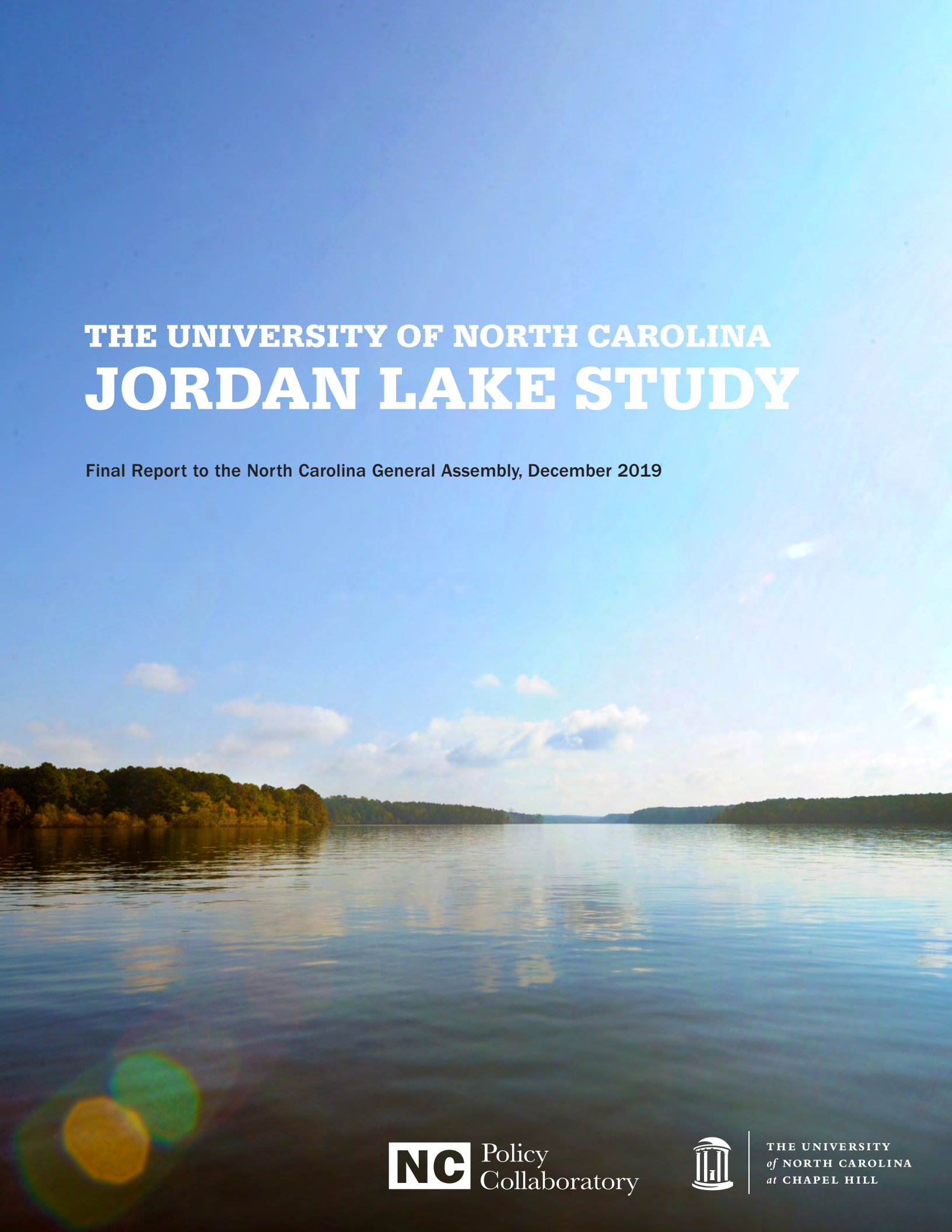
THE UNIVERSITY OF NORTH CAROLINA
JORDAN LAKE STUDY

Final Report to the North Carolina General Assembly, December 2019



NC Policy Collaboratory

THE UNIVERSITY *of* NORTH CAROLINA *at* CHAPEL HILL

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Foreword

NC Policy Collaboratory

Legislative Charge

In 2016 the North Carolina General Assembly (NCGA) approved legislation directing UNC-Chapel Hill (UNC) to conduct a multi-year study and analysis of nutrient management strategies and compilation of existing water quality data specifically in the context of Jordan Lake and Falls Lake (Sections 14.13.(a) through (c) of Session Law 2016-94 as amended by Sections 13.8.(a) through (e) of Session Law 2018-5). The legislation outlines two specific provisions that are to be included in the study:

- Review data collected by the Department of Environmental Quality and by other stakeholders from water sampling in the areas subject to the Jordan Lake or Falls Lake Water Supply Nutrient Strategies and compare trends in water quality to the implementation of the various elements of each of the Strategies; and

- Examine the costs and benefits of basinwide nutrient strategies in other states and the impact (or lack of impact) those strategies have had on water quality.

Over the last three years, the UNC Jordan Lake study team addressed the specific legislative charge of reviewing existing water quality data and examining nutrient strategies in other states. Importantly, the wide scope of the study also included: gathering new water quality data in the Jordan Lake watershed, better understanding the circulation and dynamics of Jordan Lake, exploring policy and financing options for nutrient management and engaging with stakeholders.

The legislation (Section 14.13.(c) of Session Law 2016-94) appropriated $500,000 annually over six years and directed that the first three years of the study focus on Jordan Lake culminating with a final report in December 2018. During the 2017-2018 legislative session, the NCGA amended the final due date of the Jordan Lake study report back to December 31, 2019. In 2018, the NCGA also authorized the Collaboratory to utilize up to $1 million from their $3.5 million Challenge Grant (Section 27.5 of Session Law 2016-94 as amended by Section 13.8.(d) of Session Law 2018-5) to support quantitative modeling of Jordan Lake that would complement the work of the study.

Jordan Lake and shore.

Study Overview

Leadership at the university placed the UNC Jordan Lake study under the oversight and management of the North Carolina Policy Collaboratory (Collaboratory), which is an environmental and natural resources research entity housed at UNC established by the NCGA in July of 2016 (Section 11.8 of Session Law 2016-94).

Given the importance of this study and its large scope, the Collaboratory chose to allocate a portion of the funding it receives annually from the NCGA to supplement the work of the study over the last three years. As such, when including the modeling work, the three-year Jordan Lake appropriation of $500,000, and the Collaboratory supplement, the NCGA has made an investment of close to $3 million to better understand and identify solutions to improving the water quality in Jordan Lake and throughout the watershed.

The study team is comprised of more than two dozen researchers, including faculty members, graduate students and staff from UNC, UNC-Charlotte and North Carolina State University. In addition, dozens of UNC undergraduate students also contributed to the study through semester long capstone classes with a specific focus on varying aspects of water quality in the Jordan Lake watershed.

The study team had a broad and diverse expertise that brought a specialized focus in several distinct areas to help address the scientific and policy questions related to nutrient management and improved water quality (A full roster of study team members can be found in Appendix II).

Study Principles

Utilize Science-Based Results to Guide Findings

The Jordan Lake study identified topics in which advancing the research assisted in addressing existing data gaps, trends in water quality and financial consequences of management decisions.

Build Upon Previous Work to Advance the Discussion

The efforts to address water quality in Jordan Lake have taken place over a number of decades. As such, the study made every effort to build on that foundational work and not duplicate previous work.

Integrate Existing Initiatives

The research team recognized that the study is one project of several that are currently underway in relation to how North Carolina develops and implements nutrient management strategies.

Leverage Current Research

The research and work conducted as part of the study utilized ongoing research partnerships and expanded the scope of current research projects as a means of expediting results and operating in a cost-effective manner.

Operate in a Transparent Manner

Results and conclusions from the study and background information and data that formed the basis of these conclusions is publicly available.

Engage with Stakeholders

A key component of the study was to incorporate the guidance and perspectives of a diverse array of citizens and stakeholders throughout the watershed that helped inform the study's work and also adds value to future management and policy decisions for the Jordan Lake watershed.

Study Activities

Over the last three years the study team worked on a number of scientific, economic, and policy research projects for the purposes of providing actionable information to assist with management of the lake. These research projects are closely connected and are intended to provide a better understanding of Jordan Lake and the watershed and help answer the fundamental questions:

1) What are the sources of nutrients impacting the water quality in Jordan Lake?
2 What are the nutrient management options and how cost-effective are these options?

Some of the specific research and project activities undertaken during the course of the study included:

• Profilers were deployed in Jordan Lake to measure water velocities through specific locations across the lake. In addition, water quality and meteorological data was collected in a semi-continuous manner. This data can be found at: jordanlakeobservatory.unc.edu.

• Newly deployed automated sensors collected water quality data at specific points in the Jordan Lake watershed allowing for the development of a highly detailed dataset of both the hydrologic and nutrient dynamics in the streams of the watershed.

• Suspended sediments were measured weekly in waters entering Jordan Lake from creeks at four different sites.

• Biological assessments were conducted using water from Jordan Lake to determine the factors fueling algal growth in the lake.

• A review of nutrient reduction strategies was undertaken to scan other programs in the United States, and particularly, as directed by the NCGA, around the Chesapeake Bay.

• An evaluation of financing options available to local governments as they implement and pay for nutrient mitigation measures.

• An analysis of previous research on the effectiveness of nutrient mitigation measures to inform future management actions in the watershed.

• Research symposiums were held in 2018 and 2019, in addition to a series of listening sessions throughout the watershed to inform the research and policy recommendations.

UNC-Chapel Hill undergraduate students conducting research at a stream in the Jordan Lake watershed.

Executive Summary and Recommendations

The Jordan Lake rules were implemented with the goal of reducing nutrient over-enrichment, and thus controlling growth of nuisance algae. While called a lake, it is important to distinguish that Jordan Lake is a man-made reservoir. Since the design phase for the reservoir, engineers noted that Jordan Lake would have problems with excessive growth of algae. The original Environmental Impact Statement in 1971 specifically indicated the reservoir would be eutrophic soon after its construction.

Enabling legislation for this project identified critical components to be included in the study: a review of historical water quality and its connections to management interventions and a critical review of the costs and benefits other state's nutrient strategies' effectiveness in enhancing water quality.

This study was designed to provide an empirical assessment of the factors contributing to Jordan Lake's impairment using a set of fully integrated research projects and numerical models to assimilate project results and provide a platform to project future conditions in Jordan Lake under a range of management scenarios. The study sought to provide actionable information for decision-makers regarding an effective path forward to sustain water quality in Jordan Lake.

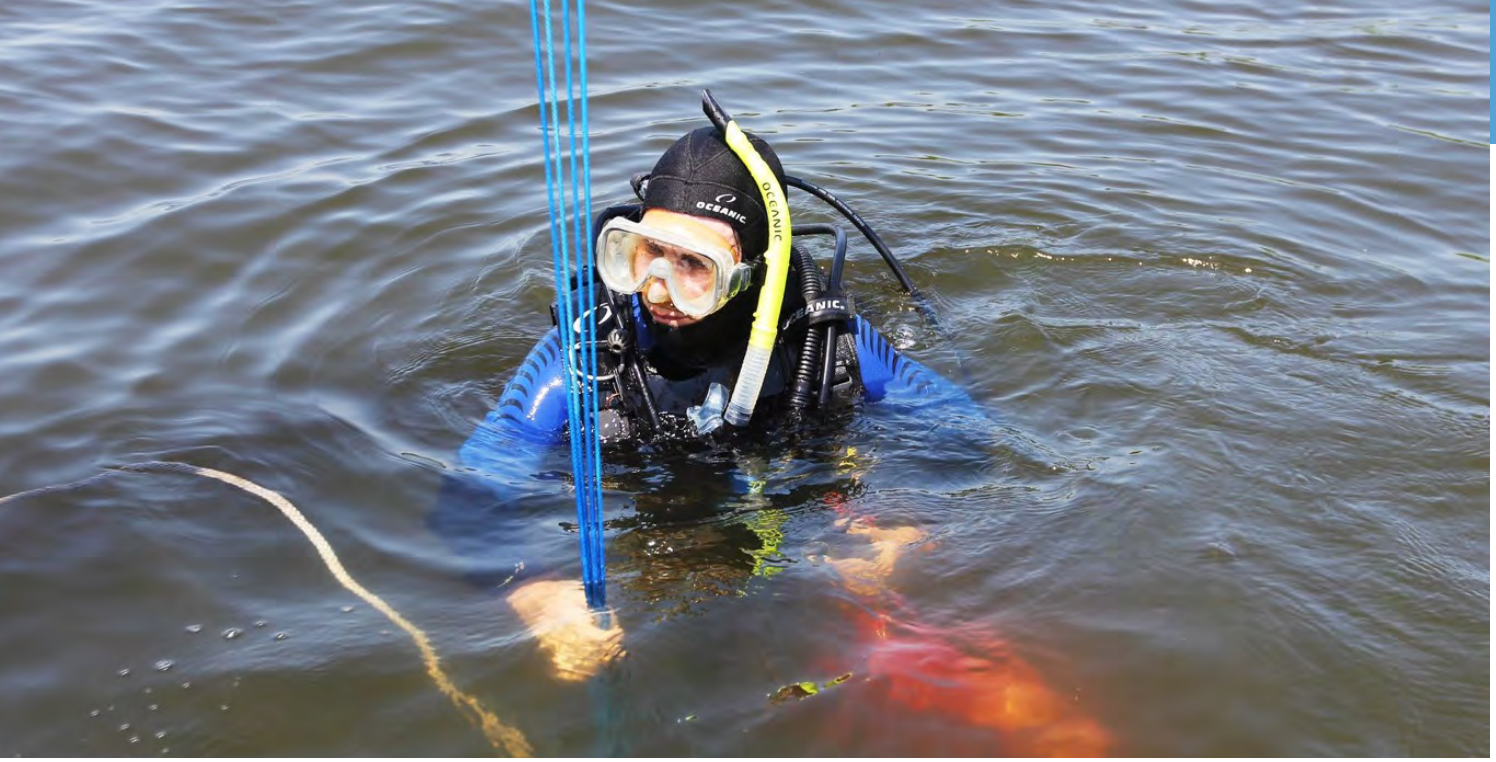
An important component of this project was the quantitative modeling of both the Jordan watershed and the reservoir itself. The modeling conducted by researchers at North Carolina State University and UNC-Charlotte provided new information about how Jordan Lake would respond to specific nutrient loading reduction scenarios. Some of those key takeaways are outlined below later in this section.

Results from this project provided valuable insights into both the function of Jordan Lake and the human systems that interact with the lake. Recommendations fell into three categories:

- Increasing revenues for management interventions and enhanced water quality;
- Strengthening local government collaboration around Jordan Lake management; and
- Addressing nutrient loading to Jordan Lake.

Jordan Lake is an incredibly valuable regional resource that requires significant attention to avoid further water quality degradation and drive future water quality enhancement.

Ryan Neve, a technician at the UNC Institute of Marine Sciences, prepares to lower equipment into the lake.



A member of the research team works to deploy monitoring equipment in Jordan Lake.

Watershed Model Key Takeaways

• Point source dischargers make up nearly 50% of TN and 25% of TP loadings to Jordan Lake. Thus, loads from wastewater treatment plants remain substantial in comparison to diffuse (nonpoint) loads from the landscape.

• Lands urbanized before 1980 are hot spots for diffuse nutrient export. They release about double the TN and TP of agricultural and post-1980 urban lands (per unit area).

• Undeveloped lands export about an order of magnitude (10x) less TN and TP than agricultural and urban lands (per unit area). Thus, development of natural lands will substantially increase nutrient loading to Jordan Lake.

• Nutrient retention in watershed streams and waterbodies is less than 20% of total point and nonpoint loads, except where TP is intercepted by reservoirs with long residence times. As a result, most of the load from the upstream portions of the watershed (e.g., Triad area) reaches Jordan Lake.

Reservoir Model Key Takeaways (NCSU)

• Due to substantial internal storage of TN and TP in reservoir sediments, it will take the lake decades to fully respond to external (watershed) nutrient loading reductions and achieve a new (less eutrophic) steady state.

• Watershed nutrient loading reductions will achieve greater water quality benefits if maintained over the long term. For example, a 50% reduction in nutrient (TN and TP) loads is expected to reduce historical chlorophyll levels by only about 6% in 1 year. After 20 years, mean chlorophyll will be reduced by about 15% and after 40 years by 21%.

• The upper portion of the reservoir (i.e., above Farrington Road), which is most eutrophic, will respond faster to nutrient loading reductions. A 50% reduction in nutrient loads will produce 7%, 21% and 28% reductions in chlorophyll in this segment after 1, 20 and 40 years respectively.

• Both TN and TP were found to be related to observed algal concentrations, though TP is found to be somewhat more frequently limiting in summer. Overall, these results suggest that a dual nutrient (TN and TP) reduction strategy is needed to reduce algal levels in the lake.

• Reducing nutrient loading to the New Hope arm of the reservoir is likely to produce greater water quality benefits than reducing nutrient loading to the Haw River arm. For instance, a 50% load reduction of the New Hope arm alone, after 20 years, is expected to decrease lake-wide chlorophyll by 13%. The corresponding reduction due to load reduction the Haw River arm would be only 4%.

Reservoir Model Key Takeaways (UNC-Charlotte)

• The majority of nutrients (N and P) entering the lake are from watershed sources, primarily from the Haw River. These nutrients are mostly in particulate and organic forms that are not immediately available to phytoplankton.

• Only a very small fraction of inflowing Haw River water makes its way to the region above the two causeways in the New Hope Creek arm of the lake. In this region, local inflows (Morgan Creek, New Hope Creek, Northeast Creek) supply the majority of nutrient inputs.

• The benthic sediments of Jordan Lake act as a sink for the particulate fraction of organic nutrients, nitrate, and dissolved oxygen. Benthic sediments are also the major source of bioavailable nutrients, providing more than 75% of phosphate and 90% of ammonia to the lake.

• For the five-year time period studied (2014-2018), the observed 90th percentile photic-zone chlorophyll a concentration at eighteen monitoring stations across Jordan Lake was 72 µg/l, which is 44% above the North Carolina water quality criteria value of 40 µg/l.

• Two-year simulations of all regions of Jordan Lake predicted that nitrogen and phosphorus watershed load reductions of 10%, 30% and 50% would reduce algal biomass by 3%, 13% and 23% respectively.

• A simulation that considered changing sediment conditions predicted that a sustained nutrient load reduction of 50% would after a decade reduce algal biomass by 43%.

Management Recommendations

Increasing Revenues for Water Quality Enhancement

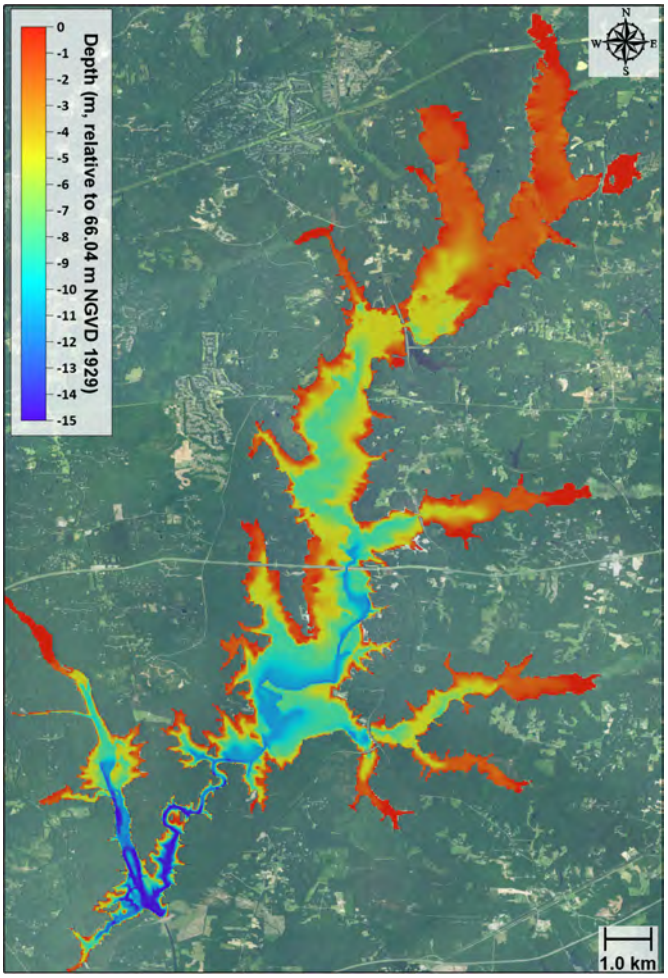
New Revenue Generation for Water Quality Protection from a Broader Mix of Participating Jurisdictions

• Those jurisdictions with a water allocation from Jordan Lake should be charged a new water allocation fee to create additional revenue for water quality improvement projects throughout the entire watershed. This additional fee will ensure that upstream communities in the Jordan Lake watershed are joined by beneficiaries of the lake in maintaining a healthy lake. For example, a water quality fee placed on the Jordan Lake water allocation holders of $0.05 per 1,000 gallons of annual water allocation would generate approximately $2 million annually, regardless of whether or not a system withdraws their entire allocation volume.

• Some type of financing approach where both upstream communities and those communities benefitting from Jordan Lake contribute towards nutrient management would likely lead to a more robust financing framework. Given the high cost of some non-point measures, it becomes even more important to find ways of spreading costs among as large a population as possible, including users of the lake outside of the watershed.

• The high costs of nutrient management increase the importance of finding new ways to implement projects that reduce costs or increase available revenue. Most of the projects attributed to the Jordan Lake rules have been financed in fairly traditional ways. Moving away from this standard approach and identifying innovative options for financing projects should be considered in the future.

Bathymetry map of Jordan Lake.



Managing Increased Revenue for Water Quality Projects in the Watershed

• New revenue would support the implementation of more robust projects throughout the watershed, including stormwater projects, septic tank programs, land conservation initiatives and continued water quality monitoring of Jordan Lake.

• New revenue generation from watershed entities could be managed under the existing Clean Water Management Trust Fund program with a carve out for projects in the Jordan Lake watershed. Alternatively, a new Jordan Lake watershed utility could be created to collect revenue and prioritize projects throughout the watershed.

Constant Concern for Cost Effectiveness

• Successful nutrient management strategies at a watershed scale require a lot of resources. In order for resource commitments to be sustainable, there must be constant concern for cost effectiveness. In other words, there must be careful attention to the least costly ways to accomplish goals.

Investment Based Approach

• Any new regulatory efforts related to addressing stormwater in the Jordan Lake watershed from existing development should focus on investment levels in water quality projects by local jurisdictions rather than the singular focus of counting pounds of nutrients.

Professor Kaylyn Gootman and one her students on the lake.

Strengthening Local Government Collaboration

Stakeholder Engagement

• The implementation of a nutrient management strategy requires serious stakeholder engagement and a commitment to the hard work of consensus building. This requires leadership and ongoing efforts to disseminate scientific knowledge that helps the stakeholders engage meaningfully. In particular, the experience from around the country shows how important local units of government and non-governmental organizations are in nutrient management.

• The ongoing work of the Jordan Lake One Water Association led by the Triangle J Council of Governments should be supported and continue to serve as a forum for ongoing dialogue among the local governments in the Jordan Lake watershed. The Upper Neuse River Basin Association, which is focused on Falls Lake, serves as a successful example of a regional watershed partnership and potential model for the Jordan Lake watershed.

Maximize Local Gains

• The primary policy goal is the sustainability of the designated uses of these reservoirs. This primary policy goal may not resonate with everyone in the watershed, especially those who do not use these reservoirs for either recreation or drinking water. Thus, no opportunity should be lost to maximize local benefits, including benefits outside the reservoirs. Each local government unit and other stakeholder in the watershed has its own set of concerns and needs for water. The Jordan Lake nutrient management strategies will be accepted and sustained much more readily if they help address those local concerns.

Addressing Nutrient Loading

State Water Quality Standards

• The state's longstanding broad nutrient sensitive waters criterion (an instantaneous chlorophyll a standard of 40 ug/l applied everywhere) should be reevaluated. For the past few years scientists have been reviewing this issue as part of the work of the Nutrient Criteria Development Plan Science Advisory Council. The Department of Environmental Quality should continue to engage in and encourage discussions related to development of new standards with an emphasis on the standards being site-specific and seasonal.

Stormwater and Wastewater Infrastructure

• Stormwater control measures must be coupled with sanitary infrastructure upgrades and maintenance. Distancing sanitary infrastructure from streams should be evaluated as a potential mitigation. Sanitary sewer trunk lines often run in close proximity to streams and at low points in the landscape. This means that even minor leaks may have a direct nexus to streams and the very presence of the sewer lines prevents the planting of vegetated riparian buffers which may mediate this loading.

Nitrogen Recycling

• Any nutrient management strategy and reduction goal for Jordan Lake should take into account the role of existing nutrients in the bottom sediment and their potential impact on driving algal growth.

Land Conservation

• Conservation of land throughout watersheds with easements and development limits is a common method for protecting the quality of drinking water sources. Effective stream restoration could be a powerful tool for managing nutrients; however, it must be approached at the watershed scale with reduction of stormwater and include reconnection to floodplains and wetlands.

• The Triangle Land Conservancy has worked with many partners to develop a Jordan Lake Watershed Conservation Strategy. Funding should be identified to initiate an ongoing conservation effort in the watershed similar to the successful Upper Neuse Clean Water Initiative.

Agriculture Trading Program

• The total amount of supply of agricultural lands is inadequate to keep up with demand in a water quality trading program, rendering the market unviable overall. Thus, when applied to the Jordan Lake program, the framework clearly shows that the traditional nutrient trading program will not be feasible or address nutrient management needs in any meaningful way.

Addressing Septic Systems as a Component of Nutrient Management Strategy

• Any effort to address the impact of nutrient loading in the Jordan Lake watershed should involve both improving sanitary sewer infrastructure and also the impact of septic systems as a source of nutrients. Several local programs across the state provide examples of addressing this problem through buyout or repair initiatives.

Adaptive Management and Ongoing Monitoring

• There is more to learn about nutrient management and criteria development, and we suspect that will remain true for decades. Hence it is important to build a strategy that makes its premises clear, and then is flexible enough to adapt if and when more learning shows those premises to have been flawed.

• One component of the work is to ensure that some type of continuous monitoring of the lake takes place as part of any new regulatory approach. This monitoring effort will ensure that as new information becomes available the management of the lake is not implemented in a static manner.

Background on Jordan Lake

JL

Jordan Lake is a reservoir west of Raleigh and south of Durham in Chatham County. Jordan Lake is owned and operated by the U.S. Army Corps of Engineers which dammed and flooded the Haw River and New Hope River between 1973 and 1983. The reservoir receives water input from the Haw River, Upper New Hope and Lower New Hope watersheds.

Watersheds Draining into Jordan Lake (Tetra Tech 2014)

	Haw River	Upper New Hope	Lower New Hope	TOTAL
Acres	859,185	147,485	71,861	1,078,531
Percent of Total	79.7	13.7	6.7	100

Associated with these water inputs are nutrients, sediments, and in some cases, significant debris. The Haw River watershed is mixed agricultural, rural and urban land while the Upper and Lower New Hope watersheds are principally urban. The primary outflow from the lake occurs over the Jordan Lake Dam and comprises the starting point of the Cape Fear River. The Haw River drains the Haw River watershed and discharges into the southern Haw River arm of Jordan Lake approximately five miles upstream of the Jordan Lake Dam. The Haw River provides 70-90% of the annual flow into the lake.

The Upper and Lower New Hope watersheds drain into the New Hope Creek arm of Jordan Lake which extends approximately 17 miles upstream from the dam. The Haw River arm and the New Hope Creek arm are naturally separated by a narrow channel referred to as the "s-bends" or "narrows."

Jordan Lake, November 2019.

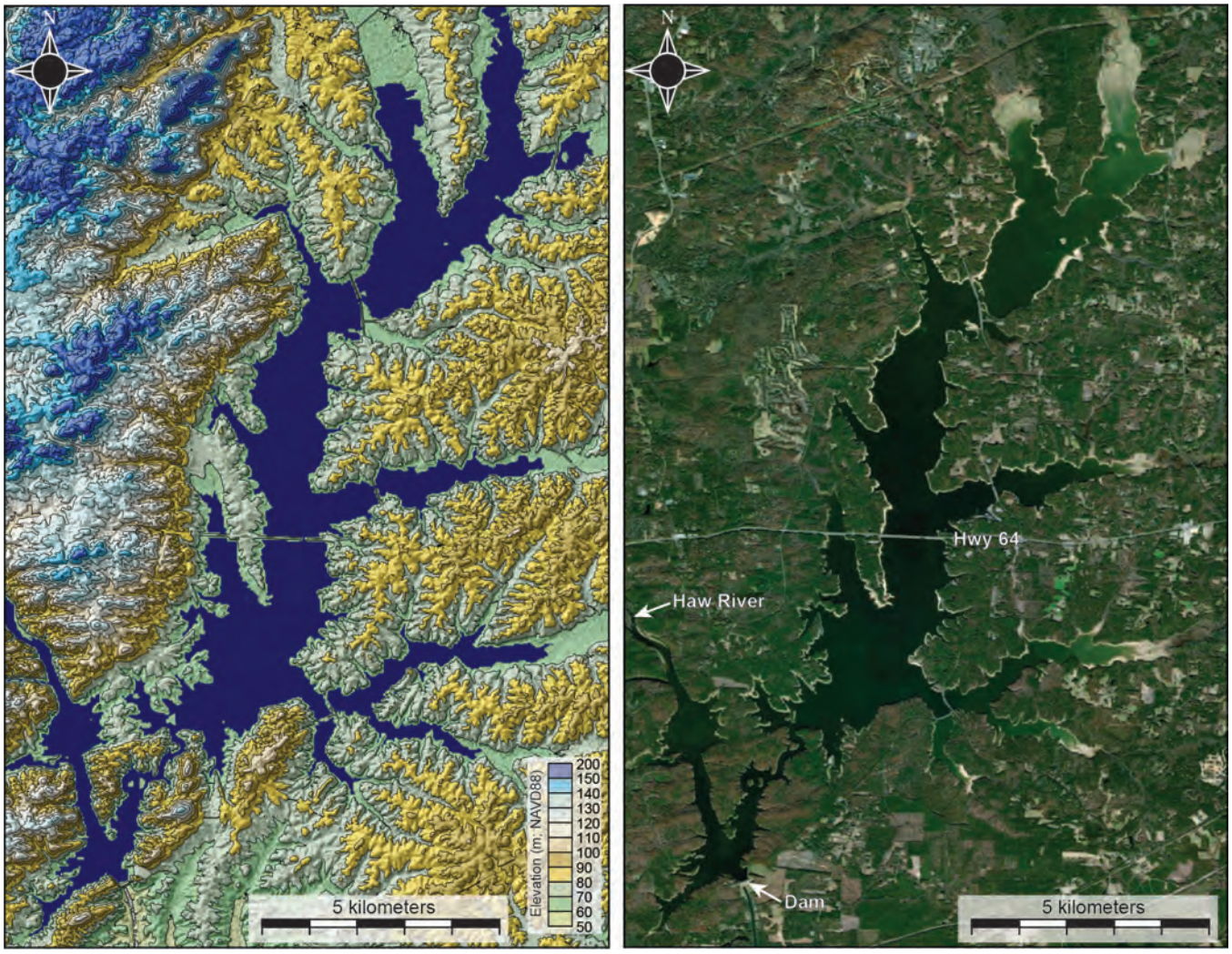
Jordan Lake serves as a drinking water supply for hundreds of thousands of Triangle residents. In addition, the lake is a prime recreation area for millions of visitors each year. Jordan Lake also provides critical aquatic habitat and flood control for the downstream region.

In 2002 Jordan Lake was designated as impaired by the U.S. Environmental Protection Agency for high levels of chlorophyll A and high alkalinity. Under this designation the Clean Water Act requires the state to prepare a plan to restore the lake's health by reducing pollution. The Jordan Lake rules are intended to serve as the state's plan.

While commonly referred to as a lake, including in this report, it is important to keep in mind that Jordan Lake is a man-made reservoir. Policy-makers have known that Jordan Lake would have problems with algae since the first plans were discussed. The original Environmental Impact Statement in 1971 concludes:

Of primary concern is the possible eutrophic tendency of the lake … The main concern expressed for the New Hope (Jordan) Lake is over the aspect of algae growth; a prime indicator of eutrophication. Studies have shown that, assuming that all other elements necessary are available, the amounts of nitrogen and phosphorous presently found in the influent are adequate to produce algae blooms in the lake. The blooms are likely to occur during the spring, summer, and fall months in the upper reaches of the lake where the nutrients enter. Excessive algae growth can become unsightly and cause taste and odor problems in water supplies. Direct withdrawal of water from the lake can be planned to avoid undesirable water characteristics.

Topography map (left) and satellite image (right) of the Jordan Lake area. Contour interval is 10 m.



INCREASED INSIGHT

Understanding the Differences Between Lakes and Reservoirs

Lakes and reservoirs are terms often used interchangeably to describe large bodies of water, despite the significant differences between them. Management of reservoir water quality and biological productivity is conducted under the preconceived models developed largely from existing knowledge of natural lakes. Jordan Lake is an example of an artificial reservoir that is regulated under uniform lake water quality standards. While there are considerable similarities between lakes and reservoirs, the notable distinctions necessitate supplemental examination into management strategies in regards to reservoirs.

Key Differences

A few key differences between lakes and reservoirs:

- On average, reservoirs have higher rates of phytoplankton productivity and eutrophication than natural lakes.
- Typically, reservoirs have higher drainage-area-to-lake-surface-area ratios and receive higher sediment and nutrient loads (per unit surface area per annum) than do most natural lakes.
- Many reservoirs, particularly flood control impoundments, lack vegetation close to the shore due to increased variability in water levels.
- Reservoirs exhibit river-like and lake-like environments, which result in a higher degree of heterogeneity in productivity and nutrient levels.
- Nutrient retention times tend to be lower in reservoirs than in lakes.
- External forces including geology, climate and morphology vary among reservoirs and lakes.
- In the U.S. a higher percentage of reservoirs were in the most disturbed category compared to lakes for: zooplankton, total phosphorus, lakeshore disturbance and chlorophyll a risk.

Accounting for the Differences

In order to account for these physical and hydrodynamic variances, measures can be taken to address the methodology used to monitor them. The following procedures could be implemented to improve our understanding of reservoirs:

- Alternative sampling techniques that account for spatial variability in reservoirs.
- Diverse management strategies corresponding to reservoirs heterogeneous environments and usages.
- Differentiated models to evaluate responses of lakes and reservoirs.

Lakes and reservoirs are often regarded as synonymous terms, which has caused their distinctions to be commonly overlooked in research and regulation. Since its impoundment, Jordan Lake has commonly been referred to and managed as a lake. Taking into consideration the substantial differences between reservoirs and lakes will allow for enhanced governance of these valuable water resources.

Jordan Lake.

Jordan Lake Rules

Simultaneous to the creation of this study the legislature put the Jordan Lake rules on hold. The rules are designed to reduce nutrient over-enrichment in Jordan Lake. The Jordan Lake rules first became effective in 2009, but have been modified by the legislature on multiple occasions in subsequent years.

While the study is not intended to focus exclusively on the Jordan Lake rules, a brief summary of the rules provides important context for the study activities.

The rules divide the Jordan Lake watershed into three arms: Upper New Hope, Lower New Hope and Haw River. Each arm of the lake has nutrient reduction goals, total allowable nutrient loads, point source waste load allocations, and nonpoint source load allocations for both nitrogen and phosphorous.

The rules further identify every local government subject to the rules, which included at the time the rules went into effect, 25 municipalities and eight counties. Because the arms have such substantial differences in allocations and reduction requirements, the expected costs for nutrient management fall heavily in certain areas. The Upper New Hope arm has a nitrogen reduction requirement of 35%, while the Haw arm has an 8% reduction goal and the Lower New Hope arm has a goal of 0%.

The Jordan Lake rules are a set of several rules designed to restore and maintain water quality in the lake. The specific rules include:

- Agriculture rules.
- Stormwater rules for new development.
- Stormwater rules for existing development.
- Riparian buffers rules.
- Wastewater discharge rules.
- Stormwater—state and federal entities.
- Fertilizer management rules.
- Options for offsetting nutrient loads rules.

Jordan Lake Modeling Reports

In the 2018 legislative session the North Carolina General Assembly provided funding in Session Law 2018-5 for quantitative modeling of Jordan Lake as part of the UNC Jordan Lake Study. Modeling of the Jordan Lake watershed was conducted and two separate modeling exercises of the reservoir were undertaken to utilize the new data that was being gathered as part of the overall study.

Models vary greatly in their spatio-temporal resolution, scope, mathematical representation of key biophysical processes, modes of calibration and validation. The research team intentionally developed two substantially different models for the reservoir to help ensure that our findings are robust to such variations in model form. One model was conducted by a team at North Carolina State University and the other by a team at UNC-Charlotte. Using multiple models improves the reliability of the predictions.

What follows in this section are summaries of a watershed model and the two reservoir models.

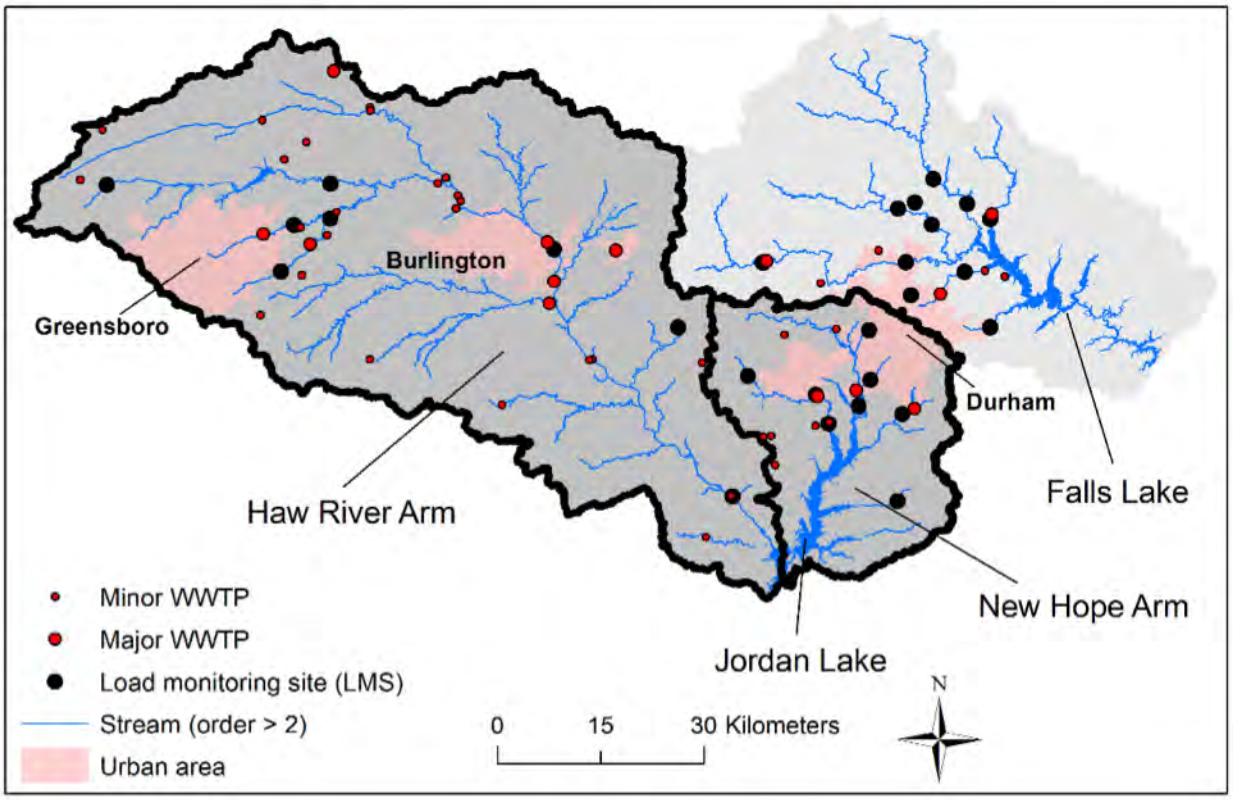
Jordan Lake, November 2019

Jordan Lake Watershed Model

Jordan Lake Watershed Model

Background

Jordan Lake is a major water supply, flood control and recreational reservoir located in Chatham County, North Carolina. Watershed nutrient loading promotes excessive algal growth in the reservoir, resulting in chlorophyll concentrations that regularly exceed the state criterion of 40 ug/l. The Jordan Lake watershed can be divided into two major sections: the Upper Haw River watershed and the New Hope Creek watershed. The Upper Haw watershed, which includes the cities of Greensboro and Burlington, discharges into the reservoir near its downstream (southern) end. The New Hope Creek watershed includes major portions of the cities of Durham and Chapel Hill, and is an important contributor of flow and load to the reservoir's upstream (northern) end.



Jordan and Falls Lake watersheds. Jordan Lake is further split between the Haw River arm and New Hope arm. Nutrient load monitoring sites (LMSs) used to collect nutrient data for calibrating the model, and major and minor wastewater treatment plants (WWTPs) are also shown. Shading represents the entire Jordan and Falls Lake watersheds.

Research Methods

To efficiently manage watershed nutrient loading, it is critical to identify the major sources and locations of nutrient loading within these watersheds. In this study, we develop and apply a "hybrid" watershed modeling approach to characterize loading rates from point (i.e., wastewater treatment plant discharges) and nonpoint (i.e., diffuse washoff from the land surface) sources of nitrogen and phosphorus. The hybrid modeling approach combines the benefits of parsimonious mechanistic modeling with a rigorous statistical framework for data-driven inference and uncertainty quantification. The approach is comparable to the well-established USGS SPARROW model, but it is enhanced to

account for interannual variability and to systematically incorporate and update prior information from previous studies through Bayesian inference. By modeling interannual variability, the model provides an assessment of how land use change and hydroclimatological variations have affected nutrient loading over time.

The spatial scope of this study includes the Upper Falls Lake watershed in addition to the Jordan Lake (Haw and New Hope) watershed. The Upper Falls Lake watershed is intensively monitored, and thus provided substantial additional data for discerning differences in loading rates from various source types within the hybrid model. The primary source categories considered were point source discharges, undeveloped land, urban land, agricultural land, and livestock. Urban land was further divided into pre versus post-1980 development, to assess whether the age of the development is related to nutrient loading rates. The model was calibrated to data collected from 1982 to 2017.

Modeling Results

Model results show that urban land contributes the greatest total nitrogen (TN) load (i.e., export) on a per unit area basis. In particular, pre-1980 development contributes 9.5 kilograms per hectare per year (kg TN/ha/yr), while post-1980 development contributes 4.1 kg TN/ha/yr. Agriculture also contributes a substantial 4.5 kg TN/ha/yr, while undeveloped land contributes a relatively low 0.6 kg TN/ha/yr. Nutrient removal within the watershed stream network is generally low (13%), except where large reservoir impoundments allow for greater removal rates of up to 75%, due to their relatively long residence times. Currently, during an average precipitation year, the New Hope watershed contributes 18% of the total nitrogen load to Jordan Lake, while the Haw River watershed makes up the rest. Point sources currently make up 48% of the load to the lake, while nonpoint sources make up the rest. Excess livestock export (beyond regular agricultural land export), which is considered part of the nonpoint source category, contributes less than 2% of the TN load to the lake.

Since 1994, there has been a slight reduction in TN loading to the New Hope arm of Jordan Lake. Though point sources in the New Hope arm have decreased, TN loading from post-1980 urbanization has been increasing. TN loading to the Haw River arm varies greatly due to yearly precipitation which is attributable to having a large amount of agricultural lands. In addition, TN loading due to point sources and urbanization are both increasing in the Haw River arm. Some watersheds were found to produce more or less nutrients than would be expected based on the estimated nutrient export rates. Of note, two highly urbanized watersheds, Third Fork Creek, and Sandy Creek in Durham, exported less TN (and TP) than expected, while Cane Creek, Morgan Creek, and Ellerbe Creek all exported more TN (and TP) than mean model parameters would suggest.

Jordan Lake marsh, November 2019

Modeling results suggest potential opportunities for reducing nitrogen loads to Jordan Lake. In general, nitrogen loads from undeveloped areas were found to be relatively low, indicating that most of the nitrogen loading in the watershed is due to human activities. For example, if point source discharges of nitrogen could be reduced by 25%, this would reduce total loading to the lake by 12%. Moreover, if pre-1980 development export rates could be reduced to the level of post-1980 development, this would result in an additional 13% load reduction to the lake. Also, if agricultural and livestock sources could be reduced by 25%, this would result in a 5% load reduction. Taken together, these example improvements would result in an overall lake nitrogen load reduction of 30% to Jordan Lake.

The total phosphorus (TP) model showed similar trends to the TN model. Pre-1980 development contributes a substantial 1.5 kilograms per hectare per year (kg TP/ha/yr), while post-1980 development contributes 0.6 kg TP/ha/yr. Agriculture also contributes 0.7 kg TP/ha/yr, while undeveloped land contributes a relatively low 0.05 kg TP/ha/yr. Mean nutrient removal throughout the stream network for TP (19%) was higher than for TN, mainly attributable to increased removal in reservoirs.

For average precipitation, the New Hope watershed contributes 20% of the TP load to Jordan Lake, while the Haw River arm contributes 80%. Point sources contribute a significantly lower percentage of the total TP loadings to Jordan Lake (24%) as compared to TN (48%), with the rest of TP loading coming from nonpoint sources. Consequently, point source reductions of 25% in TP, would only lower TP loading to Jordan Lake 6%. If pre-1980 development loads could be reduced to the level of post-1980 development, loadings could be reduced 20%. A reduction in 25% of agricultural export would reduce TP loadings in Jordan Lake 9%. If all three example improvements were implemented together, the overall lake phosphorus load reduction would be 34% to Jordan Lake.

Finally, we note that hydroclimatological variability plays an important role in the interannual variability in nitrogen and phosphorus loading. Wet years (i.e., upper 33% of years) currently produce 60% and 82% more load than dry years (lower 33%) for nitrogen and phosphorus, respectively. However, since wet years also result in 65% more flow than dry years, TN concentrations are 6% lower while TP concentrations are 10% higher.

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The full Jordan Lake Watershed Model report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Jordan Lake Reservoir Model

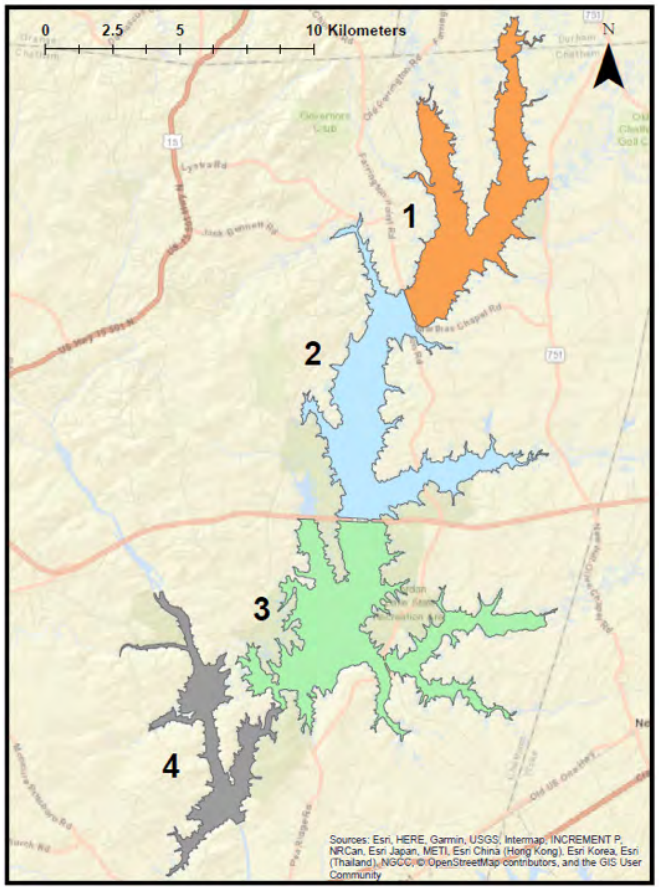
(N.C. State University)

Jordan Lake Reservoir Model
(N.C. State University)

Background

Jordan Lake is a major water supply, flood control, and recreational reservoir located in Chatham County, North Carolina. The reservoir is highly eutrophic based on algal (i.e., chlorophyll a) levels that regularly exceed the state criterion of 40 µg/l. The lake can be separated longitudinally into 4 segments with unique water quality, based on constrictions due to road causeways and natural features. The most upstream (northern) segment receives flows and nutrient loads from watersheds that include the cities of Durham and Chapel Hill. The most downstream (southern) segment receives input from the Haw River watershed, which includes the city of Greensboro. Chlorophyll a levels are particularly elevated where these major tributaries enter the reservoir.

There is a general consensus in the scientific and management community that reducing watershed nutrient (nitrogen and/or phosphorus) loads will improve water quality by reducing algal levels over time. However, it is also acknowledged in the scientific literature that internal loading from reservoir bottom sediments can continue to supply nutrients for algal growth even after watershed nutrient loading has been reduced. This phenomenon has been studied in some natural lakes, but has received less attention in man-made reservoirs. Furthermore, the degree of internal nutrient loading is likely to vary substantially among different lakes and reservoirs, considering their unique nutrient loading patterns, sediment characteristics and climate.



Map of Jordan Lake displaying the four segments and where they are separated.

Research Methods

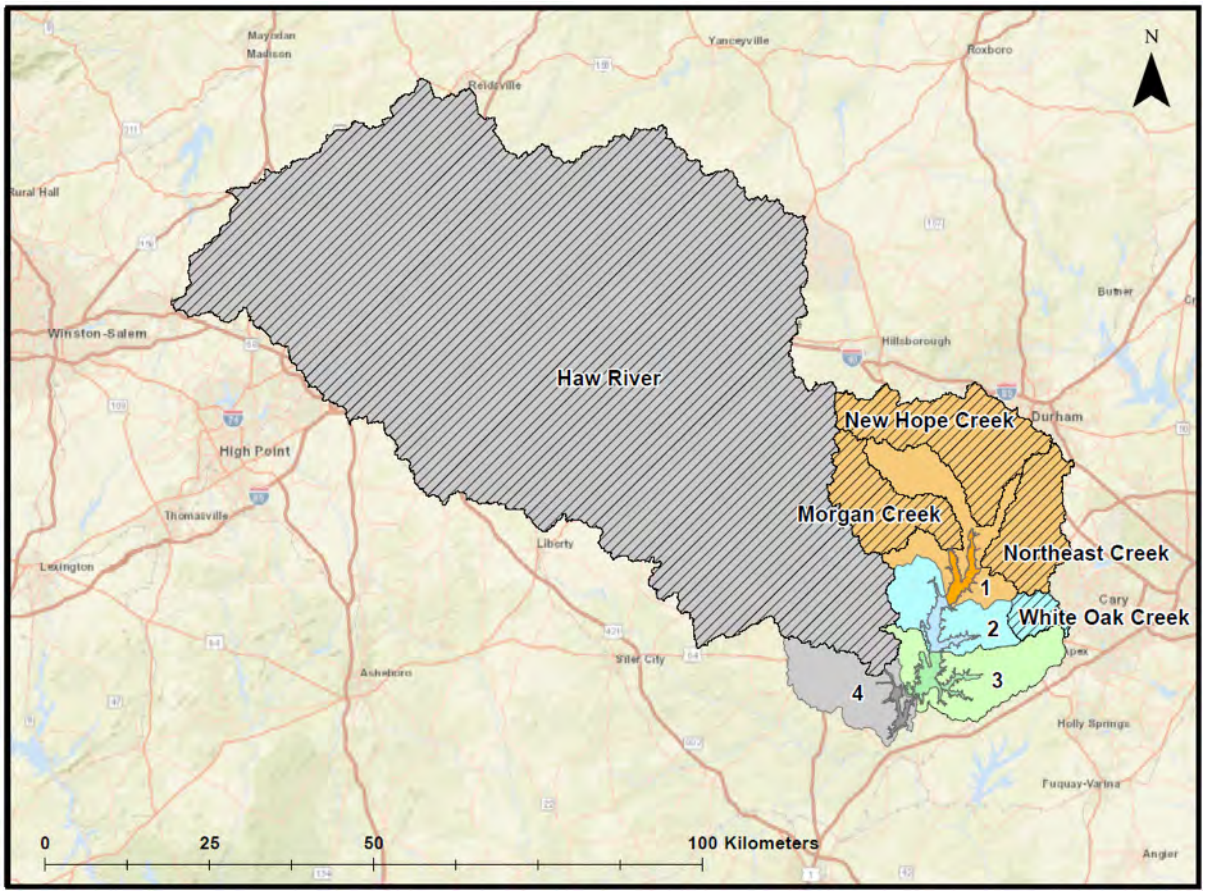
In this study, we develop and apply a water quality model to infer and simulate reservoir nutrient (total phosphorus and total nitrogen) dynamics over a multi-decadal time period (1983-2018). We use a parsimonious mechanistic formulation based on mass balances for the sediments and waters of the four main lake sections. The mechanistic formulation builds on previous modeling studies exploring long-term phosphorus dynamics in natural lakes. The model is calibrated in a Bayesian framework where prior knowledge of biophysical rates from relevant scientific literature is systematically updated based on the long-term calibration datasets for nitrogen and phosphorus in Jordan Lake. Furthermore, empirical relationships are used to relate seasonal nitrogen and phosphorus levels to chlorophyll a. The combined calibrated model is then used to make probabilistic scenario predictions of how the reservoir's internal nutrient cycling and water quality will respond to potential future reductions in watershed nitrogen and phosphorus loading over time.

Modeling results explain 58% and 41% of monthly phosphorus and nitrogen variability, respectively. This level of performance compares well with previous water quality modeling studies and higher performance would not necessarily be expected given the stochasticity in sampling results within individual months and reservoir segments. Overall, these results suggest the model is well formulated to address major drivers of nutrient variability.

Modeling Results

Phosphorus modeling results indicate that there has been a gradual (11%) decrease in phosphorus storage in the reservoir from 1992 till 2018. Phosphorus storage increased in the first decade of the period of record (1983-1992) by 5.55; a period when watershed nutrient loading was particularly elevated. In the first decade, internal phosphorus loading accounted for just 35.7% of total (internal plus watershed) nutrient loading to the water column. After 1992, internal phosphorus storage has declined at a slower rate than watershed loading, with internal nutrient loading now accounting for 51% of total loading (2009-2018).

Here, total loads do not include the portion of phosphorus load lost in the most upstream portions of the reservoir due to rapid settling of particulate material, which is estimated to be up to 46%. **Overall, these results suggest that internal nutrient loading currently plays a major role in reservoir eutrophication dynamics and will mute the impact of short-term nutrient watershed loading reductions.** Assuming no major changes in loading, the upper and lower-most reservoir segments will continue to average 90-100 µg/l in (total) phosphorus, while the middle two segments will average around 50-60 µg/l.



Map of Jordan Lake showing watershed areas, with gauged tributaries in labeled hatched zones.

Nitrogen modeling results, contrary to phosphorus, demonstrate a 30% increase in nitrogen storage in the reservoir sediment during the study period. In the last decade (2009-2018) average external loading was 7.4% lower than in the first decade (1983-1992), but internal loading increased by 20% during the same interval. Internal nitrogen loading accounted for 71% of total nitrogen loading to the water column from 2009 to 2018, compared to 65% from 1983 to 1992. These total loads do not account for nitrogen lost in upstream portions of the reservoir due to rapid settling of particulate material, which is estimated to be up to 24% of the external load. These results suggest internal nitrogen loading is an important contributor to the reservoir, and will mute the impacts of short-term watershed nutrient loading reductions.

The empirical (multiple linear regression) model linking nutrients and chlorophyll explains about 60% of the variability in the chlorophyll data. This performance is satisfactory, considering that the model operates at daily scales, whereas similar models applied at much coarser scales have shown comparable performances. Calibrated model coefficients generally indicate higher algal concentrations when nutrients (nitrogen

and phosphorus) and temperature are high and when flushing is low. The influence of nutrient concentrations appears to be highest in summer (June-September), when water residence time (the inverse of flushing rate) and temperature are high and thus less likely to limit algal growth.

The influence of flushing, on the other hand, seems to be highest in winter, when watershed inflows are highest and most variable. The chlorophyll model also provides information on rnp, the total nitrogen to total phosphorus ratio (TN:TP) at which algae switch between nitrogen and phosphorus limitation. We find that, on average, rnp ≈ 16 provides the best fit to the data. This value is substantially higher than the Redfield ratio of 7.2, which indicates that a portion of the nitrogen pool is not easily usable by the algae to foster their growth.

Given that observed TN:TP in the reservoir typically ranges from 5 to 30, rnp ≈ 16 suggests that nitrogen and phosphorus are limiting a similar fraction of the time. Interestingly, results also show phosphorous is more limiting than nitrogen in the summer. In the upper (northern) portion of the lake, about 90% of sampled summer days show phosphorous limitation, though the frequency of phosphorous limitation declines in lower sections of the reservoir. In general, the chlorophyll model highlights the importance of reducing both nitrogen and phosphorous in order to reduce algal biomass.

The combined models (nitrogen, phosphorus, chlorophyll) are applied to simulate the reservoir's likely response to potential changes in watershed nutrient loading over time. Because internal nutrient storage and loading may respond slowly to changes in external inputs, we perform these simulations over a 4-decade period. In these simulations, we sample from the variability in historical hydrologic conditions and from the uncertainties in the model itself.

Nutrient load reductions are made relative to a 1999-2018 baseline level for hydrology and nonpoint source loading, and present-day point source (wastewater treatment plant) loading rates. If nutrient loading persists at current levels, our results indicate that lake-wide concentrations will continue to change modestly over the next 20 years (+9% w.r.t. 948 µg/l for nitrogen, -5% w.r.t. 59 µg/l for phosphorus, and -2% w.r.t. 30 µg/l for chlorophyll) due to gradual changes in sediment nutrient storage. Results indicate that a 50% external nutrient loading reduction will produce approximately 9% and 5% reductions in lake-wide phosphorus and nitrogen concentrations (respectively) after one year, 25% and 12% after 10 years, and 38% and 17% after 40 years.

Further, for the highly eutrophic northern section of the reservoir (above Farrington Road), results suggest it will take about 30 years for a 75% reduction in nutrient loading to reduce the probability of exceeding 40 µg/l chlorophyll to 20% (as an April-October mean, for a given year). For the same scenario and time horizon, there is about 80% probability that concentrations in lower portions of the lake will average below 25 µg/l. When analyzing loading changes to different arms of the lake (Haw River vs. New Hope Creek), we find that nutrient loading reductions to the New Hope arm of the lake will be most impactful in improving water quality. For instance, 2%, 10%, and 11% reductions in lake-wide mean chlorophyll concentration are expected after 10 years if loads are reduced by 50% to the Haw River arm, New Hope arm, and entire lake, respectively.

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The full Jordan Lake Reservoir Model (N.C. State University) report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Jordan Lake Reservoir Model
(UNC-Charlotte)

Jordan Lake Reservoir Model
(UNC-Charlotte)

Research Methods

A new three-dimensional mass-balance-based water quality model implementation of EFDC (Environmental Fluid Dynamics Code) was developed for Jordan Lake, North Carolina. The model considered the time-varying inputs of water, nutrients, organic matter and dissolved oxygen from atmospheric, surface waters (rivers and creeks) and benthic sediments for five calendar years (January 1, 2014 - December 31, 2018).

Two separate two-year time periods (2014-2015, 2017-2018) were used to calibrate the physical, chemical and biological rate processes used by the model. A third time period (2016 calendar year) was used to validate the model calibration. The hydrodynamic and water quality model simulated the temporal and spatial dynamics in lake circulation and water quality for the two calibrated time periods for a base case and a set of scenarios that considered nitrogen and/or phosphorus load reductions from zero to fifty percent. These load reduction scenarios were used to estimate potential reductions in phytoplankton abundance as measured by chlorophyll a concentration that might be expected for load reductions of inorganic and organic nitrogen and phosphorus.

Separate hydrodynamic model runs that simulated releases of dye tracer into the lake were used to estimate the residence time of lake waters for different regions of the lake, and the relative contributions of surface water inputs from the Haw River and New Hope Creek arms of the lake. The model input files were also used to quantify the relative nutrient load contributions from various atmospheric, surface water and benthic sources.

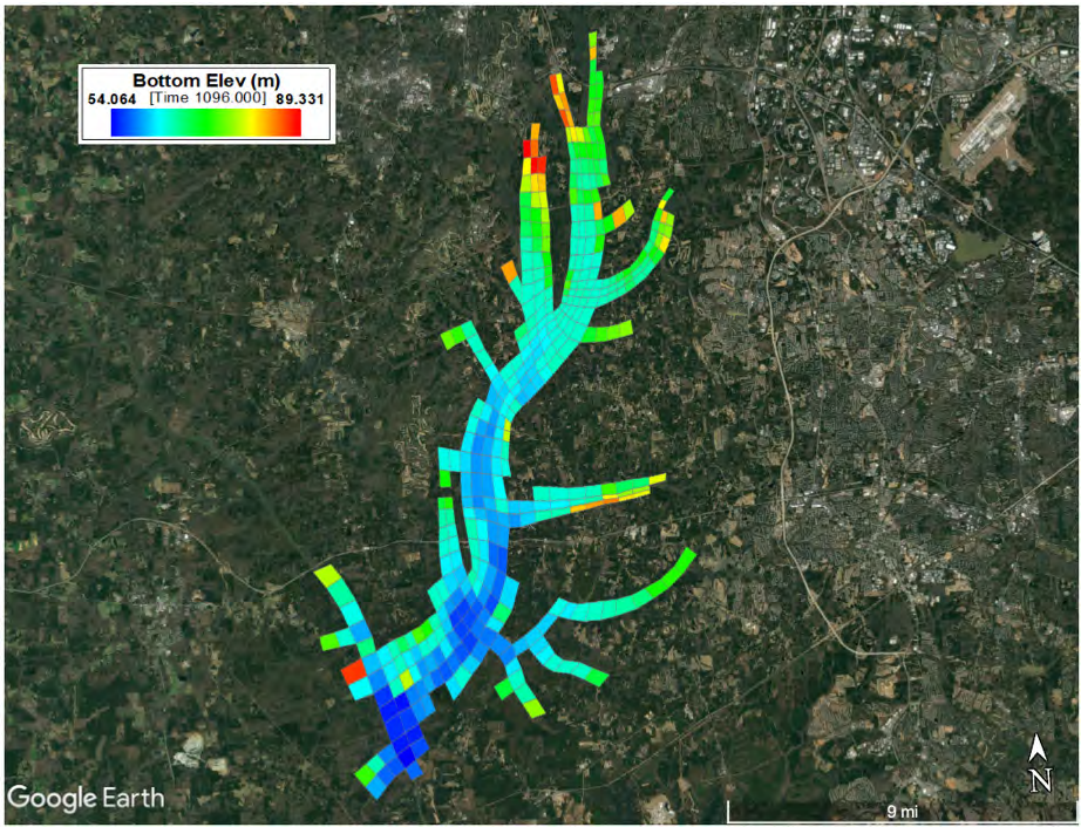
Modeling Results

The nutrient loading analysis for Jordan Lake indicated that the majority of nutrients entered the lake in organic forms that were not immediately bioavailable. The majority of water and nutrients entered the lake from the Haw River arm, but on a long-term basis only a small fraction of these inputs moved up into the upper reaches of the New Hope Creek arm of the lake. Some high flow events, however, did transport Haw River water throughout the lake, but these high flow events did not contribute significantly to the flushing of the New Hope Creek arm of Jordan Lake.

In general, local surface water sources (Morgan, New Hope, Northeast, and other smaller creeks) provided the majority of water and nutrients to the New Hope Creek arm of the lake. Atmospheric deposition was a relatively minor source of nutrients to the lake. Based upon water quality model results, benthic sediments acted as a significant sink for the particulate fraction of organic nutrients, nitrate, and dissolved oxygen. Benthic sediments were also the major source of bioavailable nutrients, providing more than 75% of phosphate and 90% of ammonia to the lake.

The relatively shallow waters and very limited flushing of the New Hope Creek arm of Jordan Lake provided highly favorable conditions for accumulation of algal biomass. For the five-year time period studied (2014-2018), the observed 90th percentile photic-zone chlorophyll a concentration at eighteen monitoring stations across Jordan Lake was 72 µg/l, which is 44% above the North Carolina water quality criteria value of 40 µg/l.

Three stations in the upper portion of the New Hope Creek arm of the lake had 90th percentile photic-zone chlorophyll a concentrations that were more than twice the 40 µg/l criteria. In general the model did a good job in simulating the distribution of chlorophyll a concentrations within the lake, and the fraction of time that high chlorophyll a concentrations were present in Jordan Lake. For the base case simulations, more than forty percent of observed and corresponding model predictions of chlorophyll a concentration were above the North Carolina water quality criteria of 40 µg/l (10% is the allowable exceedance). This analysis indicates that a substantial (40-50%) decrease in phytoplankton biomass would be needed to meet the existing NC water quality criteria for chlorophyll a.



Color contours of bottom elevations (m) for the 407 cells in the Jordan Lake model grid.

A range of nutrient reduction scenarios was simulated with the model, with reductions of nitrogen and/or phosphorus loading via surface waters ranging from zero to fifty percent. Algal abundances were sensitive to reductions in both nitrogen (N) and phosphorus (P). Likely as a result of the predominance of the benthic source of phosphate to the water column, algal abundances were more sensitive to N load reductions than P load reductions. Likely also as a consequence of benthic nutrient loading, percentage reductions in biomass were generally less than the corresponding reduction in surface water nutrient loading. For instance, N and P load reductions of 10%, 30% and 50% reduced algal biomass by 3%, 13% and 23%.

Additional scenarios examined the consequences of removing the causeways or having different load reductions for the Haw River and New Hope Creek arms of the lake. Neither of these scenarios produced results significantly different than the corresponding base cases.

Overall, none of the scenarios tested was able to produce sufficient biomass reductions to meet the water quality criteria value of 40 µg/l. Accordingly, exceedances of the 40 µg/l criteria value for chlorophyll a were well above the regulatory limit of 10% for all the scenarios tested. The 10%, 30% and 50% nutrient load reductions decreased the percentage of chlorophyll a concentrations above 40 µg/l from 45% to 43%, 38% and 32%, respectively.

A scenario using the predictive sediment diagenesis model showed that sustained reductions in nutrient loading would eventually produce a larger positive effect on chlorophyll conditions, but it would take more than ten years to see a significant positive change in the water quality of the lake due to the relatively slow response time of changes in benthic sediment conditions.

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The full Jordan Lake Reservoir Model (UNC-Charlotte) report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Jordan Lake Studies

What follows in the remainder of this document are summaries of the work conducted by distinct research teams addressing specific questions as part of the study. Each of these summaries contain a one-page overview and then a condensed version of the reports from each of the research teams.

To review the full technical reports on each of these research reports please visit the Resources section of the UNC Jordan Lake study team website: **nutrients.web.unc.edu**.

Research members at Jordan Lake.

Paying for Nutrient Reduction and Management

Paying for Nutrient Reduction and Management

QUESTIONS RESEARCH IS ADDRESSING

What is the source of revenue for the watershed management?
Who holds the revenue and what does the governance structure look like?
How is the revenue spent to improve water quality?

RESEARCH METHODS

The UNC Environmental Finance Center (EFC) researched different governance approaches, financing mechanisms and other revenue generating mechanisms that could be used to finance nutrient management. Drawing on this research, the EFC laid out four potential finance and governance approaches to consider: approaches within the existing framework, approaches within an expanded framework, the implementation of watershed fees or taxes and the creation of a regional watershed utility.

For each potential approach, the EFC compared revenue streams, governance policies and the nature of spending revenue for water quality. Researchers also compared the degree of revenue generation possible, the integration level necessary for bringing relevant entities together in collaboration, and the statutory change requirements that would be associated with each approach.

FINDINGS AND MANAGEMENT IMPLICATIONS

Operating within the existing framework requires no legislative changes, but results in low potential revenue generation. Utilizing existing revenue generation strategies within an expanded framework would maximize revenues from financing strategies already on the books in North Carolina. Examples include county level stormwater fees, watershed improvement tax, and watershed protection fees.

Watershed fees or taxes would rely on existing governance frameworks to administer fees and collect revenues, but would require new statutory revenue generation mechanisms. Ideas include:

- Lake protection fee.
- County-wide special parcel tax on impervious surfaces.
- Water allocation and withdrawal fees.

The implementation of a water withdrawal fee would require making a legislative change to allow for a volumetric fee based on actual ground and surface water withdrawals. This fee would generate revenue for water quality projects from those who use Jordan Lake as a water supply source, which has not been done in the past.

The creation of a North Carolina Regional Watershed Utility would require the most legislative change, but it provides the most streamlined potential for dedicated revenue, centralized governance, and watershed-wide spending. The utility could generate revenue through:

- Taxing authority: ad valorem taxes done by counties.
- Assessments against property.
- Debt financing through bonds.
- Fees for permits and services.
- Other creative taxing mechanisms–e.g. using revenue from sales tax.

RESEARCHERS

Erin Riggs, Evan Kirk and Jeff Hughes, UNC Environmental Finance Center

Who Pays for Nutrient Financing in the Watershed?

For the past three years, the Environmental Finance Center at the UNC School of Government has been researching options for financing nutrient management in the Jordan Lake watershed. Having found that water quality spending within the watershed is currently fragmented due to a lack of collaboration between entities, the research focused on finding better ways to connect and integrate spending into more regionalized approaches. To do so, researchers looked at examples of revenue strategies for nutrient reduction currently in place within other watersheds in North Carolina and other states across the country.

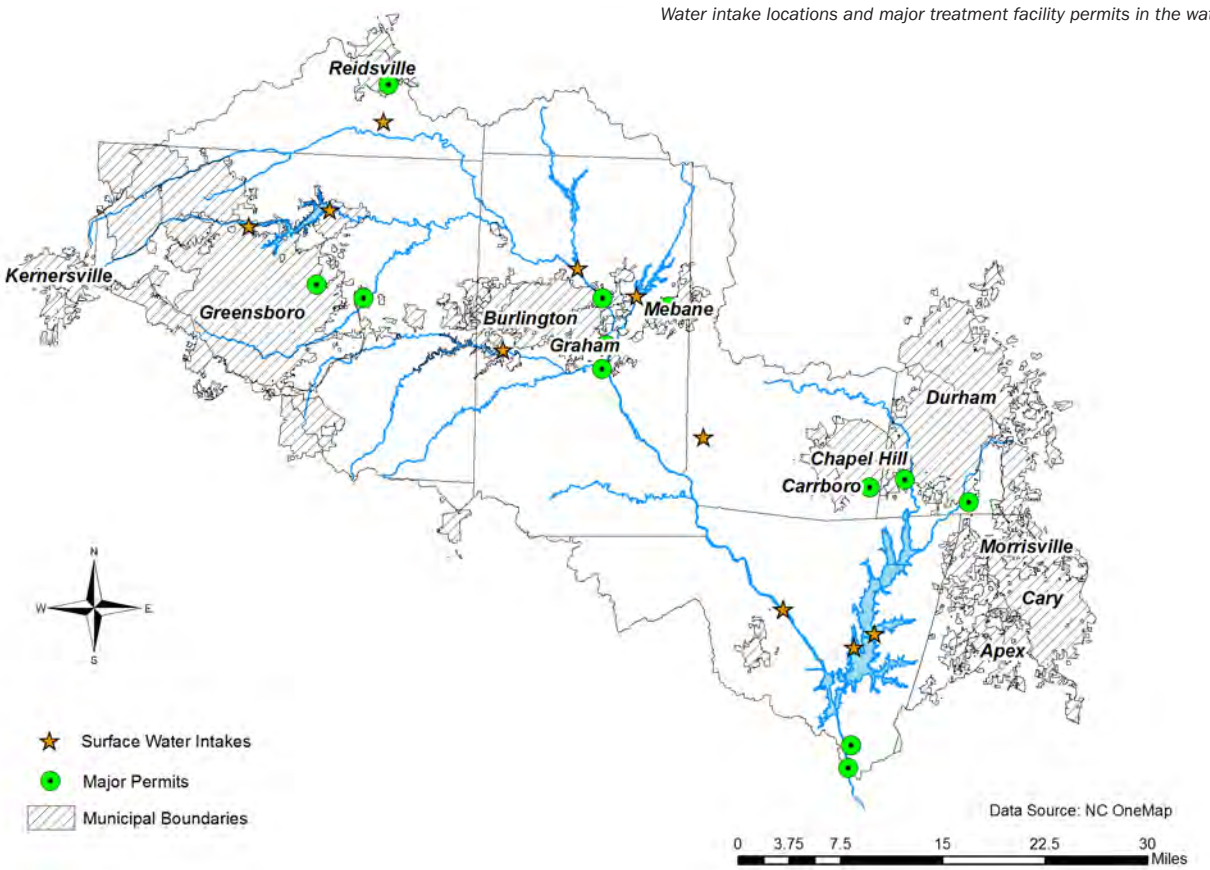
During the first year of the nutrient study, the finance team focused on identifying the entities in the Jordan Lake watershed currently contributing resources to nutrient management and how they were paying.

Different approaches emerge when evaluating how costs should be distributed among the various entities in the Jordan Lake watershed. The strongest sentiment emerging from the different groups of interested stakeholders seemed to be that which comes from the Clean Water Act itself—the polluter pays principle. The notion that everyone who contributes to the nutrient pollution should be required to pay to reduce that input is one that everyone understands and agrees with to some extent.

The current Jordan Lake rules are framed with this general premise. The rules regulate and pull revenues from various contributors. However, there is also a desire among many of the interested parties, particularly those who would be deemed contributors to the lake's nutrient issues, that beneficiaries (such as those jurisdictions using Jordan Lake as a drinking water source) should pay as well. Some, but not all of the parties responsible for nutrient loading will also receive benefits associated with improved water quality, but the farther away from the shores of the lake, the less pronounced the benefits become.

The following map breaks down the watershed such that we can see the potential for drinking water benefits flowing out of the lake (shown through water intake locations) and wastewater pollution flowing into the lake (shown through major wastewater facility permits) to help illustrate the different ways in which the two principles would impact the greater region.

Water intake locations and major treatment facility permits in the watershed.



In a complex watershed such as Jordan Lake, there does not appear to be a simple solution when it comes to financing nutrient reduction and management in the lake. If a strictly polluter pays framework is used, then the upstream communities carry the burden while the immediate users of the lake for recreation and water supply reap benefits at a lesser cost.

On the other hand, if a strictly beneficiary pays framework is used, the downstream communities pay a premium for use and benefit from the lake while the upstream communities remain unaccountable for how their contributions increase costs for others.

Some type of financing approach where both upstream communities and those communities benefitting from Jordan Lake contribute towards nutrient management would likely lead to a more robust financing framework. Given the high cost of some non-point measures, it becomes even more important to find ways of spreading costs among as large a population as possible including beneficiaries outside of the watershed.

The high costs of nutrient management increase the importance of finding new ways to implement projects that reduce costs or increase available revenue. Most of the projects attributed to the Jordan Lake rules have been financed in fairly traditional ways. Moving away from this standard approach and identifying innovative options for financing projects should be considered in the future.

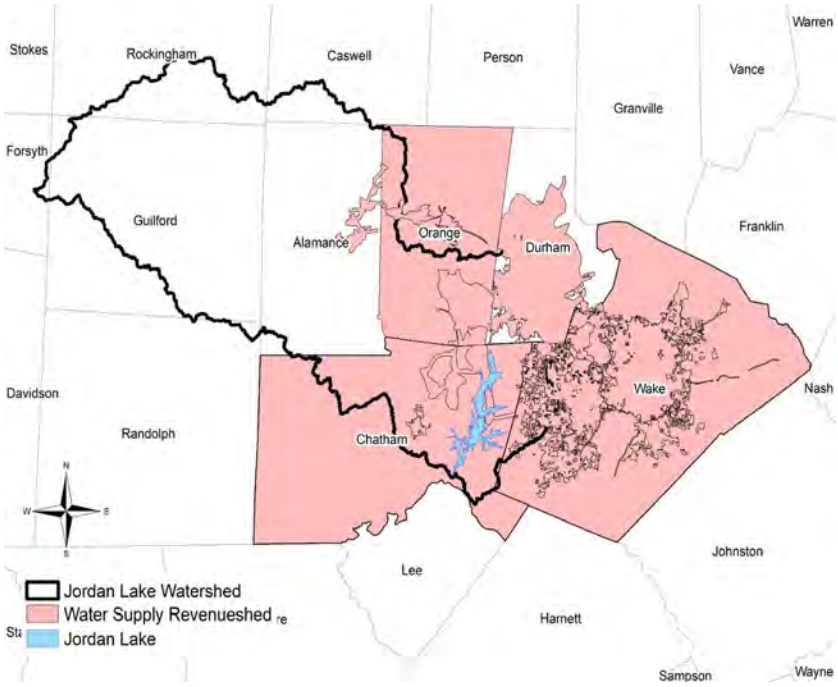
Exploring the "Revenueshed" Concept

During the second year of research, the team started by asking:

- If the system remains fragmented, what existing approaches may be used to raise revenue for more effective and likely costly nutrient management?
- What additional revenue raising tools and/or institutions could the state or local governments use to manage nutrients in Jordan Lake?

In evaluating these and other questions, the team has been working to identify how to bring in the most revenue for watershed protection, both within the existing regulatory framework, and within a new potentially more holistic nutrient management framework.

As a starting point in its second year of research, the finance team looked at expanding the revenue generation associated with the current "watershed drainage basin revenueshed,"[1] which included identifying existing mechanisms that could be used to generate revenue for watershed protection. Under current state law, there are various existing revenue generating mechanisms for local governments to use for watershed protection, some of which are not currently in use and others which could be better utilized. The team found that highlighting, expanding, or modifying such mechanisms in order to promote more widespread revenue generation should be a part of any nutrient management strategy going forward.



Water Supply Revenueshed

Because the boundary of the current "watershed drainage basin revenueshed,"encompasses only the regulated entities under the Jordan Lake rules, the finance team then began exploring ways to draw the revenueshed boundary wider, most notably pulling in the Jordan Lake water allocation holders as a new source of revenue. This more holistic approach corresponds to several national initiatives that have begun promoting different approaches to water quality, including the "One Water" approach, as well as the creation of regional watershed utilities. The team will continue to dig into other state models to identify characteristics that have made those models a success, both in terms of financial viability and ability to impact water quality.

[1] The "watershed drainage basin revenueshed" is intended to cover the current entities which are currently regulated under the Jordan Lake rules as point or nonpoint source dischargers into the watershed.

The finance team then investigated how much more revenue could be generated by bringing in additional revenue from the Jordan Lake "water supply revenueshed,"[2] which includes the pure beneficiaries[3] of the lake, and not just those contributing to nutrients. Additionally, the team explored and left open the possibility of drawing the boundary around the revenueshed to be even wider (such as to include recreation users of the lake, or to try to draw a boundary which aligns with flood control benefits).

While the first two years of research focused heavily on evaluating both the existing spending and the potential streams of future spending, the third year of research focused more on what would be required for implementation of any new spending or governance approach for Jordan lake. The research into regional watershed governance approaches looked within both North Carolina and in other states. Additionally, the research looked at some other state strategies for water quality specific revenue generation. Finally, the work highlighted some existing revenue sources in North Carolina, which could be expanded or aggregated in different ways.

[2] The "water supply revenueshed" is made up of 8 municipalities, 3 counties, and 1 water authority. These entities currently have access to Jordan Lake water or could have access in the future based on allocations and current planning initiatives, and include allocation holders as well as members of Jordan Lake Water Supply Partnership.

[3] "Pure beneficiaries" of the lake refers to those entities which are not in the drainage basin and therefore don't contribute directly to nutrients in the watershed, but which rely on the lake for water supply.

A research team member holds equipment at Jordan Lake.

Addressing Revenue Generation in an Equitable Manner

Many options exist at the legislative level for expanding the boundaries within which revenue can be generated, adding additional fees to link water quality and quantity protection, and for modifying or creating new regional utility approaches where funds can be generated and spent for watershed management. At a local level, there are options not only for generating more revenue and collaborating with neighboring jurisdictions, but also spending local revenue on water quality projects in a way to maximize ancillary benefits.

While there are a number of avenues to increase revenues for the protection of Jordan Lake, a couple of options that would require legislative changes are particularly worth noting and outlined below.

Water Allocation Fees for Jordan Lake

One new source of revenue for watershed management could be an additional fee for Jordan Lake water allocation holders. Making a legislative change to allow for such an additional fee could provide a mechanism for generating revenue from users of Jordan Lake as a water supply source, which has not been done in the past.

The momentum for identifying an opportunity to generate revenue for water quality protection from both dischargers and water supply users has been a theme repeatedly over the past three years of research on this topic.

Currently Jordan Lake allocation holders pay a minimal capacity charge to the State, but do not pay an allocation fee or volumetric fee on withdrawals. Other states have implemented such allocation fees as a means of generating additional revenues to pay for watershed protection services.

Lake Protection Fee

The Maryland Bay Restoration fee is a flat-fee approach aimed at improving water quality through very specific wastewater upgrades and on-site system repairs. A similar type of fee could be considered on a statewide or watershed basis in North Carolina, but to address a variety of water quality challenges.

Assuming the fees were implemented on a watershed basis, in the Jordan Lake revenueshed, an annual fee of $60 per year per residential structure and $240 per year per commercial structure would generate approximately $40 million for water quality projects. The above two examples assume no governance modifications with fees to be collected and managed by the state. One approach that would include a significant governance change would be the creation of a Regional Watershed Utility.

UNC Institute of Marine Sciences vehicle and boat.

Regional Watershed Utility

The Regional Watershed Utility approach starts anew. It creates a new entity with its own financing mechanisms and spending authority. While this approach would require the most legislative changes, it provides the most streamlined potential for dedicated revenue, centralized governance, and watershed wide spending.

With the implementation of a new utility approach, revenue generation would be built into the powers associated with the new entity. The key sources of revenue generation or funding that could be incorporated into a new North Carolina Watershed Utility include:

- Taxing authority: primary source of funding is ad valorem taxes done by counties.
- Assessments: against properties abutting or directly benefitting from watershed projects.
- Debt financing through bonds.
- Fees for permits and services.
- Stormwater utility fees.

The new regional utility approach could co-exist with new fees for water quality or allocation holders to be collected and utilized by the State. Additional legislative changes could be made to require or allow the State to contribute part of the added revenue from the allocation fees to the regional watershed utility.

Because the Regional Watershed Utility approach centralizes revenue generation and pooling of funds, this approach creates the greatest potential for watershed spending that focuses not on county or city specific regulatory compliance projects, but rather projects that can cross jurisdictional boundaries and benefit the watershed as a whole.

The full Paying for Nutrient Reduction and Management report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Policy Principles and Possibilities for the Jordan Lake Watershed

Policy Principles and Possibilities for the Jordan Lake Watershed

QUESTIONS RESEARCH IS ADDRESSING

What are the key policy lessons learned from historical nutrient strategies employed across the nation, particularly from the Chesapeake Bay? How can these policy lessons be applied to the UNC Jordan Lake study?

RESEARCH METHODS

In order to compile a list of successful nutrient management practices utilized in the U.S., researchers conducted an extensive literature review of various watershed governance structures, including the Gulf of Mexico and Mississippi River, the Great Lakes, Puget Sound, Lake Champlain and the Chesapeake Bay. Information collected from the review was combined with local insight from government officials, agency leaders and stakeholders associated with the Chesapeake Bay Restoration Program, to create a matrix of policy tools. Additionally, the state water quality and nutrient standards of Georgia, Kentucky, Tennessee and South Carolina were compared to the current standards in North Carolina, to evaluate possible modifications to the state's water quality standards.

FINDINGS

Assessment of the watershed governance case studies, illuminated various commonalities among success stories, which are outlined in the management implications section below.

MANAGEMENT IMPLICATIONS

Information and expertise obtained from the collection of interviews, case studies, and general research led to the creation of 'Seven Important Policy Principles'. These serve as guidelines for the development of nutrient strategy for Falls Lake and Jordan Lake, and are listed as follows:

(1) Science + Outreach + Governance- The assurance of transparent science, in order to effectively educate stakeholders and policymakers.
(2) Start by getting the primary goals right- The construction of new goals, set via collective processes based on scientific data that is both specific to season and site, and adaptable depending on the uses of the watershed and the ecology of the reservoirs.
(3) Collective responsibility and accountability– Ensure the collaboration of water-quality departments, NGOs and stakeholders.
(4) Maximize local gains and co-benefits- Design scientific models and data representation schemas that can serve local areas outside the reservoir of focus, subsequently helping to address the local concerns of communities surrounding the watershed.
(5) Stakeholder engagement- Employ funding and resources to disseminate scientific knowledge.
(6) Cost-effectiveness- Consider lowest cost strategies rather than performing a complex and time-consuming cost-benefit analysis.
(7) Adaptive Strategies- Create strategies that are flexible enough to be altered as new information is gathered.

RESEARCHERS

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Ellen Gilinsky and Jay Sauber, consultants

Policy Considerations

The researchers combined their experience with water quality programs and interviews with colleagues around the country to produce this set of recommendations and notes for use in the UNC Jordan Lake study. The Seven Important Policy Principles are recommendations that we believe should be debated, discussed and then put to use in some form as soon as possible, as the UNC team and stakeholders begin to chart a new nutrient management strategy for Jordan Lake and the entire watershed.

Science and Outreach and Governance

This is a multi-disciplinary, science-led policy effort. But the science is being done primarily for the sake of better policy, not just to expand knowledge in the involved scientific fields. This means the science must be involved with the stakeholders from the outset and governed by a concern for the policy decisions that will ultimately be made.

The requirement to make nutrient management science transparent and responsive to stakeholders and policy decision makers' needs was made clear by our interviews all around the Chesapeake Bay. The Chesapeake Bay program is continuing to evolve as a large, complex set of committees that plan, discuss and review the science behind the models and the monitoring on which the Bay program is based. The federal/state collaborative effort of the Mississippi River/Gulf of Mexico Hypoxia Task Force is also an example of disparate stakeholders uniting around a single science-based goal of reducing nutrient inputs into the Mississippi River to improve both local water quality in their state watersheds as well as in the main stem Mississippi and the Gulf of Mexico.

The structures of the Chesapeake Bay Program and the Hypoxia Task Force are far more elaborate and costly than would be appropriate for watersheds, like Jordan and Falls, that are much smaller and that involve many fewer jurisdictions. However, the overall purpose of the Bay committee structure and the Hypoxia Task Force—to ensure all stakeholders, including policy makers, can understand and access the assumptions and data on which decisions are based—must somehow be replicated for Jordan and Falls. This will require continued funding of data collection, synthesis and communication well beyond the funding levels historically given to initiatives focused on the State's nutrient sensitive waters.

Start by Getting the Primary Goals Right

An important lesson learned from other watershed programs is that goal-setting based on up to date science is key to making progress and getting stakeholder support. The Chesapeake Bay Program spent considerable time and effort on establishing realistic and meaningful goals for a better Chesapeake – such as more oxygen in the deeper waters to support living resources and more submerged aquatic vegetation to increase crab harvests– which in turn directed them to focus on decreasing nutrient and sediment runoff into the Bay. Similarly, the Puget Sound Partnership spent considerable effort on developing shared goals and measures of progress, all based on science.

Neither the current designated uses of Jordan and Falls Lakes nor the State's long-standing, broad nutrient-sensitive waters criterion (an instantaneous chlorophyll-a standard of 40 ug/l applied everywhere) should be taken as a given. Instead, some structured, stakeholder-involved effort should create a more sophisticated, appropriate, consensus-based set of water quality standards for each reservoir based on science and accounting for actual uses and applicability. The uses will quite likely include the existing designated uses, but they should be refined to denote where each use should be applied and to what extent. For example: when, where and how there is primary contact recreation in the reservoirs? What aquatic life species and communities are most important to the stakeholders and the ecology of the reservoirs, and what are their habitat needs? What are the current and projected needs (quality and quantity) for water supply from the reservoir?

Chesapeake Bay nonpoint source challenges are similar to Jordan and Falls Lake. Stormwater runoff is a major challenge; the costs of retrofits are huge. Once the drainage infrastructure and pavement are in place, the water quality effects are likely to remain for decades. Susquehanna River at Wrightsville, Pa.

Once the designated uses are understood in greater detail and accepted by all stakeholders, then appropriate criteria can be developed to protect those uses. Chlorophyll-a may well be an important part of these criteria. But among the others that should be considered are dissolved oxygen, algal toxins and perhaps aquatic macrophytes. **The important policy principle is that the uses and the criteria should be real, widely understood and important.** This may require creation of seasonal, site-specific and narrative criteria. It will require close work between the stakeholders and the scientists, particularly ecologists, who understand the watersheds. The State's Nutrient Criteria Development Plan Scientific Advisory Council (SAC) has already begun the task of reconsidering nutrient related water quality standards. The work of the SAC, going forward, needs to be integrated with a refined understanding of the uses of the reservoirs, informed by the users themselves.

This work should begin as soon as possible, because the models that must ultimately be used to make sense of the scientific data that are already being collected have to connect with these water quality standards. The science and the goals can co-evolve for a period of time, but ultimately the models of nutrient fate and transport in the watersheds must embed the right water quality standards, or they will be practically useless, from a policy point of view.

Collective Responsibility and Accountability

All the successful programs we looked at had these things in common: levels of collective responsibility and universally clear accountability. Everyone needs to feel like a full equal partner in the solution. Similarly, there needs to be accountability for actions and public transparency of the results. Establishing clearly understood metrics that serve as measures of progress toward program goals is essential. The Chesapeake Bay Program has an elaborate online dashboard showing progress toward the goals of each source sector and by each state. The Gulf Hypoxia Task Force is currently working on common measures of success to use throughout the Mississippi River watershed.

North Carolina is recognized nationally for past work on nutrient management, and particularly for its use of collective responsibility and accountability. For example, the Lower Neuse Basin Association has demonstrated the ability of point source dischargers to work together to lower nutrient loads in a cost-effective manner. In the Neuse and Tar-Pamlico basins, the State recognized that the value of collective responsibility and accountability should extend beyond point source dischargers to include agriculture. The Jordan Lake Watershed Oversight Committee (WOC) was an example of an effort to allocate nutrient reduction loads to the agricultural sector and then let the sector figure out collectively (rather than farm by farm) the most efficient way to get reductions.

This committee is charged with developing tracking and accounting methods for nitrogen and phosphorus loss from agricultural land in the Upper New Hope, Lower New Hope and Haw River watersheds. This approach has merit. It should be continued and expanded. There should be a structure for all sectors to be involved with and aware of the practices and commitments of every other sector. For example, all the involved stormwater control programs should understand and share information on the efforts being made by other stormwater programs in the watershed. This will take careful planning, facilitation and resources.

James River at Richmond, Va. April 17, 2017 from T. Tyler Potterfield Pedestrian Bridge. The James River does not contribute a large part of the Chesapeake Bay nutrient load but the cleanup of the Bay has worked in conjunction with Richmond's own development of its waterfront, now an attractive urban amenity.

INCREASED INSIGHT

Cost-Effectiveness of Nutrient Removal Practices

Researchers from the Environmental Finance Center (EFC) at the University of North Carolina at Chapel Hill conducted a literature review of 13 studies comparing 19 different stormwater control measures (SCMs) on the basis of cost-effectiveness.

The researchers' guiding question was, **"If there is one more dollar available for nutrient removal in the Jordan Lake watershed, where should it be invested to remove the greatest amount of nutrients and have the greatest positive impact on water quality?"**

The EFC reviewed physical strategies and policy strategies using dollars per pound ($/lb) figures to represent the average cost of a specific SCM. Researchers looked at consistencies in cost-effectiveness values across studies and excluded any outliers. They then averaged clustered values across studies to generate a final cost-effectiveness estimate. By excluding outliers, the final value best represents the most prevalent cost-effectiveness estimates for nutrient reduction strategies. They found that illicit discharge control programs and wastewater treatment plant (WWTP) upgrades are the two most cost-effective options.

Illicit discharge control programs can eliminate unpermitted discharges to watersheds through a variety of methods, including educational campaigns, fines for polluters, and upgrading or repairing infrastructure. The EFC generated average values for illicit discharge control programs by examining a cost-effectiveness study conducted by the Center for Watershed Protection (2013) that specifically looked at correcting cross-connections and repairing sewer leaks. WWTP upgrades involve retrofitting or adding to the WWTP to increase nutrient removal efficacies in primary and secondary treatment systems.

The cost-effectiveness estimates for illicit discharge control programs and WWTP upgrades are significantly lower than any other SCM reviewed. The next most cost-effective options are riparian buffers, land conversion, and nutrient management programs.

Permeable pavement as an SCM is the least cost-effective option for Phosphorus reduction, and disconnected impervious surfaces as an SCM is the least cost-effective option for Nitrogen reduction. It is important to note that illicit discharge control programs and WWTP upgrades address point sources of pollution, while all of the other SCMs evaluated address non-point sources. This suggests that SCMs targeting point sources of pollution could be the most cost-effective options.

The efficacy of SCMs depend on the concentration of nutrients where the runoff meets the SCM. **Thus, the locations of SCMs matter and, all else held constant, the cost of removal ($/lb) is lowest where the nutrient concentrations entering the SCM are highest.**

Researchers emphasize that the best nutrient reduction strategy will be highly specific to location and to the entity implementing the strategy. Cost-effectiveness estimates alone should not be used to choose or rule out any measure. Researchers also recommend that Jordan Lake entities invest in a portfolio of nutrient reduction strategies, as it is unlikely that an entity will be able to meet future rule requirements by investing in just one strategy.

Maximize Local Gains and Co-benefits

The primary policy goal is the sustainability of the designated uses of these reservoirs. This primary policy goal may not resonate with everyone in the watershed, especially those who do not use these reservoirs for either recreation or drinking water (see Principle #2). Thus, no opportunity should be lost to maximize local benefits, including benefits outside the reservoirs. This includes designing scientific models and data presentations so that they can be used at local scales, not just at watershed scales. Each local government unit and other stakeholder in the watershed has its own set of concerns and needs for water. The Jordan (and Falls) strategies will be accepted and sustained much more readily if they help address those local concerns.

The Mississippi River/Gulf of Mexico Hypoxia Task Force addressed this issue head-on. While the ultimate goal of this group is to reduce the size of the hypoxic zone in the Gulf of Mexico to improve the fishery, this goal does not resonate for farmers in headwater states such as Iowa and Minnesota. What is important to them is the quality of the local streams that they use every day. Hence the focus of each state's nutrient reduction framework is local water quality that will improve the quality of the main stem Mississippi and the Gulf.

The Bay Program has also evolved to stress local benefits. For example, we met with stakeholders in West Virginia (with no direct connection to Chesapeake Bay) who have grown very committed to the Bay Program because it has helped with local projects. Similarly, the complicated models on which the Bay Program relies have increasingly been developed to work in smaller and smaller footprints, so that they can be useful to local governments as well as to the large, overall watershed.

Serious Stakeholder Engagement

Every one of these policy principles requires serious stakeholder engagement, not just "translation" of science and policy decisions to interested groups. The values of openness and consensus should underlie all policy decisions on a new nutrient management strategy for NC. Consensus here means "every stakeholder group can agree to live with every decision, or if a group disagrees, it must articulate an option that CAN be agreed to (lived with, if not supported fully) by all groups."

Constant Concern for Cost-Effectiveness

All the major nutrient management efforts of which we are aware, and that can claim some measure of success, have evolved, in some cases over decades, to a constant concern for cost-effectiveness. That is, they may have started with the desire to just make some progress on the primary goals, to get something done, to work with whatever policy options were most obvious at the time. But eventually, their leaders have come to realize that nutrient management strategies are perpetual efforts. They cannot be sustained, over the long term, without attention to cost-effectiveness. In other words, is this (whatever decision is at hand) the best way to commit resources in order to attain the policy goals?

A concern for cost-effectiveness may seem inconsistent with the principle of "serious stakeholder engagement." Many policy makers who have struggled with the difficulty of getting stakeholders "on board" retreat from the messiness and time involved. But this is a question of time-frame. Decisions that offend stakeholder groups tend to pile up discontent over time, and eventually this "slow variable" of stakeholder discontent destabilizes or destroys the original plans.

Thus, in the long run, the concern for cost-effectiveness is fully consistent with consensus decision making. It can also lead to innovative solutions, such as water quality trading, that aim for the lowest– cost reductions that can be made, rather than going after only those solutions that are easiest to administer, such as in a permit.

Regarding cost-benefit analysis: the North Carolina legislature has expressed interest in assessment of costs versus benefits for the Chesapeake Bay program. It is possible to find someone who might venture an estimate at the net benefits of the Bay program. But anyone who understands cost-benefit analysis knows that analysis of programs that extend over long lengths of time (decades, for the Bay program), wide areas of space and many different actors (six states plus the District of Columbia, with actions at all levels of government) ends up being driven more by the assumptions than the actual data. Even the cost data are imprecise, as the Research Triangle Institute explained in 2012: ""[T]he total costs required to meet the TMDL goals cannot currently be defined precisely—due in part to the extensive mix of potential implementation tools and strategies…"

Brock Environmental Center, looking out on the Lynnhaven River, Virginia Beach, Va. Environmental education through the Chesapeake Bay Foundation and many other groups has helped build a consensus around the importance of clean water in the Bay region, a consensus that transcends political and demographic differences.

The benefit side is, of course, even more difficult to quantify accurately. We believe that a more worthwhile focus for policy makers, rather than some point or range estimate of net benefits, is to maintain a constant concern for cost effectiveness.

Build a Strategy That Can Learn and Adapt

The science of nutrient fate and transport, and the system engineering (for example, water quality criteria and best management practices) that rest on that science, are still progressing. There is much that is not known and will not be known in the next several years, despite bringing the best currently available science to bear on the problems. This means the strategy must be designed from the outset as one that can learn and adapt. Investments will have to be made in control measures based on the best knowledge at the time.

But funders, regulators and stakeholders should be aware that today's solutions are not likely to make nutrient problems disappear for all time. This implies a need for flexibility. It suggests bringing in as many people as possible, including regulated entities, as "problem solvers," and listening to their experience and local knowledge. The term "adaptive management" may be overused, but it has been critical to the progress of each of the states within the Chesapeake Bay watershed as they construct and re-construct their respective watershed implementation plans, and it is also applicable here in the Jordan watershed.

The full Policy Principles and Possibilities for the Jordan Lake Watershed report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Water Quality Monitoring and Water Circulation in Jordan Lake

Water Quality Monitoring and Water Circulation in Jordan Lake

QUESTIONS RESEARCH IS ADDRESSING

What is the circulation in Jordan Lake?

How do water quality parameters vary in time and space in Jordan Lake?

Does the Haw River impact water quality in the New Hope arm?

RESEARCH METHODS

In order to address these questions Acoustic Doppler Current Profilers (ADCPs), moorings, and Autonomous Vertical Profilers (AVPs) were distributed throughout the lake to semi-continuously record various water quality and meteorological variables. Data from these instruments was compiled and assessed at the end of the study to profile the thermal stratification, circulation, nutrient composition and primary productivity of Jordan Lake.

FINDINGS

Jordan Lake does not conform to many of the traditional mechanisms of modeling lake dynamics. Major Haw River discharge events have significant impact on much of the lake. This pattern was especially prevalent during extreme climatic events like Hurricane Florence in October of 2018. Study of water transport in instances of heightened discharge illustrated spikes in lake volume and subsequent water column mixing, rendering ordinary procedures for computing residence time ineffective. It was also discovered that major discharge events resulted in water that was more turbid and of lower specific conductivity, pH and primary productivity than levels prior, and the length of time to return to previous conditions was heavily influenced by the timing of water release over the Jordan Lake Dam.

Other findings included regular oscillations that corresponded to swift changes in wind direction, and summer time declines in chlorophyll a, likely correlated to annual shifts in phytoplankton dynamics from eukaryote to cyanobacteria dominated assemblages.

MANAGEMENT IMPLICATIONS

These observations have improved and extended the understanding of water circulation in Jordan Lake and its response to extreme storm events, and can serve as a basis of knowledge by which to inform management decisions. The data collected will also be critically important to the development of the water quality models.

RESEARCHERS

Rick Luettich, Tony Whipple, UNC Institute of Marine Sciences

Harvey Seim, Molly Gilchrest, UNC Department of Marine Sciences

Monitoring Jordan Lake

Specific objectives of the observational program were:

1) To identify water circulation and exchanges in the lake, in particular, the extent to which the large volume of water entering via the Haw River influences the New Hope Creek arm of the lake.

2) To better quantify the response of important water quality parameters in the lake based on changing conditions (variations in flow, temperature, light and wind) via high frequency (hourly) in situ observations.

3) To better quantify phytoplankton dynamics in Jordan Lake, including nutrient limitation and productivity that are causing the lake to be out of compliance with water quality standards.

Lowering profiler equipment into Jordan Lake.

Lake circulation, temperature structure, and water quality parameters were observed using in-lake sensors between May 2017 and January 2019. A range of conditions were captured, including two summer seasons, an extreme cold event, and four major discharge events. The data gathered from these sensors over the last two years shows several distinctive flow behaviors that provide valuable insight into water movement and transport in the lake.

Locations of profilers in lower lake.

Locations of profilers in New Hope Creek arm.

Current and temperature profiles were monitored by recording observations approximately every ten minutes at four locations:

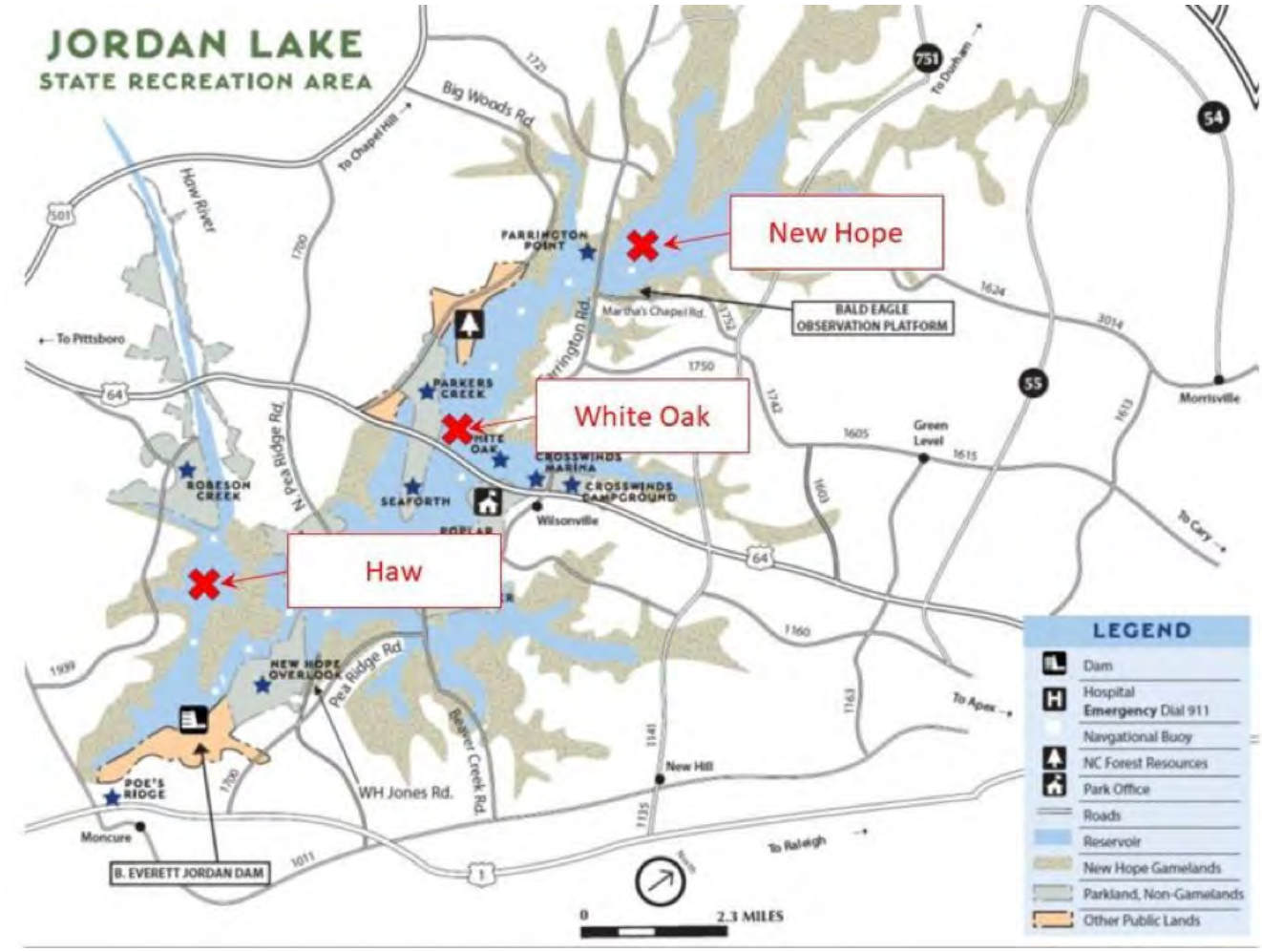
- Near the inflow of the Haw River;
- In the Narrows; and
- At the Highway 64 and Farrington Road causeways.

AVPs, which are small floating platforms that collect wind observations and profiles of water temperature, conductivity, pH, dissolved oxygen, in vivo chlorophyll florescence and turbidity recorded profiles every thirty minutes.

Autonomous Vertical Profiler (AVP) in Jordan Lake.

Two AVPs were deployed at three locations over the sampling period:

- Near the Haw River inflow;
- Near the water intake for the Town of Cary; and
- In the New Hope arm uplake of the Farrington Road causeway.



Location of placement of AVPs in Jordan Lake.

The observations document the seasonal variation in temperature, thermal stratification and water quality of the lake, and reveal several modes of circulation. Thermal stratification was established at all measurement locations by mid-April and persisted into September. During times of thermal stratification and typical river discharge, a strong thermocline develops a few meters below the surface, separating cooler, low dissolved oxygen and high turbidity water below from warmer, higher in vivo chlorophyll florescence, and highly variable dissolved oxygen and pH water above the thermocline.

Winds blowing along the main axis of the lake drive an exchange flow in the New Hope arm, with water above the thermocline flowing in the same direction as the wind, and water below the thermocline flowing in the opposite direction.

Both the wind-driven and discharge-driven circulations demonstrate that flow in the New Hope arm often has a component away from the dam, complicating estimates of residence time for that portion of the lake. During fall and winter when little thermal stratification was observed, water quality parameters were constant over depth, and the wind-driven exchange flows were less energetic.

Seiches, or natural oscillations of the lake, were also observed, and produce a flow that will help mix the lake. Most prominent was a three-hour oscillation seen throughout the lake.

An examination of transport between segments of the lake found clear evidence of transport of Haw River water into the New Hope arm, and that storage of water associated with higher lake levels plays an important role in the volume balance of the lake.

Light penetration measured at a number of sites in the lake found the depth where one percent of the ambient light remained was two to three meters, with no obvious cycle.

Major Discharge Events

Discharge into the lake from the Haw River and other minor rivers and creeks is typically very low, with brief but large discharge events occurring several times a year. The major discharge events have a number of impacts on the lake, beyond a rise in water level that can dramatically increase the volume of water held in the lake.

Remarkable amounts of floating debris often accompany these events, with both natural and human sources. The debris impacted the Haw River AVP, preventing it from profiling, until the debris could be removed. This debris ends up along the shore and on the lake bottom. Semi-annual cleanup events are organized to help remove tires, plastics, and other trash from the shore. The extent that the debris directly impacts water quality in the lake appears to be largely undocumented.

Pictures of debris near the AVP on June 20, 2017 during the second major discharge event.

The response of the lake to Hurricane Florence in September 2018 is used as an example of the impact of major discharge events. Currents at the Haw mooring were toward the dam, whereas currents in the narrows were away from the dam, demonstrating how the flow "backs up" into the New Hope arm when major discharge events occur. Water levels rose almost five meters in the lake in response to the inflows, and only began to fall in late September when release of water over the dam began.

Setting up research equipment.

Jordan Lake in October 2018, after Hurricane Florence.

Water associated with the major discharge event was more turbid and of lower specific conductivity, pH, and in vivo fluorescence than the prevailing conditions at the AVP sites. The Haw River water initially flowed into the lake along the bottom, although it quickly impacted the entire water column.

The physical change that these events imposed on the water column was extreme and persisted in this case for approximately two weeks, after which turbidity levels returned to more normal values, the water column re-stratified thermally, and a diurnal cycle re-emerged typical of normal flow conditions.

Similar time histories were observed for the other major discharge event. All disrupted the vertical properties throughout the lake and were associated with flow away from the dam in the New Hope arm on the lake. One source of variability between events was the strength of stratification prior to the discharge event, and the temperature (density) of the inflow relative to the lake conditions. The 2017 events began as mid-water intrusions because the river water temperature was in the middle of the range of temperature values present in the lake.

Another variation between events was the time until return to prior conditions, which was a week or less for smaller discharge events. The timing of water release over the dam had a significant impact on the time to return to prior conditions as well.

The full Water Quality Monitoring and Water Circulation in Jordan Lake report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Evaluation of Controls of Algal Blooms

Evaluation of Controls of Algal Blooms

QUESTIONS RESEARCH IS ADDRESSING

What are the limiting nutrients for phytoplankton productivity in Jordan Lake?
To what level do nutrients need to be decreased in order to reduce algal biomass in the lake?
How does light availability limit algal growth in the lake?

RESEARCH METHODS

The research team conducted seven nutrient addition and dilution bioassay experiments from July 2017 to June 2018, to characterize phytoplankton dynamics in Jordan Lake. A bioassay is a technique for estimating the effect of a substance on living organisms, in this case the effect of Nitrogen (N) and Phosphorus (P) concentrations on phytoplankton biomass.

Of the seven experiments, six were conducted on water samples collected from the New Hope River arm of the lake, and one was conducted on water from the Haw River arm of the lake. These samples were subject to one of four treatments conducted under natural light and temperature conditions at the UNC Institute of Marine Sciences: a Nitrogen treatment, a Phosphorus treatment, a combination Nitrogen and Phosphorus treatment, and a control with no nutrients added. In the first six experiments, addition treatments were made to lake water as well as to lake water diluted with an a major ion solution (containing no N or P) by 10, 30, and 50 percent.

Along with the water samples obtained for the nutrient and dilution bioassay study, additional samples were collected in order to measure the relationship between phytoplankton photosynthetic rate and light availability. The samples were exposed to 42 different light levels at a constant temperature matching the temperature at the time of collection.

FINDINGS

The nutrient addition bioassays indicated that N was the primary limiting nutrient for phytoplankton growth. Algal growth, as a result of the combined N and P treatment, illustrated the possible presence of 'co-limiting' effect on phytoplankton biomass. Measurements of phytoplankton photosynthesis versus light availability indicated that Jordan Lake phytoplankton are capable of achieving maximum photosynthetic rates at very low light levels, less than 5% of midday near surface light.

MANAGEMENT IMPLICATIONS

- The nutrient addition bioassays indicate that primary production in the upper New Hope Creek arm of the lake and the Haw arm is likely co-limited by N and P during summer months. **This suggests that any nutrient strategies for Jordan Lake should focus on both N and P input reductions.**

- Assessment of the nutrient mass balance results, illustrate necessary reductions in the range of 25-40% for N and about 30% for P in order to meet the current chlorophyll a standard of 40 ug/l with a 10 % allowable exceedance frequency.

- The previous Jordan Lake Nutrient Response Model from 2002 underestimates the ability of Jordan Lake phytoplankton to photosynthesize at low light. Improving this model with a more accurate representation of the light versus photosynthesis relationship will enable more reliable predictions of phytoplankton growth in response to pulses of nutrients from tributaries with high loads of suspended particulates and color.

RESEARCHERS

Hans Paerl and Nathan Hall, UNC Institute of Marine Sciences

What Impacts Algal Growth?

Researchers focused on the question of how to better quantify phytoplankton dynamics, including effects of nutrient and light limitation on the production of algal blooms that are causing the lake to be out of compliance with state water quality standards.

Researchers utilized a series of bioassay experiments, field measurements and laboratory analysis on Jordan Lake water to:

- Determine the limiting nutrient/s (N, P, or N and P) for phytoplankton growth.
- Determine the level of nutrient reductions necessary for reducing algal biomass in the lake.
- Determine the significance of light limitation in constraining algal growth by measuring the photosynthesis versus irradiance relationship.
- Provide laboratory and field measurements in support of future water quality modeling work.

Methods

A total of seven nutrient addition/nutrient dilution bioassay experiments have been conducted during 2017 and 2018. Six of the seven experiments were conducted on water collected near NCDEQ station CPF086F on the upper New Hope arm. In May 2018, an experiment was conducted on water from station CPF055C on the Haw River arm of the lake.

Researchers at UNC IMS placing water samples from Jordan Lake in outdoor incubation ponds.

Water for the bioassays was collected using a diaphragm pump into ten - 20L polyethylene carboys. The carboys were quickly transferred to a darkened truck bed and taken to UNC-IMS in Morehead City. Upon arrival (approximately 14:30) the carboys were placed in the outdoor incubation ponds to maintain ambient temperature and light conditions. The following morning water from the carboys was homogenized in a 300L fiberglass tub prior to dispersing into 4L Cubitainers ® and performing experimental nutrient addition and dilution treatments.

Nutrient additions consisted of a full factorial design of N and P additions, including a control with no nutrients added, an N treatment (0.63 mg L-1 N-NO3- plus 0.07 mg L-1 N-NH4+), a P treatment (0.155 mg L-1 P-PO4-3) and a N plus P treatment (0.63 mg L-1 N-NO3- plus 0.07 mg

L-1 N-NH4+ plus 0.155 mg L-1 P-PO4-3). For the first six experiments, addition treatments were made to whole lake water as well as to lake water diluted by 10, 30, and 50 percent with a major ion solution that contained all the major salts of Jordan Lake water less N and P. The last experiment in April 2019 contained no dilution treatments.

Total phytoplankton biomass and biomass of the dominant phytoplankton classes, and nutrient concentrations were measured on days 0, 1, 3 and 6. Total phytoplankton biomass was fluorometrically measured as chlorophyll a was measured and class-specific accessory pigments were measured by high performance liquid chromatography (HPLC). Nutrient concentrations (nitrate+nitrite, ammonium, total dissolved nitrogen, phosphate, silicate, total P, and total N) were measured colorimetrically. During the last three bioassay experiments, rates of nitrogen fixation were measured via the acetylene reduction technique and assuming an acetylene to N2 reduction ratio of 4:1.

Understanding the Relationship Between Light Availability and Phytoplankton Photosynthesis

Twelve water samples collected for each bioassay and water collected opportunistically by Dr. Rick Luettich's lab during excursions to maintain AVP and ADCP equipment were used to measure the relationship between light availability and phytoplankton photosynthesis. Immediately upon delivery of lake water to the UNC Institute of Marine Sciences (~4.5 hours after collection), aliquots of water were dispensed into 20 mL borosilicate glass incubation vials. Photosynthesis was measured by 14CO2 incorporation at 42 different light levels that span the range of light levels known to limit phytoplankton photosynthesis.

Photosynthetron set up for measuring the light vs. photosynthesis relationship. Note light increases from left to right within rows and also varies within columns.

The light gradient was produced using two photosynthetrons which consist of a white light source, and a range of light reducing filters to produce 21 light levels per photosynthetron, and an aluminum heat sink that surrounds each vial to control temperature (see side image). Light delivery to water samples within each vial was measured using a Biospherical Instruments Model QSL-100 irradiance meter with a QSL-101 4 π sensor. Water was circulated through the heat sink to a temperature-controlled water bath to maintain the water temperature present at the time of collection (8-31 °C). Samples were incubated in the photosynthetron for one hour and photosynthesis was determined by the amount of 14CO2 incorporated according to standard methods. Photosynthesis was normalized by Chl a to express observed productivity in units of carbon produced per unit of phytoplankton biomass.

Nutrient Limitation

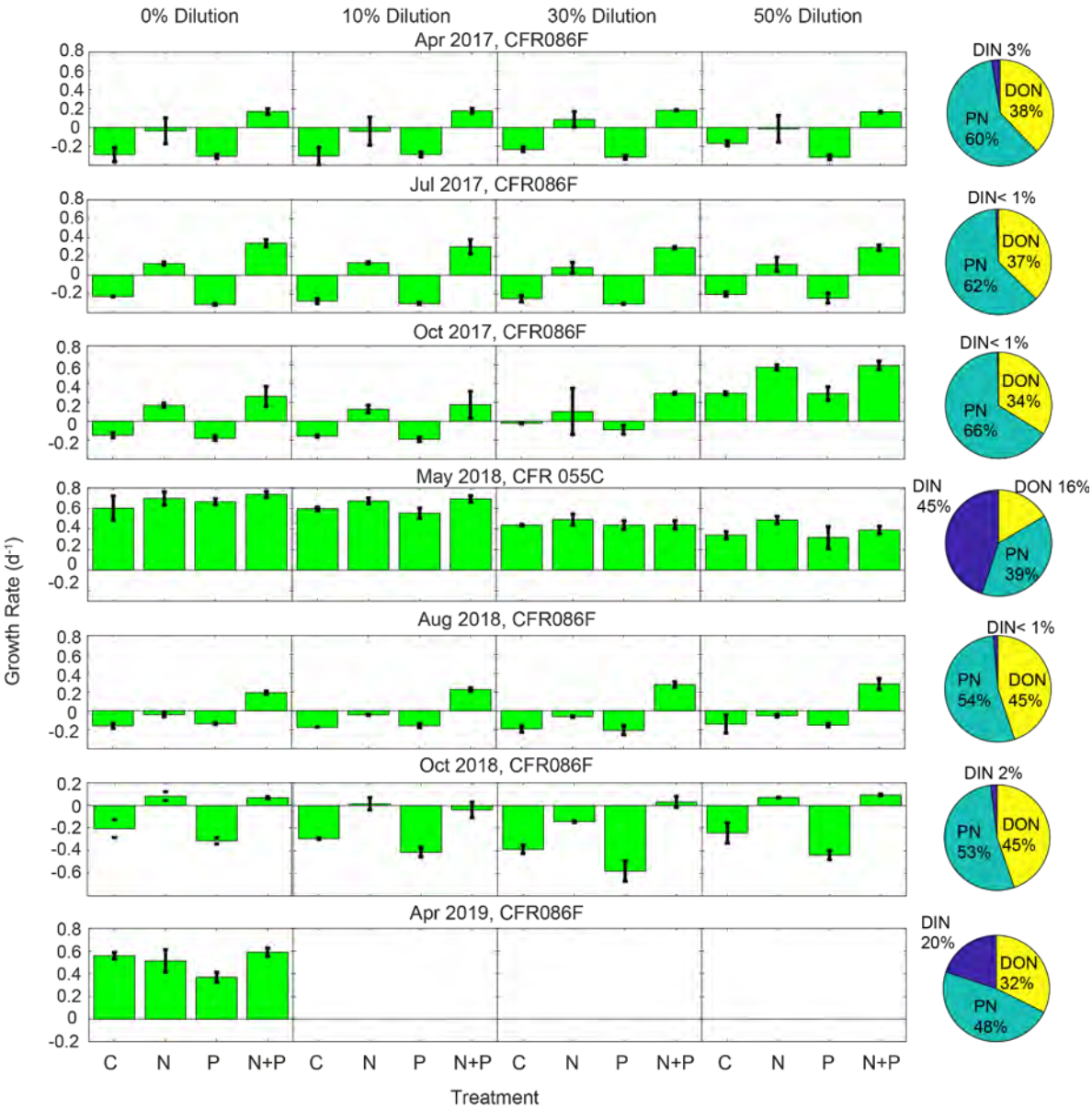
The initial growth rate response from the first to the second day of the experiments is likely most representative of the in situ nutrient limitation status of the phytoplankton community in Jordan Lake.

The initial growth response of five of the seven nutrient addition bioassays clearly indicated that N was the primary nutrient limiting phytoplankton growth during the spring through fall in Jordan Lake. In the absence of N addition, growth was negative during five of the seven experiments.

With the exception of the May 2018 and April 2019 experiments, in treatments with only P additions, biomass declined at a similar rate to the controls that received no nutrient additions. During the May 2018 and April 2019 experiments, nutrients were replete and phytoplankton growth was strong in all treatments including the controls.

In five of the six experiments that included nutrient dilutions, diluting the nutrient pools had either no significant effect or even a stimulatory effect on phytoplankton growth. The lack of a significant negative response to nutrient dilution during the 2017 experiments was likely because at the time and location in the lake during those experiments the vast majority of nutrients were contained within the phytoplankton or as recalcitrant dissolved organic forms rather than in bioavailable dissolved forms within the water.

Nutrient concentrations measured at the beginning of the 2017 experiments confirmed that dissolved inorganic nitrogen (DIN) levels were low (~0.1 mg/L) and phosphate concentrations were below the limits of detection. Nearly all (97-99 %) nitrogen was either in the particulate pool, likely as phytoplankton, or in the dissolved organic N pool with only 1-3% of nitrogen as bioavailable dissolved inorganic nitrogen. Such low inorganic nutrient but high phytoplankton biomass conditions are typical of long residence time water bodies with high nutrient loads such as the upper New Hope River arm of Jordan Lake.



Initial phytoplankton growth responses from day one to day two of seven bioassay experiments with nutrient addition and dilution treatments in seven bioassays. C = control. N = N addition, P = P addition, N + P = both N and P addition. Figure columns represent the different dilution levels from whole water (0%) to 50% dilution with a major ion solution. Bars and error bars are means and standard deviations of triplicate values for each treatment. Pie graphs to the right indicate the composition of the N pool at the beginning of each experiment.

The primary source of nutrients sustaining phytoplankton growth was likely remineralization of phytoplankton derived organic matter, which can maintain constant biomass levels over time, but cannot lead to an increase in biomass without a corresponding decrease in cell quota. Despite very low initial phosphate concentrations, it appeared that the supply of recycled N exerted a primary control on phytoplankton growth.

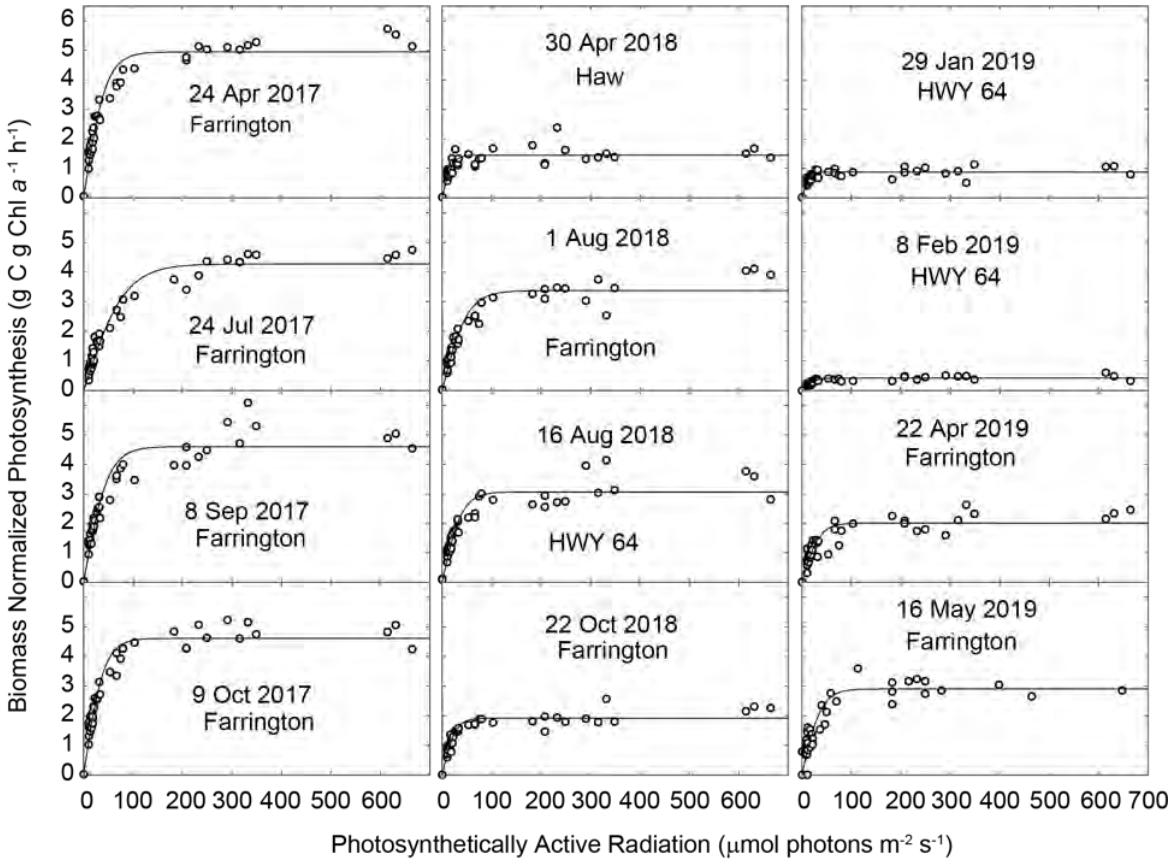
The ability to maintain high growth under low phosphate conditions results from the ability of phytoplankton to strongly modulate their internal stores of P in response to decreases in availability and due to the relatively faster rates of cycling of P compared to N. In several of the experiments but particularly noticeable in October 2017, dilutions actually increased phytoplankton growth rates. This is likely because diluting out the nutrient pools also dilutes out the grazer populations and releases grazing pressure proportionally to the dilution factor.

In the April 2017 and August 2018, N additions alone do not produce a positive growth response without additionally adding P. This indicates that the phytoplankton growth requirements for N and P were very close to being balanced (i.e., N and P co-limitation), and that by adding N, the phytoplankton were forced to P limitation. This is consistent with the strong positive growth achieved in the N plus P treatments and is common when the biomass of a phytoplankton community is fueled by nutrient cycling mediated by grazing.

In contrast, during the May 2018 and April 2019 experiments appreciable fractions, approximately 50% and 20%, of the N pool were in the form of bioavailable, dissolved inorganic N. These nutrient conditions are typical during periods of high spring runoff as occurred prior to both experiments. Growth rates were strongly positive regardless of whether or not nutrients were added, and it was the only experiment where growth was negatively impacted by diluting the ambient nutrient pool. Diluting the ambient nutrients by 50% resulted in an approximate 40% decrease in growth within the control treatments where no nutrients were added. Nutrient limitation imposed by the 50% dilution was partially alleviated by N addition which indicates again that N was the primary growth-limiting nutrient.

Light Limitation

For all twelve photosynthesis versus irradiance assays, photosynthesis normalized to chlorophyll a increased rapidly with PAR up to 20-80 µmol photons/ m2/s and were saturated at 100 µmol photons/ m2/s, or only about 5% of midday surface irradiance. These saturating values are on the low end of the expected range for natural phytoplankton assemblages, and indicate that Jordan Lake phytoplankton are highly efficient at utilizing the low levels of light typical of Jordan Lake's phytoplankton rich waters. Nutrient loading events are also accompanied by high sediment loads and the resulting turbidity can greatly increase light attenuation. Phytoplankton capable of growth under very low light levels have a significant growth advantage allowing them to exploit these new nutrient inputs.



Findings

Nutrient addition bioassays indicate that phytoplankton in the upper New Hope Creek arm of the lake and the Haw arm are primarily N limited from spring through fall. Additional stimulation by P was common, and during summer stimulation by P alone is possible due to stimulation of N-fixing cyanobacteria likely co-limited by N and P. **This suggests that efforts to reduce phytoplankton biomass will need to address both N and P input reductions.**

Based on the dilution bioassays and nutrient mass balance approaches, reductions in the range of 25-40 % for N and about 30 % for P will be necessary to reduce chlorophyll a levels that will meet the current standard of 40 ug/l with a 10 % allowable exceedance frequency.

Jordan Lake phytoplankton are much better adapted to growing in low light than represented by the previous Jordan Lake Nutrient Response Model. The robust parameterization of the light versus photosynthesis relationship will greatly improve future water quality modeling efforts. This will enable more robust predictions of questions such as how fast can phytoplankton respond to pulses of nutrients from the tributaries given that such pulses are also associated with high loads of suspended particulates and color.

The full Evaluation of Controls of Algal Blooms report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Stream Monitoring and Nutrient Loading

Stream Monitoring and Nutrient Loading

QUESTIONS RESEARCH IS ADDRESSING

Where and when are nutrients entering the urban watersheds surrounding Jordan Lake, and under what conditions?

How is nutrient loading affected by hydrology, climate, land-use and sanitary infrastructure?

How can the data in this study be utilized to inform nutrient management in developed watersheds?

RESEARCH METHODS

High spatial resolution water chemistry data sampled from 25 small watersheds and high temporal resolution water chemistry data continuously collected from a subset of five watersheds were joined to create a dataset representative of the diversity of land cover and infrastructure found in the Jordan Lake watershed. An additional subset of samples from 12 watersheds were analyzed for stable isotopes of nitrate, in order to detect the source of nutrient loading in each watershed. The locations of the sampling sites and monitoring instruments were combined with the inferred positions of septic systems and other development features via GIS, to allow for analysis of the effects of land-use and infrastructure on nutrient flows.

FINDINGS

Stormwater and wastewater proved to be dominant sources of nitrogen, independent from the development intensity of the watershed and the proximity to sanitation infrastructure. Contrarily, forested watersheds illustrated much lower nutrient loading than observed on developed landscapes. Across all land cover types loading was observed to significantly increase during heavy rainfall events. It was also revealed that several septic watersheds contained greater nitrogen loading and a larger per capita impact than detected in sewer watersheds.

MANAGEMENT IMPLICATIONS

The contributions of storm and waste water to nitrogen loading in the sampled watersheds highlights a need for the implementation of more rigorous storm water control practices dovetailed with upgrades to sanitation structures. Reconnecting floodplains and restoring riparian buffer zones illustrate two such run off prevention methods. The lowered concentrations of nitrogen found in forested watersheds corroborates the potential effectiveness of these practices. Suggested mitigation strategies are subject to alteration depending on landscape type, season and flow conditions.

RESEARCHERS

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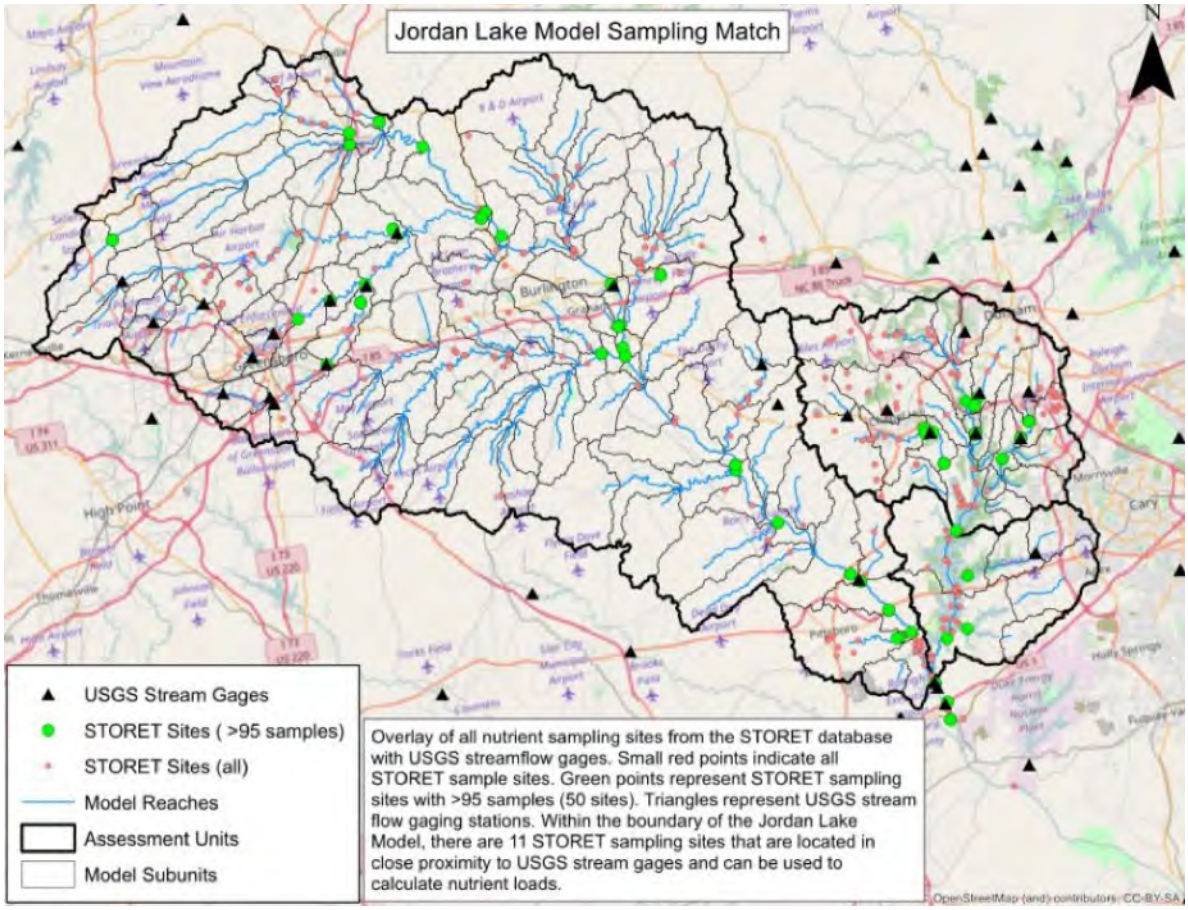
Review of Existing Water Quality Data

The work of this research team began with a collection and analysis of existing water quality data related to Jordan Lake and the watershed. Existing discharge data and water quality samples were collected by various entities over time, often in different locations and for different periods of time.



While this information is useful for background and context, the spatial and temporal resolution of the available data is often insufficient to determine where, when and what nonpoint sources are loading pollution to the stream network, which is a requirement for watershed management decisions.

To address these challenges, we took advantage of two existing models: 1) the Jordan Lake model developed by TetraTech and 2) a USGS model, SPAtially Referenced Regressions On Watershed attributes. The Jordan Lake model uses sub-basins which are fairly large and not all that different from those with existing data. In fact, one of the determinants of the model sub-basins was having existing data on which to calibrate the model. The SPARROW model has been developed at a finer spatial resolution (using catchments of the National Hydrography Dataset Plus [NHD+], produced by the Environmental Protection Agency [EPA]) and allows for separation of nutrient sources from urbanization, fertilizer application, etc., with the limitation that it is only available at an annual temporal resolution.

We compared SPARROW and Jordan Lake model resolutions by upscaling from the small catchments in SPARROW to the Jordan Lake model sub-basins, with the goal of estimating load of total nitrogen and total phosphorous.

These existing model results are useful because they highlight the spatial variability of nutrient loading in different sub-basins, but they remain too coarse to be applicable for watershed management or to develop cost-effective guiding plans or identify specific nutrient sources. **It is therefore crucial to establish a finer scale of observation, both spatially and temporally, to determine when, where and what nutrients are delivered to the stream network.** While we have made use of existing empirical data and modeling results, our primary contribution is to collect new data at high temporal frequency and fine spatial resolutions to better identify the ***timing*** and ***magnitude*** of nutrient transport to the stream network.

Jordan Lake Watershed Geographic Characterization

Land-use, land cover, infrastructure and geology were characterized across the Jordan Lake watershed. We obtained, catalogued, and reviewed road, stream, water feature, sanitary sewer, stormwater sewer, land cover, parcel and geologic mapping for the watershed. We estimated the position of septic systems as the centroid of parcels greater than 150 m from a sewer line and containing a building. We obtained limited septic data to validate these estimates for portions of Orange County.

The National Hydrography Database NHD+ scale watersheds were used as the fundamental unit of landscape analysis. These watersheds are approximately 0.5 to 3 km2. This small size provides the spatial resolution necessary to isolate important development features such as sanitary infrastructure or impervious surface cover (ISC). Numerous metrics of development, infrastructure and land-cover were calculated for each NHD+ watershed to allow us to characterize development in the whole Jordan Lake watershed.

Methods

Sampling was designed to cover a gradient from rural to urban development and optimize both spatial and temporal data collection. We collected two sets of water chemistry and flow data; a high spatial resolution, grab sampled, dataset comprised of discrete water quality samples at a total of 25 watersheds and a high temporal resolution, continuous monitoring, dataset which utilizes deployed sensors to measure water chemistry and flow every 5 – 15 min at a subset of 5 watersheds. The grab sampled dataset provides data over a large range of developed land-use, infrastructure and geology. However, this discrete sampling can't cover the full range of flow conditions in developed environments due to rapid stormflow response to rainfall which is difficult to capture and often unsafe. The continuous monitoring allows us to capture the full range of environmental conditions and evaluate patterns in water chemistry and flow.

Site Selection

Watersheds were selected for outflow sampling to span the range in development intensity, infrastructure and geologic basin with additional focus on low intensity residential development which is most common and also the largest component of new development. A total of 19 watersheds were selected in the Durham, Chapel Hill, Carrboro and the Burlington area including Haw River, Swepsonville, Graham and Mebane. These sites are located in the Upper New Hope arm and Haw arm of the Jordan Lake watershed.

A subset of five of these watersheds was selected for additional sampling in the form of continuous monitoring. Data from an additional 12 watersheds in the research Triangle region were pulled from existing data for analysis. Six of these watersheds were in the Raleigh Belt geologic basin which was found to have consistently higher loading than geologic basins in the Jordan Lake watershed and only the remaining six watersheds were included in analysis. Although some of these additional watersheds are outside the Jordan Lake watershed, they are representative of the development of the watershed.

Sites were initially selected from NHD+ watersheds based on geographic characterization metrics. All selected watersheds are headwater watersheds, meaning that streamflow originates within the study watershed and water chemistry is a reflection of the impacts within the watershed. Selected watersheds were re-delineated with QL2 Lidar Digital Elevation Models (DEM) and stormwater pipe maps were added to better generate watershed boundaries and flowpaths that account for storm sewer flow. Landscape metrics were re-calculated for the re-delineated watersheds. Each individual watershed can be observed in the map above. By selecting small NHD+ scale watersheds we can select land-use specific watersheds to isolate important variables such as sanitary infrastructure or impervious surface cover (ISC).

Study watersheds for continuous monitoring are forested (TH), rural on septic (RR), lower (BG), medium (BT) and higher development intensity (TY) on sanitary sewer. The TH watershed is nested within the RR watershed and the portion of RR that does not include TH is referred to as RRdev. Loading for RRdev is calculated by subtraction. The classification of these study watersheds is relative and because it was based on several factors such as ISC, parcel density, sanitary sewer density, septic density, and road density. Watersheds for continuous monitoring needed to be easily accessible and were limited to the Chapel Hill area in the Upper New Hope watershed.

Water Quality Sampling

Grab sampling of ten watersheds in Carrboro, Chapel Hill and Durham was conducted from July of 2017 to July of 2019. Grab sampling of nine watersheds in the Burlington area including Haw River, Swepsonville, Graham and Mebane was conducted from Oct. 2017 to Dec. 2018 with additional sampling in Feb. and Apr. of 2019. Existing grab sampled data was collected from Nov. 2013 to Mar. of 2016. Stream water samples were taken twice monthly during sampling periods at the outlet of the study watersheds and field filtered to 0.45 nm with a 0.7 prefilter into HDPE bottles. Samples were stored on ice in the field and frozen upon return to the lab.

Flow at the ten Carrboro, Chapel Hill and Durham watersheds was estimated by development of a water level–discharge rating curve. Submerged pressure transducers were deployed (HOBO U20, Bourne, MA) to measure water level every five minutes. Paired flow measurements were taken by a combination of velocity profiling by electromagnetic velocity sensors, acoustic Doppler velocity sensors and in stream acoustic Doppler velocity profilers.

All continuously monitored watersheds are in the Carrboro and Chapel Hill area and were also grab sampled throughout the sampling period. Continuous monitoring deployment period varied based on sensor availability and environmental conditions.

Flow measurement at continuously monitored watersheds was more frequent than grab sampled watersheds and utilized deployed sensors to capture stormflow observations. This allows us to modify the water level-discharge rating curve throughout time to provide a higher accuracy estimate of flow.

A member of the research team collecting water quality data.

Stable isotopic analysis of NO3- was conducted on select low flow and stormflow water samples from the outflow of a subset of 12 study watersheds that spanned the range in sanitary infrastructure and development intensity. Stormflow samples were selected from the continuously monitored sites and were selected to represent different observed patterns in nitrogen loading.

Data Analysis

Over the two-year course of data collection there were environmental and technical factors that lead to gaps in data or periods of low confidence data. These include drought and stream drying, hurricanes and flooding and sensor and power failures. These challenges are inherent to research in developed areas due to extreme flow events and disturbed landscapes. Interpolation of missing data occurred only at low flows where variation in loading is low. Continuous monitoring data was clipped to periods of high confidence data for this report. Additional data collection and modeling may allow us to constrain uncertainty and release additional data in the future.

Loading during flooding events is an important part of total nutrient loading, however these events create many challenges for data collection. During the fall 2018 hurricanes sensors were removed from TY, BT, and TH where risk of loss was substantial. Sensors remained at BG and RR and continuously monitored throughout both storm events. Water levels exceeded the banks for significant periods of both events and we have no means to directly measure flow outside stream banks.

In order to create a minimum estimate of flow, we ignored flow outside the banks, estimating flow for these periods as only in bank flow. Potential errors in nitrate concentration are negligible in comparison to flow estimates; however, high suspended sediment during these events created noisy nitrate concentration data which was smoothed. We note that our estimates should be considered as minimum loads for these over-bank events. We will refine these shortly by using stage and estimated inundation extent and flow velocities.

INCREASED INSIGHT

Addressing Failing Septic Systems

Failing septic systems are a significant contributor to nutrient pollution within urban watersheds. In North Carolina, septic system failure rates are estimated to be between 15-20%. The UNC Jordan Lake study found that, on average, higher nutrient concentrations are found in streams draining watersheds on septic systems than similarly developed watersheds on sanitary sewer. Repairing failing septic systems prevents untreated wastewater and associated bacteria, pathogens, nutrients, and chemicals from entering into local streams. These upgrades promote human and environmental health.

Successful Efforts at the Local Level

Haywood Waterways Association

In 2006, Haywood Waterways Association began providing financial assistance to repair failing septic systems. They received funding from several state grant programs and some repairs were also funded by the state's WaDE Program. The Haywood Environmental Health Department (EHD) evaluates requests for septic system repair and issues repair permits. HWA pays 75% of the cost and homeowners are responsible for the remaining 25%.

Projects are prioritized by proximity to stream and severity of failure. Projects considered blackwater adjacent receive the highest priority. After septic repairs are completed, the EHD inspects final installations and performs monitoring. They have repaired 125 failing systems and prevented 45,000 gallons of untreated wastewater per day from entering into local waterways.

Chatham County

Rebuilding Together of the Triangle (RTT) has received $100,000 in funding from the EPA's 319 program to repair septic systems throughout the Rocky River watershed in Chatham County. The project is expected to repair 18 home septic systems between July 1st, 2018 and June 30, 2020. Upon completion of the repairs, it is estimated that nitrogen loading will be reduced by 170.58 pounds per year, and phosphorus reduced by 218.04 pounds per year.

Western Piedmont

The Western Piedmont Council of Governments (WPOG) started the Unifour Septic System Repair Program to provide no-interest, revolving loans to qualifying homeowners in need of septic system repair. WPOG received a $433,354 grant from the North Carolina Clean Water Management Trust Fund for the repairs. The project concluded in 2015 and exceeded expectations by completing 63 septic system repairs.

Future Needs

These successful programs demonstrate the potential for a similar program focused on the Jordan Lake watershed. As noted in the finance section of this report, increased revenue generation from an expanded pool of jurisdictions would allow for the implementation of such a program.

Over the period of this study, over 70 total individual storm events were captured at continuously monitored watersheds. Patterns in the co-variance of flow, nitrate concentration and nitrate loading were analyzed to infer primary flow paths of nutrient loading. Although multiple analysis involving flow-concentration hysteresis have been conducted, the final inference was drawn qualitatively based on strong patterns in the position of concentration and loading peaks relative to peak flow.

Results

Trends in Low Flow N and P Loading

Low flow water chemistry for 25 single land-use headwater watersheds in the Jordan and Falls Lake watersheds shows that nutrient pollution is impacted by sanitary infrastructure type, geology and development intensity. Low flow TDN and nitrate concentration and loading indicate that nutrient pollution increases with metrics of development intensity (i.e. ISC, road density, parcel density, sanitary sewer density) for watersheds within the urban service boundary served by sanitary sewer. Higher development intensity watersheds also generally show greater variation in sampled N concentration and load than low development intensity watersheds.

Septic watershed concentration and loading does not respond to metrics of development intensity and is more variable than similar low development intensity watersheds on sewer. While mean low flow N loading was greater than the loading for comparable sanitary sewer watersheds (i.e. less than 300 parcels) the effect of sanitary infrastructure type on low flow N loading was non-significant due to the large variation in loading among septic watersheds.

Watersheds within the Triassic and Carolina geologic basins which make up the Jordan Lake watershed have similar nutrient loading and response to development intensity; however, nutrient loading was significantly higher among Raleigh Belt watersheds. The Raleigh belt is not a part of the Jordan Lake watershed, but illustrates that geology is an important consideration in nutrient loading. Per unit area N-loading of sanitary sewer served watersheds increased with development intensity; however, preliminary analysis suggests that per parcel, or per capita loading may be much larger for septic watersheds and stable across development intensity of sewer served watersheds.

A member of the research team collecting water quality data.

Soluble reactive phosphorus (SRP) loading increased dramatically with development intensity among high intensity development watersheds, but was relatively flat at lower intensity development. There were no significant differences in SRP loading with sanitary infrastructure and variation in loading was smaller among sites and through time at sites than N loading.

Assessment of Sampling Methods

Continuous monitoring of outflow of five subset watersheds indicates that total loading is not accurately represented by discrete water quality although general trends are consistent. The continuously monitored septic watershed had a median loading 40% less than the median of all the grab sampled septic watersheds. Due to the large range in loading observed from septic watersheds no single continuously monitored watershed could represent all septic watersheds.

The low and medium development intensity watersheds on sanitary sewer are generally representative of urban development in the region although there is little sampling for comparison to the high intensity study watershed. Grab sampled predictions of total loading significantly underpredict the continuously monitored total loading; however, the grab sampling closely estimates the continuous monitoring observations of low flow loading.

Jordan Lake marsh, November 2019.

Nitrate Sources and Contribution

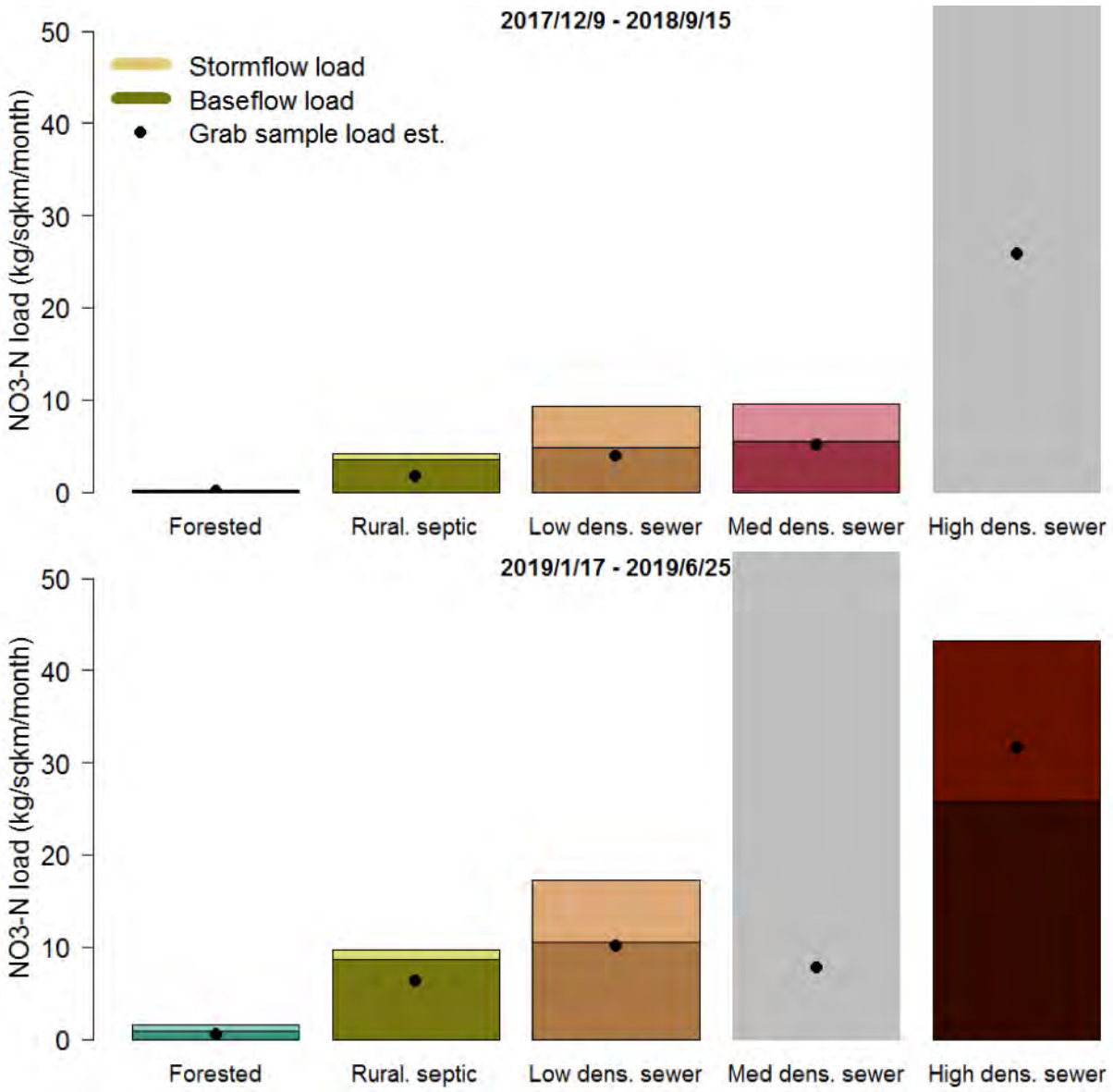
Isotopic analysis suggests that the majority of nitrate loading from developed watersheds at low flow is derived from wastewater across seasons and infrastructure type. USGS isotopic studies indicate that there is a large overlapping range between soil N and wastewater N in their assessment ranging across the US. However, low flow forested watershed nitrate loading, which is expected to be primarily soil N, is 2.5 to 208 times lower than estimated monthly concentrations from grab sampled developed watersheds. The forested TH watershed is nested within the RR watershed and N loading per km2 increases by 5.6 times between sampling points.

Without evidence that soils in developed landscapes produce much greater nitrate than forested soils, it is reasonable to assume that the majority of nitrate in the overlapping soil N/wastewater N range is derived from wastewater. The nitrate contribution from wastewater is larger for septic watersheds than sanitary sewer served watersheds; however, the difference is not significant, suggesting that both septic and sewer served watersheds contribute significantly to N loading through leaking sanitary infrastructure at low flow.

Nitrate loading during stormflow is made up of a complex mix of sources. Isotopic analysis of stormflow water sampling was not sufficient to accurately partition loading sources; however, we can identify that wastewater, atmospheric deposition, fertilizer and soil are all important contributors. Throughout individual stormflow events, the sources of nitrate change rapidly and are mixed together. This rapid change and mixing obscures analysis and further sampling and laboratory analysis will be required to partition sources and identify patterns in source timing throughout stormflow events.

Stormflow Loading

The proportion of stormflow loading (stormflow loading/total loading) was much greater for the urban watersheds on sanitary sewer than for the rural septic watershed. Stormflow was responsible for 20% of nitrate loading at the septic watersheds while it was responsible for 40-48% of loading among the urban watersheds.



Total loading for two periods of high confidence continuous monitoring data. Study watersheds are TH, RRdev, BG, BT, and TY respectively. Light colors represent stormflow loading while paired dark colors represent low flow (baseflow) loading. Data is missing for the high-density watershed in the first period and 44 days of data have been removed in QA/QC. Data is missing for the medium density watershed in the second period and 6 days of data have been removed for QA/QC. Points represent the grab sampled based estimate for nitrate loading. Peak flow for TY is estimated and therefore TY stormflow loading is a conservative estimate and is likely higher. The 2019 period of data was wetter (127 mm/mo rainfall) than the 2017/2018 period (91 mm/mo rainfall) which started in drought.

INCREASED INSIGHT

Implementing a Land Conservation Strategy in the Jordan Lake Watershed

Background

The Jordan Lake Watershed Conservation Strategy, published in July 2019 by the Triangle Land Conservancy, proposes a framework for protecting drinking water supplies from Jordan Lake through a land protection program. This framework is an integral part of the Jordan Lake One Water (JLOW) initiative, which is a partnership to facilitate cooperation and integrated water resource management in the Jordan Lake watershed.

The neighboring Upper Neuse Basin Watershed draining to Falls Lake has already implemented an immensely successful land conservation and water quality program, the Upper Neuse Clean Water Initiative (UNCWI). The Jordan Lake proposed watershed conservation strategy builds on UNCWI's model with a goal of protecting 35,000 acres in the Jordan Lake watershed over the next 35 years.

As outlined in this report new sources of revenue should be utilized to implement a program for land conservation in the Jordan Lake watershed, as it would enhance water quality for current residents and generations to come by cost-effectively reducing pollution and sediment in the watershed.

Land Conservation in the Jordan Lake Watershed

Currently, only 8% of the Jordan Lake watershed is protected from development, and 70% of the remaining unprotected area–almost 750,000 acres–is comprised of farms, fields, wetlands, and forests. As the region continues to grow and urbanize, these valuable lands are at risk of development, which will put water quality at risk at a time when there are more water customers than ever before. Development of natural lands, particularly the construction of impervious surfaces, dramatically inhibits natural water filtration, which local ecosystems currently provide at low costs.

Protecting drinking water sources by protecting the land around them is one of the most cost-effective ways of reducing water pollution. Soil filters rainwater and runoff, trapping sediments and nutrients before they reach streams and lakes.

Triangle Land Conservancy has already produced a GIS Watershed Protection Model that identifies priority conservation lands from that undeveloped land which is currently unprotected. These locations are weighed, scored, and prioritized based on four main goals:

- Protect water sources and conveyances.
- Conserve upland areas.
- Promote water infiltration and retention.
- Protect vulnerable areas.

This model has identified over 10,000 parcels for a total of over 385,000 acres within the Jordan Lake watershed that would be priority conservation lands and therefore eligible for funding, should a water fund be established.

Why Land Conservation

By protecting natural watersheds, municipalities may lower costs associated with expensive water treatment in order to purify water from degraded watersheds. A 2011 study by Industrial Economics, Inc. found that wetlands filter 63% of nitrogen, 45% of phosphorous, and retain up to 94% of sediment. This same study found that a loss of roughly 3,000 acres over 15 years equated to costing $840,00 in annualized municipal water treatment. Another 2017 study found that for every 10% increase in forest cover in the watershed, treatment and chemical costs decreased by about 20% up to 60% forest cover.

In addition to being a cost-effective way to purify water, land conservation provides a number of co-benefits, like the creation of new parks and greenways. Land conservation also protects vital ecosystem services like flood protection, air purification, and pollination.

Building Upon UNCWI's Success

The UNCWI program provides a promising model for a similar Jordan Lake Watershed Conservation Strategy. The Conservation Trust for North Carolina (CTNC) coordinates the UNCWI, a partnership of nonprofit organizations and local governments. Initiative partners work with landowners, local governments, and the public to acquire key parcels of land through voluntary purchase, donation of land, or conservation agreements. This program is non-regulatory, voluntary, and market driven. Landowners are incentivized by potential tax benefits and financial incentives, as well as the knowledge that their land is permanently protected.

From 2006 to 2016, the UNCWI successfully protected 88 properties. These properties include 84 miles of stream banks on 7,658 acres. It's estimated that these protected lands avoid at least 7,926 pounds of nitrogen and 1,408 pounds of phosphorous from entering nearby waterways annually.

The time to implement land conservation initiatives is now, since projected increases in land values in the Jordan Lake watershed over the next 30 years will make land protection efforts increasingly unaffordable. For UNCWI, financial support from local and state government agencies is critical to the program's success. The City of Raleigh contributes to the water fund through a dedicated revenue source generated by a $0.15 fee per 1,000 gallons of water used by utility customers. This volumetric fee averages just 60 cents a month per household, or less than $8 a year.

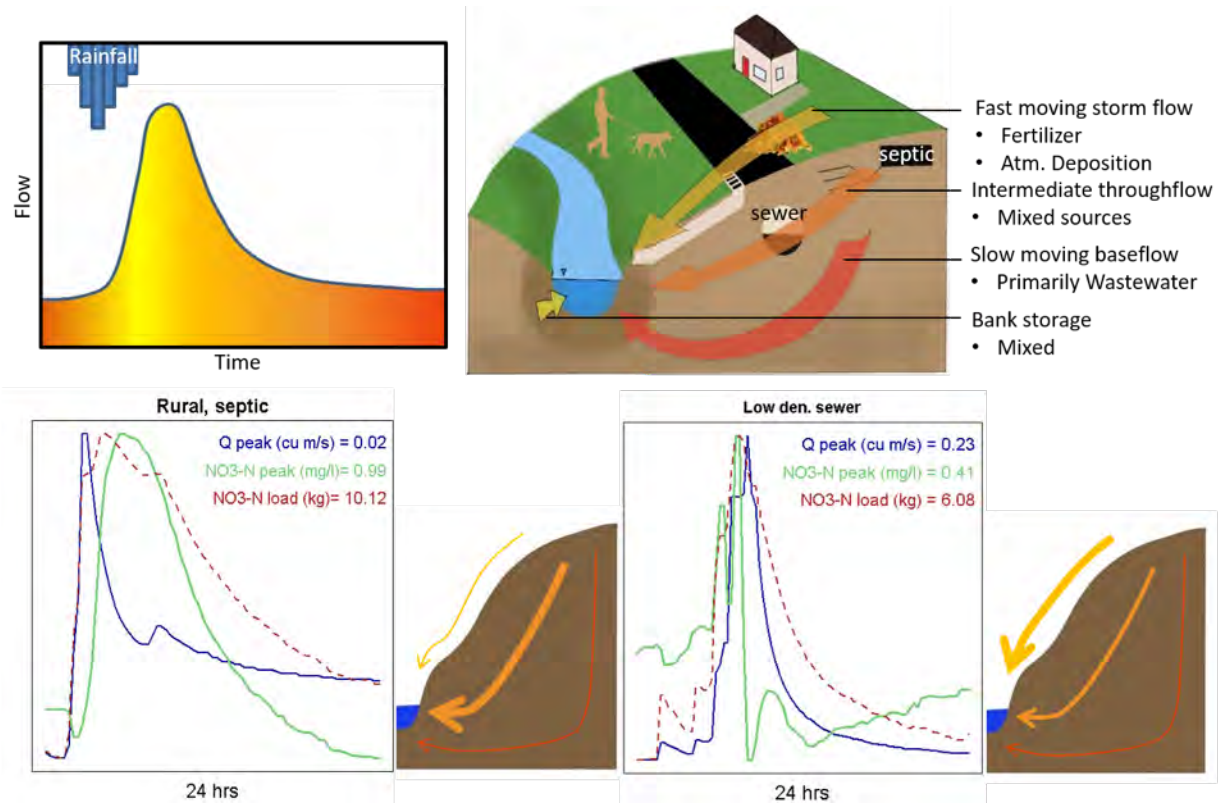
Other municipalities in the Falls Lake watershed have contributed funds to protect high priority lands, and the program has also received funding for land conservation from various grant opportunities, such as the North Carolina Clean Water Management Trust Fund. Overall, from 2007-2015, UNCWI has leveraged $72 million in funds.

As noted in this report a Jordan Lake program could generate funds from a diverse range of sources, and could likely leverage more than $24 million annually for land conservation. Adapting the strategies that have led to success for the Upper Neuse River Basin provides a successful blueprint for voluntary conservation with measurable impacts on the water quality of Jordan Lake and throughout the watershed.

Stormflow loading was highest at the high development intensity watershed (TY) and lowest at the rural watershed on septic; however, there was no significant difference between the stormflow loading of the low and medium intensity watersheds. This may be because there are two major Chapel Hill roads (MLK Blvd and Estes Dr) in the low intensity watershed despite otherwise low housing and building density. The stormflow loading for the Tanyard watershed is probably underestimated because high flow measurement was not practical and was therefore conservatively modeled. Trends in flow and nitrate concentration relationships indicate that this is because at low flow forested nitrate concentration is very low, likely as a result of biotic uptake and removal.

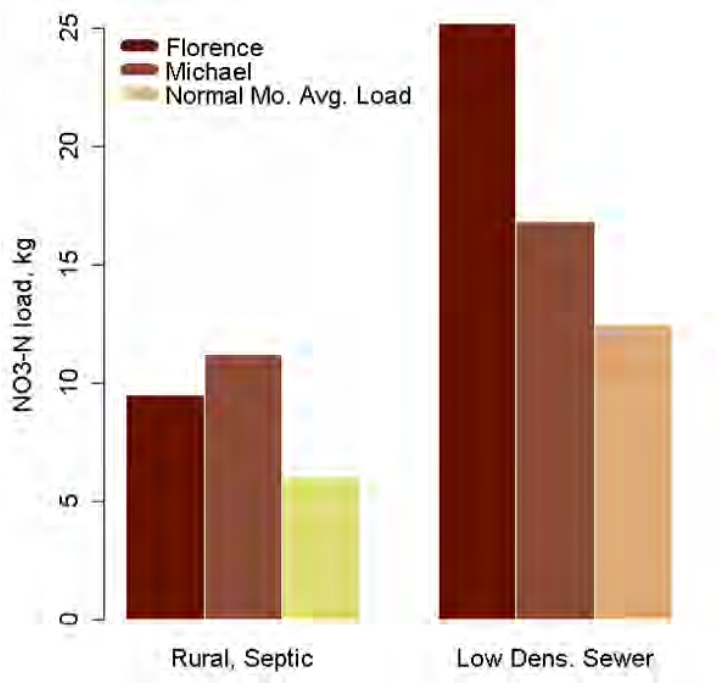
Seasonal and Flow Dependent Drivers of Loading

Inter-storm nitrate concentration patterns provide evidence for seasonal changes in nitrate loading based on land-use and sanitary infrastructure. The figure below illustrates two examples of these different patterns based on the timing of the loading and concentration pattern relative to the event flow response. For this particular storm (7/22/18), subsurface flow paths and sources contribute significantly to loading at the septic watershed while rapid surface runoff and associated sources are significant sources at the low density urban watershed.



During dry periods, the septic watershed loading was driven by subsurface stormflow. During wet periods, low flow concentration and loading greatly increased at the septic watershed and stormflow resulted in less loading than stormflow in the dry period. This suggests that during dry periods, septic systems are not hydrologically connected to watershed streams at low flow, but are connected by stormflow resulting in large episodic pulses of N. However, during wet periods, septic systems are constantly hydrologically connected at low flow, resulting in consistent N loading.

Patterns vary greatly for the urban watersheds on sanitary sewer. During dry periods, urban watershed loading is driven by fast moving surface runoff during stormflow. During wet periods loading is driven by both stormflow and highly elevated post storm N concentrations at low flows. This suggests that stormflow events during wet period hydrologically connect leaking sanitary sewer lines. The delay in increased concentration relative to stormflow suggests that stormwater may be infiltrating into wastewater pipes during events and slowly leaching out over the subsequent hours to days.



Hurricane N Loading

While not originally planned within this project, our instrumentation was deployed during the heavy rains brought by Hurricanes Florence (Sept 15, 2018) and Michael (Oct 10, 2018) and allowed for the assessment of stream nitrate dynamics during these unusual periods. **Conservative estimates of nitrate loading for both hurricanes suggest that large storms can have a disproportionate impact on nutrient loading**. Flooding event data has high uncertainty and this data is a minimum loading accounting for uncertainty in flow and sensor estimates of nitrate. Even so, our estimates show that extreme events are an important component of nutrient loading.

Bar graph comparing the average nitrate load for a normal month at the continuously monitored rural watershed and low-density urban watershed to the loading from the single rainfall events from hurricanes Florence and Michael. Estimates are a minimum, not accounting for over bank flow, and true hurricane loading could be substantially higher.

Hurricane Florence nitrate loading was greater than 25.2 kg for BG and 9.5 kg for RR, or 2.0 and 1.6 months loading under normal flow conditions respectively (at least). Hurricane Michael nitrate loading was greater than 16.8 kg for BG and 11.2 kg for RR, or 1.4 and 1.9 months loading under normal flow conditions respectively (at least). Continued analysis of this data will aim to constrain uncertainty and provide an estimated loading range for flooding events. Nonetheless, the high spatial and temporal variability of hurricanes can make it challenging to characterize the full effects that these events can have on water quality.

Management Implications

Wastewater

Wastewater is a significant contributor to non-point source nitrate loading across land-use and septic or sanitary sewer severed watersheds. Septic systems are designed to discharge partially treated wastewater into the ground where natural soil processes remove the majority of remaining nutrients, but during wetter periods and storms, nutrients are transported faster, reducing treatment in the soil and resulting in greater N-loading. There was a large range in N-loading from septic watersheds that was not explained by development features or household density. Septic system performance and location relative to streams and flow paths may be of greater importance. Additional analysis of collected data will be conducted to assess this hypothesis; however, additional study will likely be necessary.

Sanitary sewers are meant to contain wastewater and transport it for treatment, but they are known to leak and surcharge. This results in low flow nitrate contribution from wastewater that is lower than that in septic watersheds, but still accounts for the majority of low flow N-loading at these watersheds. The extent and degree of leaks is unknown, however among the seven sewer served watersheds that were sampled over the course of a year for this analysis, significant wastewater derived nitrate was nearly ubiquitous.

Stormwater control measures must be coupled with sanitary infrastructure upgrades and maintenance. Distancing sanitary infrastructure from streams should be evaluated as a potential mitigation. Sanitary sewer trunk lines often run in close proximity to streams and at low points in the landscape. This means that even minor leaks may have a direct nexus to streams and the very presence of the sewer lines prevents the planting of vegetated riparian buffers which may mediate this loading.

Stormwater

Stormflow is also of great importance, accounting for 20 – 48% of total N-loading across the continuously monitored developed watersheds and generally increasing with development intensity. The many negative impacts of stormwater are well documented and stormflow contributes to nutrient loading in ways not investigated by this study such as suspended sediment transport and reduced stream health and uptake.

Because stormwater moves rapidly at high volumes, nutrient treatment options are often constrained relative to low-flow loading. Stormwater control measures can provide some reductions and they can be an important part of watershed scale planning and restoration. Connecting streams to floodplains will allow riparian buffers to provide treatment of stormwater and increases the potential treatment time by slowing flow.

Forest Cover

Forested watershed loading was 2.5 to 208 times lower than developed watershed loading and trends in concentration and flow suggest significant biotic N uptake and removal especially at low flow. Although previous work has shown moderate total organic nitrogen (TKN) loading from forested watersheds it also indicates low nitrate and ammonium loading (Boggs et. al. 2013). Much of the TKN is in the form of suspended solids and may change form, but is not immediately available to algae and may be buried in reservoirs.

Conservation of reservoir watersheds through easements and development limits is a common method for protecting the quality of drinking water sources. These findings highlight the importance of this practice. Effective stream restoration could be a powerful tool for managing nutrients; however, it must be approached at the watershed scale with reduction of stormwater and include reconnection to floodplains and wetlands.

Nutrient Loading Mechanisms

The mechanisms and timing of N-loading change with land-use and throughout the year based on rainfall and seasonal conditions. Loading can occur over different time scales based on the flow path that N loading takes. This is highly sensitive to the location of sources (e.g. surface vs subsurface and proximity to streams) and also to the seasonal wetness conditions.

These factors are important considerations for optimizing the implementation of stormwater control measures and best management practices as a part of larger regional nutrient management. Recommendations may change based on targeted landscapes, seasons or flows. For example, if we wish to target spring nutrient loading to reduce summer eutrophication, our results suggest that in rural areas low flow loading should be targeted. Stream restoration and forest cover may be good options. Likewise in urban areas stormflow and throughflow loading should be targeted. This may require a combination of bio-retention, riparian buffers and enhanced sewer maintenance to trim storm peaks, but ensure treatment and retention of nutrient in subsurface flow. Future publication will detail these findings on the hydrologic processes driving nutrient loading and the effects of land-use and hydroclimate.

Extreme Events

In 2018 North Carolina was hit by two major hurricanes which transported months' worth of nitrate from study watersheds in a few days. Very few previous studies have been able to quantify hurricane loading especially at inland headwater watersheds.

Climate change projections predict an increase in the number of extreme rainfall events which will have profound impacts on nutrient loading. Because of the high discharge of flood event loading, these nutrients are not just an issue for Jordan Lake, but the entirety of the Cape Fear River and estuary. Increased extreme event loading should be considered in management plans and future projections.

The full Stream Monitoring and Nutrient Loading report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Sediment Dynamics

Sediment Dynamics

QUESTIONS RESEARCH IS ADDRESSING

How do the sediments entering Jordan Lake from the Haw River move throughout the year?
How are the Haw River sediment inputs spatially distributed in Jordan Lake?

RESEARCH METHODS

In order to study how sediments move from the Haw River into the lower arm of Jordan Lake, five coring sites were selected and lake bottom sediment cores were collected at each site during four sampling periods within the study. A transect of coring sites between the Haw River and the middle of the lake were established to examine the transport of sediment into and through a slim and tumultuous section of the lake called the 'Narrows'. Sediment dynamics were tracked by analyzing the radioisotope Be-7, which is naturally produced in the atmosphere and swiftly absorbed by particulate matter in rivers and lakes. Be-7 has a half-life of 53.3 days, and is therefore ideal for tracking sediment deposition on a monthly scale.

Sediment cores were collected using a modified Eckman grab sampler designed to retrieve undisturbed surface sediment samples of an approximate depth of 15 cm. Sub cores were collected from each grab sample using a 4" diameter core tube, and each sub-core was sliced at 1 cm intervals in the lab. Each sample was weighed wet, then frozen and freeze dried and re-weighed to determine sediment bulk density.

FINDINGS

Based on analysis of the sediment cores, sediment discharge to Jordan Lake from the Haw River during the study period was dominated by Hurricane Florence and Tropical Strom Michael. Be-7 profiles indicate that concentrations and total inventories varied temporally and spatially. The other sediment parameters measured in each core show that the Haw River is the primary source of sediments to the study area and that there are no significant additional sources of sediments.

However, the observed distribution of sediment deposition rates stipulate that sediment supply from the Haw River is not the dominant factor determining sediment deposition at any one place or time, but rather the post-depositional movement of sediments resulting from physical processes, like suspension and redistribution by currents, play an important role. Current velocities that redistribute lake bottom sediments may be controlled by the lake water balance, as determined by periodic dam release into the Cape Fear River.

MANAGEMENT IMPLICATIONS

This study provides detailed information that can be utilized to develop a predictive model for turbidity plumes in the center of Jordan Lake, as well as supply nuanced data on the dispersal of nutrients and contaminants throughout the lake. The discovery that sediment inputs from the Haw River are secondary to physical processes in determining sediment distributions in Jordan Lake specify the need to better understand the coupling of physical circulation and sediment dispersal, especially on event scales.

RESEARCHERS

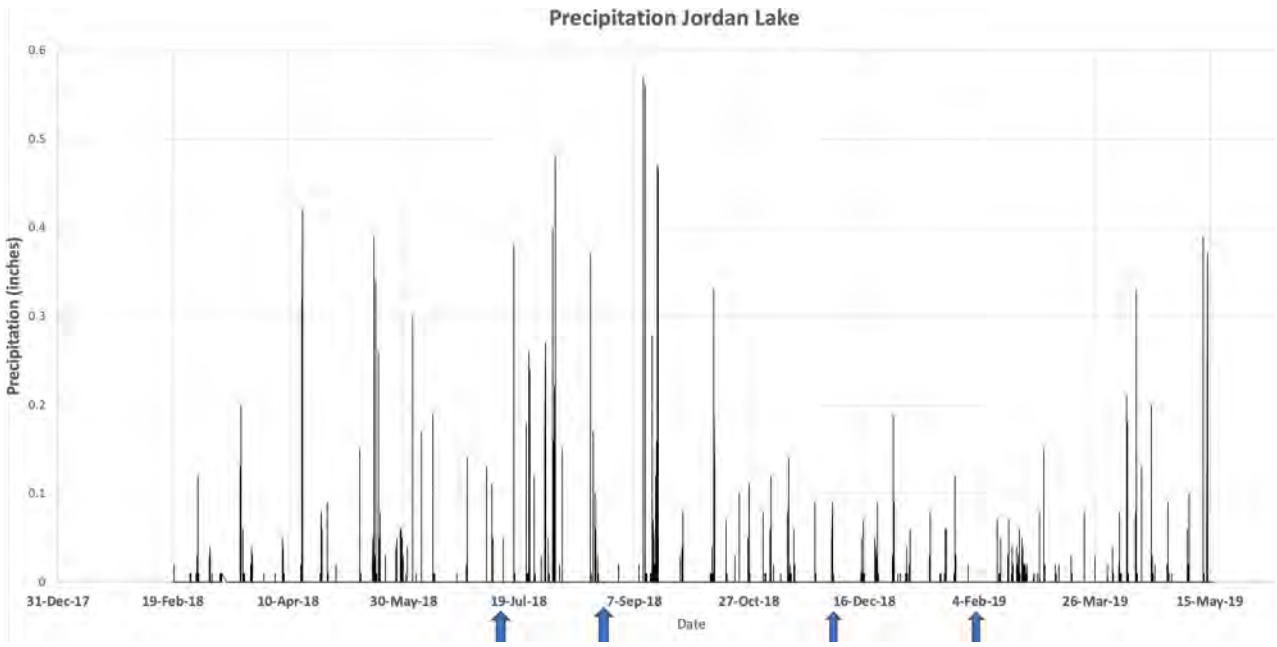
Brent McKee, Sherif Ghobrial, UNC Department of Marine Sciences
Tony Rodriguez, UNC Institute of Marine Sciences

Lake Setting

2018 was a record-breaking year in the Research Triangle area in terms of precipitation. The average annual rainfall totals for Raleigh, NC (1981-2018) is 46 inches with 100 days of rain. In 2018 a total of 63 inches of precipitation was recorded in the Raleigh area with 137 days of the year recording rainfall. This total was the second highest annual rainfall recorded during the past 129 years (1996 was the highest).

Rainfall in 2018 was dominated by Hurricane Florence (September 13-17) and Tropical Storm Michael (October 10-11). The figure above shows the precipitation at the Jordan Lake dam. Blue arrows denote the sampling dates when cores were collected.

Precipitation Measured at the Jordan Lake Dam (Moncure, NC)

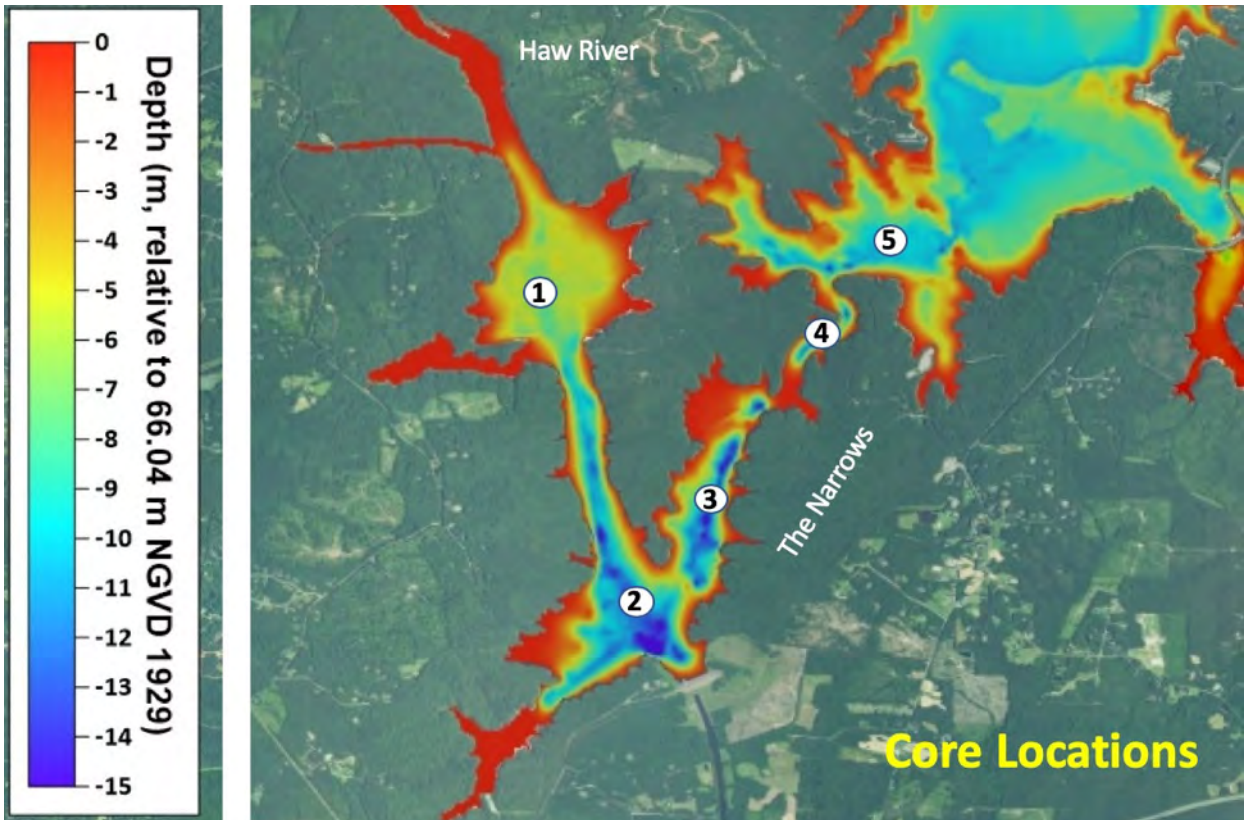


The impact of Florence and Michael are most prominently reflected in the lake levels recorded at Jordan Lake.

Experimental Design

The Haw River is the dominant source of sediments delivered to Jordan Lake, accounting for 89% of the sediment load to the lake. During the study period, an average of 67 tons of sediments were delivered to Jordan Lake each hour, including two peak events that exceeded 1200 tons per hour corresponding to Hurricane Florence and Tropical storm Michael.

Five coring locations were established, and lake bottom sediment cores were collected at each site during four sampling periods within the study. A central focus of the study was to understand the fate of sediments entering the low arm of Jordan Lake from the Haw River. Of special interest was to determine how much sediment from the Haw entered the middle lake where municipal intakes are located. A transect of coring sites ranging from proximal to the Haw River input to the middle lake were selected to examine the transport of sediment into and through the Narrows. Sampling dates were July 17, August 23 and December 4 in 2018 and February 5, 2019.



Coring Locations within the lower Jordan Lake. Base map displays water depths.

Methods

Sediment cores were collected using a modified Eckman grab sampler that consistently retrieved an intact undisturbed surface sediment sample approximately 15 cm deep. Subsequently, sub-cores were collected from each grab using a 4" diameter core tube. Upon return to the lab, each sub-core was extruded and sliced at precise 1 cm intervals downcore. Each sample was weighed wet, then frozen and freeze dried and reweighted to determine sediment bulk density. Dried sediment was packed into vials and were counted by direct gamma spectroscopy on an intrinsic geranium planar detector. All isotopes were determined by direct gamma spectroscopy.

Core collection, extrusion and sub sectioning.

Findings

The Haw River delivers 89% of suspended sediments entering Jordan Lake each year. The suspended sediment load delivered to Jordan Lake increases with the Haw River water discharge. The Haw is a "flashy" river, a hydrologic term indicating that water discharge and river levels change rapidly in response to precipitation events.

Water Discharge: 2.4 m3s-1
Total Suspended Sediment Concentration = 7 mg l-1

Water Discharge: 1213.5 m3s-1
Total Suspended Sediment Concentration = 335 mg l-1

The images above show a cross-section of the Haw River at Bynum take on consecutive days. This illustrates how rapidly water discharge and suspended sediment concentrations change in the Haw River.

Prior to the study it was widely believed that strong storm events like Florence and Michael controlled sediment dispersal and redistribution in the lower and middle regions of Jordan Lake. The restricted passage known as the Narrows would result in the trapping of sediments in the lower Haw River arm of the lake or possibly within the Narrows.

Our findings lead us to the conclusion that sediment inputs from the Haw River are a secondary factor in determining sediment distributions in Jordan Lake and that physical processes (erosion, resuspension, and redistribution by currents) are probably the driving force for sediment transport in Jordan Lake.

This conclusion points to a need for better understanding of the coupling between physical circulation and sediment dispersal, especially on event scales. The role of water removal from the lake via the dam is poorly understood as are the physical factors that lead to more sediment being shunted to the lower Cape Fear River.

The full project report on Sediment Dynamics, including references, can be found in the Resources Section of the UNC Jordan Lake Study website: nutrients.web.unc.edu.

Stormwater Control Measures

Stormwater Control Measures

QUESTIONS RESEARCH IS ADDRESSING

What is the long-term water quality performance of bioretention?

What role can floating treatment wetlands play as a nutrient reduction practice?

What is the potential treatment of sand filter columns?

RESEARCH METHODS

Researchers conducted the following studies as part of their work on this project:

- Evaluated discharge concentrations and loads of nitrogen and phosphorus from a bioretention cell (1) post-construction and (2) following 17 years of treatment.
- A comprehensive literature review of the effectiveness of floating treatment wetlands.
- Assembled nine representative sand filter columns in the lab to evaluate their efficacy.

FINDINGS

The aging bioretention cell sustained, and in some cases improved, nitrogen and phosphorus removal following 17-years of continuous performance.

Floating treatment wetlands are an increasingly popular retrofit to improve wet pond nutrient removal, particularly because of their ease of installation and relatively low-cost. Nutrient removal appears varied and dependent upon providing enough coverage and proper placement.

Sand filter columns appeared to outperform the credit assigned to them through NC DEQ, but additional data and field trials are needed to reach conclusions that are more definitive.

MANAGEMENT IMPLICATIONS

Bioretention media surveyed in this study displayed significant changes in physical and chemical characteristics with age. However, the changes detailed herein show promising results and suggest that with minimal maintenance, bioretention media should continue to provide treatment of stormwater runoff for prolonged periods of time.

Floating treatment wetlands are an increasingly popular retrofit to improve wet pond nutrient removal, particularly because of their ease of installation and relatively low-cost. Nutrient removal appears varied and dependent upon providing enough coverage and proper placement.

Researchers recommend further trials and statistical analyses are conducted to identify robust placeholder credits for sand filters.

RESEARCHERS

Bill Hunt, Jeffrey Johnson, Sarah Waickowski, NC State University Department of Biological and Agricultural Engineering

A comprehensive evaluation of stormwater control measures was beyond the scope of the UNC Jordan Lake study. However, it is important to acknowledge this issue which forms a component to any large-scale nutrient management strategy. The study benefitted from the expertise of researchers at North Carolina State University who have included information on some of their latest evaluation of stormwater control practices.

Long-Term Water Quality Performance of Bioretention

One of the most popular stormwater practices in suburban North Carolina is bioretention. While bioretention has been researched intensively to determine the most efficient designs, few long-term studies have attempted to assess the performance of older bioretention. However, previous research and design guidance for bioretention has predicted long-term water quality treatment. This study compared discharged concentrations and load of nitrogen and phosphorous from a bioretention cell (1) post-construction and (2) following 17 years of treatment.

Chapel Hill bioretention cell characteristics.

Characteristic	Chapel Hill BRC
Year constructed	2001
Underlying soil	Clay, clay loam, and silty clay
2002-2003 Drainage area (ac)	0.15
2017-2018 Drainage area (ac)	0.28
Imperviousness	100%
BRC surface area (ft^2)	970
Bowl storage (in)	4
Media depth (ft)	4
Media infiltration rate (in/hr)	1.3 – 3.0
Original media P-index	4-12 (3.7 – 11.1 mg/kg)
Underdrain type	Conventional (no IWS)
Vegetative cover	Perennial grasses, trees, shrubs

A conventionally drained bioretention cell with lateral underdrains in Chapel Hill was first monitored post-construction for 10 months in 2002-2003 and, again following continuous use for 14 months from 2017-18. Estimated mass load reductions during the initial monitoring period were 40% for total nitrogen (TN) and 65% for total phosphorous (TP)

Bioretention cell monitored in Chapel Hill.

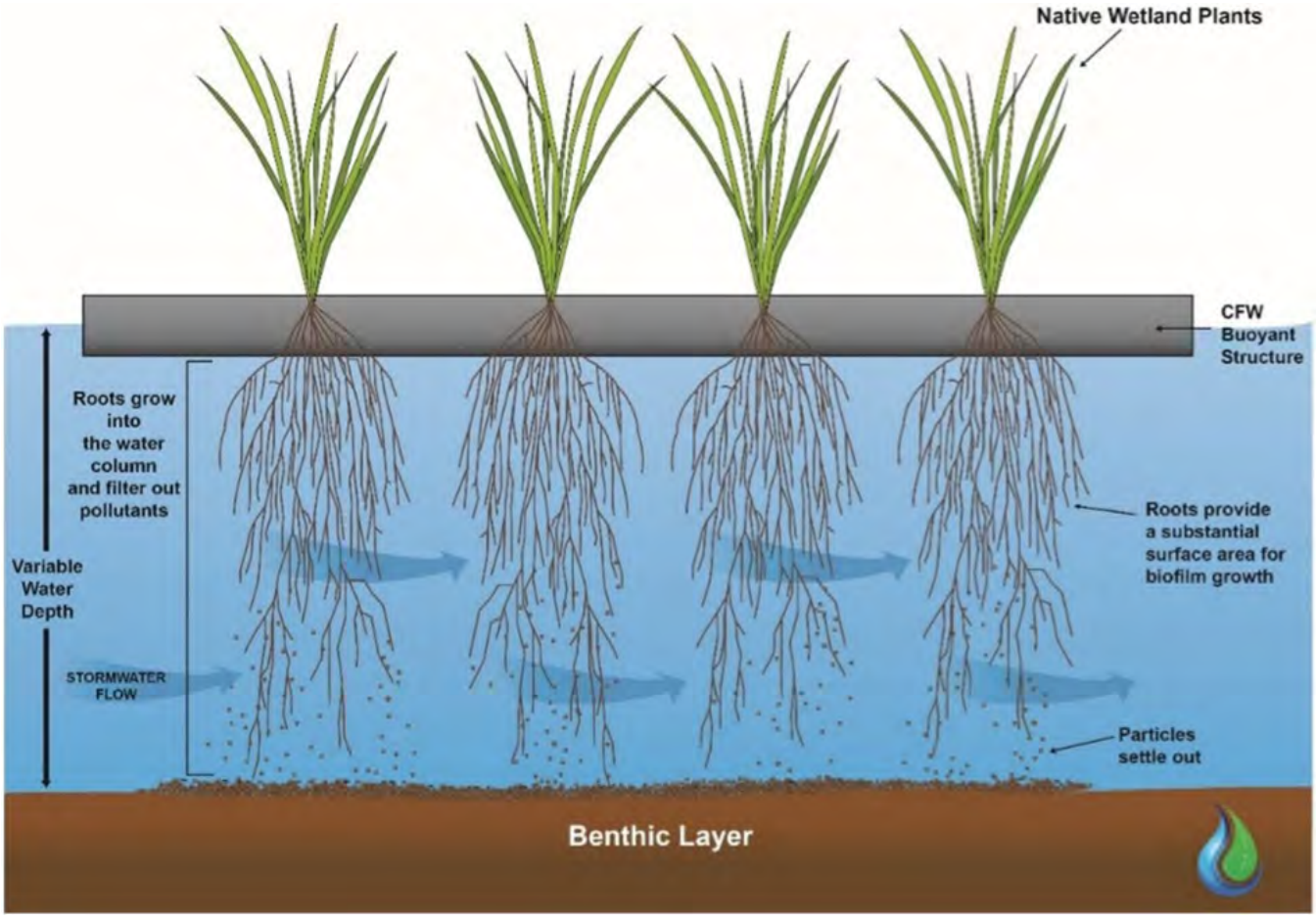
Mass load reductions were increased 17 years after construction, with reductions of 72% and 79% for TN and TP, respectively. Plant growth, death, and decay over the 17-year life of the bioretention cell are hypothesized to have contributed additional nitrogen assimilation and carbon to fill the media, serving as a catalyst for nitrogen treatment. Phosphorous removal remained relatively unchanged between the two monitoring periods. Filter media samples indicated the top 8 inches of filter media were nearing phosphorous saturation, but with 4 feet of filter media, lower depths would most likely to continue to provide treatment.

If designed, built, and maintained correctly, bioretention appears to provide sustained treatment of stormwater runoff for nitrogen and phosphorous for nearly two decades, and likely longer.

Floating Treatment Wetlands

Wet ponds have been utilized throughout North Carolina, humid regions of the United States, and the world. A wet pond includes "a permanent pool of water for removing pollutants and additional capacity above the permanent pool for detaining stormwater runoff."

Wet ponds are an effective stormwater best management practice for attenuating peak flow and thereby reducing downstream flooding; however, their efficacy in improving water quality has been inconsistent in research. A study evaluating three wet ponds in Wilmington, NC found highly variable pollutant rates. While one pond showed significant reductions in nearly all pollutants sampled, another pond had no significant removal of nutrients, and yet another actually showed increased nutrient concentrations in the outflow. Similarly, variable results were found in several other North Carolina based studies.



Example cross section of a floating treatment wetland (Lucke et al. 2019)

Because ponds treat relatively large watersheds, any means of improving their performance has the potential for widespread effect, particularly in nutrient sensitive watersheds like the Jordan Lake watershed.

One relatively proven retrofit of wet ponds is the addition of floating treatment wetlands (FTWs). FTWs are a hydroponic system that employ vegetated floating mats or trays to provide nutrient treatment in surface water settings. FTWs are quickly becoming a popular retrofit to lakes and wet detention ponds as they:

- Allow sedimentation.
- Do not compromise existing ability to mitigate peak flows.
- Do not require heavy equipment to install.
- Provide improved habitat and diversity.

Moreover, they are cost-effective and ecologically friendly alternative to a full-scale design/build retrofit to reduced loads from existing ponds.

N.C. State students installing a Floating Treatment Wetland.

Due to the low-cost/high reward potential associated with FTWs, extensive research has explored their ecosystem service and treatment performance in recent years. While the preponderance of research features laboratory based mesocosm studies, multiple field trials have demonstrated the effectiveness of FTW's as a value added retrofit for stormwater runoff.

Previous research has, importantly, studied FTWs that were somewhat haphazardly placed. Now understanding that the FTWs function best when flow is forced to pass through (or under) their dangling roots, research is needed to test hypothesis on strategic placement. For example, protective rings of FTWs around outlet structures may expose the most treatment to runoff or locating FTW's immediately downstream of the forebay may prove most effective.

Overall, floating treatment wetlands are increasingly popular to retrofit to improve wet pond nutrient removal, particularly because of their ease of installation and relatively low-cost.

INCREASED INSIGHT

Community Engagement for Integrated Stormwater Management Implementation

Background

Traditional systems of moving stormwater away from development can mitigate frequent flooding, but can also create unintended consequences. Some jurisdictions are augmenting traditional approaches to stormwater management with parcel level practices that utilize green infrastructure. Green infrastructure seeks to reduce and treat stormwater at its source and includes stormwater control measures such as rain gardens, cisterns, green roofs, permeable pavers, bioswales, and wetlands. However, the efficient implementation of this approach in an urban setting necessitates the placement of stormwater control measures on public and private property.

Danielle Spurlock, a faculty member with the UNC Department of City and Regional Planning, examined the role of community engagement in the successful implementation of green infrastructure on private property.

Research Methods

A case study design was employed to investigate the role of community engagement in carrying out green infrastructure projects on private residences. This design incorporated analysis of current and historical storm water plans and semi-structured interviews within six jurisdictions of the lower portion of the Jordan Lake watershed. Local government staff, nonprofits, developers, small business owners and residents from Chapel Hill, Carrboro, Durham, Cary, Morrisville and Apex were interviewed during the 2017-2018 study year, culminating in a project total of 89 interviews. These community members were questioned about the relationships within and between municipal agencies, community engagement strategies and overall attitude towards implementing stormwater management practices.

Findings

Analysis of the interviews revealed several key themes:

- Communication, Trust and Prioritization

Interviewees communicated an overall distrust in local government, stating an observed disconnect between the collection of local input and subsequent action. Residents who did not appear to overtly partake in environmental action, did not discount the value of environmental protection, rather indicated more pressing circumstances that took priority.

- Data and Design

Several residents supported the idea of green infrastructure, but questioned the impact of their property on the water quality of Jordan Lake.

- Engagement Methods

A number of community members suggested an emphasis on social media to bolster outreach, and many government officials disclosed a need for furthered training on community engagement.

- Funding and Incentives

Both residents and officials challenged how decentralized stormwater initiatives would be funded, and how these projects would be selected and ranked.

Management Implications

There are various courses of action local agencies can take to address the concerns brought up by residents and municipality leaders alike. The compilation of a record of past engagement efforts could help illuminate successful strategies and foster trust between local agencies and community members. A parcel-based analysis of individual property contribution to stormwater runoff could provide the empirical data to convince landowners that their land has a measurable impact on the water quality of the surrounding watershed. Another step municipalities could take is improved social media outreach training for staff and inclusion of hands-on approaches to community engagement, such as hosting tours of properties with green infrastructure.

These preliminary findings indicate areas of growth in the relationships between local governments and members of the community, which affect any restorative efforts taken to address the health of Jordan Lake.

Sand Filters

Sand filters are a commonly used stormwater control measure (SCM) in North Carolina. They are often implemented in highly impervious areas to help municipalities comply with regulations. The North Carolina Department of Environmental Quality has identified this technology as a primary SCM or device that can treat runoff from built-upon-areas for water quality without the need for additional SCMs.

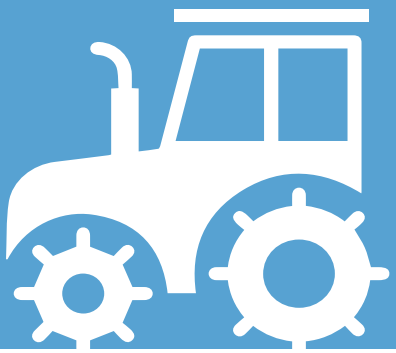
Due to a lack of North Carolina data, NC DEQ used research from sites located in Florida, Maryland, New Hampshire, and Virginia to establish pollutant removal credits for sand filters. There is a concern these data are not reflective of North Carolina sand filters and may skew effluent pollutant loads leading to a violation of stormwater regulations.

Four sand filters in Fayetteville and Greensboro are currently being monitored for water quality and hydrology by North Carolina State University (NCSU). NCSU conducted a column study to identify placeholder effluent credits until monitoring of these four sand filters has been completed.

Assembled sand filter columns.

NCSU designed and constructed nine sand filter columns reflective of field scale sand filters. Eight trials were conducted throughout the study; however trials seven and eight were excluded from the analyses. While the effluent concentrations from the trials are lower than current credits allocated by NC DEQ, the researchers recommend further trials and statistical analyses to identify robust placeholder credits for sandfilters.

The full Stormwater Control Measures report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.



Agriculture in the Jordan Lake Watershed

Agriculture in the Jordan Lake Watershed

QUESTIONS RESEARCH IS ADDRESSING

What do the latest studies and research tell us about the impact of agriculture in the Jordan Lake watershed?

RESEARCH METHODS

A review of current literature and summaries of on the ground research and farmer surveys were utilized.

FINDINGS

Changes in land use over the last twenty years in the Jordan Lake watershed indicate that there is increasing urbanization and decreasing forestation, whereas agriculture has remained consistent at less than 25% of the total land area. These land use changes have significant implications for water quality.

An on the ground agricultural survey of producers in the Jordan Lake watershed revealed that four out of nine counties had 100% agricultural land use as pasture and hay, while the other counties had agricultural land use that ranged from 25-55% cropland.

Taken as a whole survey results suggested that producers in the Jordan Lake watershed were minimizing environmental impact of nutrient and soil losses from agricultural fields due to:

- The types of cropping systems used.
- Under fertilization of crops as nutrient inputs were generally below recommended levels.
- Use of best management practices, primarily buffers and conservation tillage.

MANAGEMENT IMPLICATIONS

One important characteristic of the watershed is that erosion is well controlled and many streams (approximately 60%) are already buffered. The largest nutrient losses are derived from pasture lands due to animal excrement, but research indicates that these losses can be reduced by approximately 50% through the use of a narrow exclusion fence and nutrient management. Additional nutrient losses may also be derived from reducing phosphorus applications on fields that do not need more, but since this represents the minority of agricultural lands, it is doubtful than any real water quality reductions will be realized.

RESEARCHERS

Deanna Osmond, North Carolina State University, Department of Crop and Soil Science

Land Use and Agricultural Practices

The National Land Use Land Cover Dataset (NLCD) provides land cover information from Landsat satellite data which is then transformed into maps created by the Multi-Resolution Land Characteristics (MRLC) Consortium. There are 16-class land cover classifications nationally.

Data used to classify land use in Jordan Lake watershed from 1992 – 2011 suggest an increasing urbanizing land use. While urbanization slowed in the watershed following the Great Recession in 2008 this twenty-year period indicates increasing urbanization and decreasing forestation, whereas agriculture has remained consistent at less than 25% of the total land area. **These land use changes have significant implications for water quality.**

Land Use	Forest	Agriculture	Urban	Other
1992	62%	22%	11%	5%
2011	46%	22%	21%	11%
% Change	-16%	0	+10%	+6%

The NLCD suggests that the vast majority of the agricultural land is in pasture and hay, but an on-the-ground agricultural survey of producers in Jordan Lake watershed suggested otherwise. Agricultural fields were randomly selected and 650 were useable for further characterization. The total number of agricultural acres enumerated was 5218.2 acres. The average field size ranged from less than 1 acre to a maximum size of 70 acres; the mean was 8.0 acres per field and a standard deviation of 8.5 acres. No fields were enumerated in Durham County because all segments had become urban.

Although the majority of the agricultural land use is pasture or hay, there is cropland in Jordan Lake watershed. During the survey, sampled fields in four counties (Chatham, Forsyth, Randolph, and Wake) had 100% of the surveyed agricultural land use in pasture and hay, while cropland was found in five counties: Alamance (75% hay/pasture, 25% cropland); Caswell (70% hay/pasture, 30% cropland); Guilford (61% hay/pasture, 39% cropland); Orange (62% hay/pasture, 38% cropland), and; Rockingham (45% hay/pasture, 55% cropland). No agricultural land use was found in Durham County. The type of agriculture has profound implications for nutrient and sediment loss.

Sediment losses from agricultural lands were determined to be low (~1.5 T/ac) due to pasture and hay land uses and a predominance of conservation tillage used on croplands. All counties were under the tolerable soil loss levels as defined by USDA-Natural Resources Conservation Service.

Farm in Alamance County, in which agriculture is predominantly pasture and hay.

Riparian Buffers

Multiple studies in North Carolina have demonstrated that riparian buffers can reduce agricultural nutrient and sediment losses. Significant riparian buffers existed next to streams in the agricultural landscape of Jordan Lake watershed. Some counties, such as Wake and Forsyth, had most of their agricultural fields buffered; only 8 % of the acreage is not buffered. One county, Caswell, had more than 50% of its agricultural fields not buffered. These results suggested that some counties have greater potential for buffer installation than others.

Number of Acres and Percentage of this Area with No Buffers by County

County	Total Ag Acres	No Buffers – Acres Affected	% Ag Fields Not Buffered
Alamance	1206.3	313.6	26
Caswell	165.6	99.2	60
Chatham	544.0	200.2	37
Forsyth	60.5	4.9	8
Guilford	1983.0	699.8	35
Orange	595.9	84.7	14
Randolph	93.0	41.7	45
Rockingham	524.4	184.4	35
Wake	45.5	3.5	8
TOTAL	5218.2	1632.0	31

Taken as a whole, a 2007 agricultural survey suggested that producers in the Jordan Lake watershed were minimizing environmental impact of nutrient and soil losses from agricultural fields due to:

- The types of cropping systems used.
- Under-fertilization of most crops as nutrient inputs were generally below recommended levels.
- Use of best management practices, primarily buffers and conservation tillage. Overall, the data suggested that nutrient and sediment losses from agricultural activities would be minimal.

Nutrient Loading Studies

The objective of a recent water quality monitoring project was to document the effectiveness of a combination of livestock exclusion fencing and nutrient management implemented on a beef cattle pasture and nutrient management on crop land. Monitoring sites were located in the Jordan Lake watershed.

The quantity and quality of discharge from two predominantly pasture and two predominantly cropland watersheds were monitored for ~3.5 years prior to and following implementation of the exclusion fencing and nutrient management in the pasture treatment watershed and nutrient management in the cropland treatment watershed, while the other watersheds (control) remained unchanged and then monitoring post-treatment for ~3.5 years. Water quality monitoring included collection of flow-proportional samples during storm events and analyzing them for total Kjeldahl (TKN), ammonia (NH3-N), and inorganic (NOx-N) nitrogen as well as total phosphorus (TP) and total suspended solids (TSS). In addition, land use information was collected.

In the pasture treatment watershed, the excluded stream corridor was intentionally minimized by constructing the fence line about 10 feet from the top of the streambank on either side and limiting it to the main stream channel only. Nutrient management consisted of discontinuing biosolids and fertilizer P applications, while applying approximately 70 lb N ac-1, which is less than recommended N.

Over the last 20 years in the Jordan Lake watershed land use changes has included increasing urbanization.

Losses of nutrients from pasture watersheds were much greater than expected, although TSS losses were much lower than expected. Average nutrient losses were: TN loss of 6.1 lb ac-1 yr-1, TP of 2.8 lb ac-1 yr-1, and TSS of 312 lb ac-1 yr-1. Post-conservation practice implementation generally had greater nutrient losses due to increased rainfall and greater runoff during the monitoring period. Prior pasture studies from North Carolina demonstrated that the loads measured were similar across North Carolina piedmont watersheds.

Site	Dur.	Rain[1]	Discharge	Runoff	TN	TP	TSS
	yr	in/yr	in/yr	%	------lb ac/yr------		
Pre-Conservation Practice Implementation Period							
Past-cont	3.77	35.71	4.65	0.15	4.15	1.96	244
Past-treat	3.77	35.71	6.69	0.22	6.33	3.28	433
Post-Conservation Practice Implementation Period							
Past-cont	3.76	37.60	7.72	0.20	6.55	2.88	302
Past-treat	3.76	37.60	8.70	0.23	7.42	2.86	272
Related Studies							
Pasture[3]	3.30	28.50	7.40	0.26	5.98	3.84	128
Pasture[4]	1.70	46.30	7.83	0.17	4.54	1.26	377

Pasture watersheds in Jordan Lake watershed and measured metrics: duration of sampling, rainfall, water discharge, runoff % and total loads of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS).

It is significant that many pastures are under-fertilized in this watershed, including the pastures monitored in this work. It is clear that nutrients from cattle excrement (or any animal excrement) deposited on the surface has the potential to be lost from agricultural lands.

The use of conservation practices in this watershed demonstrated statistically significant reductions in TN (37%), TKN (34%), NH3-N (54%), TP (47%), and TSS (60%) loads in the treatment relative to the control watershed following conservation practice implementation, while storm discharge and NOx-N loads were not significantly different. These data show that even a relatively narrow exclusion corridor implemented on only the main stream channel can significantly reduce the export of TN, TP, and TSS from beef cattle pastures.

Economics and Farmer Attitudes

A water quality trading (WQT) program is one of the main policies suggested to address water quality issues, especially in the face of a rapidly growing urban sector that requires options to reduce its delivery of nutrients. Jordan Lake watershed is no exception and explicit rules were approved enabling new development to buy nutrient reduction credits from the agricultural section (North Carolina Department of Environmental Quality, 2017). **Although a WQT program is appealing in theory, it has thus far failed to prove feasible in several attempts in the United States and Jordan Lake watershed.**

An economic analysis of WQT was performed using net returns of 20 years, and amortized at a 4.6% discount rate. The Soil and Water Assessment Tool (SWAT 2012) model was used in the Jordan Lake watershed in order to predict the amount of TN and TP loads in three scenarios, control-years (1997-2001), current BMP practices (2012), and TN and TP loads after installing buffers in addition to the already installed BMPs.

Recent work in the Jordan Lake watershed found that WQT programs may not always be the most applicable approach when all factors (e.g. wedges) that diminish the chance of WQT program's success were analyzed. Implementing WQT programs requires knowledge that comes from a well-defined model that includes as many implementation wedges as appropriate. For example, adding four wedges (baseline, transaction cost, trading cost, and trading ratio) reduced the amount traded by three quarters and society's welfare by 84% in Jordan Lake watershed.

In the end, results indicated that the four wedges marginalized the market in Jordan Lake watershed, but did not make trading unviable by themselves. **The total amount of supply of agricultural lands is inadequate to keep up with demand, rendering the market unviable overall.** Thus, when applied to the Jordan Lake program, the framework clearly shows that the traditional nutrient trading program will not be feasible or address nutrient management needs in any meaningful way.

Ninety farmers selected randomly were interviewed in Jordan Lake watershed using a semi-structured interview clustered around five thematic areas: regional agricultural, farm operation and history, regional water quality issues, conservation practices, fertilizer decision-making, and water quality trading. Interviews lasted between 30-40 minutes. A demographic survey was also used to collect information on age, sex, education, farm size, land ownership, farming status, and income information.

These data were then used to determine farmer interest in the program. An additional problem with WQT in Jordan Lake watershed was the large adoption premium for this program. The adoption premium is the amount that farmers require over and above direct adoption costs to participate. In another recent study, farmers were asked at in-person interviews about their willingness to accept a payment to adopt a particular conservation practice (riparian buffers) in order to generate and sell credits. Farmers' willingness to accept a payment was compared to their direct cost of participation, which allowed estimation of the adoption premium.

Approximately 60% of the streams in the Jordan Lake watershed are buffered.

On average, the adoption premium more than doubled the cost of purchasing credits. **Even without the adoption premium, modeled results suggested that within two years of a trading program (riparian buffer installation), costs for purchasing agricultural credits would be too expensive relative to urban nutrient abatement at the development site.**

The survey demonstrated that farmers in Jordan Lake watershed are ageing but they have a deep sense of history and knowledge of their communities, awareness of environmental problems, and a solid track record for conservation practice adoption. Specifically, farmers have a strong and enduring record of conservation practice implementation, as well as frequent collaboration with state and federal programs related to conservation. The majority of farmers (93%) with cropland reported using conservation tillage. They also demonstrated widespread use of public cost-share with nearly 80% of farmers using publicly subsidized conservation programs and planning or implementation support. In addition, water quality issues of Jordan Lake were well-known; 82% of participants were aware of water quality problems in Jordan Lake. Very few farmers (18%) viewed the issues as unimportant or not a problem.

When farmers were asked about establishing a riparian buffer, 43% answered “yes”, 20% answered “no”, and the remaining 37% offering many reservations or answered “maybe.” Then farmers were then asked about the WQT program in Jordan Lake watershed. Of the 90 farmers interviewed, 26% were willing to participate, 40% were unlikely to participate, 32% were unwilling to participate and 1 person declined to respond.

Notably, of the 26% willing to participate in the program, 15 out of 24 farmers were ineligible for participation in the WQT program because they had already implemented buffers, or they lacked streams on their properties. Thus, only nine individuals, or 10% of people interviewed, were both eligible and willing to engage in WQT. Farmers unwilling or unlikely to participate in the Jordan Lake WQT program reached these conclusions despite reporting very high rates of conservation practices use on their farms and general knowledge of water quality problems in Jordan Lake.

These findings suggest that the reason is pervasive skepticism of the WQT program itself. Just as with the group of farmers who were willing to participate, we found that farmers’ decision-making was influenced by not only financial and environmental considerations, but a sense of fairness; the farmers believed that the development community should meet their own pollution reduction goals.

Farmers walk through a field in North Carolina, photo courtesy of the University of North Carolina at Chapel Hill.

Conclusions

A large and diverse body of recent agricultural research exists in the Jordan Lake watershed that allows us to make some conclusions concerning the water quality problem and possible solutions. Overall the data suggest that agricultural land use has been stable, while forested areas are being transformed to urban areas. Based on recent analysis, this will increase nutrient loads even more due to both the actual urban area and the increased potential use of wastewater treatment plants unless there is aggressive urban nutrient abatement plan and upgrades made to wastewater treatment plants.

About 60% of the agricultural land use is pasture or hay and farmers typically under apply nutrients. Nitrogen is underapplied and generally P is underapplied except for organic sources of nutrients (particularly biosolids from wastewater treatment plants) and tobacco, of which there is less and less. Erosion is well controlled in this watershed and many streams (~60%) are already buffered. Due to the characteristics of agricultural production determined from several studies it appears that there are already significant conservation practices on agricultural lands.

The largest nutrient losses are derived from pasture lands due to animal excrement but research indicates that these losses can be reduced by ~50% through the use of a narrow (10-ft) exclusion fence and nutrient management. Additional nutrient losses may also be derived from reducing phosphorus applications on fields that do not need more (e.g. nutrient management) but since this represents the minority of agricultural lands, it is doubtful that any real water quality reductions will be realized.

Water quality trading is a regulatory framework in the Jordan Lake watershed and is viewed as useful in solving nutrient over-enrichment of Jordan Lake. A number of different types of studies (land use-water quality relationship analysis, economic and social) conducted recently suggest otherwise.

The recent economic and social analyses in Jordan Lake watershed indicated financial and human constraints limiting the potential for trading. First, only 22% of the entire land area is agricultural and approximately 60% is already buffered.

Due to the scarcity of agricultural lands, it would take approximately only two years of urban new development trading needs before it would be cheaper to build larger stormwater structures after which the entire trading market would collapse. In addition, it appears that farmers would need premiums over and beyond current market prices, thus making these trades even more prohibitive. It appears that WQT as a policy strategy will have little use and even less effect; this policy should be revisited.

The full Agriculture in the Jordan Lake Watershed report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

Stakeholder Engagement in the Jordan Lake Watershed

Stakeholder Engagement in the Jordan Lake Watershed

QUESTIONS RESEARCH IS ADDRESSING

How do key interest groups in the Jordan Lake watershed view water quality in the watershed?

What approaches should be utilized to manage nutrients?

What additional information from researchers would be useful to inform decision-making of a nutrient management strategy in the Jordan Lake watershed?

RESEARCH METHODS

The stakeholder engagement team conducted focus groups in the first year of the Jordan Lake study to understand and document stakeholder's views about water quality and nutrient management in the Jordan Lake watershed. The ultimate goals of the research were to:

- Identify locally relevant perspectives that could inform scientific research and policy decisions related to nutrient management.
- Identify research needs expressed by stakeholders that could be addressed by the study team.

Participants in the focus groups included developers, local governments, environmental organizations and agricultural interest groups.

FINDINGS

Across all focus groups participants asserted that good water quality meets water quality standards and provides healthy habitat for wildlife and plant growth. Almost all participants said that having good water quality meant that the water could be used for drinking.

When it came to addressing who is responsible for maintaining good water quality participants agreed that "everyone" is responsible, yet they also recognized that allocating that responsibility equitably is difficult. Specifically, participants in the Triad local government focus group noted that users should bear more of the burden, while participants in the Triangle local government and non-profit focus groups place more of the responsibility on contributors.

MANAGEMENT IMPLICATIONS

Participants held divergent views on current water quality concerns in Jordan Lake. While all agreed that there was impairment based on current water quality standards, some participants did not see these impairments as major problems. These participants pointed to impairments only in isolated areas of the lake and its continued use for drinking water and recreation as evidence of good water quality.

The differing views on who should be responsible for maintaining good water quality relate to equity concerns between the upper watershed and those jurisdictions in the Triangle benefitting from Jordan Lake as a drinking water source. The concerns about the high cost of maintaining and improving water quality in the Jordan Lake watershed is a consistent theme of the revenue and policy recommendation in this report.

RESEARCHERS

Kathleen Gray, Grant Parkins, Megan Rodgers and Victoria Triana, UNC Institute for the Environment

Understanding Stakeholder Perspectives

As part of this study, the UNC Institute for the Environment (UNC-IE) sought to understand how key interest groups in the Jordan Lake watershed viewed water quality in the watershed, what approaches they recommended for managing nutrients and additional information they desired to inform decision making, with an emphasis on information that could be gathered by researchers on the study team.

Involving stakeholders in environmental decision-making has improved the quality of resulting decisions and provided information that shaped environmental research. Further, the participation of diverse stakeholders has increased the quality of environmental management plans. In several studies, focus groups have been used to better understand stakeholder perspectives associated with environmental management strategies. This approach is well suited to discussion of attitudes and decision making, as group dynamics typically enable participants to compare experiences, providing insights for researchers. When comparing beliefs and attitudes of groups representing distinct backgrounds or perspectives, as is the case with this study, separate and homogenous focus groups have been shown to produce a greater depth of information.

For these reasons, UNC-IE conducted focus groups in year one of the UNC Jordan Lake study to understand and document stakeholders' views about water quality and nutrient management in the Jordan Lake watershed. **The ultimate goals of the research were to identify: (a) locally relevant perspectives that could inform scientific research and policy decisions related to nutrient management and (b) research needs expressed by stakeholders that could be addressed by the study team.**

Participants in the focus groups included developers, local governments, environmental organizations, and agricultural interest groups. Their input informed the research and provided context for policy discussions among team members. Participants identified information needs and educational opportunities, and this input shaped the development of stakeholder engagement activities in years two and three. In those years, UNC-IE implemented programming that enabled researchers to share their findings with key stakeholder groups and the general public. These programs included two full-day research symposia, science seminars with stakeholder groups, science cafés for public audiences, and the development of a study website.

Stakeholders discuss impact of Jordan Lake watershed on the community.

Qualitative Research to Understand Stakeholder Perspectives, Year 1

This part of the report describes the qualitative research methods used to understand stakeholder perspectives and presents the findings and conclusions that informed subsequent stakeholder engagement.

Methods

Between April and June 2017, the stakeholder engagement team conducted four focus groups and an in-depth interview with stakeholders involved in nutrient management in Jordan Lake. In total, 61 people participated in focus groups, and three participated in the interview. All study participants were employed professionals whose work involved water resource and nutrient management, representing the following sectors: municipalities within the Jordan Lake watershed (including the Research Triangle area and the Triad), environmental nonprofits, the real estate and building industry, and farming and agriculture. Focus group participants included representatives from: ten local governments in the Triangle area, six local governments in the Triad area, 12 Triad area realty/building industry companies, and eight environmental nonprofit organizations. Among the environmental nonprofits, some focused on sub-watersheds which drain into Jordan Lake, while others focused on statewide, regional, or national environmental issues. The interview participants were representatives of the NC Farm Bureau Federation.

Researchers used a semi-structured topic guide to ensure consistency and enable varied viewpoints to be expressed. Conversations lasted up to 90 minutes and were audiotaped. Audiotapes were transcribed verbatim, and established methods for content analysis were applied. Each transcript was coded by at least two researchers, and coding differences were reconciled.

Additionally, flip chart notes taken during focus groups were referenced as needed during analysis. Despite the small sample size, analysis of transcripts indicated that saturation was reached with respect to key themes. Study procedures were approved by the Institutional Review Board at the University of North Carolina at Chapel Hill (IRB 17-0873).

Findings

In this section, we present findings from the focus groups and interview, underscoring areas of agreement and disagreement among stakeholders and identified information needs. In some cases, we present the information in participants' own words through direct quotation.

Perceptions of Good Water Quality

The focus groups and interview began by asking participants to describe good water quality in a large body of water. Across all focus groups and the interview, participants asserted that good water quality meets water quality standards and provides healthy habitat for wildlife and plant growth. They consistently used phrases like "non-polluted", "clear" and water having "low turbidity." Likewise, participants in all focus groups and the interview claimed that good quality water could be used for drinking, and participants in three focus groups (Triangle local government, Triad realty/building industry, and environmental nonprofit) noted that "good" quality drinking water should not require excessive treatment. Participants in the two local government focus groups also described good water quality by what it lacks, specifically having no "dead fish."

When discussing Jordan Lake, participants across all focus groups said that having good water quality meant that the water could be used for drinking. (This dimension was not mentioned in the agriculture interview.) Participants in both local government focus groups and the environmental nonprofit focus group also said that good water quality in Jordan Lake meant that it could be used for recreation, such as swimming and fishing. Additionally, participants in the environmental nonprofit focus group underscored the importance of good water quality in Jordan Lake for aquatic life and a healthy, sustainable ecosystem.

Water Quality Concerns

When discussing concerns, participants in the two local government focus groups and the agriculture interview acknowledged odor and taste problems with drinking water drawn from Jordan Lake. In addition, participants in the environmental focus group mentioned other evidence of poor water quality in Jordan Lake including pH levels, sediment, trash, and industrial contamination. Participants in both the environmental and the Triangle local government focus groups indicated they had concerns about swimming in Jordan Lake.

One participant from the Triangle local government focus group said "Honestly, there's a couple times a year that I just don't want to get in it." A participant in the environmental focus group mentioned advising people to shower immediately after swimming in the lake. It was also

mentioned that rashes had been observed on children after they had been in the lake.

Conversely, although participants in two focus groups (Triad local government and Triad realty/building industry) and the agriculture interview acknowledged several indicators of poor water quality, they did not believe that these impairments were causing serious problems. As evidence, they cited impairment only in isolated areas of the lake and its continued use for recreation and drinking water. However, participants in both Triad focus groups (local government and realty/building industry) and the agriculture interview indicated that they had not directly experienced problems with Jordan Lake's water quality, primarily because they rarely used the lake or its water.

Participants in the Triad focus groups supported their assertion of good water quality in Jordan Lake and the Haw River sub-basin by referencing low turbidity, limited algae, and the use of the lake for drinking and recreation. Further, participants in both Triad focus groups believed that their area was not significantly contributing to the water quality problems in Jordan Lake. A participant in the Triad realty/building industry group noted, "The water that we contribute comes in just above the dam. It runs right over the dam in just three days. And so, essentially, nobody drinks that water."

Perspectives on the Value of Good Water Quality

Focus group and interview discussion also touched on the value of good water quality in large bodies of water, and participants across all focus groups and the interview identified good water quality as important to recreation. Participants in all focus groups described good water quality as a life sustaining resource that is important to a successful economy and to local industry. Participants in three of the focus groups (realty/building industry and both local government focus groups) used the words "invaluable" and "priceless" to describe the value of good water quality, while participants in two focus groups (realty/building industry and environmental nonprofit) and the agriculture interview emphasized the cultural and societal value of good water quality. A participant in the Triad local government group summed up these sentiments by saying:

"We couldn't have textiles in this region. We couldn't have industry in this region. We couldn't have the population we have. We couldn't do much of anything that we do without good water quality."

Additionally, participants in the environmental nonprofit focus group noted that poor water quality could be detrimental to a community, because people depend on clean water for survival.

In discussing the value of good water quality in the context of Jordan Lake, participants in all focus groups and the interview recognized its importance. The phrases "intended use" and "intended purpose" were mentioned across groups; and participants in two focus groups (Triad local government and environmental nonprofit) and the agriculture interview asserted that good water quality should serve its intended use. These uses encompassed a range of activities from flood control to drinking water to recreational uses.

Responsibility for Maintaining Good Water Quality

When asked about responsibility for maintaining good water quality, participants across all focus groups and the interview agreed that "everyone" is responsible, yet they also recognized that allocating that responsibility equitably is difficult. When attempting to assign responsibility, some participants (in both local government focus groups, the environmental focus group and the agriculture interview) distinguished between people who used the resource and those who contributed to the flow of the body of water. Specifically, participants in the Triad local government focus group noted that users should bear more of the burden, while participants in the Triangle local government and environmental nonprofit focus groups and the agriculture interview focused more on the responsibility of contributors.

Participants in all focus groups also specifically named the agricultural industry as a key responsible party. Participants in three focus groups (Triangle local government, environmental nonprofit and realty/building industry) asserted that government agencies have a responsibility for enforcement and for educating residents about good water quality. Participants in the Triangle local government and Triad realty/building industry focus groups further emphasized that residents may not be aware of water quality concerns and their role in contributing to good water quality.

Similarly, when discussion focused on Jordan Lake, participants across all focus groups and the interview agreed that the responsibility for good water quality and managing nutrients in Jordan Lake was a shared responsibility. As one participant in the realty/building industry focus group noted,

"Jordan Lake is an important source of water…the effect it has upstream and downstream is important. It's not just a localized issue. We're all in this together."

A recurring aspect of the discussion of responsibility, which arose in all focus groups and the interview, was the expressed frustration that Jordan Lake originally was intended for flood control but was later designated as a drinking water source, resulting in a situation in which the lake was impaired before it was built. One participant in the Triad realty/building industry focus group asked, "How did it get built when there was such a powerful force as the [US Army Corps of Engineers] saying, 'Don't build it. You're gonna have problems'?" Another participant, in the environmental nonprofit focus group, noted, "Once Cary started drinking from it, it became all of our problem to keep it clean."

Role of Government

Participants across all focus groups and the interview recognized the need for state and federal government agencies to play a greater role in maintaining good water quality in Jordan Lake. Participants in two groups (Triad realty/building industry and Triangle local government) identified state government oversight as necessary because of the large size of the watershed.

In two groups (Triangle local government and environmental nonprofit) as well as the agriculture interview, participants mentioned the importance of and need for state government funding to address water quality issues in Jordan Lake. Participants in the agriculture interview also called for increased funding for research, particularly for programs to assist farmers in implementing best management practices, and one participant noted that "Our folks don't like regulatory programs…I don't think anybody does."

Other issues that arose in this discussion related to regulatory frameworks and the political nature of these issues. Specifically, participants in the Triangle local government and both Triad focus groups addressed the chlorophyll a standard, which certain areas of Jordan Lake have exceeded at times. They noted that the standard is the same for every water body in the state and expressed a belief that it should instead be tailored for each water body. A participant in the environmental nonprofit focus group noted that "the 'polluter pays' principle…is the foundation of federal law" but asserted that, in NC, state politics have prevented those responsible for polluting Jordan Lake from being held accountable. Frustration with the political situation was further evidenced by comments such as the following:

"It's important not to look at the experience of Jordan and say, "oh, what this shows is that we can't approach things with the Clean Water Act lens, we can't approach things through rules, a nutrient management strategy lens." That isn't broken. What's broken is the political system in the state."

Equity

Participants across all focus groups and the interview believed that the current system for achieving good water quality in Jordan Lake was unfair, though there was disagreement on how it was unfair. For example, participants in both local government focus groups and the realty/building industry group identified agriculture and forestry as significant contributors of nutrients to Jordan Lake and noted that those land uses are not regulated at the same level as other land uses. Participants in the Triad focus groups also pointed to homeowners with septic tanks or those who fertilize their lawns as significant, unregulated contributors of nutrients in waterways. At the same time, participants in the agriculture interview noted that their sector is meeting nutrient goals and questioned whether a shrinking number of farmers should be asked to meet the same goals as larger land uses or point source polluters. Participants in both Triad focus groups and the agriculture interview called the expectations for achieving good water quality in Jordan Lake unreasonable.

Participants in the Triad focus groups felt they were bearing a disproportionate financial burden for maintaining water quality. They also asserted that the Triangle region, and the City of Cary in particular, were not being asked to bear the same burden. One participant in the Triad local government focus group stated,

"Cary is the predominant water user…they don't have to do anything for Jordan Lake, so the burden of responsibility falls on everybody upstream… and Cary doesn't have to deal with the problem."

Further, these participants also questioned whether it was worth continuing to spend money to achieve better water quality in Jordan Lake, given that the lake is still impaired despite the money that has been spent to date. A participant in the Triad local government focus group expressed concern that the cost of nutrient management might prevent businesses from coming to the region, asking "Why would somebody come to [our city] when they could go 12 miles away and not have to comply with these rules?"

Though each stakeholder group had its own view of the ways in which the current system was unfair, participants across all focus groups and the interview agreed that achieving good water quality and managing nutrients in Jordan Lake was a significant financial burden. For example, one participant in the Triad local government group referenced its Capital Improvement Plan, which committed a $100 million investment for wastewater treatment. A participant in the agriculture interview mentioned concerns among farmers that the cost of meeting nutrient management goals could make farming unprofitable.

Nutrient Management Strategies

In discussing approaches to nutrient management in Jordan Lake, questions about baseline contamination and the need for tailored strategies arose as did examples of management strategies, not all of which were deemed successful. Related to baseline contamination, participants in the realty/building industry focus group and agriculture interview raised the issue of legacy contaminants, while participants in both Triad focus groups asserted their beliefs that current water quality in Jordan Lake was the best that could be achieved. Further, they felt that the current baseline should inform future nutrient management goals.

Participants in several focus groups discussed the need to redefine what constitutes acceptable water quality in Jordan Lake. As noted above, some participants asserted that the chlorophyll a standard should be unique to each body of water, instead of having a statewide standard; the realty/building industry and both local government focus groups reiterated that point when discussing specific strategies. Along these lines, participants in the agriculture interview stated that each of the three sub-watersheds draining into Jordan Lake required a unique approach to achieving good water quality as a result of some sub-watersheds being highly developed while others are more rural.

Across all focus groups, participants identified policies and infrastructure that could address nutrient management problems. For instance, in both the Triangle local government and the environmental nonprofit focus groups, participants recommended that government incentives be provided for low-impact development. Participants in the Triangle local government focus group also noted that buffers were effective at mitigating flooding, improving water quality, and even increasing home values. Participants in this focus group recommended consideration of smaller scale treatment facilities, which could recycle water for use in food production, and suggested that wastewater treatment facilities should allow treated wastewater to filter into the ground instead of discharging it to streams.

In the realty/building industry focus group, participants suggested bio-retention cells and constructed wetlands as potential strategies for improving water quality in Jordan Lake. One participant in this group also suggested restricting the amounts of nitrogen and phosphorous in residential fertilizers. This person stated that some states have implemented this approach but did not know whether research had shown positive effects on water quality as a result. At the same time, a participant in the Triad local government focus group stated, "The expectation that we are gonna clean up Jordan Lake by retrofitting the cities is borderline absurd. Participants in both Triad focus groups also emphasized the need for enhanced education and outreach about the Jordan Lake rules, water quality problems in the lake, and potential solutions to those problems."

Success Stories

Several groups provided local examples of effective nutrient management strategies. For example, a participant in the Triangle local government focus group highlighted the City of Durham's efforts to improve water quality, noting that Durham is unique because it falls within the boundaries of both the Falls Lake and Jordan Lake watersheds. This participant also asserted that the City's experience provided evidence that enacting the Jordan Lake rules would not impede growth, saying:

"Durham has enacted all of the Jordan Lake nutrient management rules within our jurisdiction, as well as the Falls Lake nutrient management rules within our jurisdiction, and I would defy anyone to say that growth and development has been impeded in the City of Durham."

A participant in the Triangle local government focus group noted that its development decisions, such as building a greenway system within the floodplain, resulted in fewer flooding problems, which directly impacted nutrient movement. Participants in the Triad local government focus group highlighted the watershed restoration plan of Little Alamance Creek, which they noted had been impaired for 100 years.

Failures

Underscoring concerns that current strategies cost too much and are ineffective, participants in the Triad focus groups provided examples of what they viewed as failed nutrient management strategies. For instance, a participant in the realty/building industry focus group described a project in the City of High Point that utilized regional ponds and wetlands designed to trap nutrients but noted, *"There were periods through the year that [the ponds and wetlands] exported nutrients. It didn't trap nutrients; it exported nutrients."* Similarly, a participant in the Triad local government focus group described a project in his city as follows:

"We retrofitted a big, municipal parking lot...we put in a huge bio-retention facility, pervious pavement, and some of these little tree boxes...and the combination of all three of those retrofits on this area cost us almost a million dollars; and we gained ten pounds of nitrogen removal—that's nothing—and we spent a million dollars doing it."

A participant in the Triad local government focus group also pointed to the Neuse River as an example of failed nutrient management, saying:

"They've spent millions and millions and millions of dollars and yet the nutrients in the basin continue to rise, even though the point sources, they're down more than 50 percent."

Information Needs Identified by Participants

Participants across all focus groups and the interview identified a need for scientifically based decision making in finding solutions to water quality problems in Jordan Lake. These participants also identified gaps in knowledge and additional information needed to better understand how to achieve and maintain good water quality in the lake. Specifically, participants in all focus groups wanted information about how much each land use is contributing to nutrient-related pollution in Jordan Lake.

Water Quality Parameters

- How has water quality in Jordan Lake changed over the last 10 years, and what changes, if any, can be attributed to specific management strategies?
- What do we know about legacy nutrients: have they been measured, and how much are they contributing to water quality the problems in Jordan Lake?
- How would prohibiting either nitrogen or phosphorous in residential fertilizers affect water quality?
- Which crops are most efficient in the uptake of nitrogen?

Costs

- How much more does it cost to treat wastewater than to treat drinking water?
- What is the return-on-investment of financing buffers for farmers (versus other strategies)?
- How do the costs of 50-foot buffers compare to those associated with 100-foot buffers? Has a cost-benefit analysis been conducted?

Modeling Future Impacts

- How will climate variability affect nutrient management in Jordan Lake?
- How did the models that were used in developing the Jordan Lake Rules account for growth in Wake County? How is current modeling incorporating growth trends?

Roles and Responsibilities

- What is the responsibility of the US Army Corps of Engineers in terms of managing nutrient pollution in Jordan Lake?
- How will the knowledge gained through the Jordan Lake study be used by UNC researchers, state legislators, the EPA and other decision makers?

Key Takeaways

The qualitative research described above represents the perspectives of several key stakeholder groups that are interested in nutrient management in Jordan Lake. Across focus groups (with Triangle and Triad area local governments and realty/building industry and environmental nonprofit professionals) as well as an interview with agriculture/farming industry representatives, **participants largely agreed on how to describe good water quality**, both in general and in Jordan Lake. Being suitable for use as drinking water was part of these descriptions, as were other uses (e.g., able to support aquatic life, recreation).

Participants all agreed that there were impairments or other water quality problems in Jordan Lake. Further, although they **agreed that achieving good water quality in Jordan Lake was a shared responsibility**, the stakeholder groups had varied ideas on what their potential contribution to shared management might be. On a related note, participants in each focus group and the agriculture interview **questioned the fairness of the current system for achieving good water quality in Jordan Lake**. Finally, they all agreed that government, particularly at the state level or higher, should play an integral role in maintaining water quality in Jordan Lake.

Despite general agreement on these foundational issues, participants held **divergent views on current water quality in Jordan Lake**. Although participants in all groups agreed there were impairments or water quality problems, some participants (specifically, in the Triad area focus groups and the agriculture interview) did not see these impairments as major problems. These participants pointed to impairments only in isolated areas of Jordan Lake and its continued use for drinking water and recreation as evidence of good water quality in Jordan Lake. Conversely, participants in the Triangle local government and environmental nonprofit focus groups identified several concerns about the water quality, including concerns about swimming in Jordan Lake.

There also were **differing views on who should be responsible for maintaining good water quality in Jordan Lake**. Participants in the Triad local government focus group indicated that water users should bear more of the burden, while participants in the Triangle local government focus group, along with participants in the environmental nonprofit group and the agriculture interview, indicated that more responsibility should fall on those contributing to impairments. Across all four focus groups, participants identified the agricultural industry as a key party responsible for maintaining good water quality. Further, both local government focus groups and the realty/building industry focus group noted that agriculture and forestry are not regulated at the same level as others. Conversely, participants in the agriculture interview stated that it is unfair to ask a shrinking number of farmers to meet the same goals as much larger land uses and point source polluters.

Interestingly, participants in all focus groups and the interview had **concerns about the high cost of achieving and maintaining good water quality in Jordan Lake**. Participants in the Triad focus groups expressed concern that they bore a disproportionate burden compared to Triangle area stakeholders, while participants in the Triangle local government group worried about the rising future costs to the region if measures weren't put in place now to protect Jordan Lake's water. Participants in the environmental nonprofit focus group expressed frustration that federal laws based on the "polluter pays" principle were not enforced in NC.

The study also identified **information needs among the stakeholders**. All groups expressed interest in knowing more about how different land uses are contributing nutrients to Jordan Lake. Many participants also had questions about the cost of implementing measures that would achieve water quality goals in the Jordan Lake watershed. Several participants also had questions regarding water quality in the Jordan Lake watershed and what is known about how specific nutrient management strategies can reduce pollution.

As noted above, this research sought to identify stakeholder perspectives that could inform scientific research and policy decisions related to nutrient management. Toward that end, these findings were shared with the Jordan Lake study team and the NC Department of Environmental Quality team that managed a stakeholder engagement process for nutrient management in Jordan Lake. The team also sought to identify research needs expressed by stakeholders that could be addressed by the Jordan Lake study team. A number of the questions raised during focus groups already were being explored by the Jordan Lake study team (e.g., dynamics of water movement in the lake, determining nutrient contributions by different areas and land uses, management strategies implemented in other geographic areas), highlighting opportunities for team members to engage with stakeholders and other public audiences to share results. Additionally, new questions raised during this research were discussed with the study team, to develop responsive research.

Part II: Stakeholder Engagement, Years 2 & 3

The findings described above informed the research and provided context for policy discussions among team members. Information needs and educational opportunities identified by participants also shaped the development of stakeholder engagement activity in years 2 and 3 of the study. During that time, UNC-IE planned programs that enabled researchers to share findings with key stakeholder groups and public audiences. These programs included full-day research symposia, science seminars with stakeholder groups, science cafés, and a website that includes research findings and legislative reports.

Research Symposia

Two full-day research symposia were conducted, on March 22, 2018 and on April 3, 2019. The goals of these symposia were to: (a) represent the breadth of research included in the study, (b) share initial research results, and (c) facilitate dialogue among researchers and stakeholders. In total, 235 participants from across the watershed attended, representing local and state government, academia, developers, and environmental nonprofits, among others. The symposia featured 17 researchers, and topics were organized in four segments: natural science research, stakeholder and community perspectives, policy and finance, and modeling. In each segment, researchers provided brief overviews of their protocols and initial results and answered participant questions. Presentations were followed by small group discussions (occurring at 15 tables in the room), organized around a relevant question. An overview of the symposia and links to researcher presentations can be found on this web page: nutrients.web.unc.edu.

Stakeholders discuss impact of Jordan Lake watershed on the community.

Participants also wrote comments on notecards, which were collected by symposium facilitators and transcribed. A review of these comments provided insights into participant concerns and questions. In the natural science research segment, many participants had questions about sources of sediment and rates of sedimentation in Jordan Lake. Another common question was whether existing nutrient management practices had a measurable effect on reducing nutrient levels within the lake. Participants also raised questions about the sources of nutrients in Jordan Lake and the extent to which the Haw River contributed water and nutrients to the lake. In the stakeholder and community perspectives segment, participants noted the need to engage decision makers and the public (including people of all ages) in finding solutions

to nutrient management issues. They also described a need to more effectively share research findings and incorporate research results into decision making related to nutrient management. In the policy and finance segment, in response to the question about how lessons learned from other regions could inform Jordan Lake's nutrient management policies, participants' comments focused on modeling. Specifically, they mentioned a need to examine the previous Jordan Lake modeling efforts, learn from other similar models, and use current data to develop a new model for the lake. Additionally, several participants emphasized the value of getting a broad cross-section of stakeholders in the watershed involved in the development of nutrient management policies.

A survey was sent to participants after the 2019 symposium to evaluate the symposium and provide an opportunity for attendees to share feedback about the study. Most respondents (97%) indicated that they "found the symposium to be informative," and 82% stated that they would "be able to apply findings shared during the symposium to [their] work."

Science Seminars

In year one, focus group participants expressed strong interest in learning about the science underpinning the Jordan Lake nutrient management strategy. For this reason, we conducted two science seminars, one each in the Research Triangle and Triad regions, reaching a total of 46 stakeholders. Each seminar lasted about 90 minutes and featured researchers presenting their work and engaging with stakeholders. In advance of each seminar, stakeholders identified research that would be of most interest in their regions.

The first of these seminars was held in Greensboro, NC and featured Jeff Hughes and Erin Riggs of UNC's Environmental Finance Center. This seminar included a brief overview of several research projects and an in-depth presentation on options for paying for nutrient management in Jordan Lake. Participants included water resource professionals from Triad-area municipalities as well as representatives from the Triad-area real estate and building industries.

The second seminar was held in Durham, NC and featured Mike Piehler, PhD, technical lead and director of the UNC Institute for the Environment. Piehler shared an overview of several research projects and gave an in-depth presentation on water circulation within Jordan Lake. Participants included water resource professionals from Triangle-area municipalities, representatives from environmental nonprofits, and elected officials from the Jordan Lake watershed.

Science Cafés

To reach broad public audiences, two science cafés were conducted, in partnership with the NC Museum of Natural Sciences in Raleigh, NC and the Kathleen Clay Public Library in Greensboro, NC. Science cafés typically feature brief presentations by scientists in casual environments, to encourage dialogue about the impact of science on daily life. Each science café featured an JLNMS research project and lasted about 45 minutes. In all, 43 people attended these sessions.

At the Raleigh science café, PhD student Joseph Delesantro presented his research exploring how septic systems and sanitary sewers contribute nutrients to waterways within the Jordan Lake watershed. This talk was streamed live over the internet and also was recorded and can be viewed online: livestream.com/naturalsciences/cafe/videos/173581105. Delesantro is part of a team led by Dr. Diego Riveros-Iregui, assistant professor of geography at UNC-Chapel Hill. At the Greensboro science café, Grant Parkins presented a brief overview of the nutrient management study and shared findings from the research on stakeholder perceptions of water quality in Jordan Lake.

Project Website

The project website, nutrients.web.unc.edu, introduces investigators, research questions, and findings and includes associated reports, publications, and public presentations. This website will include each research group's final report and will host all legislative reports, including the overall project report due to the NC legislature in December 2019.

The full Stakeholder Engagement in the Jordan Lake Watershed report, with references, can be found in the Resources section of the UNC Jordan Lake study website: nutrients.web.unc.edu.

From the Classroom to the Lake

One of the more interesting aspects of the UNC Jordan Lake study has been the involvement of undergraduate students as part of the study. Over the past three years, UNC has administered capstone courses as part of the study. These semester long classes give undergraduate students an opportunity to work on a current issue and present their findings and recommendations. As part of the study, these semester long classes have taken on independent research projects that have supported the ongoing work of the study.

Students working on Jordan Lake project featured at RDU Airport.

The Effect of Land Use and Stormwater Control Measures in the Jordan Lake Watershed

In the fall of 2017, a capstone class of students studied the effects of urbanization on nutrient loading by conducting research on five sites within the Jordan Lake watershed that vary by land use and stormwater control measures (SCM) implementation. Metrics concerning land cover and stormwater control measures were calculated in ArcGIS for both data analysis and inputs into a model. The students looked at determining the potential impact urban streams can have on nutrient loading to Jordan Lake. The results indicated that SCM, canopy cover and impervious surface cover (ISC) are important drivers of nutrient concentration and that low ISC development and implementation of SCM retrofits may reduce the impacts of development on nutrient loading.

Programs and Institutions Addressing Nutrient Reduction in Jordan Lake

In the spring of 2018, another class of students explored the nutrient management programs and their impacts on the Jordan Lake watershed. Government and non-profit questionnaires were sent to institutions implementing nutrient management programs to gather information about costs, impacts, strengths and weaknesses, and incentives. They analyzed the projects to determine program drivers and cost-effectiveness, and whether there were opportunities for collaboration that were not occurring. Positive correlation was found between program cost and overall nutrient reduction. The class tried to link all of the initiatives to the concept of One Water, which focuses on managing drinking water, wastewater, and stormwater in an integrated manner. An interactive map was created during the course of the semester that tracks all of the nutrient management initiatives.

Bathymetry of White Oak Creek, Jordan Lake: Fieldwork and GIS Approaches

In the fall of 2018, a capstone of students conducted a study to analyze the bathymetry and water quality of the White Oak Creek portion of Jordan Lake. A couple of findings from the class were:

- The geology of the Jordan Lake watershed is dominated by softer, sedimentary rock, whereas the waterbodies that directly feed the lake are dominated by harder, metamorphic rock. The underlying geology may contribute to sediment loads that reach Jordan Lake.

- Bathymetric analyses of White Oak Creek, a popular tributary of the main lake body, revealed that shallow lake areas are not well characterized by existing Jordan Lake maps. There are also gradual changes from shallow to deeper depths moving from the creek mouth to lake body.

Students from the 2018 fall semester Jordan Lake capstone class.

Chatham Park: Following the Creation of the Best Master Planned Community Yet?

In the spring of 2019, capstone students explored the creation of Chatham Park, the triangle's newest "city," which is currently in the process of being developed in Chatham County on the banks of both the Haw River and Jordan Lake. Students identified main stakeholders and organizational units involved in creating a new "city" within an existing critical watershed, and created a website that showcases the participating organizations, planning documents, environmental regulatory permitting processes, and internal and external community concerns and needs. The class also researched examples of other planned developments in North Carolina and nationwide that have been successful, and analyzed the success or missed opportunities in the Chatham Park development process.

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 UNC Jordan Lake Study Team Members

Name	Affiliation
Mike Piehler, Technical Lead	UNC Institute for the Environment
Marc Alperin	UNC Department of Marine Sciences
Jim Bowen	UNC-Charlotte Department of Civil and Environmental Engineering
Joseph Delesantro	UNC Environment, Ecology and Energy Program
Kaylyn Gootman	UNC Environment, Ecology and Energy Program
Kathleen Gray	UNC Institute for the Environment
Nathan Hall	UNC Institute of Marine Sciences
Jeff Hughes	UNC Environmental Finance Center
Bill Hunt	NCSU Department of Biological and Agricultural Engineering
Jeffrey Johnson	NCSU Department of Biological and Agricultural Engineering
Evan Kirk	UNC Environmental Finance Center
Rick Luettich	UNC Institute of Marine Sciences
Brent McKee	UNC Department of Marine Sciences
Jonathan Miller	NCSU Department of Civil, Construction and Environmental Engineering
Dan Obenour	NCSU Department of Civil, Construction, and Environmental Engineering
Deanna Osmond	NCSU Department of Crop and Soil Sciences
Hans Paerl	UNC Institute of Marine Sciences
Grant Parkins	UNC Institute for the Environment
Erin Riggs	UNC Environmental Finance Center
Diego Riveros-Iregui	UNC Department of Geography
Megan Rodgers	UNC Institute for the Environment
Tony Rodriguez	UNC Institute of Marine Sciences
Harvey Seim	UNC Department of Marine Sciences
Danielle Spurlock	UNC Department of City and Regional Planning
Sarah Waickowski	NCSU Department of Biological and Agricultural Engineering
Richard Whisnant	UNC School of Government

UNC Jordan Lake Study Capstone Students

Semester: Fall 2017
Course Title: "The Effect of Land Use and Stormwater Controls in the Jordan Lake Watershed"
Instructor: Joseph Delesantro
Department: UNC Environment, Ecology and Energy Program
Students: Drew Hoag
Celia Jackson
Naomi Lahiri
Maddie Omeltchenko
Aditya Shetty

Semester: Spring 2018
Course Title: "Inventory of Nutrient Management Strategies in Jordan Lake"
Instructors: Erin Riggs, Jeff Hughes and Evan Kirk
Department: UNC Environmental Finance Center
Students: Maya Burgess
Erin Danford
Jane Ehrbar
Jere Freeman
Ayla Gizlice
Katie McQuillan
Robby Morgan
Basil Rodts
Gunar Swartzlander

Semester: Fall 2018
Course Title: "Jordan Lake Bathymetry and Water Quality"
Instructor: Kaylyn Gootman
Department: UNC Environment, Ecology and Energy Program
Students: Gus Elmore
Caitlin Gross
Carter Schmitt
Tyler Souza
Vanessa Wigmall

Semester: Spring 2019
Course Title: "Chatham Park: Following the Creation of the Best Master Planned Community Yet?"
Instructor: Erin Riggs, Jeff Hughes and Evan Kirk
Department: UNC Environmental Finance Center
Students: Erin Ansbro
Laurina Bird
Walker Harrison
Kess Hendrix
Katia Lezine
Christina Lim
Lily Schwartz
Amy Vaughn

NC Policy Collaboratory Staff

Jeff Warren, Acting Executive Director

Steve Wall, Outreach Director

NC Policy Collaboratory Advisory Board

Al Segars, Chair
PNC Distinguished Professor of Strategy and Entrepreneurship and Faculty Director of the Center for Sustainable Enterprise, Kenan-Flagler Business School

Anita Brown-Graham
Professor of Public Law and Government, School of Government

Jaye Cable
Senior Associate Dean for Natural Sciences, Professor, Department of Marine Sciences

Greg Characklis
Phillip C. Singer Distinguished Professor, Department of Environmental Sciences and Engineering

Don Hobart
UNC Associate Vice Chancellor for Research

Mark Little
Executive Director, the Frank Hawkins Kenan Institute of Private Enterprise

Rick Luettich
Professor and Director, UNC Institute of Marine Sciences

Mike Piehler
Director, UNC Institute for the Environment

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NC Policy Collaboratory

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