Effectiveness of the Neuse River Nutrient Management Strategy: A Case Study on the Influence of Land Use

by
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ABSTRACT

WEBSTER, ELISABETH. Effectiveness of the Neuse River Nutrient Management Strategy: A Case Study on the influence of Land Use. (Under the direction of Dr. Tamara Pandolfo).

Due to its vital role in contributing to the ecosystem of the APES and as a recreational and water supply watershed, the quality of water running through the Neuse River is very important to the state of North Carolina. However, the Neuse River Basin has been plagued by poor water quality primarily caused by an influx of nutrients attributed to anthropogenic sources such as agricultural and stormwater runoff. Over saturation of nitrogen and phosphorus within the basin led to eutrophic conditions, ultimately causing algal blooms, increased turbidity, low dissolved oxygen, and fish mortality. Consequently, the Neuse River was first identified as an impaired water body per Section 303(d) of the Clean Water Act in 1988. Management efforts have been in place since 1988. However, decades later the goals of the Neuse Management Strategy have not been met, and the Neuse River remains classified as nutrient sensitive waters with impaired status. This study aimed to evaluate potential sources of nutrient-enriched runoff within the basin by using Geographical Information Systems (GIS) to identify areas of developed and agricultural land with the highest potential for runoff within two representative counties, Lenoir and Wake. Results indicated that agricultural cultivated cropland was thelargest land use category in the Neuse River basin, accounting for 838,686 acres or 21% of the entire basin. Within Lenoir County there were 8,394 acres of agricultural land with a high potential for agricultural runoff, 79,066 acres with moderate potential, and 15,245 acres with low potential. In comparison, Wake County had 785 acres of agricultural lands with high potential for runoff, 18,778 acres with moderate potential, and 4,676 acres with low potential for agricultural runoff. Agriculture-based Lenoir County contained 2,128 acres of land with high potential for stormwater runoff, 21,704 acres with moderate potential, and 4,723 acres with low potential. The more developed Wake County had 28,119 acres with high potential for stormwater runoff. This was followed by an additional 147,132 acres with moderate potential, and 59,537 acres with low potential for stormwater runoff. This study suggests that significant nonpoint sources of nutrient-polluted runoff still remain within the Neuse River Basin. Although a Nutrient Management Strategy exists for the Neuse River, it may not be adequately protective against nutrient inputs from nonpoint sources. If the current rules are not eliciting the desired water quality outcomes it is unlikely that the water quality will improve or even hold steady as the population, and

corresponding urban development and agricultural operations, continues to grow . Regulatory authorities should consider additional management approaches, especially for nonpoint nutrient sources.

BIOGRAPHY

Elisabeth Webster graduated from the North Carolina University’s Environmental Technology and Management Program in 2015. After graduation, Elisabeth was an environmental consultant until 2019. During this time, she worked on multiple stream restoration projects and large NC DOT roadway projects, sparking her desire to peruse a graduate degree. As a Lenoir County native, the water quality of the Neuse River has always been an important topic for Elisabeth.

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Introduction

The Neuse River basin consists of nearly 4 million acres of land across 16 counties in North Carolina (NCDENR 2010). The Neuse originates in Durham and Orange County within the Piedmont region of the state and ends in Carteret and Pamlico County on the eastern coast. The Neuse River provides significant recreational waters and is a water supply watershed for multiple municipalities, including the City of Raleigh, Town of Garner, and City of Kinston (NCDENR 2010). In addition, the Neuse River is a major tributary for the Albemarle-Pamlico Estuarine Sound (APES) which is one of the largest estuarine systems in North America (Bhattacharya et al. 2020). Due to its vital role in contributing to the ecosystem of the APES and as a recreational and water supply watershed, the quality of water running through the Neuse River is very important to the state of North Carolina.

As the human population along the Neuse River has grown over the last century, the subsequent urbanization and industrialization has brought an increase in pollution affecting the water quality of the Neuse River (Harned 1982). Most critically for the Neuse River, the anthropogenic change from undisturbed and natural landscapes surrounding the river to urban areas and intensive agricultural areas has been identified as a primary source of increased levels of nutrients, specifically nitrogen (N) and phosphorus (P) (Wossink 2002; Mallin et al. 2009; Voli et al. 2013). N and P concentrations are crucial in maintaining estuarine ecosystems and overall water quality as they are controlling factors in primary production. Over-enrichment of N and P leads to eutrophic conditions, ultimately causing algal blooms, increased turbidity, low dissolved oxygen, and fish mortality (Harned 1982; Lebo et al. 2012)

Prior to the Clean Water Act in 1972 there were minimal regulations regarding discharges into the nation’s rivers and streams. This was also true for the Neuse River. Decades of growth and development along the Neuse River with little regulatory oversight caused the Neuse River to experience excessive eutrophication in the 1960s and 70s (Harned 1982). The resulting algal blooms and fish kills compromised the water quality of the Neuse River and threatened the overall productivity of the APES (Glasgow & Burkholder 200). The Neuse River was first identified as an impaired water body per Section 303(d) of the Clean Water Act in 1988 (NCDENR 2010). In response, the State of North Carolina passed a series of regulations to limit nutrient inputs to the system. In 1988, a phosphorus detergent ban was put in place (Lebo et al. 2012). This ban prohibited the use and sale of P-based cleaning agents and required municipalities to remove P at their waste water treatment facilities (Lebo et al. 2012). Then, in 1997, the Neuse River was designated as "nutrient sensitive waters", and a management plan was established. The Neuse River Nutrient Sensitive Waters Management Strategy went into effect in 1998. The strategy included rules intended to protect and maintain riparian buffers and to reduce nitrogen loads from stormwater, agricultural practices, and wastewater discharges (Lebo et al. 2012). The goal of the Neuse Nutrient Strategy was to reduce the average annual load of nitrogen from both point and nonpoint sources by a minimum of 30% below 1991-1995 levels (Title 15A – Environmental Quality, 15A NCAC 02B .0711 1998).

Although management efforts have been ongoing since 1988, the goals of the Neuse Management Strategy have not been met, and the Neuse River remains classified as nutrient sensitive waters with impaired status. This analysis aimed to investigate the potential role of stormwater and agricultural runoff as nonpoint sources of nutrients to the Neuse River. Geographical information Systems (GIS) was used to analyze slope and soil characteristics in two different counties within the Neuse River Basin, Wake and Lenoir. Areas of agricultural and developed land uses were isolated to identify areas with the highest potential for agricultural and stormwater runoff. Wake County represents areas of the basin experiencing rapid urbanization and consists of mostly developed land where stormwater runoff would be more prevalent. Lenoir County represents areas of the lower basin that have not experienced much development and would be more likely to contribute agricultural runoff to the Neuse River Basin. By better understanding the source and composition of runoff pollution entering the Neuse River, regulatory authorities can evaluate the effectiveness of their existing management strategies and consider adaptations for future management plan revisions.

Methods

ArcMap version 10.8.1 was used to identify and compare areas with potential for agricultural and stormwater runoff in Wake and Lenoir County within the Neuse River Basin. Runoff potential was calculated based on soil type and land slope for each land use classification.

Soil Type Reclassification

Lenoir County and Wake County Soil Survey shapefiles were obtained from the USDA Web Soil Survey (USDA 2020). Once the shapefiles were brought into GIS the attribute tables were opened and the different types of soils were examined. Lenoir County had 43 different soil types, and the Wake County soil attribute table had 78 soil types. For simplification purposes, soil types were reclassified into one of the 12 soil texture classes illustrated by the Soil Texture Triangle (Soil Survey Staff n.d.). This was done by exporting the attribute table to Microsoft Excel and adding a new column for reclassification (Table 1; Table 2). Reclassification was largely based on the soil name. For example, Norfolk loamy sand was reclassified as loamy sand. Some soils required additional research to reclassify them. Soils like Pamlico Muck and Umbric Ochraqualfs were classified based off their description in the Soil Survey for Lenoir County (Jurney & Davis 1977). Dam and Urban Land soil types were reclassified as non-soil.

Once reclassification was complete, the Excel worksheet was rejoined with the attribute table in ArcMap. Next, the Polygon to Raster tool was used to convert the vector soil shapefiles into raster datasets with the input feature being the reclassification field. This was done so that soil data was compatible for analysis alongside the land cover raster and the slope raster data.

Table 1: Lenoir County Soil Name and Reclassification

MUSYM	Soil Name	Soil Reclassification
BB	Bibb soils, frequently flooded	sandy loam
Bn	Blanton sand, 0 to 6 percent slopes	sand
Ch	Chewacla loam, frequently flooded	loam
Co	Coxville loam	loam
Cr	Craven fine sandy loam, 1 to 4 percent slopes	sandy loam
Cv	Craven fine sandy loam, 4 to 8 percent slopes	sandy loam
GoA	Goldsboro loamy sand, 0 to 2 percent slopes, Southern Coastal Plain	loamy sand
Gr	Grifton sandy loam	sandy loam
JS	Johnston soils	loam
Jo	Johns sandy loam	sandy loam
Ka	Kalmia loamy sand, 0 to 2 percent slopes	loamy sand
Kb	Kalmia loamy sand, 2 to 6 percent slopes	loamy sand
Ke	Kenansville loamy sand, 0 to 6 percent slopes	loamy sand
Kn	Kinston loam, frequently flooded	loam
Le	Leaf loam	loam

Table 1: Lenoir County Soil Name and Reclassification Continued

La	Lakeland sand, 0 to 6 percent slopes	sand
Ln	Lenoir loam	loam
Lo	Leon sand	Sand
Lu	Lumbee sandy loam	sandy loam
Ly	Lynchburg sandy loam, 0 to 2 percent slopes	sandy loam
Me	Meggett fine sandy loam	sandy loam
Mu	Murville fine sand	sand
Na	Norfolk loamy sand, 0 to 2 percent slopes	loamy sand
Nb	Norfolk loamy sand, 2 to 6 percent slopes	loamy sand
Nc	Norfolk loamy sand, 6 to 10 percent slopes	loamy sand
Pa	Pactolus loamy sand	loamy sand
Pc	Pamlico muck	sandy loam
Pe	Pantego loam	loam
Po	Pocalla loamy sand, 0 to 6 percent slopes	loamy sand
Pr	Portsmouth loam	loam
Ra	Rains sandy loam, 0 to 2 percent slopes	sandy loam
St	Stallings loamy sand	loamy sand
To	Torhunta loam	loam
Uo	Umbric Ochraqualfs	loam
W	Water	water
Wb	Wagram loamy sand, 0 to 6 percent slopes	loamy sand
Wc	Wagram loamy sand, 6 to 10 percent slopes	loamy sand
Wd	Wagram loamy sand, 10 to 15 percent slopes	loamy sand
Wk	Wickham loamy sand, 1 to 6 percent slopes	loamy sand
Wn	Woodington loamy sand	loamy sand
Bp	Borrow pit	sand
M-W	Miscellaneous water	water
Go	Goldsboro loamy sand, 0 to 2 percent slopes, Atlantic Flatwoods	loamy sand

Table 2: Wake County Soil Name and Reclassification

MUSYM	Soil Name	Soil Reclassification
CrD	Creedmoor-Green Level complex, 10 to 15 percent slopes	sandy loam
CrB	Creedmoor-Green Level complex, 2 to 6 percent slopes	sandy loam
CrC	Creedmoor-Green Level complex, 6 to 10 percent slopes	sandy loam
EnB	Enon fine sandy loam, 2 to 6 percent slopes	sandy loam
EnC	Enon fine sandy loam, 6 to 10 percent slopes	sandy loam
GeB	Georgeville silt loam, 2 to 6 percent slopes	silt loam
GeC	Georgeville silt loam, 6 to 10 percent slopes	silt loam
HeB	Helena sandy loam, 2 to 6 percent slopes	sandy loam
HrB	Herndon silt loam, 2 to 6 percent slopes	silt loam
HrC	Herndon silt loam, 6 to 10 percent slopes	silt loam
VaB	Vance sandy loam, 2 to 6 percent slopes	sandy loam
W	Water	water
EnD	Enon fine sandy loam, 10 to 15 percent slopes	sandy loam
GoA	Goldsboro sandy loam, 0 to 2 percent slopes	sandy loam
HrD	Herndon silt loam, 10 to 15 percent slopes	silt loam
NaE	Nanford silt loam, 15 to 25 percent slopes	silt loam
RaA	Rains sandy loam, 0 to 2 percent slopes	sandy loam
RoA	Roanoke loam, 0 to 2 percent slopes, occasionally flooded	loam
LyA	Lynchburg sandy loam, 0 to 2 percent slopes	sandy loam
CaB	Carbonton-Brickhaven complex, 2 to 6 percent slopes	silt loam
CaC	Carbonton-Brickhaven complex, 6 to 10 percent slopes	silt loam
CaD	Carbonton-Brickhaven complex, 10 to 15 percent slopes	silt loam
DAM	Dam	clay
Ur	Urban land	clay
ChA	Chewacla and Wehadkee soils, 0 to 2 percent slopes, frequently flooded	loam
DuB	Dothan-Urban land complex, 0 to 6 percent slopes	sandy loam
AuA	Augusta fine sandy loam, 0 to 2 percent slopes, rarely flooded	sandy loam
DoA	Dothan loamy sand, 0 to 2 percent slopes	loamy sand
DoB	Dothan loamy sand, 2 to 6 percent slopes	loamy sand
NaD	Nanford silt loam, 10 to 15 percent slopes	silt loam
PaC	Pacolet sandy loam, 6 to 10 percent slopes	sandy loam
PaD	Pacolet sandy loam, 10 to 15 percent slopes	sandy loam
PaE	Pacolet sandy loam, 15 to 25 percent slopes	sandy loam
MrA	Merry Oaks-Moncure complex, 0 to 2 percent slopes, occasionally flooded	silt loam
VaC	Vance sandy loam, 6 to 10 percent slopes	sandy loam
AaA	Altavista fine sandy loam, 0 to 4 percent slopes, rarely flooded	sandy loam
ApB	Appling sandy loam, 2 to 6 percent slopes	sandy loam
ApC	Appling sandy loam, 6 to 10 percent slopes	sandy loam

Table 2: Wake County Soil Name and Reclassification Continued

BbA	Bibb sandy loam, 0 to 2 percent slopes, frequently flooded	sandy loam
CcC	Carbonton-Brickhaven-Urban land complex, 0 to 10 percent slopes	silt loam
CeB	Cecil sandy loam, 2 to 6 percent slopes	sandy loam
CeC	Cecil sandy loam, 6 to 10 percent slopes	sandy loam
CfC	Cecil-Urban land complex, 2 to 10 percent slopes	sandy loam
CuC	Creedmoor-Green Level-Urban land complex, 2 to 10 percent slopes	sandy loam
DaA	Dorian sandy loam, 0 to 4 percent slopes, rarely flooded	sandy loam
GrC	Gritney sandy loam, 6 to 10 percent slopes	sandy loam
MaD	Madison sandy loam, 10 to 15 percent slopes	sandy loam
MaE	Madison sandy loam, 15 to 25 percent slopes	sandy loam
MaB	Madison sandy loam, 2 to 6 percent slopes	sandy loam
MaC	Madison sandy loam, 6 to 10 percent slopes	sandy loam
MdB	Mayodan sandy loam, 2 to 6 percent slopes	sandy loam
MdC	Mayodan sandy loam, 6 to 10 percent slopes	sandy loam
PbD	Pacolet-Urban land complex, 10 to 15 percent slopes	sandy loam
PkF	Pinoka gravelly fine sandy loam, 15 to 30 percent slopes	sandy loam
PkD	Pinoka gravelly fine sandy loam, 4 to 15 percent slopes	sandy loam
RgD	Rawlings-Rion complex, 10 to 15 percent slopes	loamy sand
RgB	Rawlings-Rion complex, 2 to 6 percent slopes	loamy sand
RgC	Rawlings-Rion complex, 6 to 10 percent slopes	loamy sand
RkA	Riverview fine sandy loam, 0 to 2 percent slopes, occasionally flooded	sandy loam
UdE	Udorthents loamy, 0 to 25 percent slopes	loam
WaD	Wake-Rolesville complex, 10 to 15 percent slopes, very rocky	loamy sand
WaE	Wake-Rolesville complex, 15 to 25 percent slopes, very rocky	loamy sand
WaB	Wake-Rolesville complex, 2 to 6 percent slopes, very rocky	loamy sand
WaC	Wake-Rolesville complex, 6 to 10 percent slopes, very rocky	loamy sand
WeD	Wedowee sandy loam, 10 to 15 percent slopes	sandy loam
WeE	Wedowee sandy loam, 15 to 25 percent slopes	sandy loam
WeB	Wedowee sandy loam, 2 to 6 percent slopes	sandy loam
WeC	Wedowee sandy loam, 6 to 10 percent slopes	sandy loam
WfB	Wedowee-Saw complex, 2 to 6 percent slopes	sandy loam
WgB	Wedowee-Urban land complex, 2 to 6 percent slopes	sandy loam
WgC	Wedowee-Urban land complex, 6 to 15 percent slopes	sandy loam
WhD	White Store-Polkton complex, 10 to 15 percent slopes	sandy loam
WhB	White Store-Polkton complex, 2 to 6 percent slopes	sandy loam
WhC	White Store-Polkton complex, 6 to 10 percent slopes	sandy loam
WkF	Wilkes loam, 15 to 30 percent slopes	loam
FrB	Fuquay loamy sand, 0 to 6 percent slopes	loamy sand
FuB	Fuquay-Urban land complex, 0 to 6 percent slopes	sandy loam

Slope Calculation

Digital Elevation Model (DEM) data was obtained from the USGS Earth Explorer Access Viewer (USGS 2010) to assess slope within the Neuse River Basin. Once the raster was brought into GIS it was clipped to the Lenoir County shapefile using the Extract by Mask tool. Next, the Slope tool was used to calculate the percent slope of Lenoir County. This process was repeated for Wake County with the additional step of using the Mosaic to New Raster tool to combine the two DEM tiles needed to cover Wake County.

Land Cover Classification

Agricultural and developed land uses were extracted from the National Land Cover Database (USGS 2021). Once the land cover raster was added to the map document, the Extract by Mask tool was used to clip the raster to the Neuse River basin shapefile that was downloaded from NC One Maps database. Then the Extract by Attribute tool was used to isolate the cultivated crop area as a measure of agricultural land use, and the developed land area was used as a measure of land use with stormwater potential within the basin. All developed land categories were included, including high, medium, and low intensity, as well as developed open space. Next, the Zonal Geometry as Table tool was used to calculate the total area of cultivated crop land and developed land in the Neuse River Basin.

Runoff Potential

Once the soil shape file was converted to a raster data file and the DEM file was converted to a raster of percentage slope, the Reclassify tool was used to classify the values of the slope and soil rasters based on their potential for contributing to runoff in the Neuse River Basin (Table 3; Table 4). Since the goal was to identify areas of high potential runoff, soils were reclassified based off their texture and permeability. Soil types such as sand and loamy sand were assigned low values due to their porous nature and high infiltration rate (Mahmoud & Alazba 2015). In contrast, loam and silt soils were given higher values because of their low permeability and greater potential for contributing to runoff (Mahmoud & Alazba 2015). To reclassify the slope raster, greater slope percentages were given higher values to account for the increased water velocity anticipated on steeper slopes (Mahmoud 2015; Aragaw et al. 2021).

Table 3: Reclassification Values for Slope and Soil Type in Lenoir County

Soil Type	Reclass Value	Slope Percentage	Reclass Value
Water	0	0 - 2.92	1
Sand	1	2.92 5.0	2
Loamy Sand	2	5.0 – 9.1	3
Sandy Loam	3	9.1 - 100	4
Loam	4		

Table 4: Reclassification Values for Slope and Soil Type in Wake County

Soil Type	Reclass Value	Slope Percentage	Reclass Value
Water	0	0 - 2.92	1
Non-soil	0	2.9 - 5.0	2
Loamy Sand	2	5.0 - 9.1	3
Sandy Loam	3	9.1 - 100	4
Loam	4		
Silt loam	5		

Lastly, the weighted overlay tool was used to identify overall runoff potential within the Neuse River basin by assessing the reclassified slope raster alongside the reclassified soil raster. Both slope and soil were weighted equally in this analysis. The evaluation scale of the weighted overlay is from 1 through 9, where 1 indicates areas with the lowest potential for runoff and 9 indicates areas with the highest potential for runoff. Values of 1-3 were considered to have low potential for run off, values of 4-6 were considered to have moderate potential for runoff, and values of 7-9 were considered to have high potential for runoff. Areas within the basin that had the greatest runoff potential were associated with dense, less permeable soils and sloped elevation.

Results

The largest land use category in the Neuse River basin is cultivated crops, taking up 838,686 acres or 21% of the entire basin (Figure 1). This is followed by woody wetlands at 19% of the basin, taking up 751,345 acres. The third largest land use is developed land consisting of 573,452 acres or 15%. Developed land is the largest use of land in Wake County, occupying 235,113 acres or 42% of the county (Table 5). The next largest land use in Wake County is evergreen forest and mixed forest occupying 73,826 and 72,153 acres respectively, making up an additional

26% of the land in Wake County. Only 4% or 24,154 acres of Wake County is dedicated to cultivated crop land. In comparison, 40% (103,372 acres) of Lenoir County is dedicated to cultivated crop land and is the largest land use in the county (Table 5). This is followed by woody wetlands at 54,215 acres at 21% of the county. Only 28,686 acres or 11% of Lenoir County is developed land. The predominant soil type in Wake County is sandy loam, making up 55.24% of the soils, followed by loamy sand making up an additional 18.65% (Table 6). Lenoir County consists of mostly loamy sand, making up 50% of the county, followed by sandy loam making up an additional 24% (Table 6). Lenoir County had 8,394 acres of agricultural land identified as having a high potential for runoff, 79,066 acres identified as having a moderate potential for runoff, and 15,245acres of agricultural lands identified as having a low potential for runoff (Figure 2; Table 7). In comparison, Wake County had 785 acres of agricultural lands that are identified as having a high potential for runoff, 18,778 acres that are identified as having a moderate potential for runoff, and 4,676 acres of agricultural lands that are identified as having a low potential for runoff (Figure 3; Table 7). Lenoir County contained 2,128 acres of land identified as having a high potential for stormwater runoff, 21,704 acres of moderate potential, and 4,723 acres identified as low potential for stormwater runoff (Figure 4; Table 7). Wake County had 28,119 acres identified as having a high potential for stormwater runoff. Followed by 147,132 acres identified as having a moderate potential for runoff, and 59,537 acres identified as having a low potential for runoff (Figure 5; Table 7).

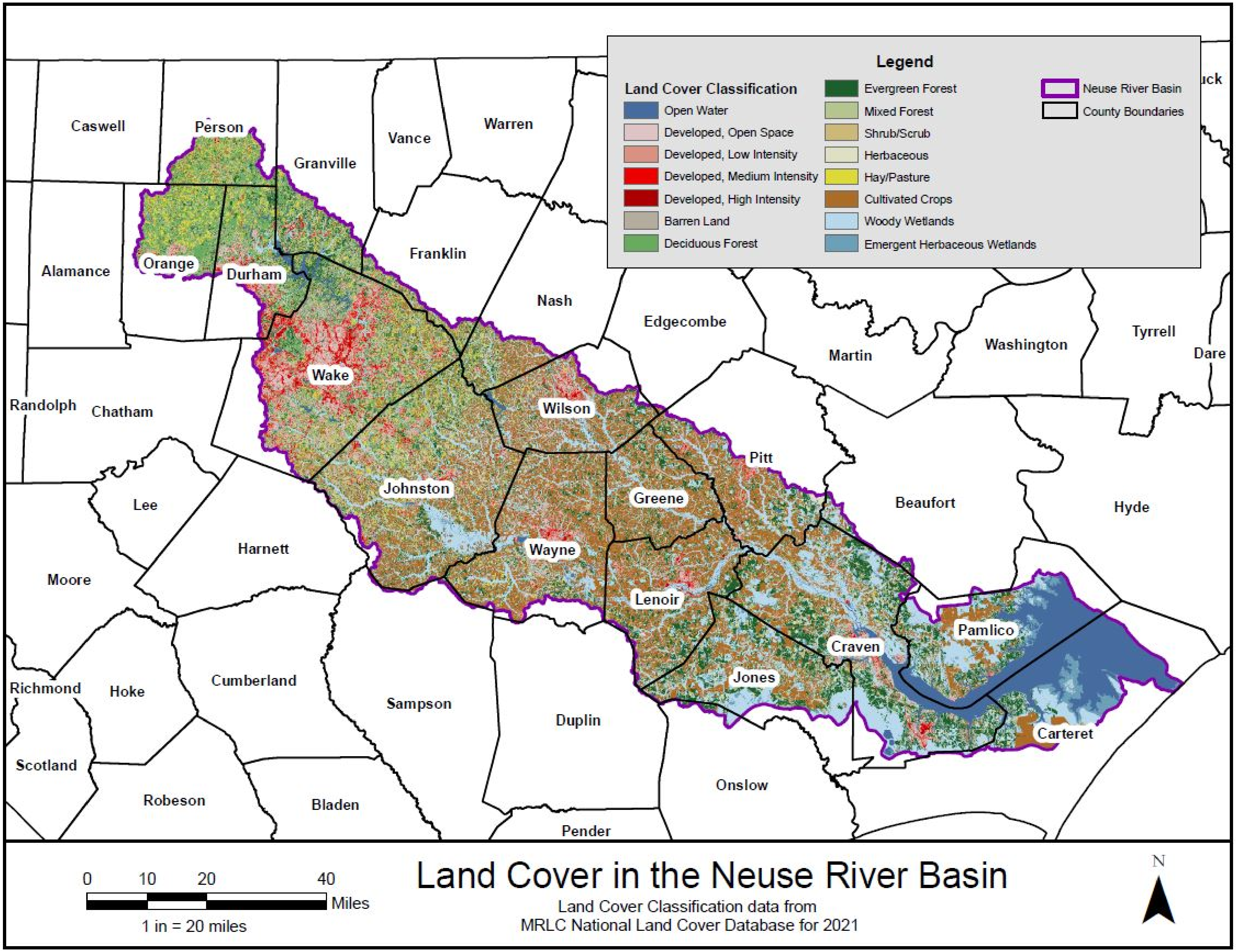


Figure 1. Land Use Classifications that make up the land cover in the Neuse River Basin, NC.

Table 5: Land Cover Area in Wake and Lenoir County, NC

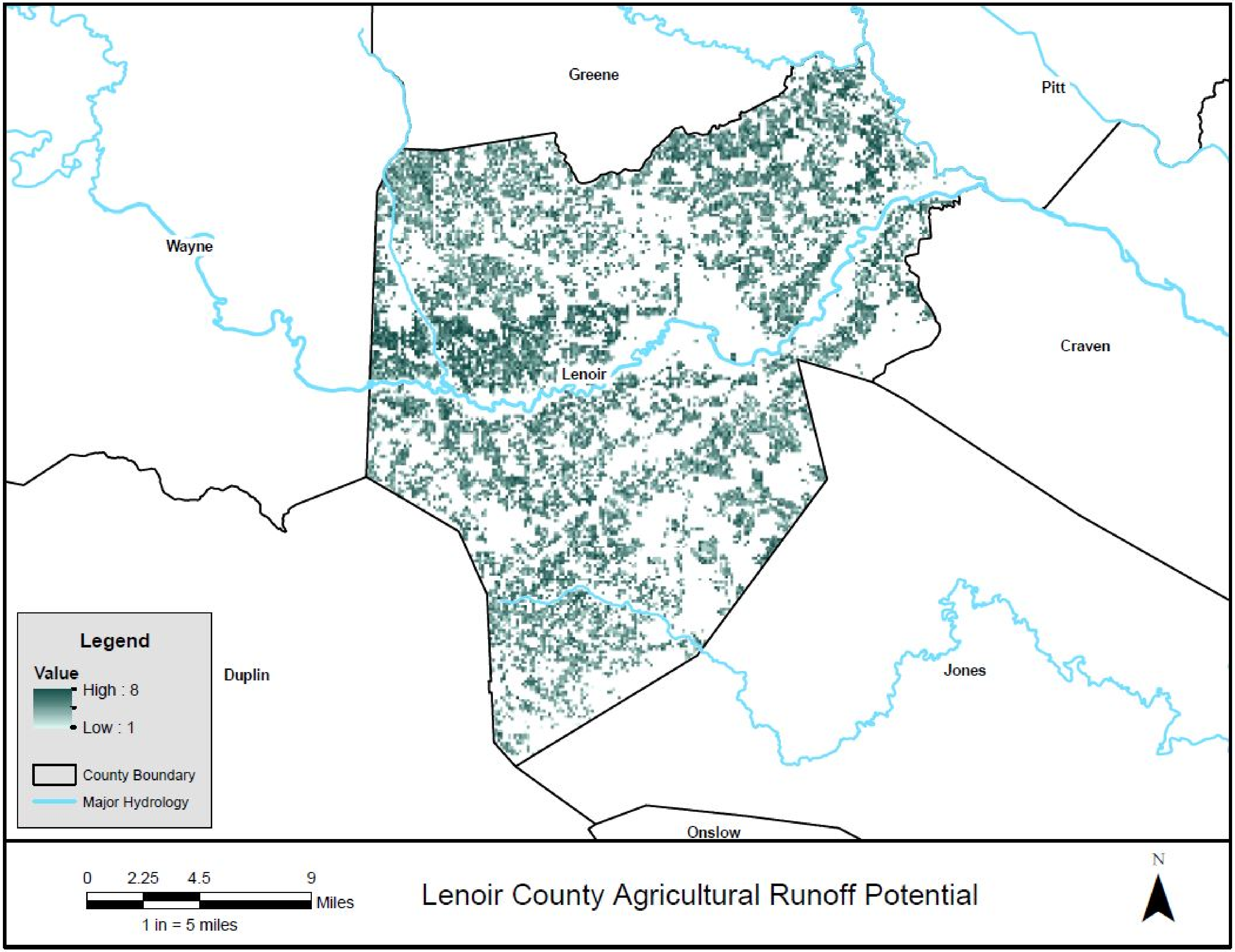
Land Cover	Lenoir County	Wake County
	Area (acres)	Area (acres)
Total Developed	28,686	235,113
Cultivated Crops	103,372	24,154
Other Land Uses		
Barren Land	157	2,170
Deciduous Forest	1,516	48,139
Evergreen Forest	40,126	73,826
Mixed Forest	6,668	72,153
Shrub/Scrub	8,770	5,244
Herbaceous	5,592	13,391
Hay/Pasture	1,765	34,548
Woody Wetlands	54,216	22,148
Emergent Herbaceous	3,448	1,615

Table 6: Soil Composition of Wake and Lenior County, NC

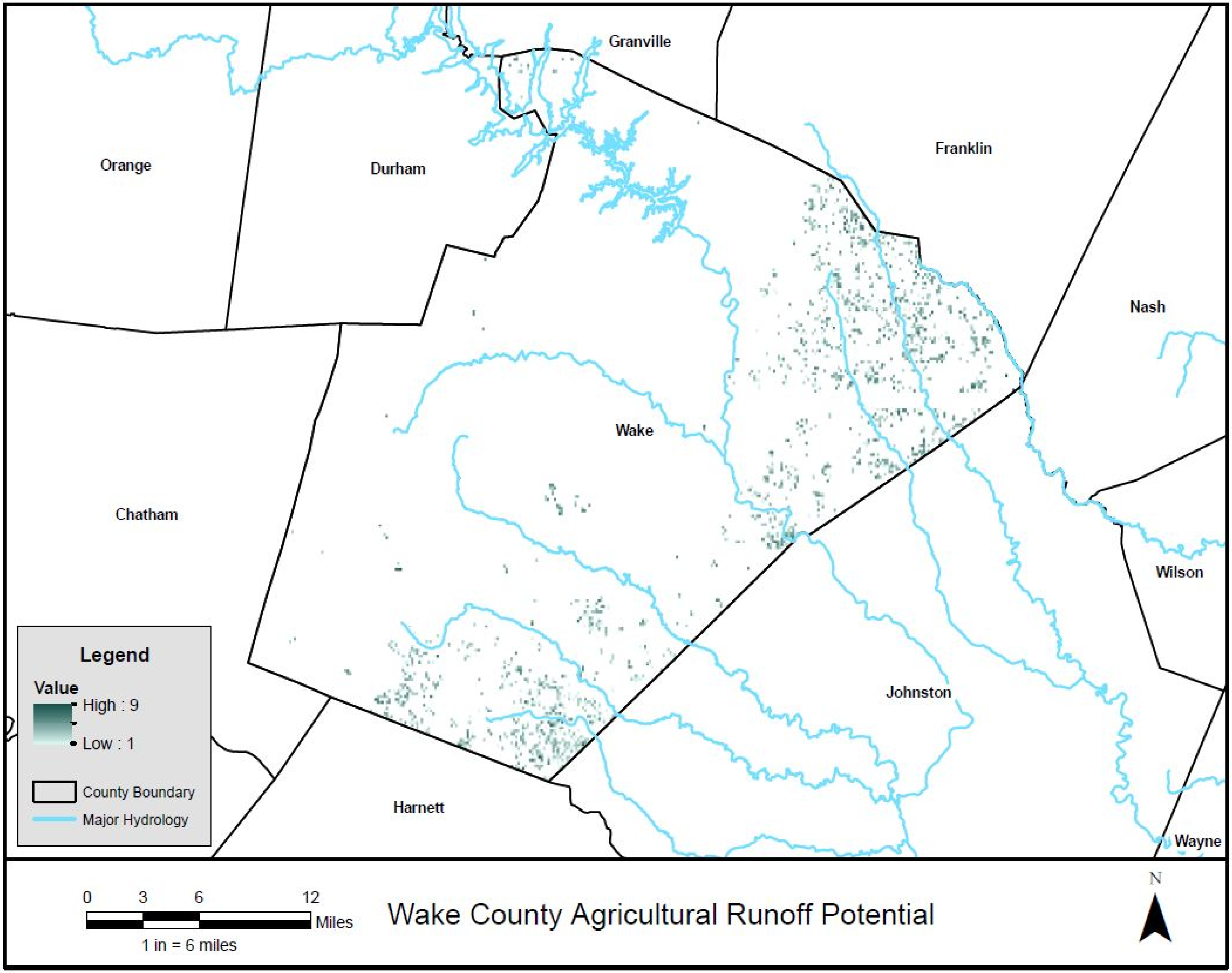
LENIOR COUNTY		
Soil Type	**Area (acres)**	**Percentage**
Loamy Sand	129,362	50%
Sandy Loam	62,415	24%
Sand	16,953	17%
Loam	45,946	15%
Water	2,401	4%
WAKE COUNTY		
Soil Type	**Area (acres)**	**Percentage**
Loamy Sand	101,958	19%
Sandy Loam	302,742	55%
Loam	49,436	9%
Silt Loam	13,693	3%
Clay	62,467	11%
Water	17,799	3%

Table 7: Areas of Potential Runoff in Lenoir and Wake County, NC

	Stormwater Land (acres)		Agricultural Land (acres)	
	Lenoir County	Wake County	Lenoir County	Wake County
Low	4,723	59,537	15,245	4,676
Moderate	21,704	147,132	79,066	18,778
High	2,128	28,119	8,394	785



Lenoir County Agricultural Runoff Potential



Wake County Agricultural Runoff Potential

Discussion

This study suggests that significant nonpoint sources of nutrient-polluted runoff exist within the Neuse River Basin. In urbanized, highly developed Wake County, there are over 28,000 acres of land with a high potential for stormwater runoff. In Lenoir County, a less populated, agriculture-centered county, more than 8,000 acres of cropland exhibit significant runoff potential. Although a Nutrient Management Strategy exists for the Neuse River, it may not be adequately protective against nutrient inputs from nonpoint sources. A comprehensive understanding of nonpoint nutrient sources, such as agricultural and stormwater runoff, is important for evaluating and implementing effective management strategies.

The Role of the Neuse River Basin

With the Neuse River's designation as a water supply watershed and its integral role in the ecological and economic productivity of the APES, maintaining acceptable water quality is crucial. The Neuse River contains reservoirs that serve as drinking water supplies for multiple municipalities in the basin (NCDENR 2010). The most notable is Falls Lake, which is located at the top of the basin and provides the City of Raleigh with drinking water. In addition to Falls Lake there are 14 other drinking water supply reservoirs throughout the Neuse River. In addition to being a water supply water shed, the Neuse River also provides critical habitat for endangered and protected species (NCDENR 2010). For example, the Eno River, a major tributary of the Neuse River located in Durham and Orange County, contains the only North Carolina population of the panhandle pebblesnail as well as 13 other rare species (NCDENR 2010). The Neuse River is also home to a number of state-listed mollusk species, the majority of them being freshwater mussels (NCDENR 2010).

Additionally, the Neuse River is a tributary for the APES, one of the largest estuarine ecosystems in the United States (Glasgow & Burkholder 2000; Pearlet al. 2006). The APES plays a crucial role as a nursery for almost all the commercial seafood species caught in North Carolina as well as spawning habitat for multiple fish species (Glasgow & Burkholder 2000; NCDEQ 2013). Due to the shallow waters and lack of tidal effect of the APES, nutrients in the APES remain and are recycled numerous times, making the sound very sensitive to nutrient inputs (Glasgow & Burkholder 2000; Pearl et al. 2006).

Elevated Nutrients in the Neuse River Basin

Nutrient levels in the Neuse River have been high for several decades leading to toxic algal blooms and low dissolved oxygen levels (Harned 1982; Lebo et al. 2012). Although the Neuse River Basin makes up only 20% of the drainage area for the APES, it is estimated that the Neuse River contributes 35% of N and 50% of P loading into the APES (Glasgow & Burkholder 2000). These anthropogenic sources of nutrient loading have been identified as a key factor in harmful algal blooms (HABs) (Hathaway et al. 2012).

Research suggests that agricultural operations such as cultivated cropland are a major contributor of N and P inputs (Wossink 2002). This study found agriculture to be the largest land use currently in the Neuse River Basin. While this study focused specifically on runoff potential for row crop production, other agricultural operations such as swine and poultry production exist in the Neuse River Basin. These operations are likely contributing to non-point sources of N and P entering the water through lagoon seepage and runoff (Glasgow & Burkholder 2000). In addition to nonpoint runoff from agricultural activities, nutrient runoff from urban and industrial development and impervious surface adversely affects water quality and ecosystem health (Allan 2004; Hathaway et al. 2012).

Effectiveness of a Management Plan in a Dynamic System

In response to nuisance blue-green algal blooms plaguing the upper Neuse River during the late 1970s and 80s, nutrient management rules were enacted. The first of these rules was a P detergent ban. The impetus for this was the determination that the freshwater portion of the Neuse River is P-limiting (Paerl et al. 2004). The North Carolina General Assembly passed §43-214.4 in 1987 which prohibited the production or sale of cleaning agents containing P in addition to requiring municipalities that discharge to nutrient sensitive waters to remove P at their waste water treatment plants (Title 15A – Environmental Quality, 15A NCAC 02B .0713 ; Paerl et al. 2004). While the P detergent ban effectively decreased P concentrations in the upper Neuse River, it increased the N:P concentration ratio in the lower river. This led to large-scale fish kills in the lower basin in the 1990s that caused great public concern. As a result, The Neuse River Nutrient Sensitive Waters Management Strategy was established in 1997 (Title 15A – Environmental Quality, 15A NCAC 02B .0233 1997). The primary goal of this strategy was to limit N loading in the Neuse River Basin. The management strategy established rules pertaining to stormwater, agricultural runoff, waste water discharge, and riparian buffer protection. The stormwater nutrient strategy required local governments and municipalities to implement stormwater management plans and required new development in those municipalities to meet rule standards. These rules also required municipalities to develop a plan to ensure maintenance of stormwater control measures (SCMs), to develop a plan to ensure enforcement and compliance of the rules, to develop a public education program, to develop a mapping program that includes the major components of the stormwater system, and to develop a program to identify and remove illegal discharges. When first passed in 1997, fifteen municipalities were designated to comply, including Raleigh, Garner, Cary, and Wake County. In 2020 when the stormwater nutrient strategy was readopted, an additional fourteen municipalities were designated. The agricultural nutrient rule requires agricultural producers to implement land management practices such that on a basin level, a 30% reduction in total N from the 1991-1995 base level is achieved. This rule also established advisory and oversight committees to monitor and report on progress. The wastewater rule established total maximum daily loads (TMDLs) for point source discharges within the basin that are associated with an NPDES permit. (Lebo et al. 2012; Stow et al. 2001). Finally, the riparian buffer rule required that the first 50-feet from the top of bank of all intermittent streams, perennial streams, lakes, ponds, and reservoirs shown on the latest USGS and latest Soil Survey remain untouched to help preserve their nutrient removal abilities. All of these rules were most recently readopted in 2020 by the state legislature.

Dual nutrient management strategies have been used successfully in other waterbodies, such as the Chesapeake Bay. Successful nutrient management strategies are critical for maintaining water quality, especially in estuarine basins like the Neuse River where nutrients actively cycle and have long residence times (Paerl et al. 2004; Glasgow et al. 2000). There has been some success since the implementation of the Neuse River Nutrient Management Strategy. Point source N loads have been reduced by 65%, and agricultural inputs have been reduced by an estimated 45% (NCDEQ 2009). Since the Nutrient Management Strategy went into effect, almost 2,000 fertilizer applicators have received training on nutrient management practices. Additionally, certain portions of the Neuse River have been removed from the 303(d) list (NCDEQ 2009). However, after over two decades of dual nutrient management is the Neuse River, there has not been a significant reduction in nutrient loading to the Neuse estuary, nor has the original goal of an overall 30% reduction in nitrogen from the 1991-19995 base line level been achieved (DEQ 2009).

This may be at least partially attributed to the fact that over 70% of N and P inputs are from nonpoint sources (Paerl et al. 2006; Stow et al. 2001). Nonpoint sources have continued to increase since the 1960s (Paerl et al. 2004). While TMDLs are helpful in limiting point sources they are not as effective on nonpoint sources, such as agricultural and stormwater runoff unless there is sustained interest from relevant stakeholders (Voli et al. 2013). This analysis determined that Wake County has a combined 29,000 acres of high potential for stormwater and agricultural runoff and an additional 166,000 combined acres of moderate potential for runoff, accounting for 36% of all the land in Wake County. Comparatively, Lenoir County has 10,500 acres of high potential for runoff and an additional 100,000 acres of moderate potential for stormwater and agricultural runoff, making up 43% of the county acreage. These results demonstrate the potential for significant nutrient loading into the Neuse River Basin from nonpoint runoff sources.

Another reason why major water quality improvements have yet to be seen in the Neuse River could be inadequate data behind the original regulations. The original 30% reduction target for nitrogen in the Neuse River was based on its similarities to the Pamlico River. However, differences exist between the two rivers such as the fact that the Pamlico River sit on major geological P deposits (Glasgow et al. 2000). Glasgow et al. 2000 speculate that the bioassays used for N were a decade old at the time and only accounted for the upper freshwater portion of the Neuse River and not the lower estuarine portion. Additionally, the literature suggests that had the original 30% N reduction goal been set just ten percent higher at 40%, the N reduction could have resulted in a 50% decrease in the chlorophyll a standard (Glasgow et al. 2000). This indicates that a more ambitious goal may be necessary to enable substantial improvement in the Neuse River.

Existing nutrient managements rules for the Neuse River were readopted in 2020 although the lack of improved water quality over the previous 20 years suggest that the current rules are not adequate to address the issues facing the Neuse River. If the current rules are not eliciting the desired water quality outcomes it is unlikely that the water quality will improve or even hold steady as the population continues to grow, and increases in development and intense agricultural operations occur. Regulatory authorities should consider additional management approaches, especially for nonpoint sources. A starting point could be enacting more lucrative cost share methods with local farmers to incentivize nitrogen load reduction on a more individual scale. Additionally, it is important to ensure that SCMs set out the stormwater management plan account for seasonal changes and predicted increases in storm events with potentially significant rainfall as the climate continues to change over coming decades.

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