FOREST CONSERVATION AS A NUTRIENT CREDIT IN THE JORDAN LAKE WATERSHED

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EXECUTIVE SUMMARY

The B. Everett Jordan Reservoir (Jordan Lake) was designated as a Nutrient Sensitive Water upon its impoundment in 1983 and was subsequently added to the US EPA 303(d) list of impaired waters in the early 2000s due to excessive loads of nitrogen and phosphorus from its watershed. The Jordan Lake watershed, comprised of more than 50% forested land at the time of its impoundment, is rapidly urbanizing while continuing to be impacted by agricultural operations; urban and agricultural land uses generally export nutrient loads at a higher rate than forests. Per the North Carolina Department of Environmental Quality's website for the Jordan Lake Nutrient Strategy, "The Jordan Lake Rules are a nutrient management strategy designed to restore water quality in the lake by reducing the amount of pollution entering upstream" (jordanlake.org). A credit trading system was developed to help facilitate efficient implementation of the Jordan Lake Rules; the system allows nutrient offset credits to be traded between regulated nutrient dischargers. The purpose of this report is to discuss forest conservation as a potential nutrient offset credit as a part of the Jordan Lake Rules.

An initial literature review was conducted to explore nutrient export rates from forested, agricultural, and developed land uses in the North Carolina Piedmont ecoregion. The review was broken into three categories: (1) monitoring studies reporting nutrient unit-loading rates, (2) monitoring studies reporting nutrient concentrations in streams, and (3) watershed modeling studies. As few monitoring studies have been conducted in local agricultural watersheds, it is difficult to draw definitive conclusions comparing agricultural to forested land use export rates; however, nationwide studies show substantially higher nitrogen and phosphorus export loads from agricultural watersheds than forested watersheds. Monitoring results from urban and forested watersheds in North Carolina verify higher unit-loading rates of nutrients from urban watersheds than forested watersheds; however, results within land use classifications were highly variable, emphasizing that a single land use unit-loading rate cannot be pinpointed without consideration for other factors such as soil type, vegetation type, and degree of development. Modeling efforts from the

North Carolina Piedmont also predict higher loads from agricultural and developed land uses as compared to forests. The literature review demonstrated that nutrient export rates are highly variable within, and between, land uses in the North Carolina Piedmont, but forested watersheds are generally expected to export nutrients at a lower rate than agricultural or developed watersheds.

A subsequent policy analysis was conducted to discuss the merits and shortcomings of forest conservation as a nutrient offset credit as a part of the Jordan Lake Rules. Two predominant topics are presented regarding forest conservation and nutrient reduction. First, two nutrient management strategies are described and compared: (1) reduction of nutrient loads from a defined baseline condition and (2) minimization of anticipated future nutrient loads; interpretation of the Jordan Lake Rules and the nutrient offset crediting system relies on this important distinction. Second, the relationships between forest conservation strategies and resultant land development patterns are explored.

The Jordan Lake Rules define a “baseline” period from 1997-2001 as the reference condition for quantifying the nutrient reduction targets required for the lake’s Total Maximum Daily Load (TMDL). For point sources, agricultural lands, stormwater from existing developments, and stormwater from state and federal entities, the Jordan Lake Rules specify reduction targets in reference to the baseline period. Thus, nutrients from these sources are intended to be actively reduced as compared to the 1997-2001 baseline condition. However, the rules for riparian buffer protection and stormwater from new developments do not reference the baseline condition and do not specify an aggregate load reduction target for the watershed. Therefore, the Jordan Lake Rules implement a combination of strategies to actively reduce nutrient loads (point sources, agricultural lands, existing developments) and passively minimize future anticipated loads (new developments and buffer protection). This inconsistency is the ultimate crux of the arguments for and against forest conservation as a nutrient offset credit. On one hand, since forest conservation maintains the status quo rather than reducing nutrient loads from the 1997-2001 baseline condition, some argue that it should not be eligible as a nutrient credit. On the other hand, forest conservation may minimize future nutrient load increases by preserving forests, so others argue that it should be credited. While no definitive conclusions were drawn following the policy analysis, there does appear to be precedence for crediting forest conservation as a potential "added benefit" to the required riparian buffer rules. However, since a forest's nutrient retention capacity tends to diminish as distance from the stream increases, the relative weight of such a credit may be lower than those received from buffer restoration projects or other nutrient offset options.

In addition to the policy discussion of forest conservation as a nutrient offset credit, there is a broader concern – would additional forest conservation efforts slow the pace of development in the Jordan Lake watershed? An abbreviated literature review was conducted and found that forest conservation rarely reduces the rate of land development; instead, development is simply displaced to lands adjacent to conserved areas. Some of these studies also compared different forest conservation strategies and land development policies; for example, one strategy may optimize the protection of high-priority lands (like buffers and floodplains) while another strategy may aim to maximize the overall area of land to be conserved (by promoting higher-density developments). These studies showed that forest conservation strategies may have an influence on environmental effects at the watershed scale. In other words, forest conservation objectives can be formulated to optimize certain environmental outcomes, such as (but not limited to) the minimization of future nutrient loads. These findings suggest that disorganized forest conservation approaches may not affect the environment but coordinated efforts across the watershed could support the Jordan Lake Nutrient Management Strategy; by extension, forest conservation credits could be used to promote such watershed-wide conservation efforts. Furthermore, the consideration of multiple environmental outcomes (not just reducing nutrient loads, but also providing habitat, sequestering carbon, etc.) should also be explored; these benefits, in addition to nutrient retention, may strengthen the arguments for crediting (or otherwise incentivizing) forest conservation in the Jordan Lake watershed.

In summary, forested watersheds in the Jordan Lake watershed export nutrient loads at lower rates than agricultural or developed watersheds. According to the Jordan Lake Rules, most, but not all, nutrient sources are required to reduce loads from the 1997-2001 baseline, which raises the question forest conservation's applicability as a nutrient offset credit since conservation minimizes future loads (i.e., no reduction from the baseline). Furthermore, coordinated forest conservation approaches are needed to successfully minimize future nutrient loads. Based on literature reviews, policy analyses, and interpretation of the Jordan Lake Rules, according to their current status, forest conservation efforts will not produce nutrient offset credits. However, it is recognized that forest conservation and reforestation efforts could be credited if part of a broader cohesive plan to optimize positive environmental outcomes, such as minimizing nutrient loads, providing habitat, and sequestering carbon.

TABLE OF CONTENTS

Problem Statement ... 1

Background ... 2

Land Use, Hydrology, and Nutrients ... 2

Forest Conservation ... 2

Jordan Lake Watershed ... 3

Jordan Lake Nutrient Strategy ... 6

Nutrient Export Rates in the North Carolina Piedmont ... 10

Monitoring Studies: Nutrient Loads ... 10

Monitoring Studies: Nutrient Concentrations ... 13

Limitations of Monitoring Studies ... 16

Modeling Studies ... 17

Conclusion ... 19

Forest Conservation as a Nutrient Reduction Strategy ... 20

Nutrient Loading and Land Use Change ... 20

Conservation, Restoration, and Conversion ... 23

Land Development Patterns ... 25

Summary: Challenges and Opportunities ... 28

Challenges ... 28

Opportunities ... 28

References ... 30

Problem Statement

The B. Everett Jordan Reservoir (Jordan Lake) was designated as a Nutrient Sensitive Water upon its impoundment in 1983 and was subsequently added to the US EPA 303(d) list of impaired waters in the early 2000s for excessive nutrient loads. The Jordan Lake watershed, more than 50% forested land at the time of its impoundment, is rapidly urbanizing while also being impacted by agricultural operations; urban and agricultural land uses generally export nutrient loads at a higher rate than forests. The Jordan Lake Nutrient Management Strategy is designed to reduce overall nutrient loads reaching the lake from both point and non-point pollutant sources. A credit trading system was developed to help facilitate efficient implementation of the Jordan Lake Rules that allows nutrient reduction credits to be traded between the regulated nutrient dischargers. The purpose of this report is to discuss forest conservation as a potential nutrient reduction credit as a part of the Jordan Lake Rules. First, a literature review was conducted to verify that forested lands export nutrients at a lower rate than agricultural and developed land uses in the North Carolina Piedmont ecoregion. Second, a policy analysis was conducted to discuss the merits and/or shortcomings of forest conservation as a nutrient reduction credit as a part of the Jordan Lake Rules. Further opportunities to incentivize forest conservation efforts in the Jordan Lake watershed were also discussed.

Background

Land Use, Hydrology, and Nutrients

Nitrogen and phosphorus are naturally occurring environmental nutrients, but human alterations have caused severe enrichment across the globe. Sources of nutrient pollution include wastewater treatment plants, agricultural runoff (fertilizers, manure, and sediment-bound nutrients), septic tanks and sanitary sewers, urban runoff (construction sites, lawn fertilizers, and pet wastes), erosion of nutrient-bound stream sediments, and atmospheric deposition of nitrogen (via agricultural operations and combustion of fossil fuels) (Vitousek et al. 1997; Carpenter et al. 1998). Excessive nutrient loading rates to surface waters result in eutrophication which can lead to harmful algal blooms, fish kills, and other negative environmental and human health outcomes (Smith, Tilman, and Nekola 1999; Anderson, Glibert, and Burkholder 2002).

Nutrients from non-point sources are particularly challenging to manage due to their diffuse nature and the prevalence of human-altered drainage systems that affect hydrologic processes and nutrient transport. Historically, agricultural and urban drainage systems were designed to optimize stormwater export using ditches and/or subsurface conveyance infrastructure; consequently, the export of nutrients from agricultural and urban land uses also increased (Carpenter et al. 1998). Biological conditions in streams have been linked to the degree of human alteration in the associated watershed, with nutrient enrichment and hydrologic alteration acting as principle mechanisms for degradation (Allan 2004). Modeling exercises have demonstrated that the risk of nitrogen and phosphorus export increases as forests are replaced by agricultural and urban land uses (Wickham and Wade 2002). A synthesis of studies from the rapidly urbanizing southeastern United States verify these patterns locally (O'Driscoll et al. 2010).

Forest Conservation

Environmental degradation is widely recognized as an anthropogenically driven global phenomenon. The conservation of natural landscapes has emerged as a potential method to prevent further environmental losses and potentially counteract humanity's impacts on the environment. Objectives of forest conservation are often multifaceted and can include the protection of biodiversity, natural resources, and areas of cultural importance. In the United States, forest conservation efforts are often targeted in supply watersheds to protect water quality (Gartner et al. 2013). Researchers have demonstrated additional environmental benefits of source water protection, including positive economic and societal impacts (Abell et al. 2017). Forest conservation efforts are often prioritized according to needs of the watershed. For example, riparian buffers provide many ecosystem services, such as preventing erosion, providing habitat corridors, and retaining pollutants, so buffer conservation programs are often highly prioritized (Lovell and Sullivan 2006). Despite the numerous benefits of forest conservation programs, economic drivers often undermine conservation efforts in areas experiencing rapid population growth and economic development.

Jordan Lake Watershed

In the early 1980s, the B. Everett Jordan Reservoir (herein Jordan Lake) was impounded for flood control, low flow augmentation, fish and wildlife conservation, recreation, and water supply. The Jordan Lake watershed is approximately 1,700 square miles and contains portions of Greensboro, Durham, and Cary and fully contains Chapel Hill, Burlington, and other smaller communities (Figure 1). The reservoir provides water supply to the following communities: Town of Cary, Town of Apex, Chatham County, City of Durham, Town of Holly Springs, Town of Morrisville, Orange County, and portions of Wake County. The Haw River drains most of the watershed but its average hydraulic retention time is only 5 days. The majority of the reservoir's volume is on the New Hope Creek arm, which has an average hydraulic retention of over 400 days. Because these two arms are hydraulically distinct, the Haw River and New Hope Creek arms, and their associated watershed areas, are often treated as two separate management entities (North Carolina Division of Water Resources 2007).

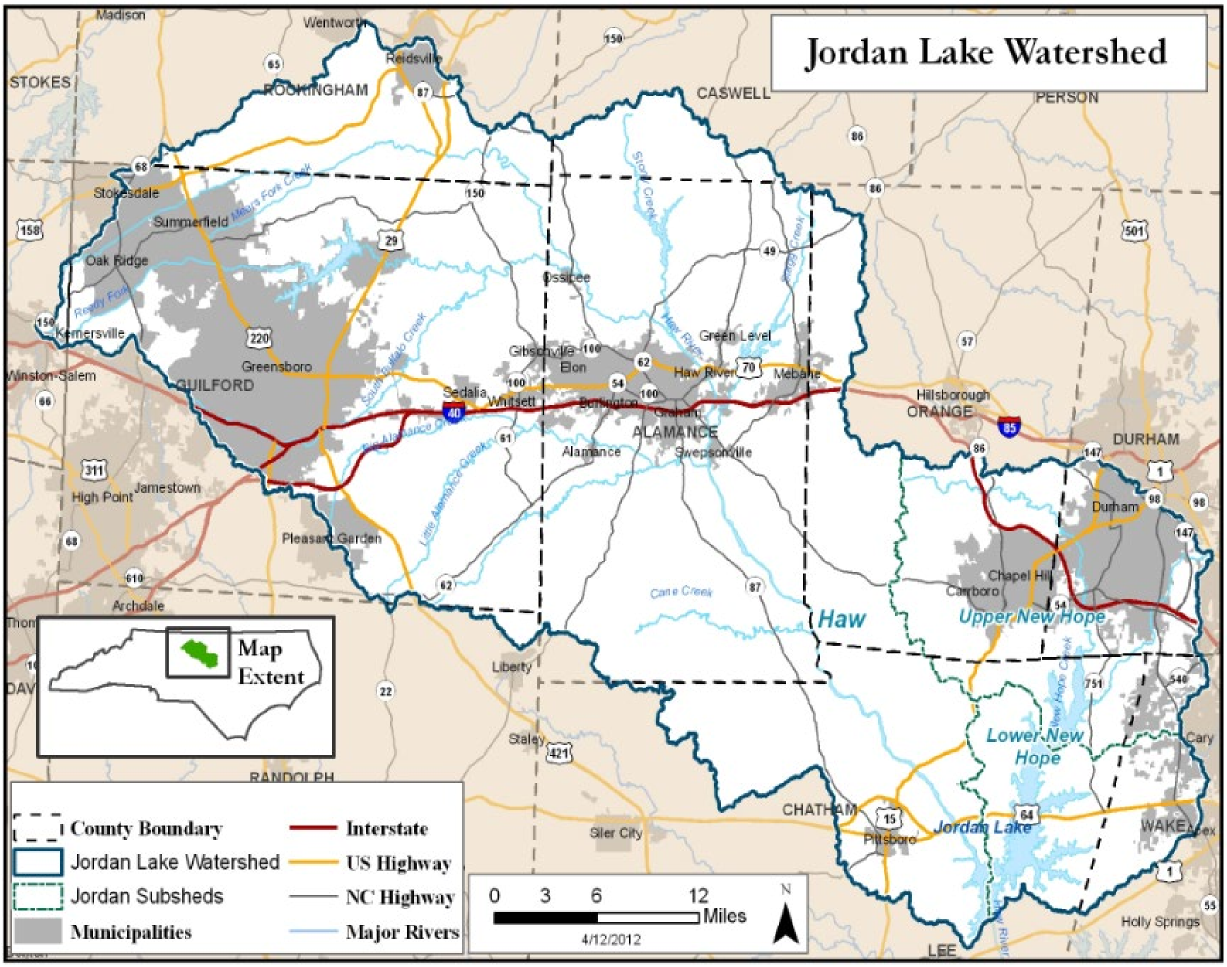

Figure 1. Map of the Jordan Lake watershed (jordanlake.org).

North Carolina's population growth rate is approximately 1.1% per year, the ninth fastest growing state in the country (United States Census Bureau 2018). Most of that population growth is occurring in the central North Carolina communities of Charlotte, the Triad (consisting of Greensboro, Winston-Salem, and High Point), and the Triangle (consisting of Raleigh, Durham, and Chapel Hill). Of these population centers, two are partially located in the Jordan Lake watershed (Figure 1). Table 1 shows land use percentages in the Jordan Lake watershed in 2001 and 2016 according to the National Land Cover Dataset; it appears that forested and agricultural lands are being replaced by developed or barren land uses (Homer et al. 2004; Yang et al. 2018).

Table 1. Land use classes in the Jordan Lake watershed. The lumped land uses are summed across the following NLCD codes: "Forested" codes 41, 42, and 53; "Developed" codes 21, 22, 23, and 24; "Agricultural" codes 81 and 82; "Water and Wetlands" codes 11, 90, and 95; and "Barren, Shrub, and Herbaceous" codes 31, 52, and 71.

Land Use	2001	2016	Change (%)	Change (sq mi)
Forested	51.3%	48.5%	- 2.8%	- 49
Developed	19.3%	21.8%	+ 2.5%	+ 43
Agricultural	22.7%	21.1%	- 1.6%	- 26
Water & Wetlands	4.5%	4.5%		
Barren, Shrub, & Herbaceous	2.3%	4.2%	+ 1.9%	+ 31

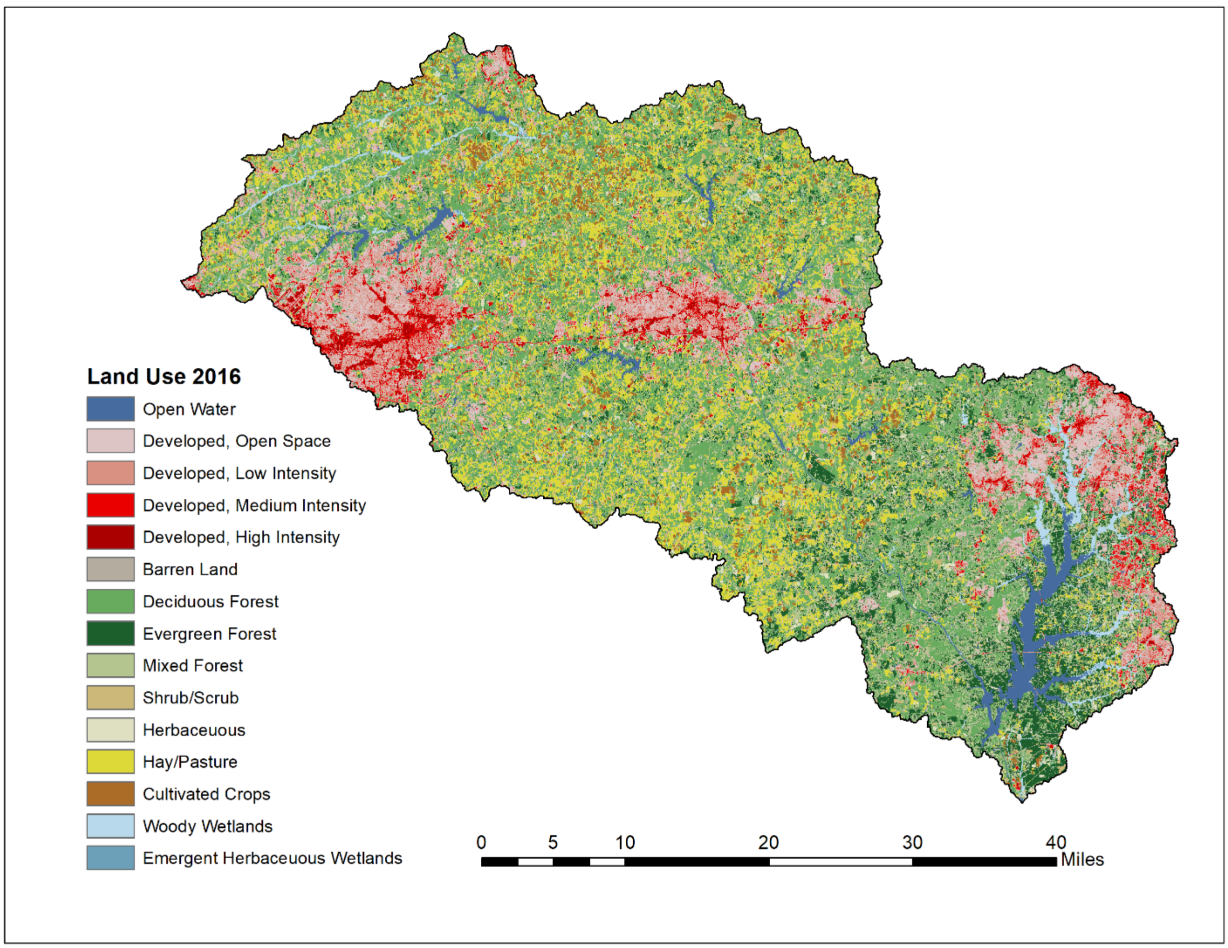

Figure 2. Land uses in the Jordan Lake watershed in 2016 (Yang et al. 2018).

Jordan Lake was designated as a Nutrient Sensitive Water upon its impoundment in 1983. Despite proactive plans to limit point source pollution throughout the watershed, the lake still regularly experienced eutrophic conditions resulting from excessive nutrient loads, leading to the placement of the Upper New Hope arm of Jordan Lake on the US EPA 303(d) list of impaired waters for chlorophyll *a* impairment in 2002; the remainder of the reservoir was added to the 303(d) list in 2006. High levels of chlorophyll *a* and a high pH in the lake result from the input of excessive loads of nitrogen and phosphorus from the watershed. Consequently, a Total Maximum Daily Load (TMDL) was developed for the watershed (North Carolina Division of Water Resources 2007).

Jordan Lake Nutrient Strategy

Following the issuance of TMDLs, intensive monitoring and modeling efforts were conducted from 1997 through 2001 to determine the maximum total nitrogen and total phosphorus capacities of Jordan Lake. Based on these studies, nutrient load reduction targets (as compared to the 1997 to 2001 nutrient loads) were established, as shown in Table 2 (North Carolina Division of Water Resources 2007).

Table 2. Nutrient reduction targets according to the Jordan Lake TMDL.

Subwatershed Management Area	TN Reduction (% lower than 2001)	TP Reduction (% lower than 2001)
Upper New Hope Creek Arm (above SR1008)	35%	5%
Lower New Hope Creek Arm (below SR1008)	0%	0%
Haw River Arm	8%	5%

As outlined in North Carolina Administrative Code, the above nutrient reduction targets are to be met collectively between all point and non-point sources (*15A NCAC 02B .0262* 2009). Details of the Jordan Lake nutrient reduction strategy, commonly referred to as the Jordan Lake Rules, are described in subsequent sections of the North Carolina Administrative Code. Rules were established for wastewater dischargers, agricultural lands, fertilizer management, stormwater management for new developments, stormwater management for existing developments, stormwater management for state and federal entities, and the protection of existing riparian buffers. Options for offsetting nutrient loads are also specified along with their associated rates. Subsequent session laws have amended details, or delayed the implementation, of the Jordan Lake Rules; however, for the purposes of this report, focus will be given to the general intent of the Rules rather than their current legal status. The remainder of this report will focus specifically on non-point nutrient source reduction.

Agricultural rules, as described in *15A NCAC 02B .0264* (2009), are implemented at the subwatershed and county levels. In other words, each jurisdictional unit (in this case, a county/subwatershed unit) must collectively meet their associated nutrient reduction goals as shown in Table 2. Nutrient reductions can be achieved in several ways. For instance, reduction of productive agricultural lands or fertilizer application rates leads to reductions in overall nutrient export. Other agricultural nutrient reduction strategies include crop shifts (e.g., transitioning to crops that have lower nutrient export rates), livestock exclusion, riparian buffers, animal waste reduction, conservation tilling, and other agricultural best management practices. These nutrient reduction credits are accounted for using tools such as the Nitrogen Loss Estimation Worksheet (Osmond 2018) and the Phosphorus Loss Assessment Tool (Osmond et al. 2014). In addition to these agricultural rules, farms are required to attend fertilizer management training provided by the North Carolina Cooperative Extension program (*15A NCAC 02B .0272* 2009). Fertilizer rules are also applicable to golf courses, horticulture or floriculture operations, and any other hired fertilizer applicators.

Nutrient reduction rules for developed lands fall into one of three categories: (1) new developments, (2) existing developments, and (3) state and federal entities. For each of these categories, stormwater runoff is the targeted source/pathway for nutrient reduction. In addition to some of the more common stormwater rules in North Carolina, such as the one-inch rainfall capture volume and no net increase to pre-development peak flows, unit-area mass loading rate limits were established in each subwatershed (Table 3; *15A NCAC 02B .0265* 2009). Any development project that disturbs one or more acres in residential areas or one-half acre or more in commercial, industrial, institutional, or multifamily areas are subject to these rules unless the development would replace or expand upon existing structures as of December 2001. New developments that are subject to the rules must use the Stormwater Nitrogen and Phosphorus (SNAP) Tool to calculate expected nutrient loads based on future land cover characteristics and then select stormwater control measures that limit annual loads below the subwatershed target (North Carolina Division of Water Resources 2018). Offset nutrient credits can also be purchased if the development project cannot achieve the required nutrient load limits on-site.

Table 3. Unit-area mass loading rate limits for stormwater runoff from new developments.

Subwatershed Management Area	Annual TN Mass Loading Rate Limits	Annual TP Mass Loading Rate Limits
Upper New Hope Creek Arm (above SR1008)	2.47 kg/ha	0.92 kg/ha
Lower New Hope Creek Arm (below SR1008)	4.93 kg/ha	0.87 kg/ha
Haw River Arm	4.26 kg/ha	1.60 kg/ha

Stormwater runoff from existing development has a separate series of nutrient reduction rules (*15A NCAC 02B .0266* 2009). The existing development rules have been heavily contested, causing implementation to be delayed; that said, this discussion focuses on the original intent of the rules. Stage 1 of the existing development rules is an adaptive management approach that involves public education, mapping of existing stormwater infrastructure, identification and removal of illicit discharges, and maintenance of existing stormwater best management practices. If monitoring results from Jordan Lake do not show adequate nutrient reductions following the implementation of the Jordan Lake Rules and the completion of the Stage 1 stormwater from existing developments rule, a second series of regulations could be enforced in Stage 2. Stage 2 rules require an eight percent reduction in TN load and a five percent reduction in TP load for each subwatershed that does not comply with the TMDL. Stage 2 reductions can be achieved by installing new stormwater control measures to treat runoff from existing developments or by directly reducing impervious surface areas in the subwatershed.

Separate stormwater rules are in place for state and federal entities, including all roadways under the control of the North Carolina Department of Transportation (*15A NCAC 02B .0271* 2009). The general intent of these rules is similar to the stormwater for new development and existing development rules with adjustments to account for type of publicly owned developed lands (mainly roadways).

In addition to the rules for point source (not discussed) and non-point source nutrients, an extensive set of buffer protection rules were established for the Jordan Lake watershed (*15A NCAC 02B .0267* 2009). Riparian buffers reduce erosion, capture and retain pollutants from surrounding lands (including nitrogen and phosphorus), protect floodplains, and provide habitat (Lovell and Sullivan 2006). Although protecting existing buffers does not reduce nutrient loads from the 1997-2001 baseline rates, the avoidance of future buffer degradation, and subsequent increases to nutrient export, was codified because riparian buffers are considered a priority landscape.

To facilitate efficient nutrient load reduction throughout the watershed, a nutrient offset credit trading system was established (*15A NCAC 02B .0273* 2009). Nutrient loading reductions in excess of load reduction goals are eligible to be sold as credits. Agricultural landowners must receive approval to purchase nutrient credits from the Watershed Oversight Committee, while owners of developed properties must meet on-site nutrient reduction minimums. Nutrient offset credits must be sold and purchased within the same subwatershed management area (Upper New Hope Creek Arm, Lower New Hope Creek Arm, and the Haw River Arm). The agricultural and stormwater best management practices previously discussed in this section are eligible options for nutrient offset credit transactions, while landscape restoration efforts are also eligible; these include stream, wetland, and riparian buffer restorations. Restoration credits are often generated by mitigation bankers or the North Carolina Division of Mitigation Services. To date, buffer restoration projects on agricultural lands are the most commonly purchased nutrient offset credit due to their cost effectiveness (North Carolina Division of Water Resources 2019).

Nutrient Export Rates in the North Carolina Piedmont

Monitoring Studies: Nutrient Loads

Nutrient load estimates are an important component of land-water resources management and planning exercises. Nutrient export depends on many factors, including but not limited to: climate, weather, season, geology, soils, topography, vegetation, land cover, land use, land management, and nutrient sources (Carpenter et al. 1998). Because so many factors affect nutrient export, continuous measurements of nutrient concentration and streamflow are needed to accurately quantify nutrient loads. However, measuring nutrient concentrations and streamflow across an entire watershed is rarely feasible; instead, models are used to estimate nutrient loading and transport at broader spatial and temporal scales.

Export coefficient models estimate nutrient loads by assigning unit-loading rates to different land use categories. This simple modeling approach was popular before more complex hydrodynamic and water quality modeling packages were widely available. Results from the National Eutrophication Survey, conducted from June 1972 through December 1975, were used to inform the first generation of nutrient export coefficient models. Per Omernik (1977), the average TN annual export from forested, agricultural, and developed lands is 3.51, 7.59, and 7.30 kg/ha, respectively, while average TP annual export from forested, agricultural developed lands is 0.11, 0.26, and 0.35 kg/ha (Table 4). This nation-wide preliminary study of nutrient loads by land use suggested that forested lands export less nitrogen and phosphorus than agricultural or developed lands; however, as the findings are generalized national averages, they do not account for regional biases. A follow up analysis of Omernik (1977) found distinct differences between physiographic regions, emphasizing the need for region-specific unit-loading rates (Rohm et al. 2002).

The Albemarle-Pamlico Estuarine System Watershed Plan determined nutrient unit-loading rates applicable to the Albemarle-Pamlico watershed (Dodd, McMahon, and Stichter 1992). The Albemarle-Pamlico watershed, located in northeast North Carolina and southeast Virginia, is an example of an export coefficient model in the southeastern United

States; its estimated unit-loading rates may closer represent the conditions expected in the Jordan Lake watershed. Per Dodd, McMahon, and Stichter (1992), average annual TN export from forested lands is 2.33 kg/ha, agricultural lands is 9.80 kg/ha, and developed lands is 7.50 kg/ha, while the average TP annual export from forested lands is 0.13 kg/ha, agricultural lands is 0.99 kg/ha, and developed lands is 1.06 kg/ha (Table 4). Compared to Omernik (1977), the Albermarle-Pamlico TN unit-loading rates are lower in forested lands, higher in agricultural lands, and similar in developed lands, while the TP unit-loading rates are similar in forested lands and higher in agricultural and developed lands. Although differences between the national and regional studies were identified, both studies consistently found forested lands to export nitrogen and phosphorus at lower unit rates than agricultural or developed lands.

Table 4. Summary of average measured nutrient export unit-loading rates from studies conducted at the national scale (Omernik 1977) and in the southeast (Dodd, McMahon, and Stichter 1992).

Land Use	Omernik (1977)		Dodd et al. (1992)	
	TN (kg/ha/yr)	TP (kg/ha/yr)	TN (kg/ha/yr)	TP (kg/ha/yr)
Forested	3.51	0.11	2.33	0.13
Agricultural	7.59	0.26	9.80	0.99
Developed	7.30	0.35	7.50	1.06

To account for the importance of land use changes within central North Carolina following Omernik (1977) and Dodd et al.'s (1992) analyses, a literature review was conducted to explore nutrient export studies in central NC published after 1992. With these specific restrictions in place, only four studies were identified that measured nutrient export loading rates from forested watersheds (Table 5; Figure 3) and from developed watersheds (Table 6; Figure 3). Only one study was identified from an agricultural watershed, so agricultural watersheds have been omitted from discussion. The lack of studies that measured nutrient export in the North Carolina Piedmont since 1992 can be attributed to multiple factors, including the prevalence of studies and reviews completed prior to 1992 and the *a priori* knowledge of nutrient export differences across land uses. Thus, the values are limited and are only meant to confirm the assumptions from broader nation-wide or regional studies.

Table 5. Summary of mean annual nutrient export from forested watersheds in central NC.

TN (kg/ha/yr)	TP (kg/ha/yr)	Source
11.40	1.00	Daniel E. Line et al. (2002)
6.30	0.50	D.E. Line and White (2007)
2.05	0.48	Daniel E. Line (2013)
1.92	0.47	Daniel E. Line (2013)
1.19	0.16	Boggs, Sun, and McNulty (2016)
1.37	0.17	Boggs, Sun, and McNulty (2016)
1.56	0.19	Boggs, Sun, and McNulty (2016)
1.92	0.47	Median from studies in NC Piedmont
1.19 – 11.40	0.16 – 1.00	Range from studies in NC Piedmont
3.51	*0.11*	*Omernik (1977)*
2.33	*0.13*	*Dodd, McMahon, and Stichter (1992)*

The monitored watersheds show a high range of nutrient export rates within land use classes, emphasizing that land use is only one of many factors that contribute to nutrient loads. Although the median values across these studies differ from Omernik (1977) and Dodd, McMahon, and Stichter (1992), the generalization that forested lands export lesser nutrient loads than developed lands still appears to hold true in the North Carolina Piedmont.

Table 6. Mean annual nutrient export from developed watersheds in central NC.

TN (kg/ha/yr)	TP (kg/ha/yr)	Source
5.60	1.05	Bales, Weaver, and Robinson (1999)
19.62	2.45	Bales, Weaver, and Robinson (1999)
5.95	0.35	Bales, Weaver, and Robinson (1999)
9.46	2.10	Bales, Weaver, and Robinson (1999)
23.12	4.55	Bales, Weaver, and Robinson (1999)
30.50	3.00	Daniel E. Line et al. (2002)
18.00	1.70	D.E. Line and White (2007)
6.65	0.91	Daniel E. Line (2013)
3.23	0.39	Daniel E. Line (2013)
2.60	0.38	Daniel E. Line (2013)
2.77	0.39	Daniel E. Line (2013)
6.65	1.05	Median from studies in NC Piedmont
2.60 – 30.50	0.35 – 4.55	Range from studies in NC Piedmont
7.30	*0.35*	*Omernik (1977)*
7.50	*1.06*	*Dodd, McMahon, and Stichter (1992)*

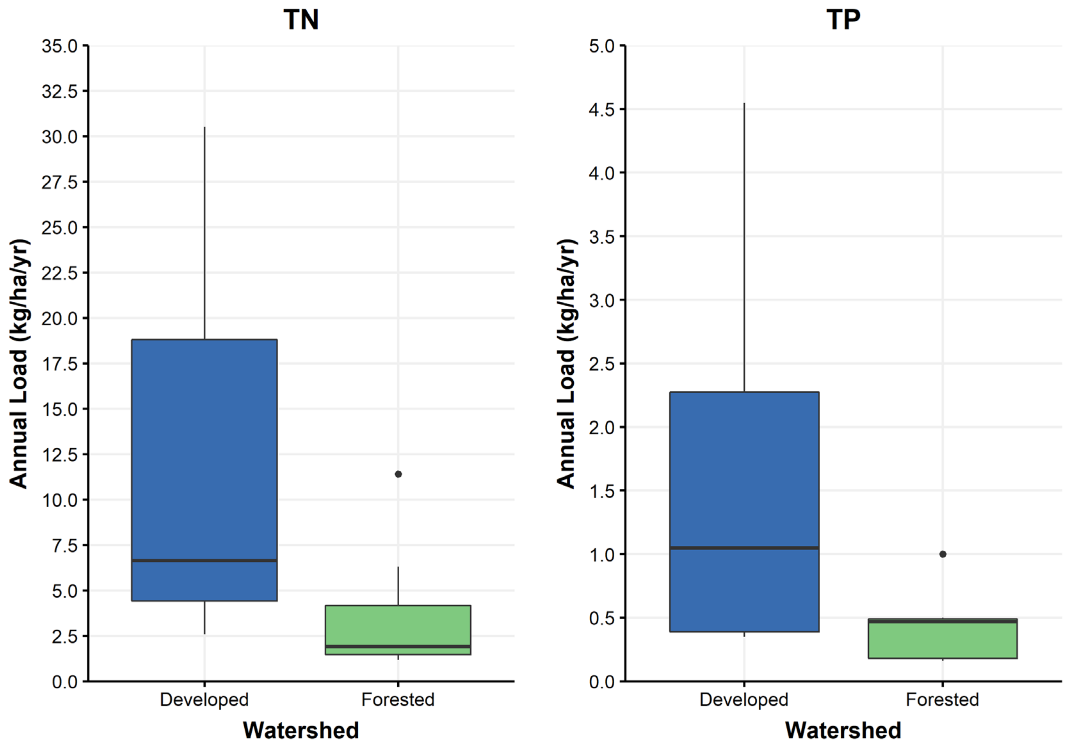

Figure 3. Literature reported annual export of TN and TP from developed and forested watersheds.

Monitoring Studies: Nutrient Concentrations

Due to the scarcity of studies measuring nutrient export rates in the North Carolina Piedmont since 1992, a supplemental literature review was conducted to identify studies that measured nutrient concentrations in streams that drained forested or developed watersheds (Figure 4). Increases in runoff volumes due to the transformation of forested land to developed land is well documented; therefore, if nutrient concentrations are similar across forested and developed streams, nutrient loads are expected to be higher from developed watersheds.

Tables 7 and 8 summarize the results of the supplemental literature review. Like the review of nutrient export loads, mean nutrient concentrations are highly variable across watersheds of the same land use. Total phosphorus concentrations in streams draining developed watersheds are similar to concentrations in streams draining forested watersheds, but total nitrogen concentrations appear higher in developed streams than in forested streams. These results suggest that streams draining developed watersheds are likely to have equal or higher nutrient concentrations than forested streams; thus, in conjunction with higher streamflow volumes, developed watersheds would export higher nutrient loads than forested watersheds.

Table 7. Mean stream nutrient concentrations from studies conducted in forested watersheds located in the North Carolina Piedmont. Omernik (1977) is shown for reference.

TN (mg/l)	TP (mg/l)	Source
1.70	0.09	Lenat and Crawford (1994)
4.58	0.35	Line et al. (2002)
1.39	0.14	Giddings et al. (2007)
0.40	0.04	Line (2013)
0.28	0.03	Line (2013)
0.63	0.08	McSwain, Young, and Giorgino (2014)
0.33	-	Ferrell et al. (2014)
0.71	0.08	Boggs, Sun, and McNulty (2016)
0.52	0.06	Boggs, Sun, and McNulty (2016)
0.66	0.07	Boggs, Sun, and McNulty (2016)
1.05	0.03	Journey et al. (2018)
0.76	0.05	Journey et al. (2018)
0.69	0.07	Median from studies in NC Piedmont
0.28 – 4.58	0.03 – 0.35	Range from studies in NC Piedmont
0.62	*0.02*	*Omernik (1977)*

Table 8. Mean stream nutrient concentrations from studies conducted in developed watersheds located in the North Carolina Piedmont. Omernik (1977) is shown for reference (continued the following page).

TN (mg/l)	TP (mg/l)	Source
1.42	0.10	Lenat and Crawford (1994)
1.16	0.24	Bales, Weaver, and Robinson (1999)
2.73	0.45	Bales, Weaver, and Robinson (1999)
2.57	0.38	Bales, Weaver, and Robinson (1999)
1.99	0.34	Bales, Weaver, and Robinson (1999)
2.78	0.55	Bales, Weaver, and Robinson (1999)
6.71	0.59	Line et al. (2002)
1.85	0.27	Line et al. (2002)
1.76	0.03	Giddings et al. (2007)
0.80	0.02	Giddings et al. (2007)
0.33	0.04	Giddings et al. (2007)
1.06	0.05	Giddings et al. (2007)
0.65	0.06	Giddings et al. (2007)
1.25	0.03	Line (2013)
4.55	0.17	Line (2013)
0.36	0.03	Line (2013)
0.81	0.05	Line (2013)
0.63	-	Ferrell et al. (2014)
1.55	-	Ferrell et al. (2014)
0.50	-	Ferrell et al. (2014)
0.60	0.07	McSwain, Young, and Giorgino (2014)
0.78	0.16	McSwain, Young, and Giorgino (2014)
0.79	0.09	Journey et al. (2018)
0.88	0.10	Journey et al. (2018)
0.66	0.03	Journey et al. (2018)
0.85	0.06	Journey et al. (2018)
0.93	0.09	Journey et al. (2018)
0.82	0.07	Journey et al. (2018)
0.85	0.10	Journey et al. (2018)
1.08	0.05	Journey et al. (2018)
0.59	0.04	Journey et al. (2018)
0.62	0.04	Journey et al. (2018)
0.79	0.05	Journey et al. (2018)
0.94	0.06	Journey et al. (2018)
0.88	0.05	Journey et al. (2018)
0.86	0.10	Journey et al. (2018)
0.84	0.15	Journey et al. (2018)
0.75	0.06	Journey et al. (2018)
1.01	0.16	Journey et al. (2018)
0.63	0.05	Journey et al. (2018)
0.96	0.16	Journey et al. (2018)
0.86	0.07	Median from studies in NC Piedmont
0.33 – 6.71	0.02 – 0.59	Range from studies in NC Piedmont
1.82	*0.09*	*Omernik (1977)*

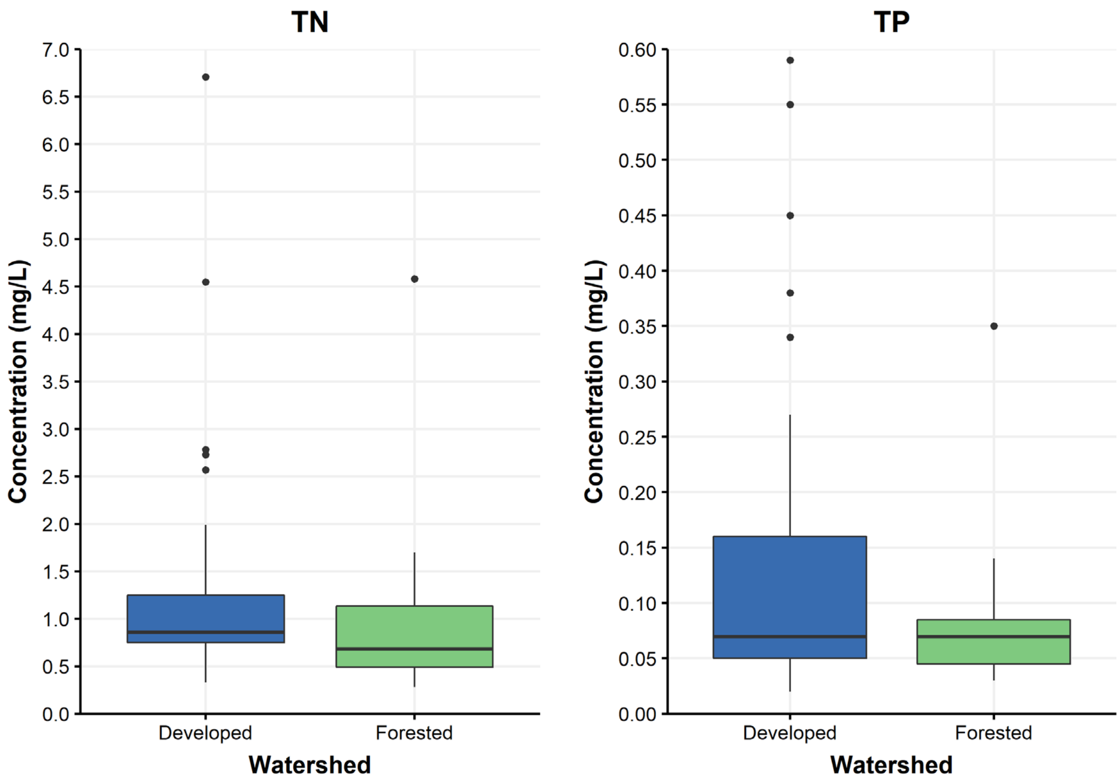

Figure 4. Comparison of literature values for TN and TP concentrations in central NC streams in developed and forested watersheds.

Limitations of Monitoring Studies

Although the literature reviews conducted herein suggest that forested watersheds export less nutrients than developed watersheds in the North Carolina Piedmont, these results have many limitations and the values shown in Tables 5-8 and Figures 3-4 should be evaluated with care. Very few watersheds across the United States consist of a single land use, and researchers often use best judgement to determine the threshold required to label a watershed as forested, developed, or agricultural. Even within land use classifications there can be major differences between study areas which are not always reported in the literature. For instance, forested watersheds with different vegetation types may export nutrients at different rates or developed watersheds may or may not contain wastewater treatment plants or various degrees of non-point source controls. Another limitation is that researchers across studies may have used different sampling methods or collected a different number of samples, both of which would impact the uncertainty of reported results. Additionally, not all studies clearly state if samples are collected during baseflow only or across a wide range of flow conditions. For all the above reasons, simple unit-loading rates are often unreliable and export coefficient models are now considered outdated. Still, from a qualitative perspective, the results of the literature reviews suggest that forested watersheds export less nutrients than developed (and agricultural) watersheds, but exact unit-loading rates cannot be pinpointed.

Modeling Studies

More complex modeling approaches are now used to estimate nutrient export. The North Carolina Department of Environmental Quality, in partnership with nearby universities and other researchers, have developed tools for nutrient crediting and management purposes such as the Stormwater Nitrogen and Phosphorus Tool (North Carolina Division of Water Resources 2018), the Nitrogen Loss Estimation Worksheet (Osmond 2018), and the Phosphorus Loss Assessment Tool (Osmond et al. 2014). These practical tools estimate how land cover or land management changes affect local nutrient export and help landscape designers integrate nutrient reduction strategies to meet regulatory requirements.

Many other hydrologic modeling tools have been developed for use at larger spatial scales, some of which were specifically designed to estimate nutrient dynamics in the Jordan Lake watershed. A Generalized Watershed Loading Function (GWLF) hydrologic and water quality model of the Jordan Lake watershed was developed per the requirements of Jordan Lake's TMDL reporting procedures (Tetra Tech, Inc 2003). In addition to more refined nutrient unit-loading rates based on land use subclass (Table 9), the GWLF model's nutrient calculations considered soil and hydrologic properties, vegetation types, groundwater seepage and transport, nutrient buildup on various land cover types, and in-stream nutrient transformation and transport considerations. Therefore, each hydrologic response unit (or HRU) throughout the Jordan Lake watershed had unique nutrient loading rates.

Table 9. Nutrient unit-loading rates from the GWLF model used to determine the nutrient reduction targets for the Jordan Lake TMDL (Tetra Tech, Inc 2003).

TN (kg/ha/yr)	TP (kg/ha/yr)	Land Use Description
51.51	33.54	Barren
26.96	4.15	Commercial/Heavy Industry
1.78	0.37	Forest
18.46	2.95	Office/Light Industrial
6.38	1.21	Pasture
16.85	2.77	Residential <0.25 ac per du (sewered)
13.29	2.24	Residential 0.25-0.5 ac per du (sewered)
13.14	2.17	Residential 0.5-1.0 ac per du (sewered)
46.43	2.28	Residential 0.5-1.0 ac per du (unsewered)
12.21	2.03	Residential 1.0-1.5 ac per du (sewered)
32.18	2.08	Residential 1.0-1.5 ac per du (unsewered)
10.50	1.92	Residential 1.5-2.0 ac per du (sewered)
24.76	1.95	Residential 1.5-2.0 ac per du (unsewered)
2.79	0.67	Residential >2 ac per du (sewered)
12.78	0.71	Residential >2 ac per du (unsewered)
14.99	5.96	Row Crop
4.00	0.68	Urban Green Space
0.00	0.00	Water
2.47	0.45	Wetland

Statistical models can also be used to estimate nutrient loading rates across a watershed. For example, the Spatially Referenced Regression on Watershed Attributes (SPARROW) model identifies relationships between watershed characteristics (such as land use) and measured nutrient concentrations and loads to estimate nutrient export rates from different sources throughout the watershed. A SPARROW model was recently developed for the entire state of North Carolina; the model estimates annual TN export across the Jordan Lake watershed at approximately 5.4 kg/ha and annual TP export at approximately 0.58 kg/ha. The main sources of TN in the SPARROW model were wastewater dischargers, land development, and atmospheric deposition, while the main sources of TP were wastewater dischargers, agricultural fertilizers, and land development (Gurley et al. 2019).

Conclusion

Although the studies referenced within reported a wide range of concentrations and loads from forested and developed watersheds, and none of the monitoring or modeling studies are directly comparable to one another, the general assumption that forested watersheds contribute lesser nutrient loads than either developed or agricultural watersheds appears to hold true in the Jordan Lake watershed.

Forest Conservation as a Nutrient Reduction Strategy

Nutrient Loading and Land Use Change

Table 10. Land use change scenarios expected in the Jordan Lake watershed.

From…	To…	Summary of rules and credits
		New development stormwater and buffer protection rules apply. New developments must achieve a set nutrient loading rate.
		New development stormwater and buffer protection rules apply. New developments must achieve a set nutrient loading rate.
		Existing development stormwater and buffer protection rules apply. Reductions from already developed areas are only required in Stage 2.
		Agriculture, fertilizer management, and buffer protection rules apply. Many opportunities exist to reduce nutrients from agricultural lands. Nutrient reductions that exceed requirements may be sold as offset credits.
		No rules and no credits available.

Because of the rapid population growth occurring in the Jordan Lake watershed (Table 1), the most likely land use transitions are from agricultural or forested lands to developed lands. Under both scenarios, the new development stormwater rules and buffer protection rules are applicable. Per *15A NCAC 02B .0265* (2009), stormwater from new developments must achieve a required unit nutrient export rate (Table 3), which is dependent upon the subwatershed rather than existing conditions (e.g., forest or agriculture). Consequently, developers are held to the same nutrient reduction requirements if the newly developed land is replacing mature forest or agricultural land. Developments replacing forested lands are unlikely to reduce nutrient loads as compared to the 1997-2001 baseline loads using on-site stormwater control measures; instead of actively reducing loads from the baseline condition, future nutrient loads are being limited. As shown in Tables 4-6, forested lands generally export TN at a rate of 3.5 kg/ha/yr, or lower, and generally export TP at a rate of 0.5 kg/ha/yr, or lower. Aside from the TN stormwater nutrient load limits from new development in the Upper New Hope Creek watershed (Table 3), allowable nutrient loads from new developments likely exceed forested conditions. Therefore, when new development replaces forested lands, the Jordan Lake Rules are designed to minimize anticipated future nutrient loads. By extension, nutrient loads across the entire watershed are not likely to reduce when all the regulations are followed, but future nutrient loads from the newly developed lands will be lesser than if it were uncontrolled.

Land developed prior to the 1997-2001 baseline scenario, that remains unchanged, is subject to the existing development stormwater nutrient rules and buffer protection rules. These rules require stormwater management improvements in Stage 1 but do not require active measures that reduce nutrient loads from the baseline condition until Stage 2. Thus, prior to Stage 2, nutrient reduction responsibilities from existing developments are deferred to point dischargers, new developments, and agricultural lands until otherwise proven necessary. Moreover, since the new development rules minimize future load increases rather than reduce baseline loads, point dischargers and agricultural landowners carry the burden of achieving watershed-wide nutrient reduction as compared to the 1997-2001 baseline loads.

Existing agricultural lands are required to reduce nutrient loads from the 1997-2001 baseline condition. Reduction is accounted for at the subwatershed and county-level. Therefore, an individual farm is not required to change its agricultural management practices if other farms in the county/subwatershed have collectively achieved the required nutrient load reduction. That said, because there are many methods to reduce nutrient loads from agricultural lands, the Division of Mitigation Services and mitigation banks often work with farmers to exceed required nutrient reductions and subsequently resell these excess reductions as offset nutrient credits. Offset credits are often sold to developers who either cannot, or choose not to, entirely achieve stormwater nutrient load limits using on-site stormwater control measures.

Although the Jordan Lake Rules contain regulations aimed to reduce nutrient loads from both agricultural and developed lands, nutrient reduction strategies for these two land uses are not equivalent. From agricultural lands, nutrient load reductions must meet a collective percent reduction in each subwatershed, representing an active reduction from the 1997-2001 agricultural baseline loads. However, unlike agricultural lands, developed lands are not treated as a collective unit; rather, newly developed parcels or subdivisions must meet a predetermined unit-loading rate limit independent from the 1997-2001 land use. Furthermore, existing developed lands are not required to actively reduce nutrient loads until Stage 2, after other nutrient reduction approaches have already been exhausted. Even if the stormwater rules from new and existing developments are met, collective nutrient loads from developed lands are likely to increase from the 1997-2001 baseline due to population increases and continued land development. In short, the stormwater rules aim to minimize future nutrient load increases, not reduce loads from the baseline levels from developed lands.

There are multiple reasons why non-point nutrient sources are regulated differently between agricultural and developed lands. First, reducing nutrient loads in stormwater runoff from developed parcels is not as cost effective as other nutrient reduction strategies, such as buffer protection or large-scale agricultural best management practices (McManus, Kirk, and Rosenfeld, 2019). As previously explained, there are numerous methods to reduce nutrients from agricultural lands including crop shifts, cattle exclusion, buffer restoration, fertilizer reductions, soil management, and animal waste management. From developed lands, nonpoint source nutrient reduction practices are limited to stormwater control measures and non-structural best management practices such as pet waste pick-up programs and public education (e.g. – proper use of lawn fertilizers). Furthermore, the number of landowners of developed parcels far exceeds those of agricultural lands, and space to build structural nutrient reduction practices in urban areas is limited; thus, nutrient reduction efforts are more efficient in agricultural lands. Another reason why nutrient reduction rules for new and existing developments are different from agricultural lands is the broader consideration of economic growth. As population growth continues in central North Carolina, too strict of development rules may stifle economic growth and receive pushback from the developers who do business in the Jordan Lake watershed. The offset nutrient crediting system further transfers the burden away from land developers by redistributing additional nutrient reduction efforts to agricultural lands. An understanding of these two considerations helps explain why the nutrient reduction rules differ between agricultural and developed lands; however, it is worth noting that non-point nutrient sources from different land uses are not regulated equally. Markedly, the nutrient reduction rules meant for developed lands are intended to minimize future nutrient loads rather than actively reduce nutrient loads from the 1997-2001 baseline condition.

Conservation, Restoration, and Conversion

Although forested lands have lower nutrient loading rates than agricultural or developed lands, the conservation of forests does not reduce loads from the 1997-2001 baseline for the Jordan Lake watershed. Forest conservation may avoid future increases to nutrient loads by limiting the growth of agricultural or developed lands, but conservation, by definition, maintains the status quo. In fact, the inability to reduce nutrient loads from the 1997-2001 baseline levels is one of the main reasons why forest conservation has not been accepted as a potential nutrient offset credit (NCDEQ, personal communication, April 12, 2019). If a nutrient credit is not actively reducing nutrient loads, its role as an offset is invalid.

However, not all of the Jordan Lake Rules are meant to reduce nutrient loads. Notably, buffer protection rules are intended to avoid future increases to nutrient loads resulting from encroachment of agricultural or developed lands into riparian buffers (*15A NCAC 02B .0267* 2009). Generally, conservation efforts tend to prioritize forested riparian buffers and floodplains above upland forests. Furthermore, the preservation of buffers cannot be used as nutrient offset credits because existing riparian buffers, like existing forests, do not reduce nutrient loads from the 1997-2001 baseline levels.

Although buffer protection is not credited, riparian buffer restoration or enhancement projects can generate nutrient offset credits (*15A NCAC 02B .0295* 2015). Nutrient offset credits are weighted based on prior land cover. Restoration projects, which completely re-establish riparian zones, receive the most credit; enhancement projects, which improve coverage, density, and/or diversity in existing riparian buffers, receive lesser credit that full restorations. Similarly, riparian buffer credits are weighted by the proximity of riparian buffer work with respect to a stream. Buffer restoration and enhancement projects receive full credits at widths up to 100 feet; beyond 100 feet, only partial credits are awarded. The proximal weighting scheme encourages restoration and enhancement efforts up to 100 feet to ensure that the ecosystem services provided by riparian buffers are fully functional, but also recognizes that buffers widths exceeding 100 feet may have diminishing returns due to their distance from the stream.

Buffer restoration and enhancement credits may set a precedent for establishing eligibility for upland reforestation as a nutrient offset credit. Instead of crediting forest conservation, which does not reduce nutrient loads from the 1997-2001 baseline level, credits may be generated by transitioning agricultural or development lands to forested lands. Rather than forest conservation, this practice is referred to as land conversion. In the Jordan Lake watershed, aside from the possibility of floodplain buyouts, land conversion from developed to forested lands is highly unlikely due to population increases; however, conversion from agricultural lands to forested lands is a more likely possibility. Indeed, farmers can achieve nutrient reductions by ceasing production on a portion of previously agricultural lands. However, unproductive lands are treated equally without consideration of the future land use. In other words, agricultural lands that transition to forests and agricultural lands that transition to developments are considered equivalent from the farmer's perspective; both instances count equally towards the county and subwatershed collective reduction goals from agricultural lands. Although the developer is required to meet the stormwater requirements for new developments, these limits are generally higher than the expected loading rates from forested lands.

Although the objective of this report is to investigate forest conservation as a *nutrient* offset credit, it should be noted that forested lands are valued for many environmental benefits beyond nutrient retention. The United States Forest Service recognizes the multiple benefits of forest ecosystems, including but not limited to watershed services, carbon sequestration, biodiversity protection, and human health and wellbeing (https://www.fs.fed.us/ecosystemservices/). The Jordan Lake Rules aim to reduce nutrient loads (and, as previously discussed, minimize future nutrient load increases), but do not recognize other ecosystem services because the TMDL is strictly focused on nutrient pollution. Therefore, while forest conservation may not strictly fit needs of the "as-is" Jordan Lake Rules nutrient offset crediting system, the valuation of forested lands' other ecosystem services may provide additional opportunities to incentivize and promote forest conservation (and reforestation) in the Jordan Lake watershed.

Land Development Patterns

Another concern regarding forest conservation as a nutrient offset is that the practice would not slow or reduce development in the Jordan Lake watershed; instead, developers would simply choose nearby lands for future development projects. In the long term, it would reduce the amount of land that could potentially become developed, but there is still so much other available land that the pace of new development would not be impacted. This concern is not unique to North Carolina; indeed, it is an entire branch of research within the field of forest conservation.

Theoretical land-market interactions involving conservation and nearby land were described by Armsworth et al. (2006) in terms of economic feedbacks. Purchases of land for conservation purposes tend to increase the value of surrounding lands, thus increasing the likelihood of development due to economic drivers. Fragmentation of natural lands surrounding the conservation area limit the effectiveness of conservation at large spatial scales and may even counteract the objectives of conservation. These land-market interactions were demonstrated in a study conducted by McDonald et al. (2007) which evaluated land conversion patterns in proximity to conserved lands. McDonald et al. (2007) found no correlation between development rate and proximity to conserved lands. In a few cases, development rates were higher near conservation areas, supporting the framework proposed by Armsworth et al. (2006). Zipp, Lewis, and Provencher (2017) also found that the conservation of open spaces caused land development to redistribute instead of reducing the rate of development.

Modeling studies to estimate the effects of forest conservation at larger spatial scales, similar to the size of the Jordan Lake watershed, have also been conducted. Lang, Prendergast, and Pearson-Merkowitz (2018) found that conservation decisions made at the municipal level did not have any impact on conservation decisions of neighboring jurisdictions. For example, if Greensboro elected to aggressively conserve lands, Burlington's likelihood to conserve would not increase and the watershed, as a whole, may not benefit. Dorning et al. (2015) modeled population growth and land development scenarios in the central North Carolina Piedmont to predict the effectiveness of different conservation strategies. They found that no single conservation strategy was able to preserve high-priority lands, such as riparian buffers and wetlands, while also preventing fragmentation of forested areas. Although Dorning et al. (2015) did find that certain conservation strategies can achieve some objectives more effectively than others, it can be difficult to implement a forest conservation strategy at the watershed level that meets the needs of the entire watershed. In the context of the Jordan Lake watershed, the buffer protection rules and buffer restoration efforts (with eventual placement under a conservation easement) represent the high-priority lands to conserve, but the tradeoff is that more upland areas are available for development. On the contrary, if a conservation strategy's goal is to maximize the total land area to be conserved across a watershed, the high-priority lands might have to be sacrificed for land development or agricultural expansion. Balancing these tradeoffs is a key consideration when planning a forest conservation strategy (Dorning et al., 2015).

A recently published study by Shoemaker, BenDor, and Meentemeyer (2019) combined land development models in the Charlotte region with evaluations of resultant ecosystem services. They found that no conservation approach was able to maximize nutrient retention, store additional carbon, and retain sensitive habitat. Like Dorning et al. (2015), Shoemaker, BenDor, and Meentemeyer (2019) identified tradeoffs between forest conservation and North Carolina's economic drivers. That said, the land use policy titled "increased density" was able to minimize future nutrient pollution increases as compared to other scenarios, including "decreased density," "sprawl,", "infill,", and "business-as-usual." Therefore, there is a theoretical forest conservation strategy that could support the Jordan Lake Nutrient Management Strategy's aim to minimize future nutrient load increases; however, such a strategy may not optimize other ecosystem services and would require cooperation from all jurisdictions in the watershed.

SUMMARY: CHALLENGES AND OPPORTUNITIES

Challenges

Two main challenges are preventing forest conservation from being eligible as a nutrient offset credit in the Jordan Lake watershed, per the current specifications of the Jordan Lake Rules:

1. Conservation of forested lands will not actively reduce nutrient loads from the 1997-2001 baseline condition. Although forest conservation may limit future nutrient load increases, its effectiveness is relatively uncertain (see Challenge 2).
2. Conservation of forested lands will not reduce the rate of land development within the Jordan Lake watershed; rather, future development plans will relocate to non-conserved areas within the watershed boundaries. Therefore, the collective area of urban lands (and, subsequently, nutrient loads from urban lands) will not be affected by forest conservation efforts. Furthermore, conservation goals will need to be adopted by all jurisdictional units within the watershed; otherwise, municipalities that do not formalize conservation efforts may undermine conservation goals at the watershed level.

Opportunities

Despite the above challenges, three main opportunities have been identified that may further advance forest conservation efforts in the Jordan Lake watershed.

1. Reforestation efforts may reduce the collective loads from the watershed by increasing forest coverage. However, upland reforestation will have less impact on nutrient loads than reforestation of riparian buffers. Still, there is an opportunity to incentivize reforestation of formerly agricultural lands; currently, the Jordan Lake Rules account for the reduction of productive

agricultural lands equally no matter the intended future land use (forest or urban).

2. While the rate of land development in the Jordan Lake watershed may not be impacted by forest conservation programs, the total nutrient load that reaches Jordan Lake is dependent upon land development (and conservation) patterns. Therefore, high priority lands can be targeted for conservation to minimize future nutrient load increases. High priority lands include riparian buffers, wetlands, and forested areas.
3. The existing framework for watershed management in the Jordan Lake watershed is driven by nutrients and the Jordan Lake TMDL; therefore, regulations and credits are evaluated according to nutrient loading rates. However, there are many co-benefits to forest conservation that are not accounted for in the current regulatory framework. The push for co-benefit evaluation is indeed a topic of interest across many environmental fields, not just forest conservation. Forested areas provide many ecosystem services beyond nutrient retention, and these services could be considered.

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