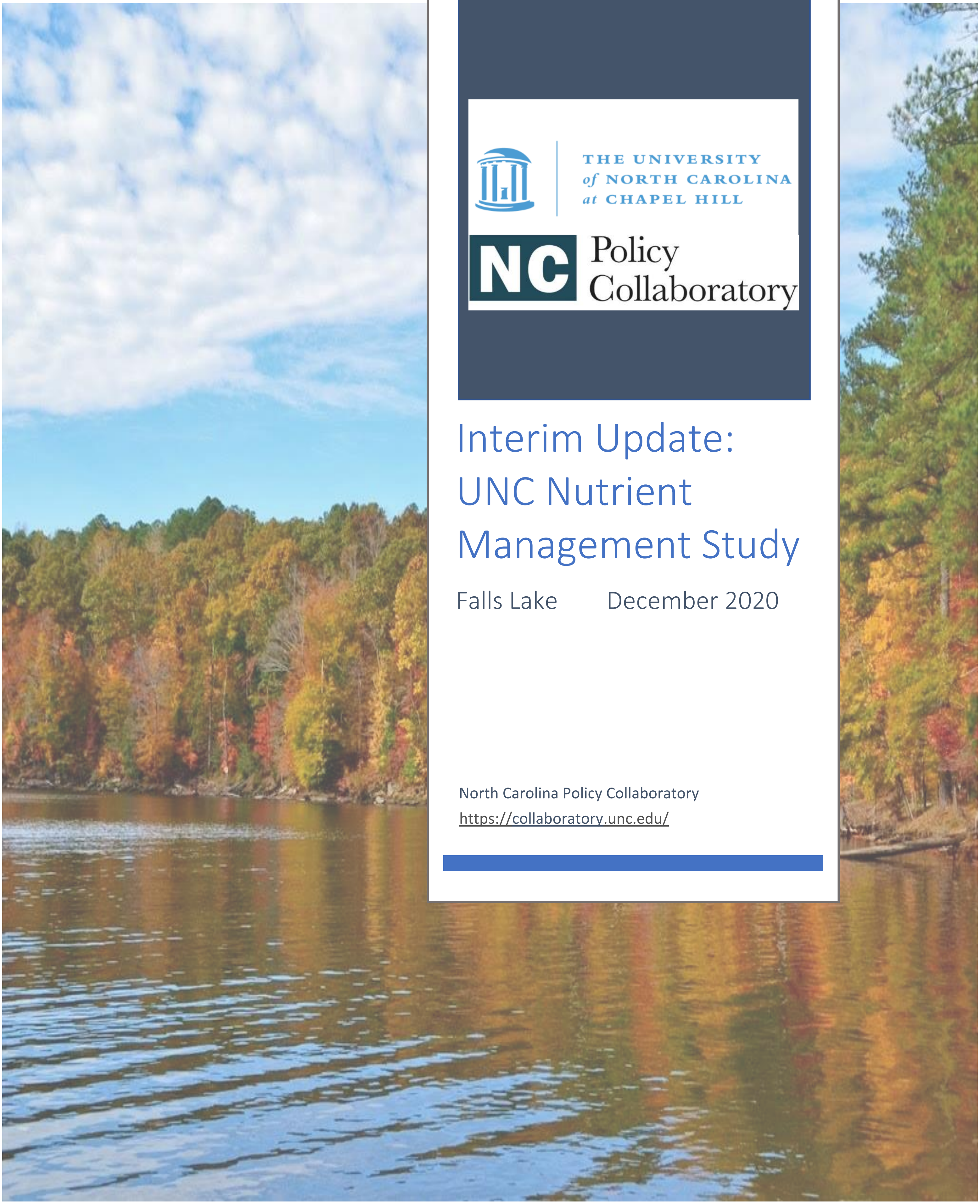

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

NC Policy Collaboratory

Interim Update: UNC Nutrient Management Study

Falls Lake December 2020

North Carolina 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 directs 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 UNC 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.

Over the course of 2019 and 2020 researchers from UNC, 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.
- 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. Falls and Jordan Lake Monitoring. Source: deq.nc.gov

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. Researchers collected data from several sites around the lake to create accurate models that reflect fluctuation with varying seasons, timescales, environmental factors, and flows into and out of the lake. GIS analysis and literature reviews were used to monitor current onsite wastewater treatment systems and their drainage, and a financial team inventoried existing costs and revenue related to nutrient management as well as rates, fees, and tax schedules for local governments to organize revenue strategies for funding nutrient management.

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?

Are year-round patterns of cyanobacterial abundance in Falls Lake associated with toxin presence? Can specific environmental factors be associated with algal abundance or toxin concentrations in Falls Lake?

Based on the nutrient removal capabilities of a suspended pavement street system, what is the potential impact of scaling green street retrofits on water quality in Falls Lake?

Do onsite wastewater treatment systems increase nutrient concentrations in streams draining to Falls Lake? How much N and P from onsite wastewater treatment systems drains to tributaries in the Falls Lake watershed?

Model Improvement Initiatives

Formulate an accurate mass balance of Nitrogen by including nitrogen fixing cyanobacteria as a group to help update the nutrient response model.

Understand the benthic habitat and controlling factors for the significant members of a cosmopolitan group of algae and bacteria to identify significant points in the nutrient migration pathway and create targeted intervention and improved models of ecosystem function.

Study Activities

The research underway at Falls Lake and in the watershed represents a comprehensive approach to understanding the current nutrient issues and potential solutions for policy-makers. Some of those activities underway as part of the study include:

- Utilize Acoustic Doppler current profilers (ADCPs) at four locations along the lake to measure water velocities through water columns.
- Deploy moorings to measure temperature, irradiance, conductivity, and water depth to support the understanding of thermal stratification and light extinction in the lake, measure atmospheric pressure, and measure water depth and position of sensors.
- Conduct monthly surveys to collect whole lake water at 11 stations to determine particulate and dissolved toxin levels and chlorophyll a (chl a) concentrations, screen for MCY and CYL, detect specific dissolved toxins, measure chl a, and collect physiochemical parameters (DO, temperature, conductivity, and pH).
- Measure water column N_2 fixation using acetylene reduction assays and used samples of the photic zone to test the effects of light, temperature, conductivity, dissolved oxygen, pH, and photosynthetically active radiation on four dominant phytoplankton classes.
- Estimate whole lake denitrification rate based on the ratio of N:P retention and mass ratio of surface sediments
- Analyze stormwater control measures such for possible implementation in Falls Lake watershed. Report drafted to provide guidance to retrofit North Carolina wetlands with floating treatment wetlands and littoral shelf filters.
- Inventory existing costs and revenue related to nutrient management, examine the UNRBA's role in regulatory compliance, and compile rates, fees, and tax schedules for local governments to help with organization of raising revenues for nutrient management using existing mechanisms.
- Use literature review, GIS analysis, and field monitoring of tributaries to analyze onsite wastewater treatment systems and their drainage into the watershed.
- Collect sediment cores and bottom water along transect of six sites spanning main stem in Falls Lake from east to west. Run incubations with bottom water in environmental chamber matching average in situ temperatures of lake water.

Preliminary Findings

The work of the study teams identified several issues worth highlighting as research continues including:

- Outflow from the dam may significantly control the advancement of freshwater input. The upriver section cools more quickly than the deeper downriver section, causing long-lake density driven currents.
- Multiple stations tested positive for up to four of the toxins throughout water surveys. Further toxin analysis is still in progress after being delayed by COVID-related laboratory closures.
- Parameters were identified to refine N_2 fixation measurements including depth, light, availability, and volume represented by each depth strata in the lake. Current values indicate N losses by denitrification.
- Annual TN and TP loading rates were well below target rates, indicating the units have potential to mitigate the environmental impacts associated with development.
- Local governments are responsible for the majority of the cost burden of nutrient management efforts. Over the next two years, the financial analysts will move toward a set of recommendations for how governments can meet these costs.
- A new model including NO_3-amended denitrification rates increased the potential for removal to 55% of the modeled load.

The initial findings outlined above represent issues of significance to local jurisdictions within the watershed and resource managers of Falls Lake. They will be further explored in the continuing research before the final report is complete.

Introduction

Study Background

Fall Lake's nutrient content and fluctuation, the factors that affect it, mitigation strategies and their effectiveness, and financial implications of proposed processes were analyzed by an interdisciplinary team of researchers. Mike Piehler, the Director of the UNC Institute for the Environment serves as 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.

Falls Lake Background

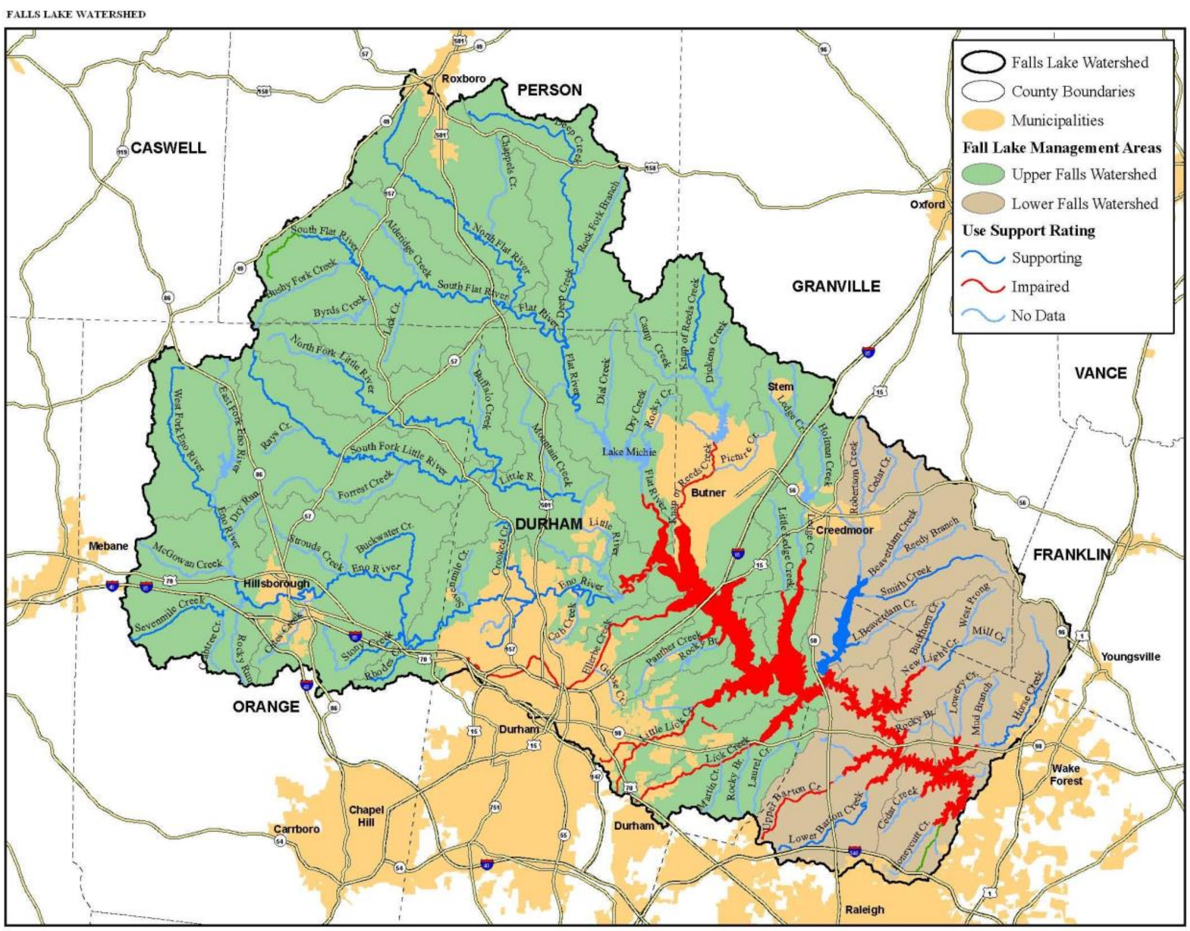

Figure 2. Falls Lake Map. Source: http://portal.ncdenr.org/web/fallslake

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 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.

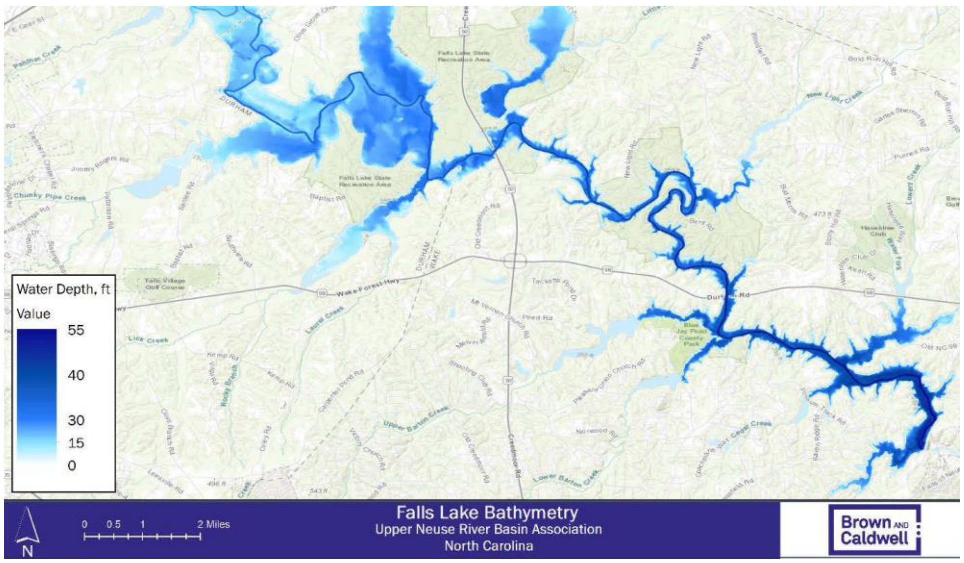

Figure 3. Falls Lake Bathymetry, data collected 2017 (UNRBA 2019)

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 were developed by DWQ and focus 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.

Upper Neuse River Basin Association

The UNC Falls Lake Study is working closely with the UNRBA to ensure that the research efforts do not duplicate previous work and will assist in the development of management actions. As such, this update includes the language below submitted by the UNRBA as a status report of their ongoing work.

The Upper Neuse River Basin Association (UNRBA) was formed in 1996 to examine water quality conditions and regulatory controls within the Falls Lake watershed. The UNRBA's principal focus is to develop pollution reduction and management strategies that efficiently and effectively provide a sustainable water supply for the region. Seven municipalities, six counties, and local Soil and Water Conservation Districts voluntarily formed the UNRBA.

The UNRBA is in the process of its re-examination of Stage II of the Rules. The UNRBA began planning for the reexamination in 2011 in accordance with the procedures and requirements outlined in the Rules (15A NCAC 02B.0275 Section (5)(f)). This section of the rules is generally referred to as the adaptative management provision. The UNRBA supports its members in the implementation of Stage I of the Management Strategy however, the UNRBA believes that the reduction goals for Stage II are infeasible and beyond the limits of technology. This conclusion is supported based on a technical review of the Stage II provisions.

UNRBA Stage I efforts to reduce nutrient loading have already contributed to water quality improvements in Falls Lake. Based on DWR's 2016 Status Report for Falls Lake, agriculture, wastewater treatment plants exceeding 1 million gallons per day, and NC Department of Transportation have all met or exceeded Stage I load reduction targets. New development regulations were adopted in 2012 by all local governments in the watershed to reduce loading from development activities. Though the Stage I load reduction targets for existing development have not been set by DWR and the EMC, the UNRBA has worked to develop actions and program proposals to reduce loading from existing development. This effort involves two initiatives: the Nutrient Credit Development Project and the Stage I existing development Interim Alternative Implementation Approach (IAIA).

The UNRBA completed its four-year monitoring program in 2018 and is currently focused on development of models to evaluate nutrient loading from the watershed and water quality in the lake. These models will be calibrated in 2021 after which they will be used to test nutrient management scenarios. The UNRBA will work internally and with external stakeholders including the UNC Collaboratory to evaluate the predictions for nutrient management actions and to consider feasibility and costs in the revised strategy. The UNRBA will propose a revised strategy in 2023, considering the work of UNC Collaboratory. The Collaboratory's final report on Falls Lake is due later that year.

In Situ Observational Study of Falls Lake

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 placed at four locations along the lake (*Figure 4*), mounted on bottom stands and pointing upward (*Figure 5*), to measure water velocities through water columns. The ADCPs were programmed to store 3-minute averaged water velocities every 10 minutes, with a vertical resolution of 0.5 m. They were deployed in November of 2019, then recovered and redeployed in June of 2020.

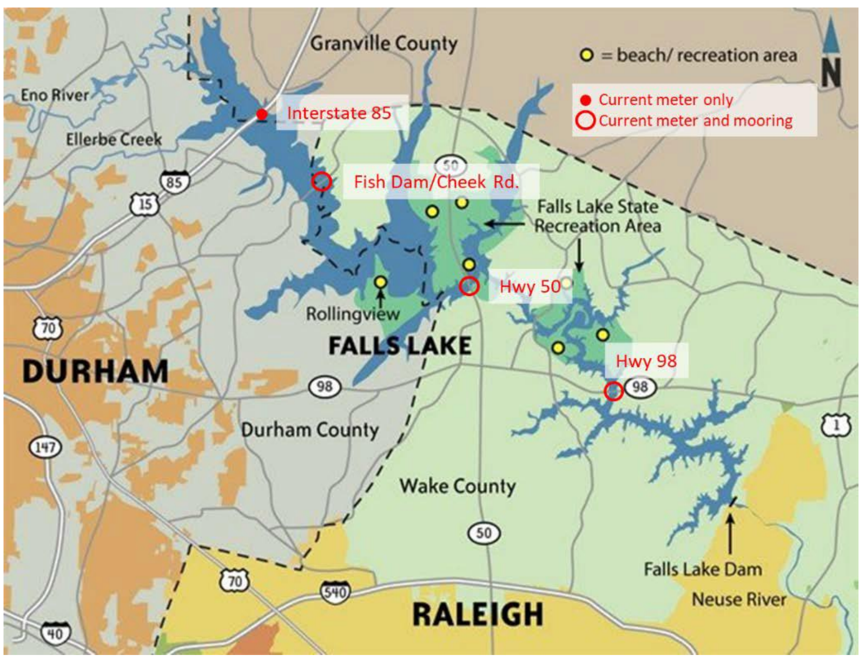

Figure 4. Locations for ADCPs and moorings in Falls Lake

Downriver, moorings were deployed to measure temperature, irradiance, conductivity, and water depth to support the understanding of thermal stratification and light extinction in the lake. Pressure sensors measured atmospheric pressure from the top of the surface float. Others measured water depth and position of sensors from the top and bottom of surface and bottom mooring components. Data were collected every 6-12 minutes, and temperature data from all sensors were aggregated and mapped onto a grid for subsequent analysis.

Findings

Freshwater input totals above 2000 cubic feet per second were reflected in conductivity levels as quick increases followed by rapid and longer lasting reductions in conductivity. Sites further downriver do not show the initial rapid rise and fall in conductivity associated with these freshwater inputs, and the differences between these responses indicate that outflow from the dam may significantly control the advancement of freshwater input.

The majority of sediment influx associated with runoff and high river flow enters the system upriver. The wider and shallower shape of the upriver half causes an increase in light penetration downriver, which can be expressed as an extinction coefficient based on an exponential decay function with depth. These extinction values can be rewritten to show the euphotic zone depth where 1% of the available light remains. The median values of euphotic zone depths describe similar trends with 1% light levels of 1.9m, 2.4m, and 3.2m from Fish Dam/Cheek Rd, Highway 50, and Highway 98 respectively. Data from shipboard profiles connected during site visits helped confirm the trend by showing that turbidity levels were greatest at Fish Dam/Cheek Rd, followed by Highway 50, then Highway 98.

Figure 5. Acoustic Doppler Current Profiler (ADCP) in a typical mounting stand.

During periods of cooling, the upriver section cools more quickly than the deeper downriver section, and the increased density of cooler water can lead to long-lake density driven currents. Stratification was observed at all sites during periods of warming.

Researchers

Rick Luettich and Tony Whipple, UNC-CH Institute of Marine Sciences
Harvey Seim, UNC-CH Department of Marine Sciences

Cyanotoxin Presence and Year-Round Dynamics in Falls Lake

Questions addressed

Are year-round patterns of cyanobacterial abundance (chlorophyll a) in Falls Lake associated with toxin presence for microcystin (MCY), cylindrospermopsin (CYN), anatoxin (ANA), saxitoxin (STX), and/or beta-Methylamino-L-alanine (BMAA)?

What are the relationships between CyanoHAB dynamics and pertinent physiochemical parameters? Can specific environmental factors be associated with algal abundance and/or toxin concentrations in Falls Lake?

Research methods

Monthly surveys were conducted in which whole lake water was collected at 11 stations to determine particulate and dissolved toxin levels and chlorophyll a (chl a) concentrations. Four of the stations screened for MCY and CYL using an integrative *in situ* screening tool which allows for the detection of specific dissolved toxins when traditional monitoring approaches cannot resolve toxin presence. Chl a was measured following previously established non-acidification protocols, and physicochemical parameters were collected using a YSI sonde equipped to measure DO, temperature, conductivity, and pH.

Findings

Chl a averaged slightly higher within the upper, wider portion of the lake compared to the narrower, lower part of the lake. Chl a levels remained relatively high throughout late fall and early winter months. Low MCY and CYL concentrations primarily detected in the dissolved phase (with little or no detectable concentrations in the particulate phase) indicated that sampling may not have coincided with peak bloom conditions when toxins were expected to be mostly bound inside the cells.

In contrast to MCY and CYL, both ANA and BMAA were exclusively detected in particulate fractions at the three stations prioritized for these less common toxins and STX. No STX was detected at any of the three priority stations. Overall, multiple stations tested positive for up to four of the toxins throughout the surveys. Further toxin analysis is still in progress after being delayed by COVID-related laboratory closures.

Management Implications

The results indicated potential risks from chronic low-level exposure to multiple toxins, especially due to the presence of MCY and its possible transfer to higher trophic levels (i.e., fish) which could pose a risk when consumed by humans. It is likely that monthly observations did not reflect maximal toxin concentrations during peak bloom conditions, and preliminary data suggests that regular toxin monitoring seems warranted to assess water quality and ecosystem health for Falls Lake. The study will create a baseline for cyanotoxin dynamics in Falls Lake and inform future evaluations of food web impacts and public health exposure risks for the lake.

Researchers

Astrid Schnetzer, North Carolina State University
Marco Valera, Mark Vander Borgh, Elizabeth Fensin, North Carolina Department of Environmental Quality

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

Research Overview

The current nutrient response model for Falls Reservoir was used to substantiate Stage II of the Falls Reservoir Nutrient Management Strategy in its goal to reduce N and P loads and phytoplankton biomass to levels that meet the water quality standard. The model included substantial uncertainties in tributary inputs, sediment nutrient fluxes, and other components, which are now being reduced through a monitoring and modeling project.

The balance between N_2 fixation and N removal via denitrification is a critical driver of phytoplankton nutrient limitation and still represents a substantial uncertainty in the model. This project uses direct measurements of planktonic N_2 fixation and a mass balance approach to calculate a lake-wide rate of denitrification. System-specific data on these critical rates of nitrogen transformations can be used in the formulation and parameterization of a more accurate updated nutrient response model.

Methods

Five N-fixation assessments were conducted (between July 2019 and July 2020) from depth-integrated, photic zone (surface water reached by sunlight) surface water samples collected at six stations (Fig. 6). Water column N_2 fixation was measured using acetylene reduction assays, an indirect method which uses the ability of the nitrogenase enzyme to reduce triple bounded substrates. At each station, 50 mL samples of the photic zone (surface water reached by sunlight) were added to six vials, and a seventh vial was wrapped in black tape for opacity. The vials were suspended at 0.5 m depth intervals from the surface to 3 m deep with the opaque bottle hung at the lowest depth. At each depth, water samples were incubated alongside a bottle of acetylene-amended deionized water as a control. At each sampling station, profiles of temperature, conductivity, dissolved oxygen, pH, and photosynthetically active radiation, and dissolved nutrients were measured. . Biomass of four dominant phytoplankton classes were calculated based on taxa-specific accessory pigments, and subsampleswere preserved for species-level microscopic identification and enumeration of the phytoplankton community. N_2 fixation rates were compared to light availability at each depth level and to the nutrient concentrations in each sample.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 season 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).

Results

Evident but statistically insignificant relationships were observed between N_2 fixation and light availability, and negatively between ammonium and N_2 fixation. Phosphate levels and N_2 fixation were positively correlated. The annual N input due to N_2 fixation was estimated at roughly 8460 kg N/y, and future work will refine the estimate by considering variation with depth, light availability, and volume represented by each depth strata (layer) in the lake. The estimate made up only 1-2% of the total tributary flux of N to Falls Lake. On average, the ratio of TN to TP retention was higher than the mass ratio of TN to TP in the surficial sediments, which indicated N losses by denitrification.

Mass balance estimates of lake-wide denitrification (3.6×10^4 kg N/y) were 25% lower than the average rate (4.8×10^4 kg N/y) directly measured from sediment core incubations (see section below on Quantifying Sediment Nutrient Processing in Falls Lake). Both methods showed that denitrification removed a modest portion (<20%) of tributary N loads.

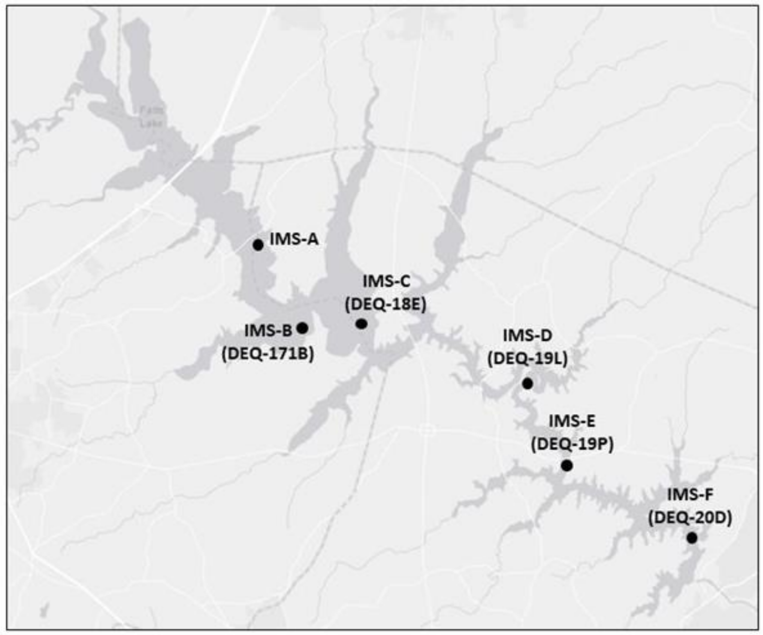

Figure 6. Map of sampling stations for measurements of N fixation rate. Five of the six stations coincided with stations sampled monthly by NC Dept. of Environmental Quality (DEQ).

Researchers

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

The Importance of Lake and Impoundment Ecosystems to Global Organic Carbon Cycling

Research Overview

The objective of this study was to better understand sediment fluxes associated with Falls Lake, ranging from rates of sediment inputs to the fate or particulate materials within the lake on time scales from seasonal to decadal. The study aimed to quantify temporal and spatial inputs of suspended sediments, characterize spatial and temporal variability in seasonal sediment and organic carbon inputs to bottom sediments, and collect cores for future quantification of bottom sediment mixing and accumulation rates. Researchers examined the relationship between total suspended matter (TSM) and particulate organic carbon (POC) concentrations and between POC concentration and water discharge.

Methods

The four rivers were sampled every two weeks for eight months using one to two liters of surface water which were filtered using pre-weighed polycarbonate filters to collect suspended matter. The samples were then dried and reweighed to determine particulate mass accumulated. Pre-combusted glass microfiber filters were used to filter separate surface water samples, and they were frozen to dry and transported under cold, dark conditions to a CHN analyzer to determine particulate carbon and nitrogen concentrations. Discharge data was retrieved from the USGS site and used for examination of the relationship between discharge and the date the water samples were collected.

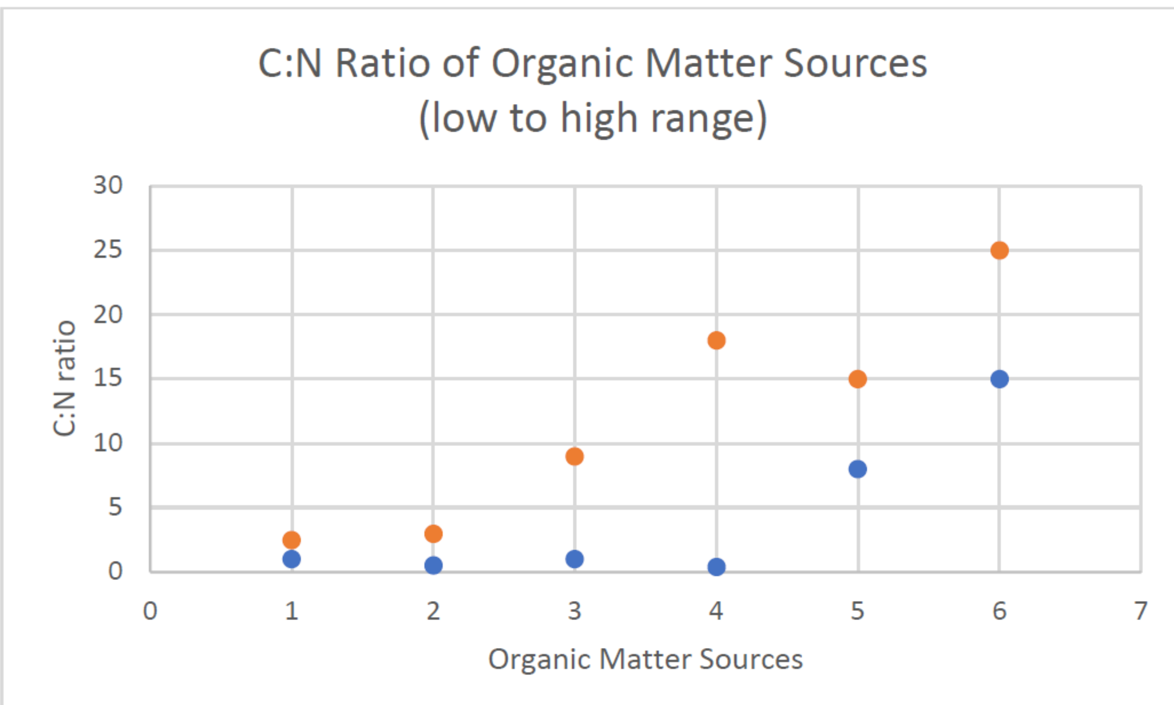

Figure 7. C:N range for each site and representative ranges for 6 potential organic matter sources. 1 Septic, 2 Sewage, 3 Forest, 4 Fertilizer, 5 Soil organic matter, 6 Terrestrial plants.

Table 1. Suggested sources of organic matter in suspended sediments collected, given the overserved ranges for C:N.

Site	C:N Range	Possible Sources
Ellerbe Creek	2-16	Include fertilizer, septic, sewage
Eno	8-14	Soil organic matter (SOM)
Flat	8-12	SOM
Little	7-11	SOM

Results

Relationships between discharge and sampling dates were plotted to examine trends over the 8-month sampling period. Other relationships that revealed relationships when plotted include: suspended sediment concentration and water discharge, organic carbon concentrations and discharge, POC and TSM, percent carbon and TSM, and carbon to nitrogen ratios and TSM.

Conclusions

Good rating curves were established for each input, with weakness related to uncertainty in predicted values when discharge exceeded the values sampled in this study. These curves can be used to predict TSM concentrations based on water discharge. POC values were found to be strongly correlated with TSM values, exhibiting the possibility of predicting POC values of Falls Lake inputs based on discharge values. Percent Carbon content and carbon to nitrogen molar ratios for suspended sediments provide a semi-quantitative approach to identifying an organic matter source in each input at a low expense compared to alternative approaches like stable isotopes of C, N and S. Relatively constant %C values indicate that sediment being supplied in each of the four basins are similar in character. At all sites except Ellerbe Creek, C:N ratio ranges indicate that the most likely sources of organic matter discharge come from soil organic matter. At Ellerbe Creek, fertilizer, septic, and sewage likely influenced the discharge.

Researchers

Brent McKee, Sherif Ghobrial and Alyson Burch, UNC-CH Department of Marine Sciences

Quantifying Sediment Nutrient Processing in Falls Lake

Research Overview

Nutrient level quantification informs nutrient level maintenance, and reactions mediated by a cosmopolitan group of algae and bacteria determine almost every chemical transformation of C, N, and P affecting the nutrients' levels. When the benthic habitat and controlling factors for these microorganisms are understood, managers can identify significant points in the nutrient migration pathway and initiate targeted intervention to improve ecosystem function models.

Methods

Sediment cores and bottom water were collected from six sites along the main stem in Falls Lake, and incubations were run with unaerated bottom water in an environmental chamber set to match *in situ* temperatures of lake water.

Results

The lake was not thermally stratified (<1-degree difference from surface to bottom). Dissolved oxygen was uniform throughout depths at western sites and slightly varied at eastern stations, except at 5E where bottom waters were hypoxic (oxygen-deficient). Dissolved inorganic nitrogen (DIN) concentrations were very low for NO_x and NH_4 levels trended higher in the eastern lake sites.

Net N_2 fluxes showed low rates for most sites, and the addition of excess nitrate to the feed water decreased the flux to net denitrification for all sites. Of the added nitrate, 10-20% was taken up by the cores, and mean denitrification efficiency (N removed via denitrification compared to flux from the cores) was 26%. After the NO_3^- addition, N_2 flux showed a significant positive relationship with sediment oxygen demand (SOD).

Conclusions

Low DIN concentrations demonstrated that denitrification rates were limited by N availability, and rates increased after the NO_3^- addition. While the water was not thermally stratified, TN concentrations were lower in bottom water. Labile carbon availability was a secondary regulator. Negative net N_2 fluxes were observed at site 5E, but became positive with the nitrate addition.

Extrapolation of denitrification rates at ambient nitrate concentration showed an estimated 16% removal by denitrification of loaded total nitrogen reaching the lake, and 55% at the nitrate amended concentration. Low photic-zone DIN levels maintained by high primary production in the water column indicate a significant potential for lake sediments to remove nitrate if seasonal competition for DIN is alleviated. Similar nitrate removal can be expected during pulsed loading in rain events.

Researcher

Mike Piehler, UNC-CH Institute of Marine Sciences and UNC-CH Institute for the Environment

Estimating the Influence of Onsite Wastewater Treatment Systems on Nutrient Loading

Research Questions

Do onsite wastewater treatment systems cause elevated nutrient concentrations in streams draining to Falls Lake?

On a per capita basis, approximately how much nitrogen and phosphorus from onsite wastewater treatment systems drains to tributaries in the Falls Lake watershed?

Methods

The research questions were addressed through different sources of evidence including a literature review, GIS analysis, and field monitoring of stream water quality data in the Falls Lake watershed. Sampling locations were selected based on watershed and septic system characteristics of sub-watersheds draining into the Falls Lake watershed. The field monitoring evaluated nutrient concentrations and streamflow across watersheds including Carolina Terrane, Triassic Basin, and Falls Lake/Crabtree Terrane. At each site, direct readings were taken in the stream using a calibrated YSI multiprobe to measure water temperature, specific conductance, pH, oxidation-reduction potential, and dissolved oxygen. Water samples were collected from streams and stored on ice, then delivered to the ECU Water Resources Lab. Samples were filtered within 24 hours and frozen for preservation prior to nutrient analyses at the ECU Environmental Research Lab (ERL). Samples collected on Dec. 18, 2019 and June 2, 2020 were also sub-sampled, filtered, then frozen and sent to UC-Davis Stable Isotope Facility for N-15 analyses.

Sub-watersheds were delineated using the USGS *StreamStats* 4 program. Land cover and geological data was sourced from NC OneMap, USGS, and USDA's Web Soil Survey. Onsite wastewater nutrient loading to the soil treatment unit (STU) was approximated by utilizing water use, wastewater nutrient concentration, and nutrient attenuation factors from published studies.

Findings

The stream nutrient concentration data suggested that sub-watersheds that relied on onsite wastewater treatment systems (OWTSs) were more likely to have elevated nutrient concentrations, specifically nitrogen, relative to sub-watersheds that relied on municipal wastewater treatment (Figure 8). Through a comparison of OWTS density and stream nutrient concentration, a positive correlation between system density and nutrient concentrations was revealed. OWTS density, soil type, and land-use also showed an influence on nutrient concentrations.

Do onsite wastewater treatment systems cause elevated nutrient concentrations in streams draining to Falls Lake?

Streams draining septic sub-watersheds showed elevated total dissolved nitrogen, phosphate, and chloride when compared to predominantly sewered sub-watersheds. The data suggests that nutrients and chloride from onsite wastewater is leaching to the shallow groundwater and a fraction of the inputs are translated to the local streams. The dataset suggests that streams that are draining sub-watersheds that rely predominantly on OWTS have a greater likelihood to have elevated nutrient concentrations. More detailed streamflow data is needed to evaluate if increased discharge occurs in these watersheds associated with recharge from OWTS, this factor may also influence nutrient loading and other studies have suggested that onsite wastewater inputs can increase local groundwater recharge and stream baseflow. Overall, the results indicate that onsite wastewater nutrients can be translated to streams, but the influence on stream nutrient concentrations may vary due to a range of factors including differences in wastewater loading, system density, variations in system type, soil, aquifer, and in-stream nutrient attenuation, the effectiveness of riparian buffers, hydrogeological setting, and stream-groundwater interactions. These and other factors may result in variability in onsite wastewater nutrient loading to streams.

On a per capita basis, approximately how much nitrogen and phosphorus from onsite wastewater treatment systems drains to tributaries in the Falls Lake watershed?

Per capita potential onsite wastewater nitrogen loading from sub-watersheds ranged from 0.07 to 2.7 kg-N/person/yr. When comparing sites based on loading per watershed area, several sites showed elevated nitrogen loading. Other data suggest that additional nitrogen sources are contributing to elevated loadings at these sites and the calculated loadings do not likely represent strictly onsite wastewater nitrogen loading. Further study is needed to evaluate the sources and location of the elevated nitrogen inputs.

Per capita potential onsite wastewater phosphorus loading from sub-watersheds ranged from 0 to 0.19 kg-PO_4-P/person/yr. The median per capita loading was estimated at 0.015 kg-PO_4-P/person/yr. Overall, the data and literature review suggested that approximately 74-100 % of nitrogen and 90-100 % of PO4 are attenuated or reduced between the sites with conventional OWTS and streams. This level of treatment is equivalent to what would be expected at a conventional municipal wastewater treatment plant. Future work will aim to identify tributaries in Falls Lake watershed with elevated nutrient concentrations associated with onsite wastewater and develop best management approaches for nutrient attenuation.

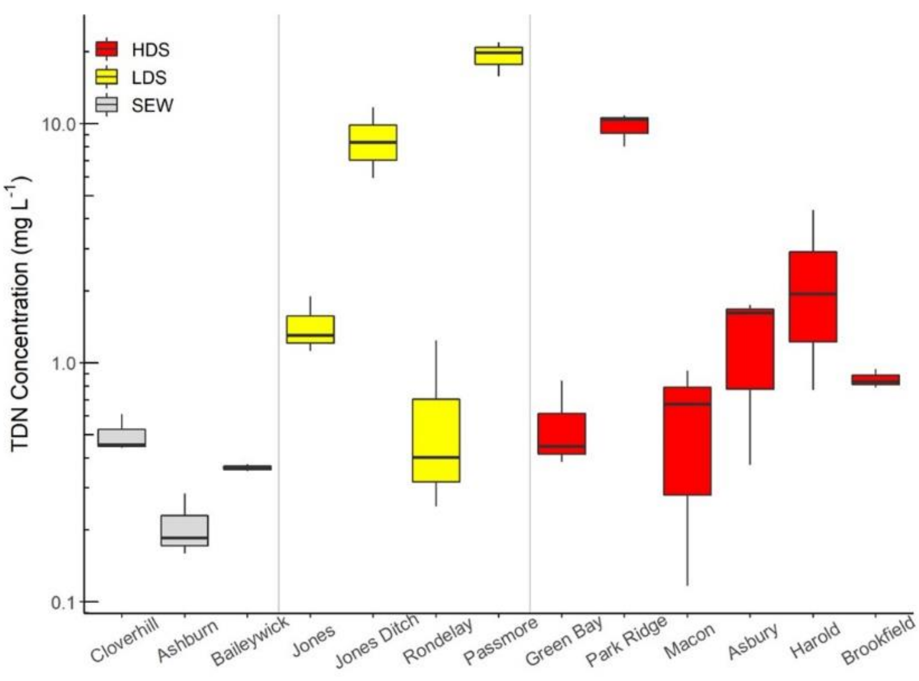

Figure 8. TDN concentrations in streams sampled in sewered, low-density septic, and high-density septic sub-watersheds.

Researchers

Michael O'Driscoll, Charles Humphrey Jr., Guy Iverson, and John Hoben, East Carolina University

Policy and Financial Considerations

Paying for Nutrient Management in Falls Lake: Summary of First Year Research

Goals for the first year of research included writing an overview of the financial components of the Falls Lake Rules, beginning an inventory of existing costs and revenue related to nutrient management, examining the Upper Neuse River Basin Association's (UNRBA) role in regulatory compliance and its Path Forward Committee's development of an Interim Alternative Implementation Approach, compiling rates, fees, and tax schedules for local governments into a 'revenueshed,' and creating a visualization of the affordability for a typical household of raising revenues for nutrient management using existing mechanisms.

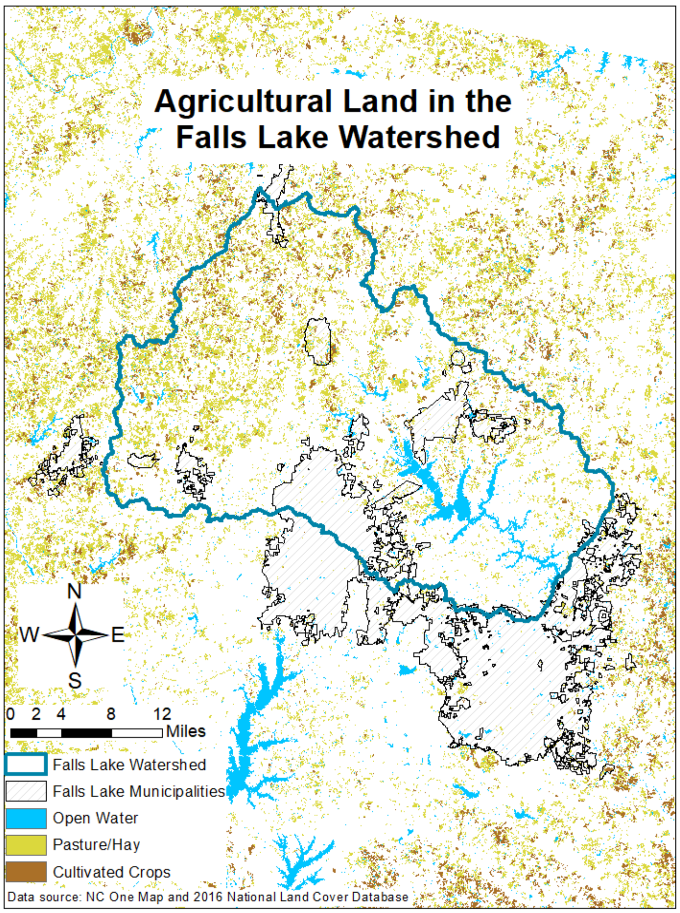

Figure 9. Agricultural land in the Falls Lake watershed is concentrated in the upper watershed.

Falls Lake Rules and Estimated Costs

Nutrient reduction goals were divided into two stages. Stage I aims to achieve and maintain water quality standards in the Lower Falls Reservoir, and was estimated to cost $605 million. Stage II includes water quality standards throughout the entire Reservoir, and was projected to cost $946 million.

The sectors of requirements include Stormwater Management for New Development, Stormwater Management for Existing Development, Wastewater Discharge Requirements, Agriculture, Stormwater Requirements for State and Federal Entities, Options for Offsetting Nutrient Loads, and Fertilizer Management. Each sector includes the estimated cost of compliance with the rules set for each stage.

Inventory of Existing Costs and Earmarked Revenues

Costs of complying for included areas were outlined through the stakeholder interview process, showing that Wake Forest's main costs come from their general fund, Durham County's from a stormwater enterprise fund, and Hillsborough's from the cost of upgrading their WWTP to comply with Stage I requirements and a stormwater enterprise fund.

UNRBA Path Forward Committee on the IAIA

The IAIA offers an investment-based approach to compliance with Stage I, rather than the nutrient reduction-based approach outlined within the Rules. Recognizing that Stage I requirements for nutrient loading among UNRBA members have been met, the IAIA suggests that participants would contribute funds based on the same formula used for the group's dues, which is based on a flat fee for all members, water allocation from Falls Lake, and land area within the Watershed. Participants would spend the funds using interlocal agreements or by funding existing local organizations.

Stakeholder Interviews

Stakeholder interviews were conducted to identify measures taken by each local government because of the Falls Lake Rules. Wake Forest's main measure taken was the writing of their stormwater and erosion ordinance, Durham County's were the implementation of a new development ordinance, the specification of acceptable nutrient loads for new development, and the creation of a stormwater utility, and Hillsborough's was the upgrading of their wastewater treatment plan.

Development of the Falls Lake 'Revenueshed'

Funding mechanisms under examination include property tax, water and wastewater rates, stormwater fees, sales tax, water allocation fees, and a fee for watershed protection. Research in the next year will include adding a recreation or hunting and fishing revenue stream and ways in which recreational taxes could be used to fund water quality initiatives.

Conclusion

The cost burden associated with the Falls Lake Rules is significant, and local governments are responsible for the majority of costs. Costs for compliance were estimated to be $905 million for Jordan Lake and $1.54 billion for Falls Lake, which were conservatively high values. The continuation of work in the next two years will move towards a set of recommendations for how local governments can meet the costs of a nutrient management strategy under the rules, using the 'revenueshed' tool to demonstrate scenarios for the use of existing or modified revenue generation frameworks.

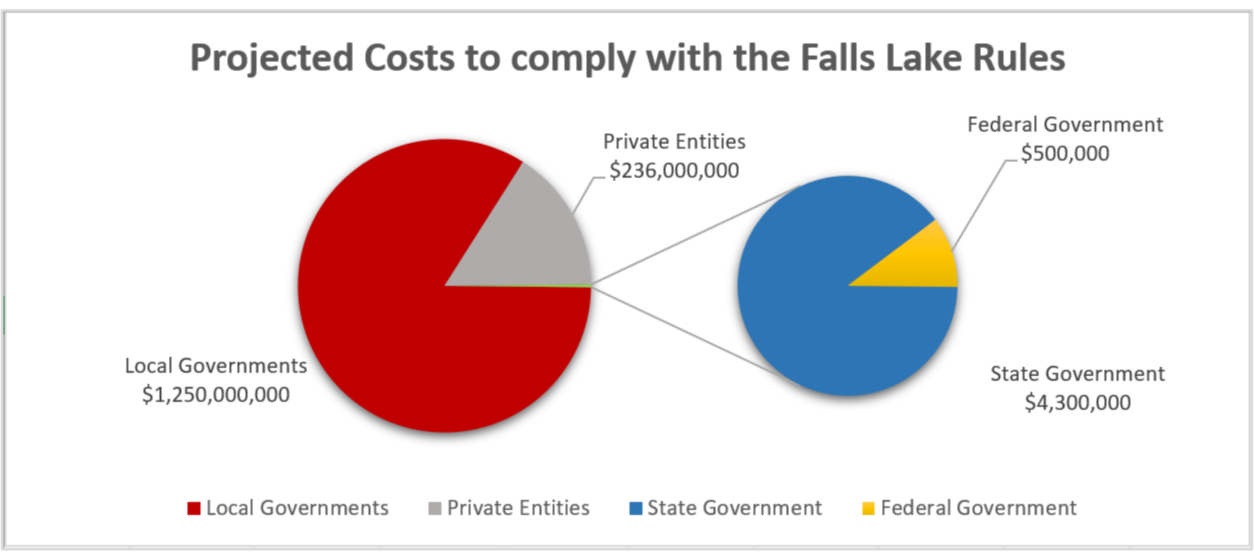

Figure 10. Projected Costs to comply with the Falls Lake Rules.

Researchers

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

Green-Street Retrofit Study & Wet Pond Retrofit Design Guidance

Research Overview

Green streets are "transportation corridors in which low impact development is employed as a design principle by using a variety of green stormwater infrastructure (GSI) practices to treat direct transportation surface drainage in the right-of-way" (Shaneyfelt et al., 2017). Suspended pavement street systems utilize un-compacted native soil or engineered soil media underneath sidewalks to treat stormwater runoff and include full-canopy trees to provide evapotranspiration and nutrient uptake. This research examined the nutrient removal capabilities of a popular suspended pavement street system to determine the potential impact of scaling green street retrofits on water quality in Falls Lake.

Methods

NCSU and the City of Durham monitored two undersized Silva Cell systems (North and South) with in-situ HSG D soils for water quality and hydrologic improvement from May 2019 to June 2020. Data were collected using automated stormwater samplers, pressure transducers, and rain gauges. Nonparametric methods were used to statistically analyze paired influent and effluent water quality data, which were then tested for symmetry. Using R 3.6.2 software, symmetrical data were analyzed for statistical significance between influent and effluent EMCs, and non-symmetrical data were analyzed for significance using the paired samples sign test.

The project site's target TN and TP loading rates were calculated using the NCDEQ Stormwater Nitrogen and Phosphorus Tool. Annual loading rates from each Silva cell system were calculated using effluent and bypass volumes and respective EMCs.

Results

NCSU collected 16 and 5 effluent water quality samples from the North and South systems, respectively. The South Silva Cells generated outflow when the rainfall depth was at least 1 inch. At the North site, bypass or overflow occurred during 12 of the 61 hydrologic events, while the South site generated bypass during 11 of the 61 storm events.

Conclusions

Reductions in pollutants are attributed to filtration, sedimentation, and the system's internal water storage (IWS). Previous research has shown that IWS promotes denitrification, and paired with this study's results, suggest that Silva Cells can provide water quality treatment regardless of the in-situ HSG. The annual TN and TP loading rates from North and South systems were well below the site's target rates and indicate undersized Silva Cells have the potential to mitigate the environmental impacts associated with development.

Wet Pond Retrofit Design Guidance

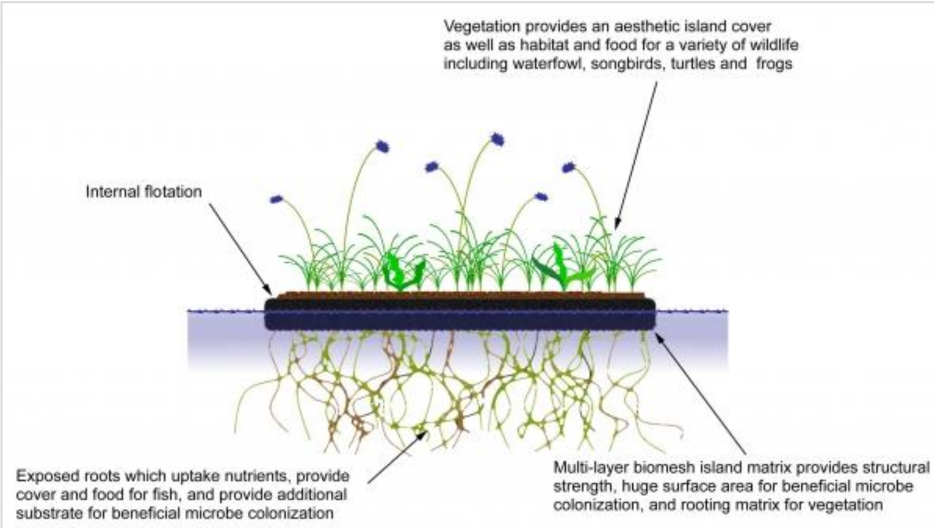

Figure 11. Floating Treatment Wetland

To address stormwater runoff and improve nutrient and pathogen removal in ponds, recent efforts have focused on retrofitting existing wet ponds to improve their water quality performance. Floating treatment wetlands (FTWs) employ vegetated floating mats of trays to provide pollutant removal in surface water settings, as shown in *Figure 10*. This retrofit option is straightforward to design and install, and does not impair a wet pond's ability to mitigate peak flows. Littoral Shelf Filters are installed at the edges of ponds at the permanent pool elevation and receive runoff as a pond fills to temporary pool elevation. Runoff is routed through the filter and receives treatment via filtration and chemical reactions. Installation of a littoral shelf filter requires more heavy equipment than FTWs, but both system types require ongoing maintenance.

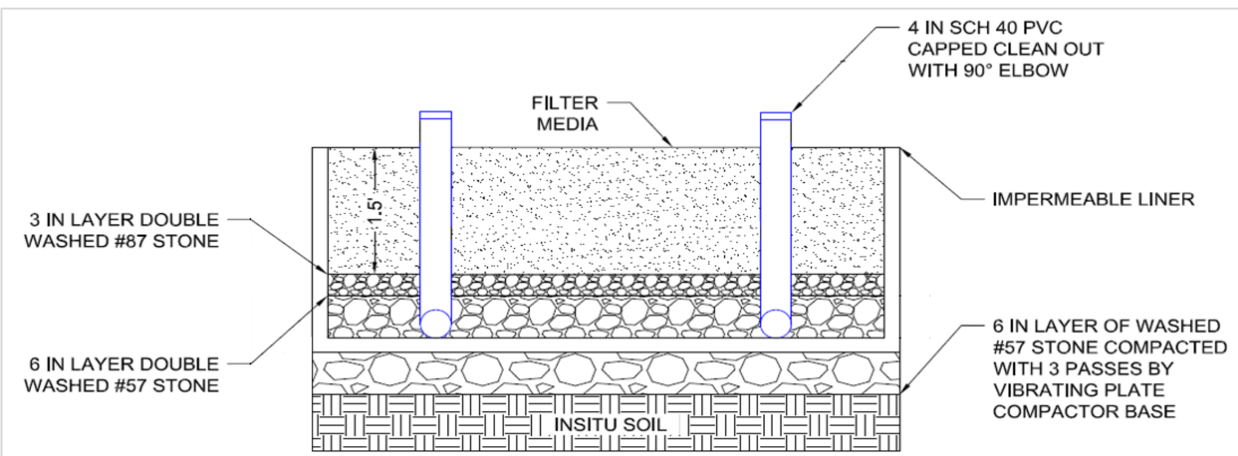

Figure 12. Example cross-section schematic or a littoral shelf filter.

Researchers

Bill Hunt, Jeffrey Johnson and Sarah Waickowski, NCSU Department of Biological and Agricultural Engineering

The Year Ahead

The work outlined above will continue forward during the year ahead. Research teams will continue to monitor nutrient levels in Falls Lake and enhance models that evaluate and predict nutrient fluxes. Stakeholder interviews with five more jurisdictions will help researchers understand stakeholder perspectives more clearly. Sediment inputs, community engagement for stormwater implementation, and data analysis and isotopic evaluation will all be examined and reported in the completed draft.

Scientific Review of Watershed and Water Quality Modeling to Support Nutrient Management in the Falls Lake Watershed

The Upper Neuse River Basin Association has deployed four models to better understand the feasibility of improving water quality through watershed nutrient management. The UNRBA developed a Watershed Analysis Risk Management Framework (WARMF) model to evaluate nutrient loading, along with three other scientific lake models. These models work to contribute to informing effective watershed management, and potential application in cost-benefit analyses.

This scientific review, proposed by Dan Obenour Associate Professor at NCSU, will analyze the UNRBA watershed and water quality models in comparison to scientific literature on model development and biophysical rate estimates. This study will further focus on the representation of nutrient sourcing, transport, and fate within the watershed. The UNRBA, along with other NC entities involved in nutrient and eutrophication management, will receive the literature review, model assessment, and list of recommendations, furthering collaboration and guidance. Reports will identify each models' strengths, limitations, and suggestions for future improvements.

Falls Lake Study Symposium in the Spring of 2021

The UNC Center for Public Engagement with Science is partnering with the UNRBA to plan a public forum to share research plans and initial findings of the UNC Falls Lake study. This public event will provide the opportunity for researchers to receive direct feedback from citizens in the watershed and local and state resource agency staff. The forum will be designed similar to Jordan Lake Study forums held in 2018 and 2019, which proved successful in providing information to the public and hundreds of interested stakeholders.

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
Burch, Alyson	UNC-CH Department of Marine Sciences
Fensin, Elizabeth	NCDEQ Water Sciences
Ghobrial, Sherif	UNC-CH Department of Marine Sciences
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Hall, Nathan	UNC-CH Institute of Marine Sciences
Hoben, John	East Carolina University
Humphrey Jr., Charles	East Carolina University
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Iverson Guy	East Carolina University
Johnson, Jeffrey P.	NCSU Department of Biological and Agricultural Engineering
Evan Kirk	UNC Environmental Finance Center
Luettich, Rick	UNC-CH Institute of Marine Sciences
McKee, Brent	UNC-CH Department of Marine Sciences
Elsemarie Mullins	UNC Environmental Finance Center
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Steve Wall, Outreach Director
Hope Thomson, Graduate Research Assistant

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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
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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

Acknowledgments

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

Mandy Pitz, an Environmental Policy Intern with the Collaboratory, made significant contributions to the drafting of this report. Environmental Policy interns, Scarlett Van Dyke and Caroline Patterson, provided background research in support of this report.