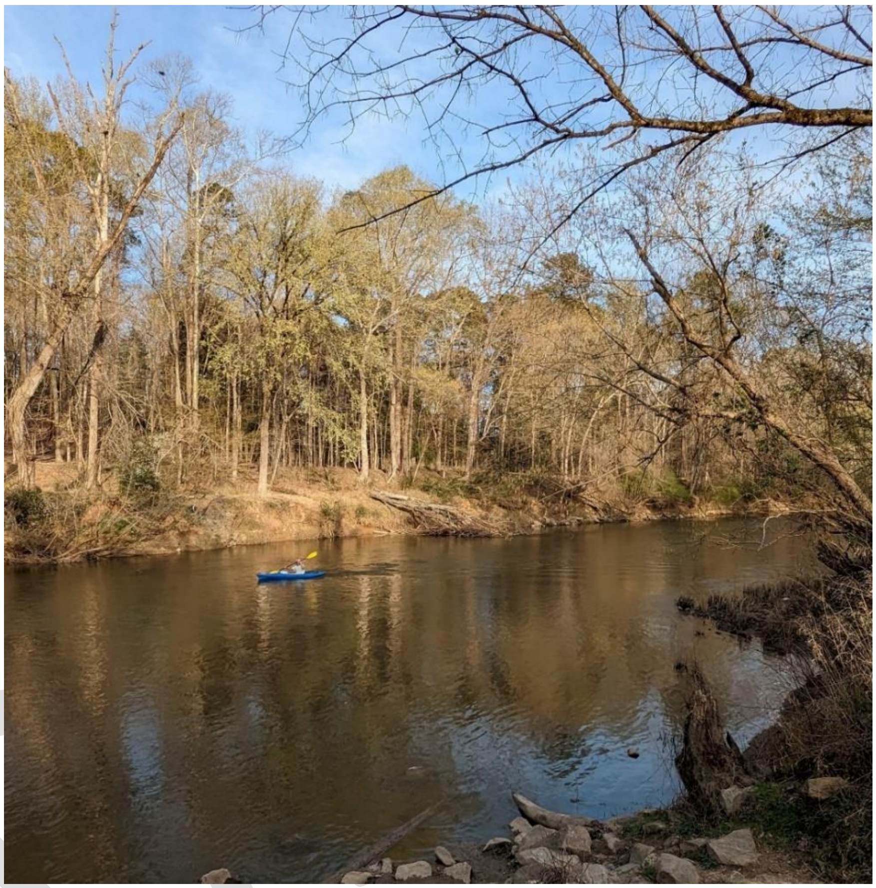
20-Year Neuse and Tar-Pamlico Nutrient Management Strategy Retrospective:

An Analysis of Implementation and Recommendations for Adaptive Management - *DRAFT*



Neuse River – Quarter Mile Below Falls Dam (2023)

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Developed by the N.C. Division of Water Resources
Nonpoint Source Planning Branch

NORTH CAROLINA
Department of Environmental Quality

The Nonpoint Source Planning staff gratefully acknowledges the input and recommendations offered by the following individuals and organizations during various stages of this report:

Adugna Kebede, N.C. Division of Water Resources
Allie Dinwiddie, N.C. Division of Soil & Water Conservation
Andy Painter, N.C. Division of Water Resources
Daniel Wiltsie, N.C. Division of Water Resources
David Williams, N.C. Division of Soil & Water Conservation
Craig Hoover, N.C. Division of Water Resources
Ellie Rauh, N.C. Division of Water Resources
Elliot Tardiff, N.C. Division of Air Quality
Elizabeth Fensin, N.C. Division of Water Resources
Forest Shepherd, N.C. Division of Water Resources
Haywood Phthisic, Neuse River Compliance Association & Tar-Pamlico Basin Association
Joey Hester, N.C. Division of Water Resources
Katie Merritt, N.C. Division of Water Resources
Kelly Williams, N.C. Division of Mitigation Services
Mark Vander Borgh, N.C. Division of Water Resources
Michelle Raquet, N.C. Division of Water Resources
Nathaniel Thornburg, N.C. Division of Water Resources
Niki Maher, N.C. Division of Water Resources
Nora Deamer, N.C. Division of Water Resources
Pam Behm, N.C. Division of Water Resources
Rajbhandari Narayan, N.C. Division of Water Resources
Rich Gannon, N.C. Division of Water Resources
Sushama Pradhan, N.C. Department of Health and Human Services
Trish D'Arconte, N.C. Division of Water Resources
Virginia Baker, N.C. Division of Water Resources

Questions or comments regarding this report may be directed to:

N.C. Division of Water Resources
Nonpoint Source Planning Branch
1617 Mail Service Center
Raleigh, NC 27699-1617

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Executive Summary

Two sets of rules enacted in succession over twenty years ago as the Neuse and Tar-Pamlico nutrient strategies represent North Carolina's first attempts at comprehensive, point and nonpoint source regulation intended to remedy the nutrient over-enrichment of these basin's estuaries. Both strategies achieved some progress, however both estuaries remain roughly as impaired today as they were when the strategies were launched. This analysis of strategies implementation, estuary conditions, watershed changes and adaptive needs suggests that nutrient reduction progress has been largely limited to point source improvements. In the more challenging field of nonpoint source management, various design features of the rules have limited their effectiveness. These include incomplete assignment of needed reductions, as well as accounting deficiencies based in limited technical information and resources at the time. As a result, it appears that loading from developed lands has increased substantially, possibly doubling, while loading from cropland agriculture does not appear to have decreased meaningfully. Watershed modeling suggests that agricultural lands are more susceptible to increased loading under high precipitation conditions, with unit-area loading dominance shifting to agricultural lands in high precipitation years and to urban areas in low precipitation years.

Analyses of nitrogen loading to the two estuaries have clearly documented a substantial decadal or longer rise in organic nitrogen delivery to both beginning around 2000, accompanied by strong evidence of the same phenomenon occurring in the Albemarle Sound as well, suggesting a broader pattern. This increase has offset the nitrogen loading gains made by point sources. An interinstitutional team of researchers has now established compelling evidence that since the late 1990's, distinct increases have occurred in coastal NC rainfall and flooding from intensified tropical cyclone activity and these storms have, among other effects, mobilized large amounts of previously stored dissolved organic carbon from freshwater wetlands, and have substantially increased nutrient loading from the watershed, including dissolved organic nitrogen, to the estuaries along with driving increased productivity in and carbon release from the estuaries and sound. The authors conclude that "we appear to have entered a new climatic regime characterized by more frequent extreme precipitation events, with major ramifications for hydrology, cycling of C, N and P, water quality and habitat conditions in estuarine and coastal waters" (Paerl et al, 2020).

Regarding organic nitrogen sources, evidence on animal operations suggests that poultry waste, which is effectively barred from regulation through statutory "deemed permitted" standards, may be contributing significant organic nitrogen loading to the Neuse estuary, on a scale rivaling point source organic nitrogen loading. There is also some evidence of increases in organic N loading from various development-related sources.

While these findings highlight a set of challenges, they also provide a basis for considering adaptive management and knowledge acquisition needs. Nonpoint Source Planning staff offer initial thoughts for the next iteration of basin nutrient strategies. Given the length of time since estuary needs were established (over 20 to over 30 years), given the compelling evidence captured here that a climatic shift has occurred affecting estuary dynamics, and given the likely advent of an additional nutrient-related estuary standard, clarity, reassessment of estuary nutrient reduction needs would seem to make sense for both basins from a conceptual standpoint. Beyond reevaluating estuary needs, certain adaptive actions would follow the path of more recent freshwater nutrient strategies. They would include fuller allocation of load reduction needs, potentially including redistribution of loads from sources not further managed, and tasking local governments with reducing loads from existing developed lands. It would appear important to address several sources of "leakage" in post-construction stormwater requirements, including treatment thresholds, offset crediting and hydrologic impacts to receiving streams. Responding to the impacts of climatic shifts appears important. One area of focus could involve expanding the set of management tools for local nutrient compliance with ecosystem restoration-focused management actions such as stream restoration, floodplain reconnection, regenerative stormwater conveyances, and renovation of hardened urban watercourses. Another need would appear to involve revisiting agricultural practices toward improving nutrient retention in the face of more challenging climatic conditions. An obvious program to seek accelerated implementation of is the Lagoon Buyout program. Another appropriate agricultural objective would seem to be increased implementation of livestock exclusion from streams. It would also appear important to establish greater transparency on poultry waste management practices to determine where improvement opportunities may exist. It would probably be useful to establish an interagency dialogue toward recommendations for improving dry litter management. Other potential strategy improvements can include addressing wastewater discharges that are currently below thresholds for receiving permit nutrient limits, and requiring waste application on higher risk fields to apply at phosphorus-based agronomic rates.

While DWR nutrient strategy planning priorities are currently focused on other watersheds, this report provides a sound start for consideration of adaptive management needs and possibilities, as well as knowledge and policy areas in which to build our understanding to better support improvements in the design of the next iteration of these important management initiatives.

Introduction

The Neuse and Tar-Pamlico nutrient management strategies have been in place for over two decades. In the set of amended rules enacted in 2020 under the statutorily mandated rules readoption process, the Division of Water Resources (DWR) tasked itself with developing a comprehensive retrospective evaluation of strategy implementation and changes in drivers of nutrient loading to the estuaries. This report satisfies that requirement by providing an update on rule implementation metrics and loading progress, watershed source changes, external forcing factors and estuary response trends, and forward-looking adaptive recommendations.

Nutrient pollution, in the form of excess nitrogen and phosphorus inputs, remains one of North Carolina's and the nation's most challenging water quality issues. To address this over-enrichment, the Division of Water Resources leads the development, implementation, and oversight of regulatory nutrient management strategies to restore North Carolina's most valuable waters. Comprehensive and customized strategies are in place to restore the Tar-Pamlico and Neuse Estuaries as well as Falls and Jordan Lakes. The Neuse and Tar-Pamlico nutrient strategies are intended to equitably reduce nutrient loading from different regulated sectors to eliminate excess algal production and resulting algal-related impairments in two of North Carolina's most environmentally and economically important estuaries.

The nutrient reductions called for from both point and nonpoint sources have resulted in some modest successes during that time, including nitrate loading reductions in both river basins despite significant population increases. However, while all regulated sectors continue to meet their obligations in these watersheds, full restoration of these estuaries has not been attained and total nutrient loads have been trending upward in recent years.

Scope of Report

One notable provision included in the revised Neuse and Tar-Pamlico Purpose and Scope Rules was the addition of adaptive management language. This new provision recognizes the ongoing water quality issues in both estuaries and that the availability of more information to evaluate implementation over time which may result in further refinements to the rules should they be needed. It also adds a date by which an evaluation of progress will be completed, and recommendations made by the Division including the requirement for the Division to report on implementation progress to the Water Quality Committee of the Environmental Management on a biannual basis.

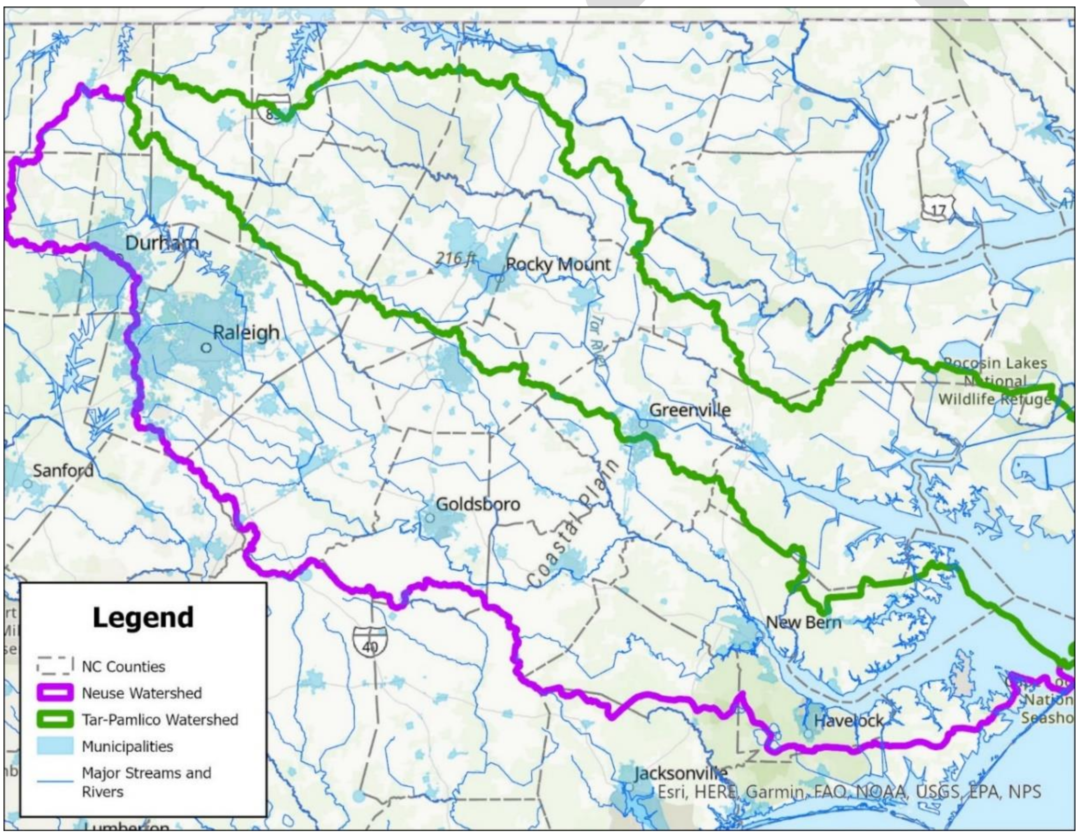
Pursuant to Paragraph (e) of the Neuse Nutrient Strategy's Purpose and Scope rule (15A NCAC 02B .0710) and Item (4) of the Tar-Pamlico Nutrient Strategy's Purpose and Scope rule (15A NCAC 02B .0730), the Division is charged with developing a comprehensive retrospective evaluation of strategy's implementation metrics and loading progress, watershed source changes, external forcing factors and estuary response trends, along with forward-looking adaptive recommendations.

> *"The Division shall valuate the basin's nutrient dynamics to inform and guide adaptive management. This evaluation shall utilize all sources of available information. Including stakeholder input, and shall consider drivers, character, and shifts in the impairment with time, trends, and character of loading delivered to the estuary, and distribution and character of loading inputs to the basin and changes to those inputs over time. The evaluation shall address the extent to which the reduction goals identified in [….] of this Rule have been achieved and shall provide recommendations on management needs.*

> *The Division shall complete the evaluation within three years of the effective date of this Rule and shall distribute the findings upon completion. The Division shall also report biannually to the Water Quality Committee of the Commission on implementation progress and reductions achieved by sources subject to the Neuse nutrient strategy."*

The remainder of the report is presented in five sections. After a general overview of each basin, a status of strategy implementation is provided rule by rule. This is followed by an assessment of water quality metrics regarding the response of the estuaries to rule implementation to date. The next two sections of the report provide updates on the shifting watershed and environmental dynamics, ranging from changes in land cover types, population and agriculture crop shifts, and climate-driven factors such as frequency and intensity of tropical storms and other extreme storm events. Finally, the Division offers some brief parting thoughts on management recommendations and our understanding of the changing dynamics impacting nutrient loading to the estuary.

FIGURE 1. NEUSE AND TAR-PAMLICO RIVER BASINS



Neuse River Basin - Overview

Eutrophication became a water quality concern in the lower Neuse River basin in the late 1970s and early 1980s. Nuisance algal blooms prevalent in the upper estuary prompted investigations by DWQ. These investigations, as well as other studies, indicated that algal growth was being stimulated by excess nutrients entering the estuarine waters of the Neuse River. In 1988 the lower Neuse River basin received the supplemental classification of nutrient sensitive waters (NSW). As part of this early nutrient strategy, new and expanding NPDES discharges, as well as existing facilities with design flows greater than 0.05 MGD, were given a quarterly average phosphorus limit of 2 mg/l. Phosphorus loading was greatly reduced and algal blooms in the river and freshwater portions of the estuary were reduced as a result of this action.

The 1993 Neuse Basinwide Water Quality Plan recognized that eutrophication continued to be a water quality problem in the estuary below New Bern. Extensive fish kills in 1995 prompted further study of the problem. Low dissolved oxygen levels associated with algal blooms were determined to be a probable cause of many of the fish kills. Researchers also identified the presence of a toxic dinoflagellate, *Pfiesteria piscida*, that contributed to many of the fish kills.

The algal blooms and correspondingly high levels of chlorophyll *a* prompted DWQ to place the Neuse River estuary on the 1994 303(d) list of impaired waters. In 1996, the NC Senate Select Committee on River Water Quality and Fish Kills sponsored a workshop with numerous scientists familiar with the Neuse River water quality problems. The group reached consensus that a 30 percent reduction in total nitrogen entering the estuary was a good starting goal to reduce the extent and duration of algal blooms. In 1996, the 30 percent reduction was put into law (Session Laws 1995, Section 572). A Total Maximum Daily Load (TMDL) was developed in two stages and approved by EPA in 2002 to address the nitrogen overloading to the estuary. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. The TMDL developed for the Neuse estuary showed a minimum of 30% reduction in nitrogen loading is needed. This equates to a total load of 6.75 million pounds of nitrogen from all sources.

To address the mounting problems in the Neuse River estuary, the Environmental Management Commission (EMC) adopted a comprehensive set of permanent rules that became effective August 1, 1998, as the Neuse Nutrient Strategy. The intent of these rules was to reduce nitrogen inputs, from both point and non-point sources to the estuary by 30% from the 1991-1995 baseline. While individual implementation dates varied, all of the rules were fully implemented by 2003.

Tar-Pamlico River Basin - Overview

During the 1970s and 1980s, incidences of fish kills and diseases, nuisance algal blooms, loss of aquatic vegetation, and other nutrient-related problems increased in the Pamlico estuary. In response, the EMC designated the entire Tar-Pamlico River Basin as "Nutrient Sensitive" in December 1989 and called for a strategy to reduce nutrient inputs within the basin.

In the first phase, point sources successfully reduced discharge nutrient loads under an innovative 'trading' program. The second phase established estuary-based goals of a 30% reduction in nitrogen loading and no increase in phosphorus loading relative to a 1991 baseline condition, continued the point source caps and offset program, and called on nonpoint sources to voluntarily meet the loading goals. In 1998, the EMC initiated rulemaking to implement nonpoint source goals. Modeled after rules implemented in the adjacent Neuse River Basin in 1998, a set of rules addressing four areas (agriculture, urban stormwater, riparian buffers, and fertilizer management) went into effect during 2000 and 2001.

The rules called for a 30% reduction of nitrogen inputs to the estuary from major sources, including both wastewater and runoff pollution. That corresponds to a total maximum daily load of approximately 3 million lbs/yr TN and 400,000 lbs/yr TP. The rules called for no increase in phosphorus load compared to a baseline year of 1991. As part of the overall strategy, nitrogen and phosphorus loading caps for an association of fifteen point source dischargers, the Tar-Pamlico Basin Association, are implemented under a nutrient control agreement.

The EMC adopted a comprehensive set of permanent rules effective April 2001 to implement the Tar-Pamlico Nutrient Strategy. While individual implementation dates varied, all rules were fully implemented by 2006.

Nutrient Strategy Rule Implementation Status

The North Carolina Environmental Management Commission (EMC) adopted two comprehensive sets of nutrient management strategy rules for the Neuse and Tar-Pamlico River Basins through two separate rulemaking efforts. The Neuse Nutrient Strategy Rules went into effect in August 1998, followed by the Tar-Pam Nutrient Strategy Rules that went into effect in April 2001. While individual implementation dates varied, all the rules were fully implemented by 2003 (Neuse) and 2005 (Tar-Pamlico). The two sets of rules were revised and readopted effective April 1, 2020 (Table 1). This section of the report provides an overview of the Neuse and Tar-Pamlico strategy requirements and implementation progress.

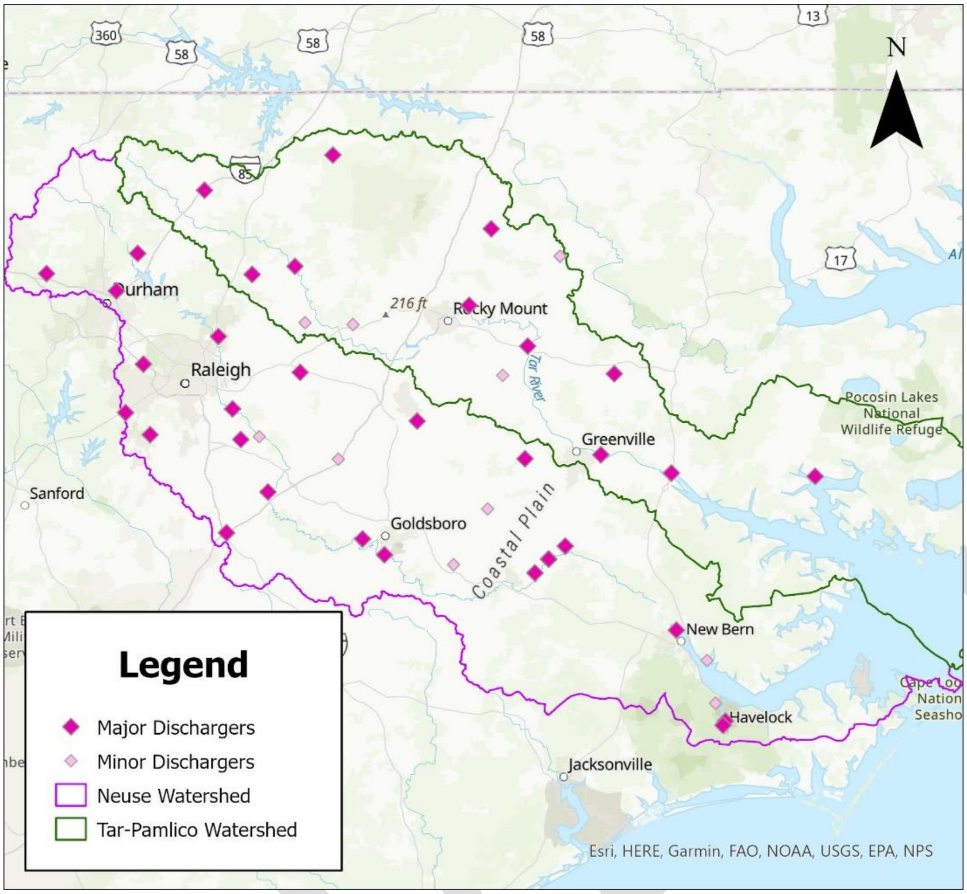
TABLE 1. NEUSE AND TAR-PAMLICO NUTRIENT STRATEGY RULES

15A NCAC 02B Rule	Rule Title
	Neuse River Basin Nutrient Management Strategy
.0701	Definitions
.0703	Nutrient Offset Credit Trading Rule
.0710	Purpose & Scope
.0711	Stormwater Management for New Development
.0712	Agriculture
.0713	Wastewater Discharge Requirements
.0714	Protection & Maintenance of Existing Riparian Buffers
	Tar-Pamlico River Basin Nutrient Management Strategy
.0730	Purpose & Scope
.0731	Stormwater Management for New Development
.0732	Agriculture
.0733	Wastewater Discharge Requirements
.0734	Protection and Maintenance of Existing Riparian Buffer
.0735	Delegation of Authority – Buffer Protection & Maintenance

Wastewater

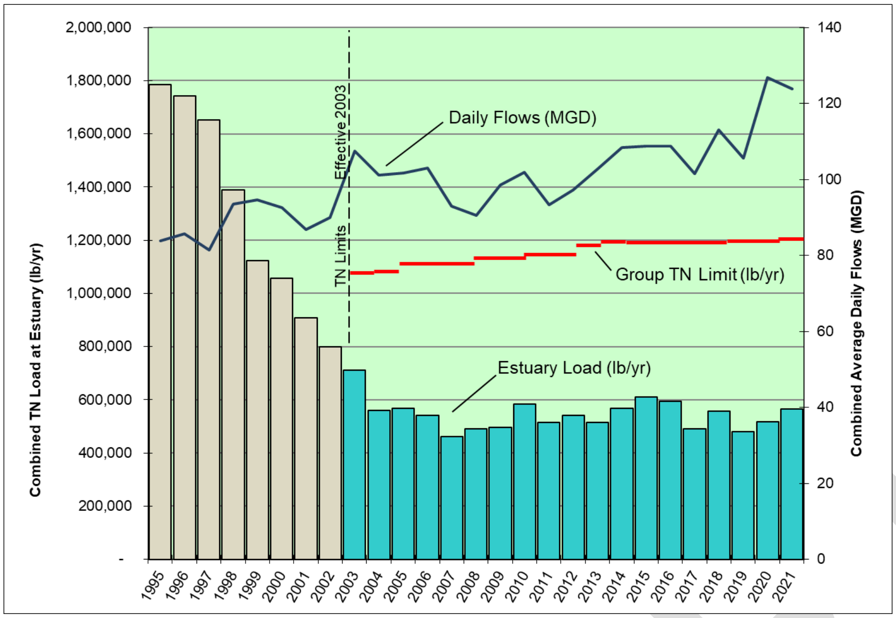
The Neuse Wastewater Discharge Requirements rule was effective in January 1998. The rule applies to all wastewater treatment facilities in the basin that receive nutrient-bearing wastewater and are governed by individual National Pollutant Discharge Elimination System (NPDES) permits (Figure 2). The aim of the rule is to achieve the mandated 30 percent reduction in nitrogen load from these dischargers to the Neuse River estuary. In the 2000 renewal cycle, the DWR modified all Neuse wastewater permits to include nitrogen and phosphorus monitoring and reporting. Where appropriate, the permits included nutrient limits and related conditions. NPDES discharges within the Neuse River Basin with permitted flows of 0.5 million gallons per day (mgd) must comply with annual mass limits equal to their assigned allocations that became effective in calendar year 2003. The rule provides NPDES dischargers the option of forming a compliance association in which members work collectively to reduce their nitrogen loadings to the estuary. Association members are subject to a combined nitrogen limit rather than to their individual permit limits and can decide the most practical and cost-effective means of meeting the group limit.

FIGURE 2. MAP OF NEUSE AND TAR-PAMLICO WASTEWATER DISCHARGERS



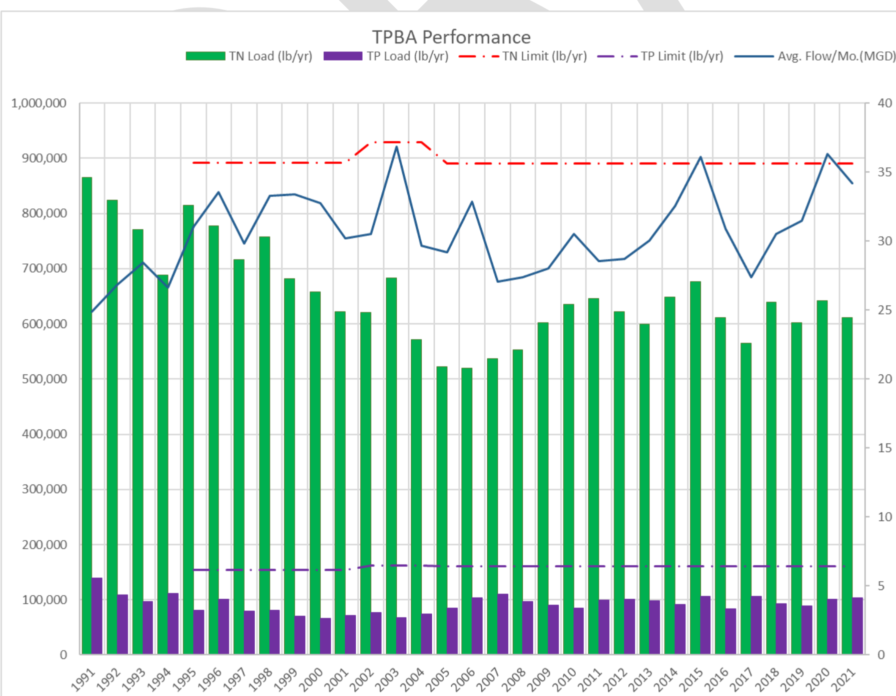
In 2002 interested permittees established the Neuse River Compliance Association (NRCA) to pursue the rule's group compliance option. DWR issued the first group permit of its kind to the Association and its co-permittee members that same year. In 2021, the Association was comprised of permittees with 27 permits and had a combined estuary limit of 124,838 lb/yr TN. In 2021, the total nitrogen load for the NRCA members' facilities was calculated as 564,859 lb/yr TN at the estuary, which represents 46 percent of the group's 2021 nitrogen limit and a 68 percent reduction in TN loading from their 1995 baseline loads (Figure 3).

FIGURE 3. NEUSE RIVER COMPLIANCE ASSOCIATION ANNUAL NITROGEN LOADS (1995-2021)



In 2021, the total nitrogen load for the 15 member facilities of the Tar-Pamlico Basin Association, an association of point source dischargers, was calculated as 610,777 lbs, which represents 68 percent of the nitrogen cap. The total phosphorus load was calculated at 102,919 pounds, or 64 percent of the phosphorus cap (Figure 4). These caps were established in the spring of 2005 when the EMC approved the third phase of the overarching basin nutrient strategy and point source "Agreement".

FIGURE 4. TAR-PAMLICO BASIN ASSOCIATION ANNUAL NITROGEN AND PHOSPHORUS LOADS (1991-2021)



Phase I of the Agreement was initiated in 1990 as a technology-based point source trading program. Phase II covered another ten years through December 2004, and Phase III spanned an additional ten years through December 2014. In July 2016 the EMC approved the fourth phase of the Agreement which spans an additional ten years through May 31, 2025. Phase IV continues the overall performance goals for the nutrient strategy of 30 percent reduction in nitrogen loading and no increase in loading of phosphorous from the baseline year 1991. Phase IV also added nitrogen and phosphorus limits to individual permit renewals in 2016 to complement the group loading caps and provide for better enforceability. In 2023 the Division began working on revising the Tar-Pamlico Wastewater rule to incorporate the requirements of the latest phase of the Agreement in anticipation of Phase IV concluding in May 2025.

Agriculture

Each Agriculture rule provides for a collective strategy for farmers to meet a 30% nitrogen loss reduction within five years. A Basin Oversight Committee (BOC) and seventeen Local Advisory Committees (LACs) were established in the Neuse, and a BOC and fourteen LACs were established in the Tar-Pamlico, to implement each watershed's Agriculture rule and to assist farmers with complying with the rule. DEQ's Division of Soil and Water Conservation staff use input from the LACs to calculate their annual reductions using the Nitrogen Loss Estimation Worksheet (NLEW) and from there produce each year's annual report, starting in 2001.

When evaluating agricultural nutrient management, the contribution of nitrogen from cropland to the watershed at large is described in terms of the amount of nitrogen "lost" from fields, that is, a different way of describing nitrogen export from cropped areas. Nutrient reduction objectives are put in terms of reducing that loss of nitrogen as compared to the amount of nitrogen lost from cropped areas during a baseline period for each watershed. In the Agriculture Rules, nitrogen loss, and reduction of that loss, is estimated collectively from all regulated agricultural operations in each watershed using the Nitrogen Loss Estimation Worksheet (NLEW). NLEW is an "edge-of-management unit" accounting tool; it estimates changes in nitrogen loss from croplands but does not capture the effects of nitrogen applied to pastureland nor does it estimate changes in nitrogen loading to surface waters.

At this time, the agricultural community in both watersheds have exceeded rule requirements of at least a collective 30% reduction of loss by achieving a collective 35% nutrient loss reduction right after Rule implementation, and more than 50% reduction in nutrient loss in the most recent crop years. In the Neuse Basin, agriculture has achieved an estimated 50 percent reduction in nitrogen loss compared to the 1991-1995 baseline (Figure 5). In the Tar-Pamlico Basin, agriculture estimates a 55 percent reduction in nitrogen (N) loss compared to the 1991 baseline (Figure 6). In each figure, different colors represent the different versions of NLEW used. The NLEW captures application of both inorganic and animal waste sources of fertilizer to cropland. Overall, nitrogen loss reductions were achieved through a combination of fertilization rate decreases, cropping shifts, BMP implementation, and cropland acreage fluctuation.

FIGURE 5. ESTIMATED REDUCTIONS IN NITROGEN LOSS FROM NEUSE BASIN CROPLAND AGRICULTURE, 2001-2021

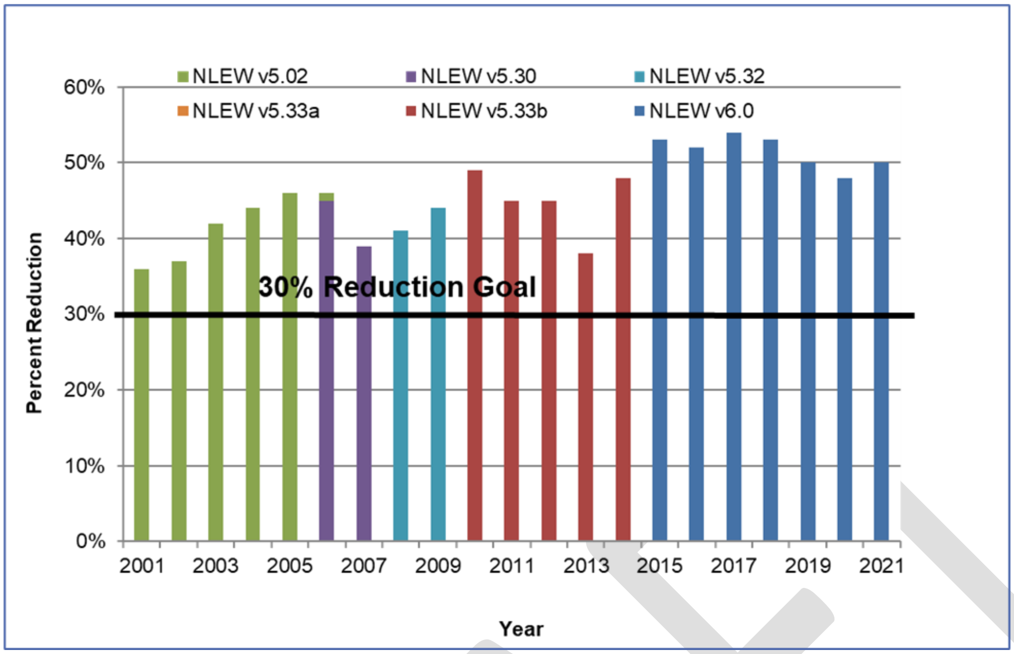
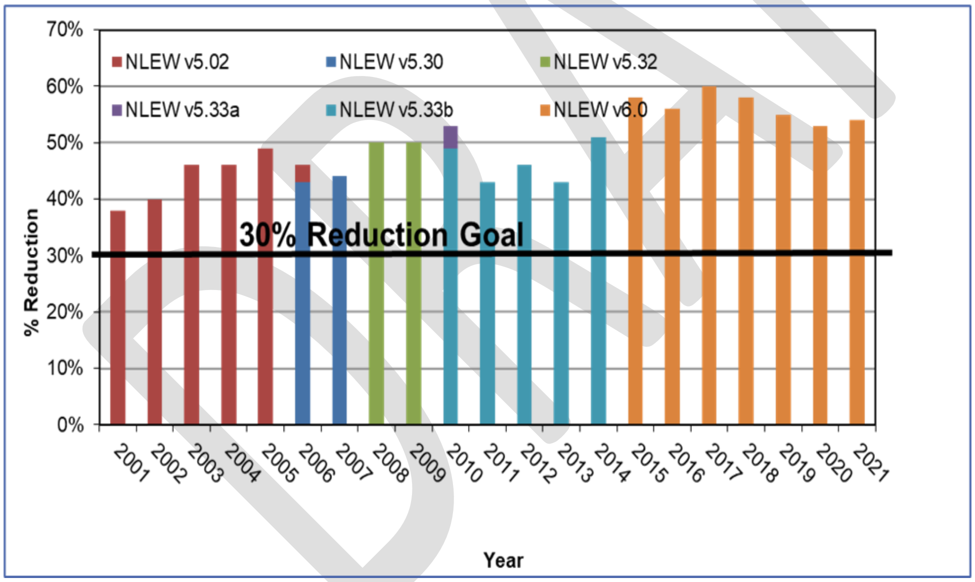


FIGURE 6. ESTIMATED REDUCTIONS IN N LOSS FROM TAR-PAMLICO BASIN CROPLAND AGRICULTURE 2001-2021



Additional metrics for changes to the agricultural landscape over the past twenty years, such as crop shifts, cropland lost, and changes in fertilizer application rates can be found in the Watershed Changes Section of this report.

New Development Stormwater

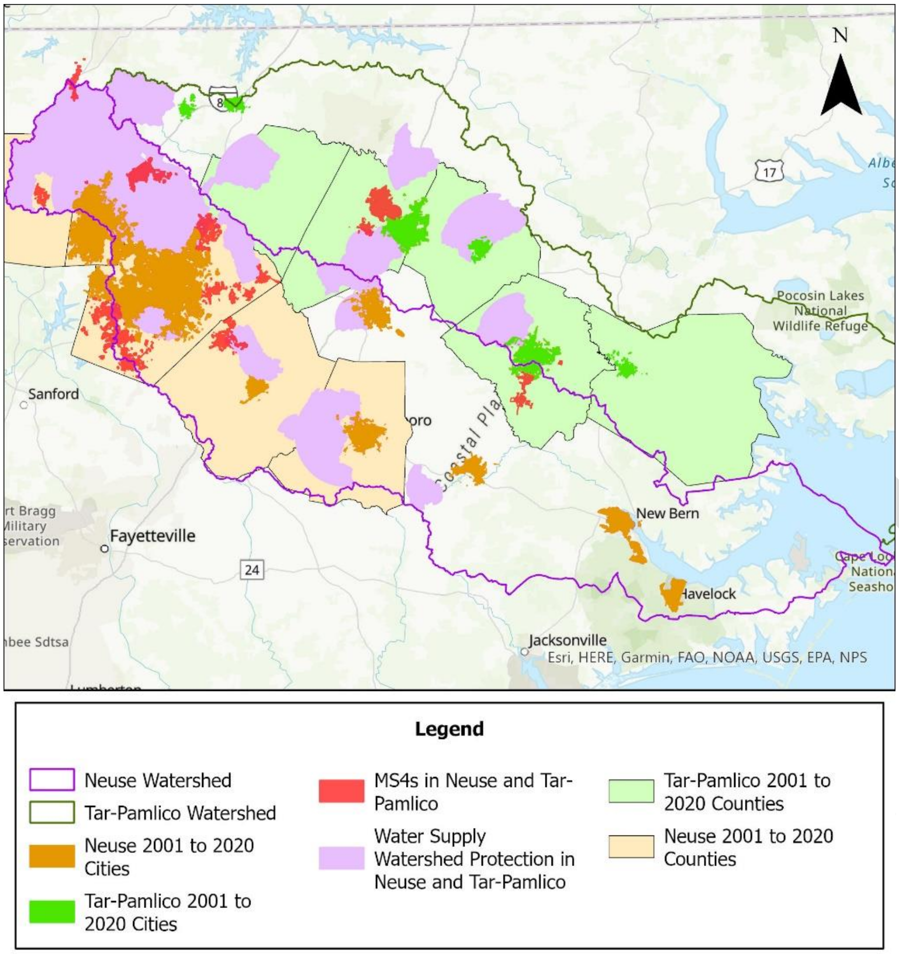
During 2002, the fifteen local governments in the Neuse Basin subject to the basin stormwater rule developed and enacted stormwater programs. All new development activity in these communities is required to implement stormwater control measures to reduce nitrogen export to meet the basin goals. All of the local governments subject to the Neuse Stormwater Rule have also developed ordinances and programs that, in addition to requiring the nutrient export goal be met, establish local authority for the removal of illegal discharges and public education programs to assist in reduction of nutrient export from developed lands. Each local government is required to submit an annual stormwater report by the end of October each year to document their continued implementation of the stormwater rule.

During 2004, eleven local governments subject to the Tar-Pamlico Basin stormwater rule developed and enacted stormwater programs. Local regulatory programs for new development were implemented between September and December 2004. All new development activity in these communities is required to implement stormwater control measures to reduce nitrogen and phosphorus export to meet the basin goals. All of the local governments subject to the Tar-Pamlico Stormwater Rule have also developed ordinances and programs that, in addition to requiring the nutrient export goal be met, establish local authority for the removal of illegal discharges and public education programs to assist in reduction of nutrient export from developed lands. Each local government is required to submit an annual stormwater report by the end of October each year to document their continued implementation of the stormwater rule.

In 2020, 15 additional communities in the Neuse Basin and one local government in the Tar-Pamlico Basin were added to the set of local governments implementing the Stormwater Rule based on increases in population and development activity over the past 20 years. The revised rule clarifies implementation details and uses a regulatory structure similar to the State's Stormwater Rules, which include water supply watershed protection and NPDES MS4. This simplifies implementation for the many local governments implementing these other programs and takes advantage of the many lessons learned.

Both rules were also revised to address an unintended gap in onsite treatment requirements in the original rules that allowed developers to get the bulk of their reductions through offsite offsets. The revised rules stipulate treatment through at least one stormwater control measure when development reaches 24% built-upon area, which invokes minimum statewide MS4 rule requirements. Finally, through the Stormwater Nitrogen and Phosphorus (SNAP) tool, the rules incorporate the latest developments in stormwater science and expand the suite of stormwater control measures and design variations available to developers to reflect DEMLR rule changes and guidance. Implementation of these changes is set to take place in stages in 2023. A map of major stormwater program coverage in both basins is provided in Figure 7.

FIGURE 7. STORMWATER PROGRAMS MAP



Nutrient Offsets Trading

In the Neuse and Tar-Pamlico, a developer must meet rule-specific nutrient loading rate targets for stormwater exiting the property. The developer's nutrient load is calculated using the development plan and the SNAP stormwater accounting tool. Most developments exceed the rate targets absent any stormwater treatment practices. Once the minimum onsite treatment obligation is met, the developer may pay an in-lieu fee to purchase the remainder of their nutrient loads as credit from an offsite reduction activity to meet the loading rate targets, a process referred to as nutrient offset.

The nutrient offset rule, NCAC 02B .0703, generally establishes standards for the creation of nutrient offset credits by the Division of Mitigation Services and private nutrient offset providers. These credits are purchased by regulated parties to earn nutrient credit away from their project site when it provides a more cost-effective compliance option. The regulatory objective of this rule is to lower the costs of rule compliance while achieving equivalent nutrient reductions elsewhere. To meet this objective and ensure the integrity of the trading market, credited nutrient reductions must be equivalent in magnitude and certainty with the excess nutrient loading increases allowed by their use.

Nutrient offset has evolved over time through a series of session laws into a 2-option system; private offset banks and the N.C. Division of Mitigation Services (DMS) in-lieu fee program. While there are multiple options for obtaining offsets, the purchase of third-party offsets from private banks is the most popular. This is because most local government entities and all private developers seeking third-party nutrient offsets must do so through a state-approved private nutrient bank within the watershed where the development project is located (G.S. §143-214.26). When credit from approved private banks is not available, seekers of nutrient offsets are then eligible to participate in the DMS Nutrient Offset Program.

The trend in North Carolina over the past decade has been toward using the least cost alternative for offset credits, despite the preference of local governments to have offsets implemented closer to the impacts. Because of their relative low cost, the predominant practice used by nutrient credit providers is restoration and enhancement of farmed riparian areas into protected forested buffers that reduce nutrients by filtering farm runoff. Presently these practices are credited at a rate of 75.77 lbs. N/acre/year nitrogen and 4.88 lbs. P/acre/year. Assuming a life expectancy of 30 years, riparian buffers have a lifetime credit value of 2,273 lbs. N/acre and 146.4 lbs. P/acre.

There are currently 53 private banks established in the Neuse and Tar-Pamlico watersheds for the purpose of providing of nutrient offset credits. Of thee, 28 banks are in the Neuse 01 HUC. Eight private banks are located in the Falls watershed. Additionally, DMS has a 25 nutrient offset projects in the two river basins, with five of those 25 located in the Falls watersed.

A summary of the combined total of nutrient credits sold between 2001 and 2022 from all private banks and DMS projects is provided in Table 2. Perhaps the most striking observation from Table 2 is the order-of-magnitude difference in scale of total offsets between Neuse and Tar-Pamlico Basins, with roughly 3.7 million pounds N sold in the Neuse vs. just under 200,000 lb in the Tar-Pamlico. Also notable in the Neuse is that approximately 3.2 of the total 3.7 million pounds, or about 86% were sold in the upper subbasin, 01, encompassing the Raleigh growth area. By contrast in the Tar-Pamlico, roughly 62% of offsets occurred in the lower subbasin, 03, encompassing the Greenville area, with most of the rest, 34%, occurring in the upper subbasin, 01, reflecting growth in Raleigh bedroom communities.

TABLE 2. THIRD-PARTY NUTRIENT OFFSETS - NEUSE AND TAR-PAMLICO RIVER BASIN (2001-2022)

Neuse River Basin – Nutrient Offsets By 8-digit HUC		
	Nitrogen	**Phosphorus**
Private Bank Credits Sold (lbs.)		
3020201	1,947,981	0
3020202	14,493	0
3020203	94,807	0
3020204	24,391	0
Falls Lake Watershed	102,750	12,658
Total Private Bank (lbs.)	**2,184,421**	**12,658**
DMS Credits Sold (lbs.)		
3020201	1,281,327	0
3020202	78,482	0
3020203	100,800	0
3020204	39,315	0
Falls Lake Watershed	15,485	7,313
Total DMS (lbs.)	**1,515,409**	**7,313**
Neuse Total (lbs.)	**3,699,830**	**19,971**
Tar-Pamlico River Basin – Nutrient Offsets By 8-digit HUC		
	Nitrogen	**Phosphorus**
Private Bank Credits Sold (lbs.)		
3020101	19,934	1,284
3020102	0	0
3020103	70,497	6,174
3020104	18	0
Total Private Bank (lbs.)	**90,449**	**7,438**
DMS Credits Sold (lbs.)		
3020101	48,234	4,434
3020102	825	91
3020103	53,060	3,468
3020104	6,176	349
Total DMS (lbs.)	**108,295**	**8,342**
Tar-Pamlico Total (lbs.)	**198,744**	**15,780**
Total (Neuse + Tar-Pamlico) Private Banks + DMS	**3,898,574 (lbs.)**	**35,751 (lbs.)**

Buffer Protection

Since implementation of the Tar-Pamlico buffer rule (2000 – 2020) Division staff have issued 1,060 buffer authorizations and variances impacting approximately 19,286,519 ft2 of buffers in the basin requiring buffer mitigation. Most of the buffer impacts are the result of activities listed in the table of uses in the Rule that are approved by a buffer authorization. Buffer variances are a small subset of the overall buffer impacts approved, with just 34 major and 81 minor variances approved since the inception of the Tar-Pamlico buffer program (Figure 8).

There have been more than four times as many square feet of buffer impacted in the Neuse than in the Tar-Pamlico during this same time frame. Under the Neuse buffer rule Division staff have issued 3,535 buffer authorizations and variances impacting approximately 83,599,690 ft2 of buffers in the basin requiring buffer mitigation. As in the Tar-Pamlico, most of the buffer impacts are the result of activities listed in the table of uses in the Neuse Buffer Rule that are approved by a buffer authorization. Buffer variances remain a small subset of the overall buffer impacts approved, with just 67 major and 267 minor variances approved since the inception of the Neuse buffer program (Figure 9).

As a result of limited staff resources, DWR has limited ability to monitor for buffer compliance related to impacts. DWR often relies on notification from other agencies or citizen reports and therefore, the true number of buffer impacts that exist in NC are difficult to determine. DWR began tracking buffer enforcement cases in 2005. Records indicate that from 2005 through 2000 there were 17 buffer violation enforcement cases in the Tar-Pamlico which impacted 575,457 ft2 of riparian buffers, resulting in civil penalty assessments of approximately $158,223. There were 38 buffer violation enforcement cases in the Neuse which impacted 917,755 ft2 of riparian buffers, resulting in civil penalty assessments of approximately $262,740.

FIGURE 8. NEUSE BUFFER AUTHORIZATIONS & VARIANCES (2000-2020)

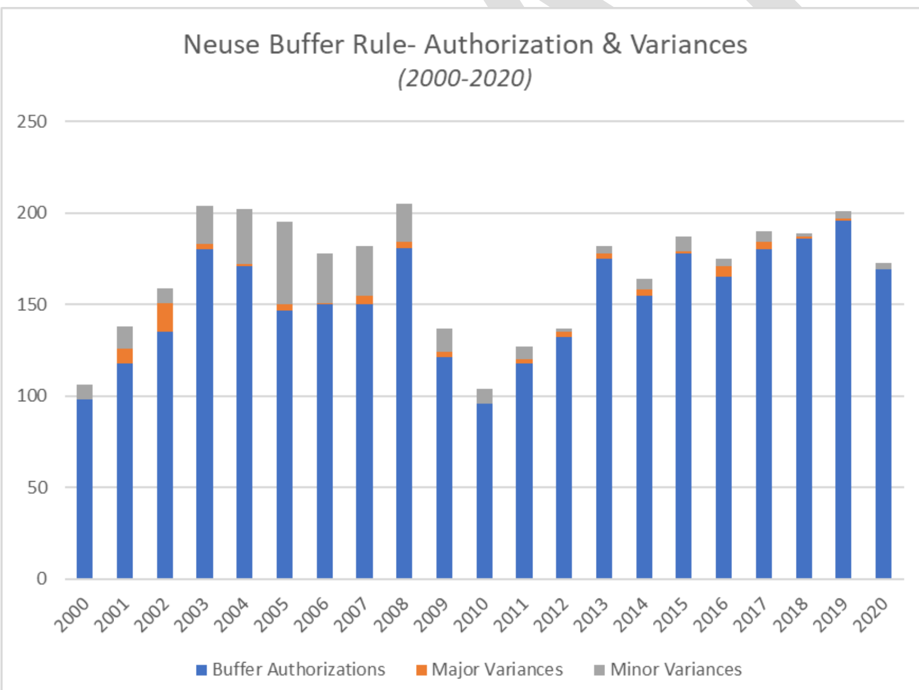
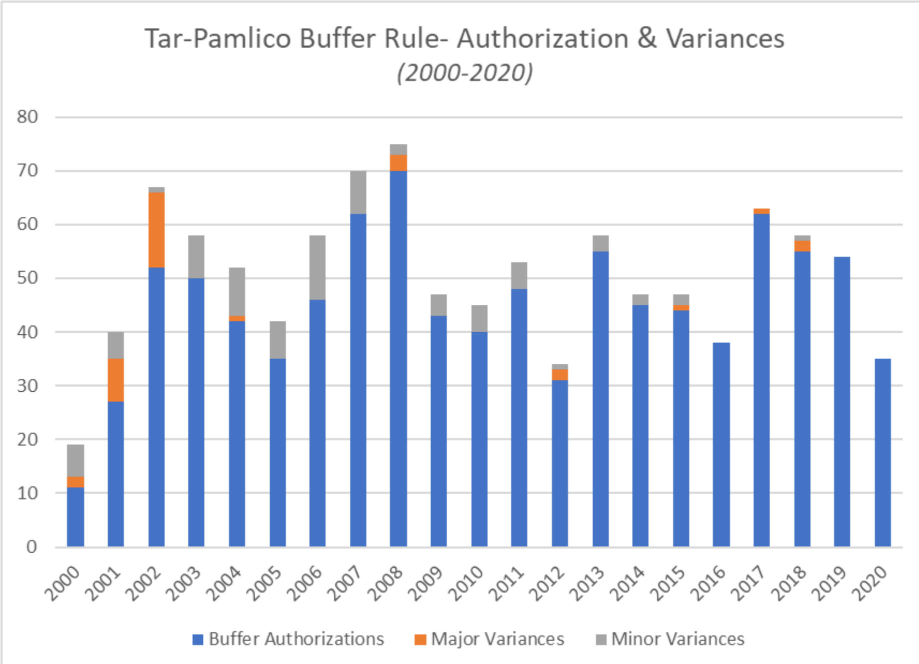


FIGURE 9. TAR-PAMLICO BUFFER AUTHORIZATIONS & VARIANCES (2000-2020)



DWR intends to improve the database currently used for tracking buffer compliance to include the length of buffer impacted at each site visit, a description of the type of buffer impact, and impacted buffer location information. These improvements to the database will hopefully allow DWR to better measure the success of the buffer rules on reducing nutrient loading.

Water Quality Status and Trends

Changes in Loading to the Estuaries

Evaluating changes in nutrient loading to the Neuse & Tar-Pamlico estuaries is a useful evaluation because it provides a measurement of what the estuaries are experiencing in terms of pounds of nitrogen and phosphorus delivered to the waterbodies. However, it is also important to recognize that the loading changes presented in this report are estimates that are heavily influenced by climate and changes in hydrologic conditions in each basin that in some years may impact the reductions achieved by regulated sources. Nutrient loading estimates vary year by year based on differences in annual rainfall and corresponding increases and decreases in flow. As such, the loading estimates provided in this section were evaluated to demonstrate how highly variable loading can be and are not presented as an indicator of how well the regulated community have complied with the reduction requirements of the two nutrient management strategies.

Load Estimation Methods

Nutrient loads to both estuaries were calculated using two primary methods; the first uses the USGS LOADEST method. LOADEST creates a regression model based on stream flow, concentration, and time to develop mean load estimates with 95 percent confidence intervals on a monthly basis (Runkel et al. 2015). This regression equation can then be used to predict raw loading estimates by filling in the monitoring gaps where paired observations for flow and water quality are not available. This method is best used to understand the total mass of flow and nutrients being delivered by the river for given years, which can vary greatly year-to-year due to changes in annual rainfall and resulting flows. Total flow and load are valuable to know when considering what the estuary actually has to process in particular years.

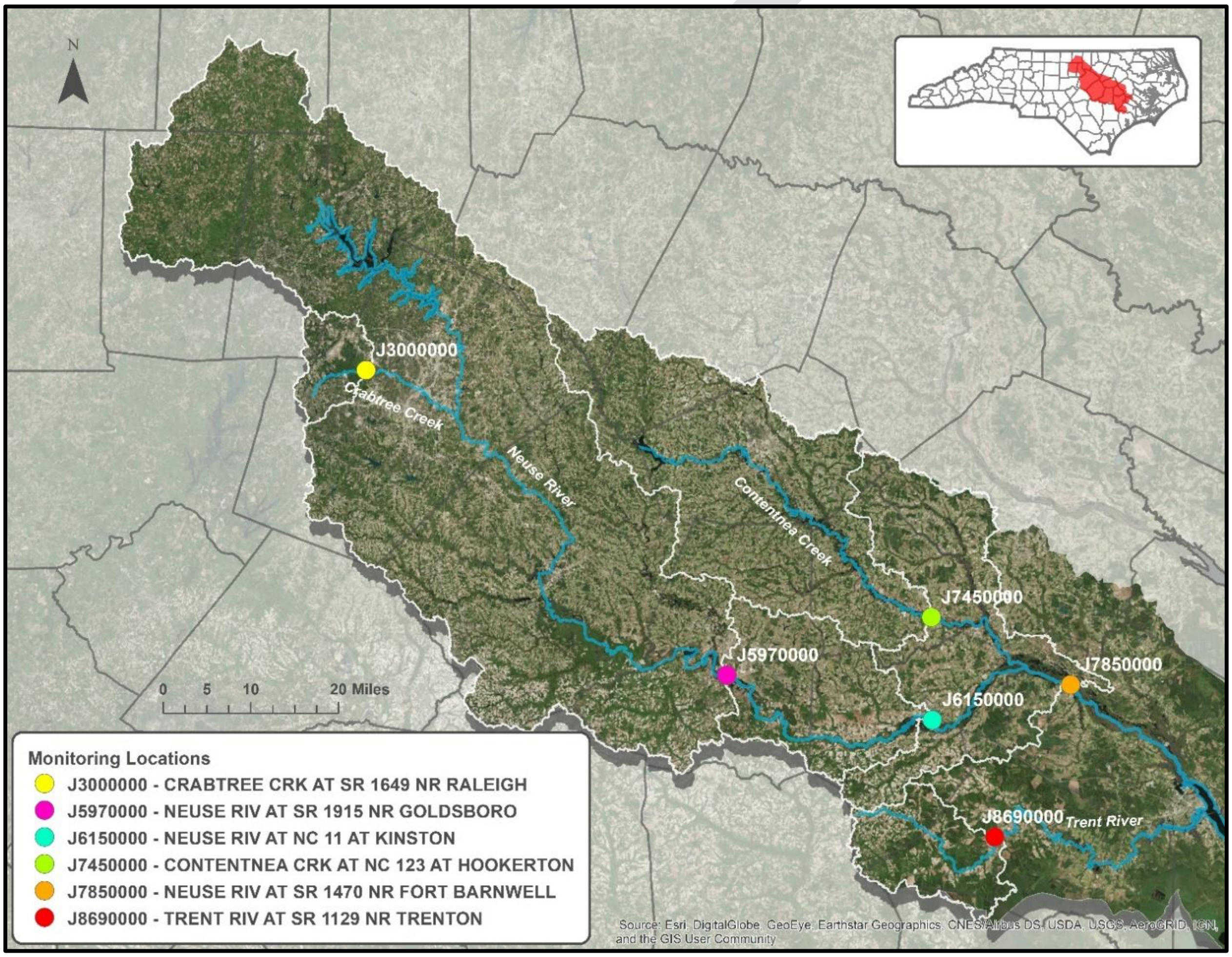
The second loading method is a non-computationally intensive flow-normalized (FN) analysis to evaluate annual nutrient loading trends (Lebo et al. 2012). This is done by developing loads using simple averages of flow and concentrations in three flow regimes and over a rolling 5-year time period. The simplified FN loading analysis allows evaluation of changes under the various flow regimes and provides feedback on effectiveness of point and nonpoint source nutrient management actions. Nutrient concentrations are estimated from the mean of available data and flow-weighted average concentrations. Nutrient loads for the long-term flow distribution are computed from the average concentration and the average flow volume calculated from the low, medium, and high flow intervals over the full period of record.

A third method of load analysis was also used in the more recent Tar-Pamlico loading analysis. This third approach develops flow-normalized nutrient loads and concentrations using the USGS Weighted Regressions on Time, Discharge, and Season (WRTDS) method. This method is a recently developed exploratory data analysis approach that provides insight about the characteristics of water quality data and can be used to evaluate changes in nutrient concentration and loads (Hirsch and De Cicco, 2015; Hirsch et al., 2010). This approach is more computationally intensive than the Lebo flow-normalized method described above. WRTDS estimates concentration and load for every day of the analysis based on the closest data point, taking into consideration the flow, season (day of year), time (number of days from the observed point to the predicted one), and is given a weight to use in the prediction of the unknown concentration that day. This method is more useful to observe nutrient reduction progress (or lack thereof) by reducing effects of year-to-year variability in discharge on the record of trend in water quality. This approach also uses probability distributions of daily streamflow to reduce or eliminate the influence of random, year-to-year streamflow variability on estimates of trends in concentration and load while preserving the influence of long-term trends in streamflow.

Neuse Estuary – Estuary Loading Analysis

For this report, DWR analyzed 1991-2017 water quality and flow data collected from four monitoring stations located at various locations upstream of the estuary in addition to the Fort Barnwell station, which drains approximately 63% of the Neuse River Basin and serves as the compliance point for the nutrient management strategy. The location of the DWR monitoring stations and USGS flow gauges used in this analysis are provided in Figure 10.

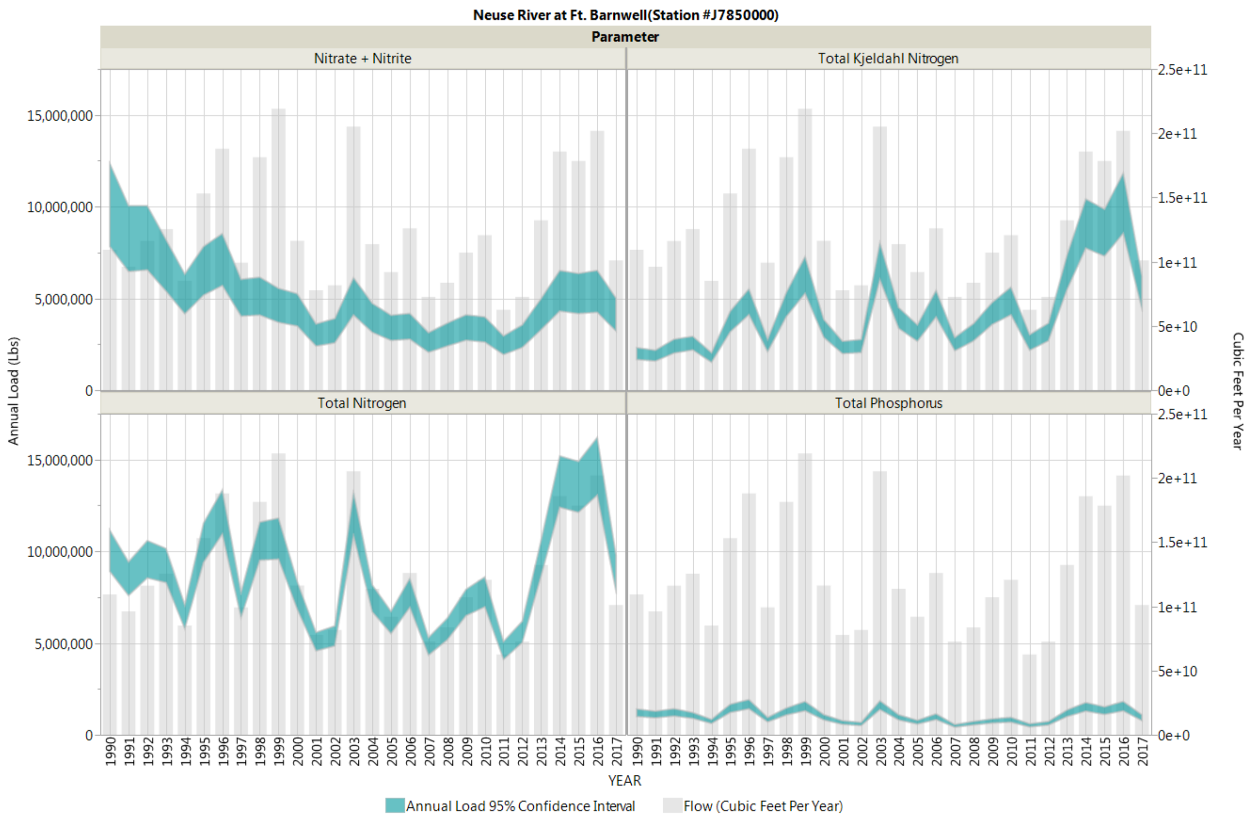
FIGURE 10. SELECTED MONITORING STATIONS IN THE NEUSE RIVER BASIN



Neuse Estuary: LOADEST Loading Estimates at Fort Barnwell

The load estimates developed using the LOADEST method are intended to provide a range of annual loading estimates based on flow and concentration records from the selected stations. Figure 11 below provides the resulting annual nitrogen and phosphorus load contributions as well as annual flow at the Fort Barnwell station. This provides a visual assessment of the general loading pattern since the baseline time period and how loads vary but are highly impacted by the year-to year variability of flow. The loading trend results for the other five stations that DWR evaluated in the Neuse River basin are provided in an Appendix B of this report.

FIGURE 11. LOADEST ANNUAL LOADS AT FORT BARNWELL STATION – NEUSE BASIN



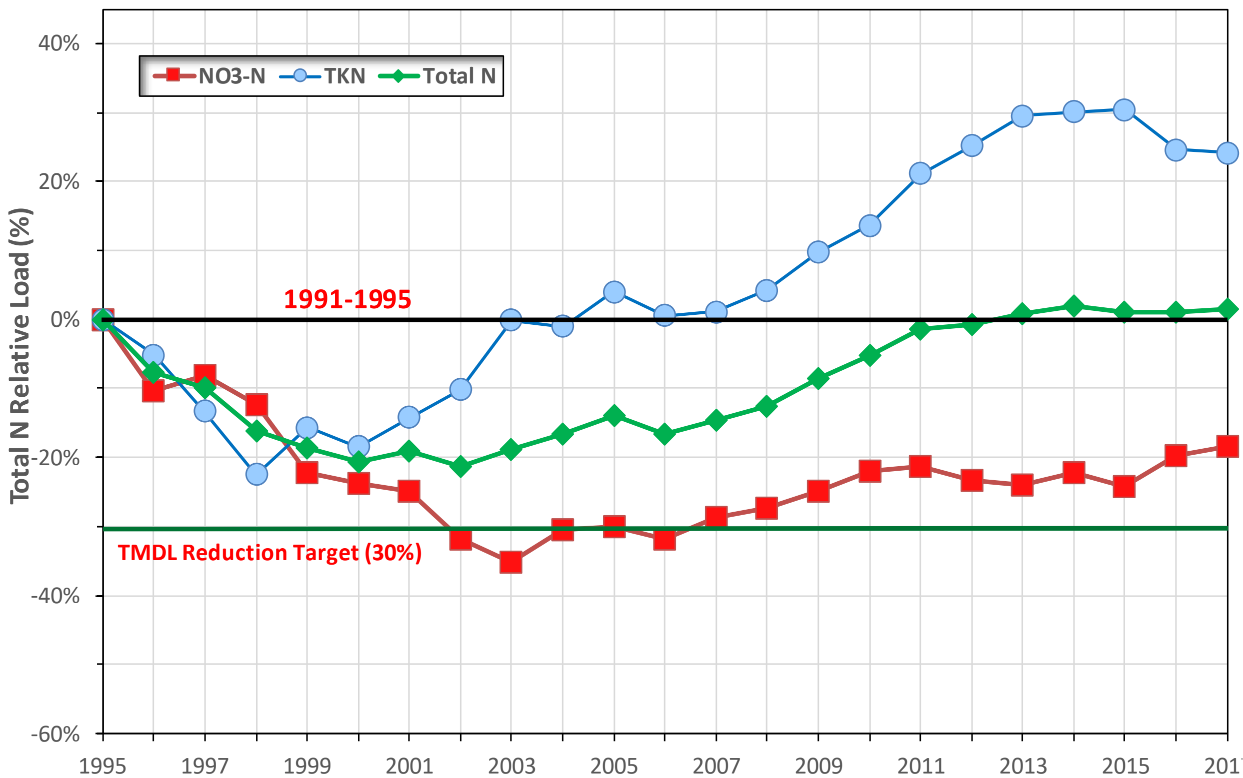
The loading estimates using the LOADEST method at the Fort Barnwell station generally show that overall, NOx loading decreased until mid-2010s. While the NOx loading currently remains below baseline levels it has slightly increased in recent years. Total Kjeldahl nitrogen, on the other hand, has generally increased at Fort Barnwell over the study period. Total nitrogen loading followed the combination of increasing patterns of NOx and TKN resulting in an overall 38 percent increase in raw nitrogen loading to the estuary relative to the 1991-1995 baseline period. The increases in total nitrogen load correlates well with increases in flow, suggesting that the increased precipitation experienced in the basin in recent years has resulted in additional inputs from nonpoint source runoff.

During the study period no discernible change was observed in phosphorus loading, which is typically less susceptible to increases in flow. Phosphorus loading holding steady despite the increases in flow suggest management activities in the watershed have had some impact on loads. However, determining the exact reason behind changes in loading is challenging because the loads have been shown to vary from year to year due to changes in hydrologic conditions. Use of flow-normalized loading analysis is one way to attempt to tease out the factors that influence loads.

Neuse Estuary: Flow-Normalized Nutrient Loading Trends

To improve the loading analysis by removing the year-to-year variability of flow, the Division performed a second analysis using a simplified flow-normalized method (Lebo et al. 2012). By eliminating the influence of flow, this approach provides the ability to observe signs that factors other than changes in rainfall may have impacted loading in the watershed. Using this method, flow-adjusted statistics are used to account for substantial annual variability attributable to rainfall and are measured at the compliance point at Fort Barnwell. Figure 12 shows the combined tributary flow-normalized nutrient loading at the Fort Barnwell monitoring station compared to the 1991-1995 baseline.

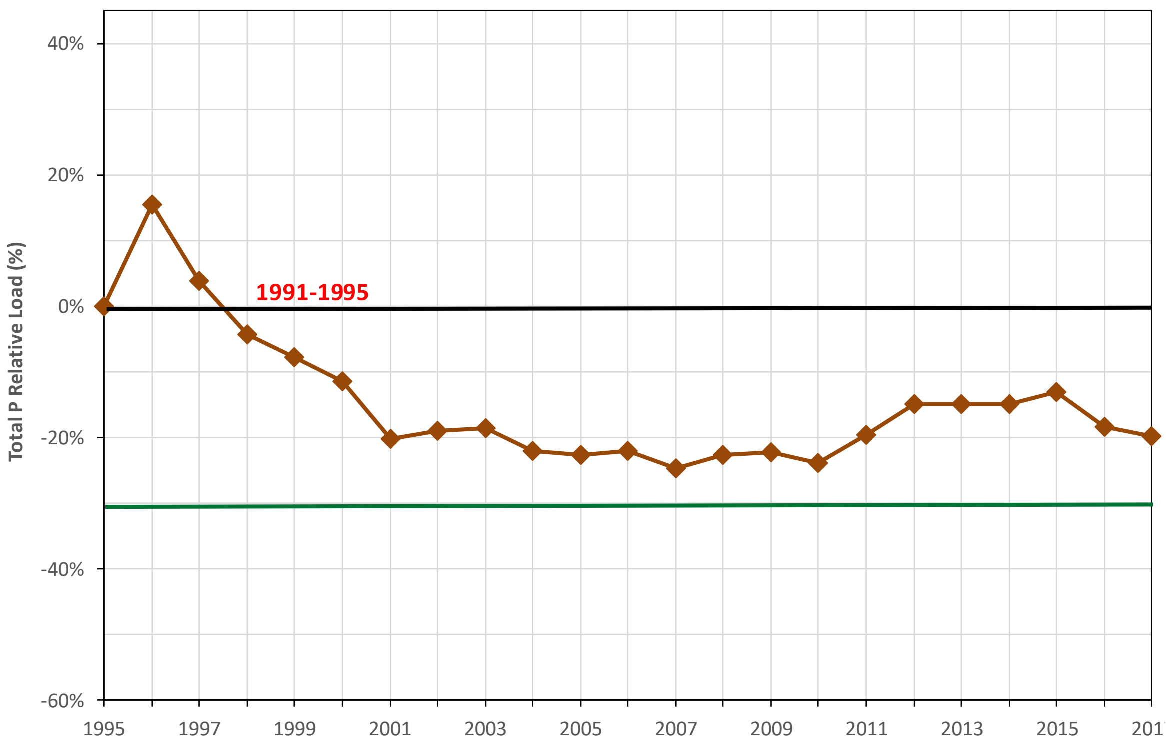
FIGURE 12. NITROGEN REDUCTION FOR AVERAGE FLOW CONDITION COMPARED TO 1991-1995 (FORT BARNWELL)



The results using this flow-normalized method of analysis show that following implementation of the Neuse rules in 1999, flow-adjusted total nitrogen loading to the Neuse Estuary fell approximately 20% by 2002. Since 2002, total nitrogen levels have crept back up to just slightly above the baseline levels. However, while inorganic nitrogen levels have seen only slight increases, total Kjeldahl nitrogen (comprised of ammonia and organic nitrogen) has risen as much as 30% above baseline levels with total nitrogen loading rising just slightly above baseline levels since 2013.

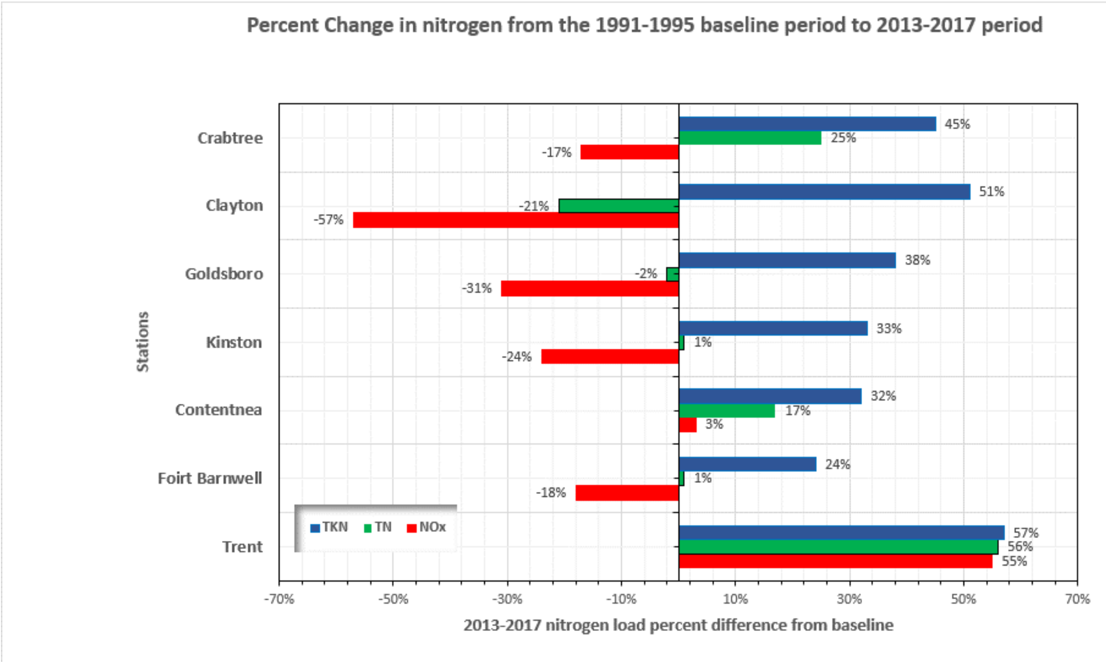
Overall, this analysis indicates that significant reductions in NOx loads were achieved in the early 1990s, but the loads have shown increases in the mid-2000s but have largely remained constant over the past ten years. In contrast, the TKN loads have continued to increase steadily over the years resulting in total nitrogen loads to trend upward to just over the 1991-1995 baseline loads. The increase in organic nitrogen loading is largely associated with high flow events suggesting that nonpoint sources and processes, including natural background organic nitrogen and runoff from both urban and agricultural sources, play a major role in the increased Org-N loading in the watershed.

FIGURE 13. PHOSPHORUS REDUCTION FOR AVERAGE FLOW CONDITION COMPARED TO 1991-1995 (FORT BARNWELL)



The reductions in total phosphorus relative to the 1991-1995 period have been largely holding steady since 2000 and continue to hover between 15% and 20% below the baseline levels (Figure 13). These early reductions in phosphorus loading are likely a result of a combination of the statewide ban on phosphate detergents that was implemented in 1988 and the fact that point source discharges to the Upper and Lower Neuse River Basin were required to meet phosphorus discharge limits in the early 1990's as required by the NSW classification. Dischargers with permitted flows greater than 0.05 mgd to the Upper Neuse were required to meet a 2 mg/L quarterly total phosphorus discharge limit by 1990. While in the Lower Neuse River basin, existing dischargers with permitted flow greater than 0.5 mgd and new or expanding dischargers with permitted flows of greater than 0.05 mgd were required to meet the new 2.0 mg/L quarterly average concentration TP limit by 1993.

FIGURE 14. UPSTREAM TO DOWNSTREAM: % CHANGE IN NEUSE BASIN NITROGEN LOAD FROM 1991-1995 BASELINE



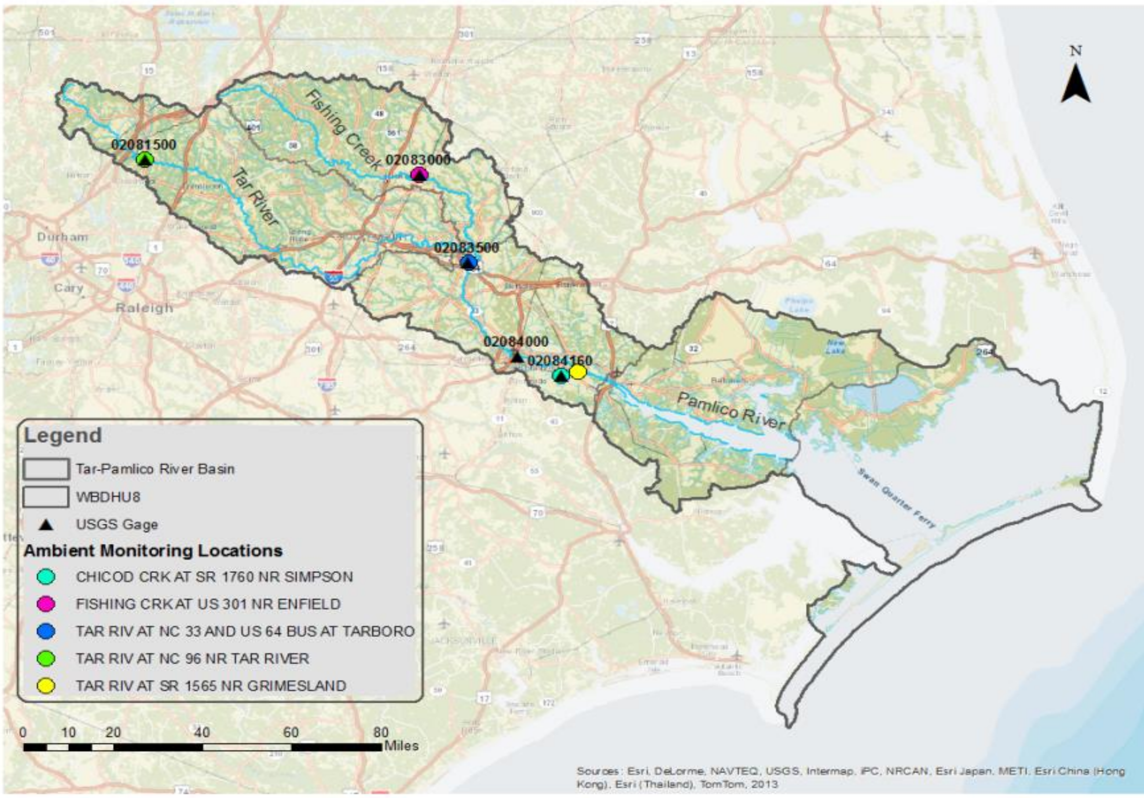
A comparison of the flow-normalized results for each the monitoring stations evaluated throughout the basin indicates a decrease in flow normalized NOx loads at five of the seven stations evaluated starting at the upper end of the basin at Crabtree Creek (Figure 14). These reductions in NOx track urban areas and discharge points in the upper basin, with a 57% reduction near Clayton downstream of Raleigh followed by diminished reductions as you move lower in the basin past Goldsboro and Kinston to the compliance point for the estuary at the Fort Barnwell. The Fort Barnwell station has mixed results of a decrease in NOx offset by a significant increase in TKN resulting in an overall slight increase in total nitrogen loading relative to the 1991-1995 baseline period of the analysis. The Trent River station which shows the greatest percent increase for all three nitrogen parameters, but represents significantly less flow and relative total load in comparison to the compliance point at Fort Barnwell

Overall, the 2017 analysis indicates that significant reductions in NOx loads were achieved in the early 1990s, but the loads have shown increases starting around 2003 and continuing through 2017 while remaining below baseline levels. Meanwhile after an initial decrease in TKN loading in the late 1990's it has continued to increase steadily over the years and continue to offset the nitrate & nitrite reductions. Both the Seasonal Kendall test and the FN loading analysis show that there was a reduction in NOx loading and an increase in Org-N loading. The increase in Org-N loading is largely associated with high flow events suggesting that nonpoint sources and processes, including natural background Org-N and runoff from both urban and agricultural sources, play a major role in the increased Org-N loading in the watershed. The results of this analysis confirm the nutrient loading trends and increased Org-N inputs in the Neuse River Basin reported in recent studies (AquAeTer, 2016, and Osburn, et al., 2016,). There remains a need for future studies that focus on identification of Org-N sources and effective management options.

Tar-Pamlico – Estuary Loading Analysis

As with the Neuse, DWR's Modeling and Assessment Branch used multiple trend and loading estimation tools to assess the progress towards meeting the Tar-Pam nutrient management strategy goals. The trend analyses focused on data from the ambient monitoring station O6500000, between 1991–20202, to evaluate progress towards meeting NSW reduction goals. This station is located at Grimesland, which is approximately 7 miles upstream of Washington. The location of the DWR monitoring stations and USGS flow gauges used in this analysis are provided in Figure 15.

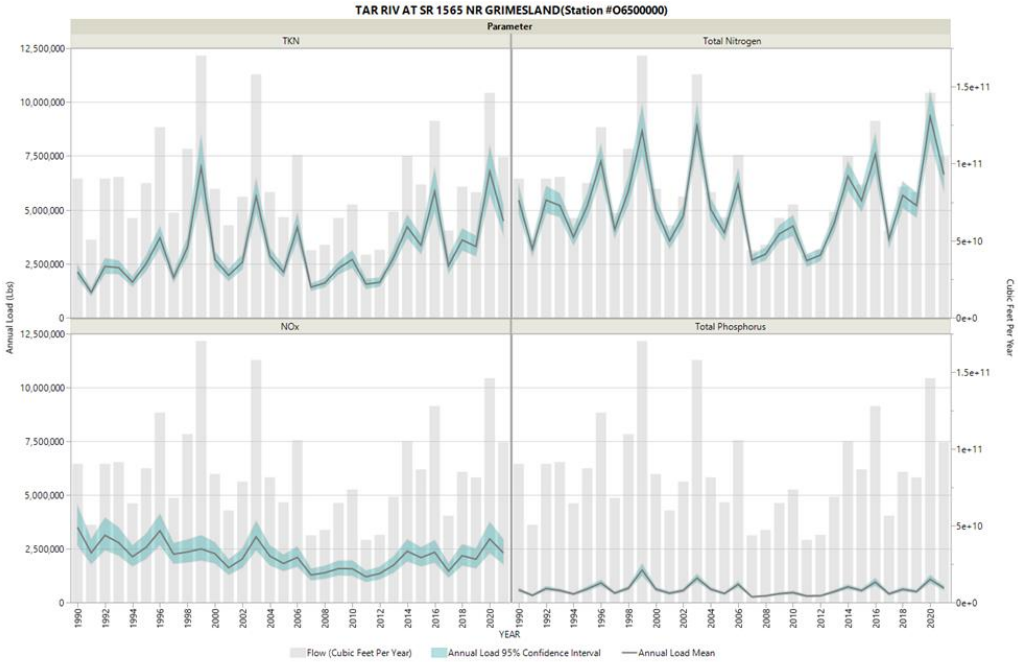
FIGURE 15. SELECTED TAR-PAMLICO RIVER BASIN WATER QUALITY MONITORING STATIONS



Tar-Pamlico LOADEST Results

These load estimates are intended to provide a range of annual loading estimates based on flow and concentration records from the selected stations. Figure 16 below provides the resulting annual nitrogen and phosphorus load contributions as well as annual flow at the Grimesland monitoring station. This provides a visual assessment of the general loading pattern since the baseline and how loads vary but are highly impacted by the year-to year variability of flow. The loading trend results for the other four stations DWR evaluated in the Tar-Pamlico basin are provided in an Appendix B of this report.

FIGURE 16. LOADEST ANNUAL LOADS AT GRIMESLAND - TAR-PAMLICO



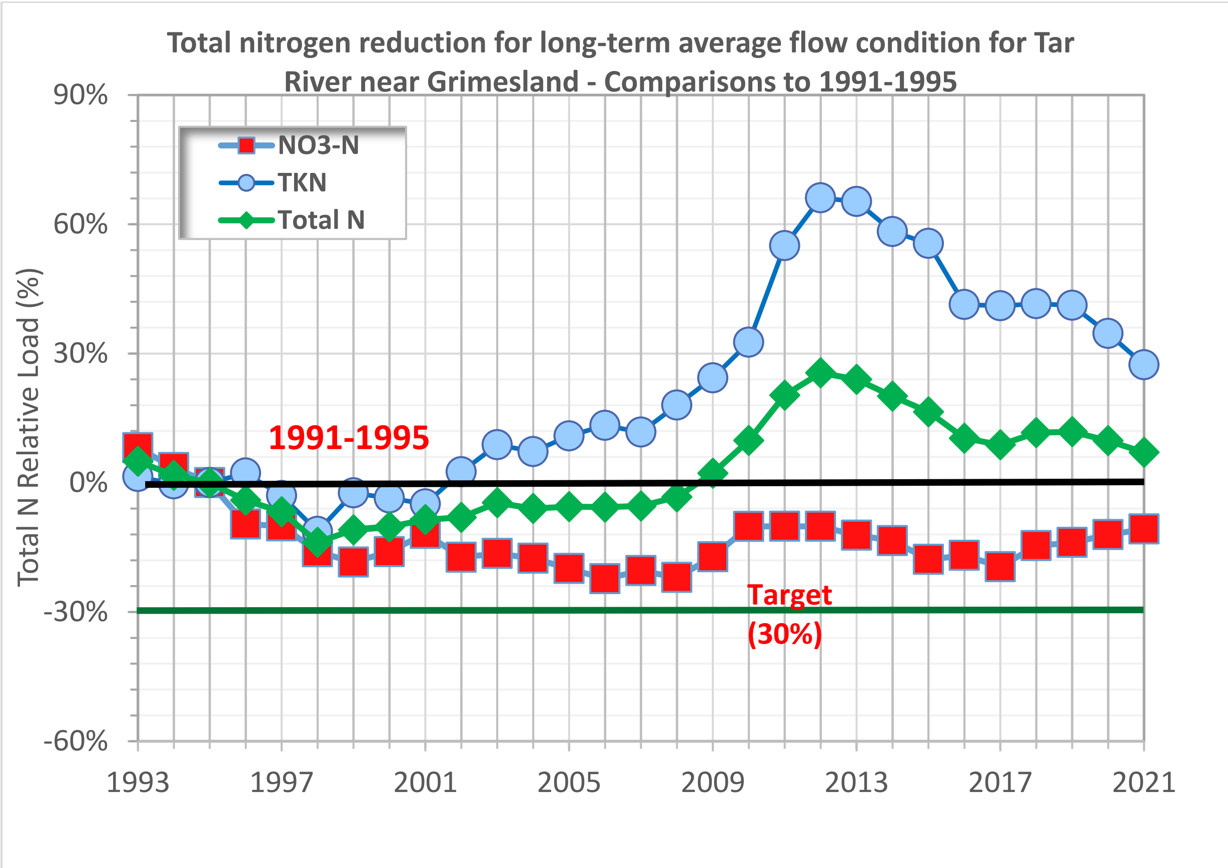
As seen with the analysis performed in the Neuse, the loading Tar-Pamlico estimates using the LOADEST method at the Grimesland station generally show that NOx loading decreased overall in the basin until mid-2010s and has slightly increased in recent years (Figure 16). Total Kjeldahl Nitrogen, on the other hand, has generally increased over the study period and appears to correlate very strongly with the increases and decreases in annual flows. Total Nitrogen loading followed the combinations increasing patterns of NOx and TKN resulting in an approximately 22 percent increase in raw nitrogen loading at the Grimesland station relative to the baseline period.

Despite the increase in flow relative to baseline no discernible change was observed in phosphorus loading to the estuary based on the LOADEST estimates. As with the analysis performed for the Neuse basin, determining the exact reason behind changes in loading is challenging due to the year-to-year changes in hydrologic conditions. Use of flow-normalized loading analysis, as described in the next section, is one way to attempt to tease out the factors that influence annual loads.

Tar-Pamlico: Flow Normalized Loads

In order to evaluate progress in achieving the nutrient reduction goal set by the Tar Pamlico River Basin nutrient management strategy, Flow-Normalized (FN) load estimated under long-term average flow conditions were compared to the average load for the 1991-1995 period. Five-year moving averages of NOx-N, TKN, TN and TP loads were computed and compared with the corresponding value for the 1991–1995 period (Figure 17).

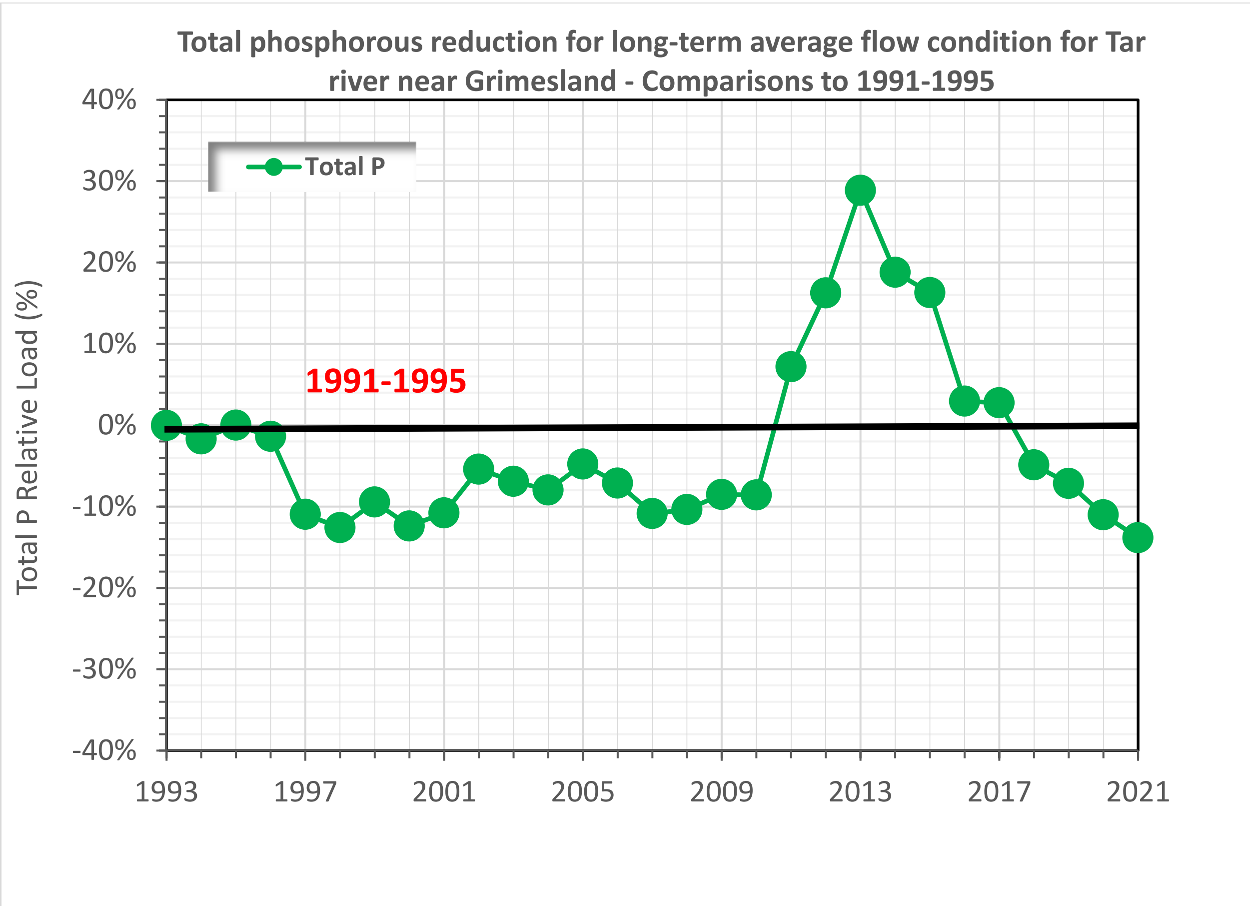
FIGURE 17. NITROGEN REDUCTION FOR AVERAGE FLOW CONDITION COMPARED TO 1991-1995 (GRIMESLAND)



The results of the flow normalized loading analysis indicate a reduction in NOx loading, but an increase in TKN loading relative to the 1991-1995 baseline period. Flow-normalized NOx loading gradually decreased from the 1991-1995 period to the end of the study period in 2021. It reached a minimum value of -24.1% in the 2004-2008 period. The average reduction achieved was approximately -15% for all periods beginning with 1992–1996. Flow-normalized TKN loading at Grimesland decreased from the baseline period and reached the minimum values of -5.0% in the 1997-2001 period and increased substantially afterwards reaching a maximum increase of 66% during the 2008-2012 period. Flow-normalized TKN loading has been consistently higher than the 1991–1995 period since the 1998-2002 time-period and increased by about 33% during this period. Since Ammonia loading declined over the same period, the increase in TKN loading was primarily due to an increase in the organic nitrogen fraction. The recent increase in TKN flow normalized loadings appears to be mainly due to increases for the high flow intervals.

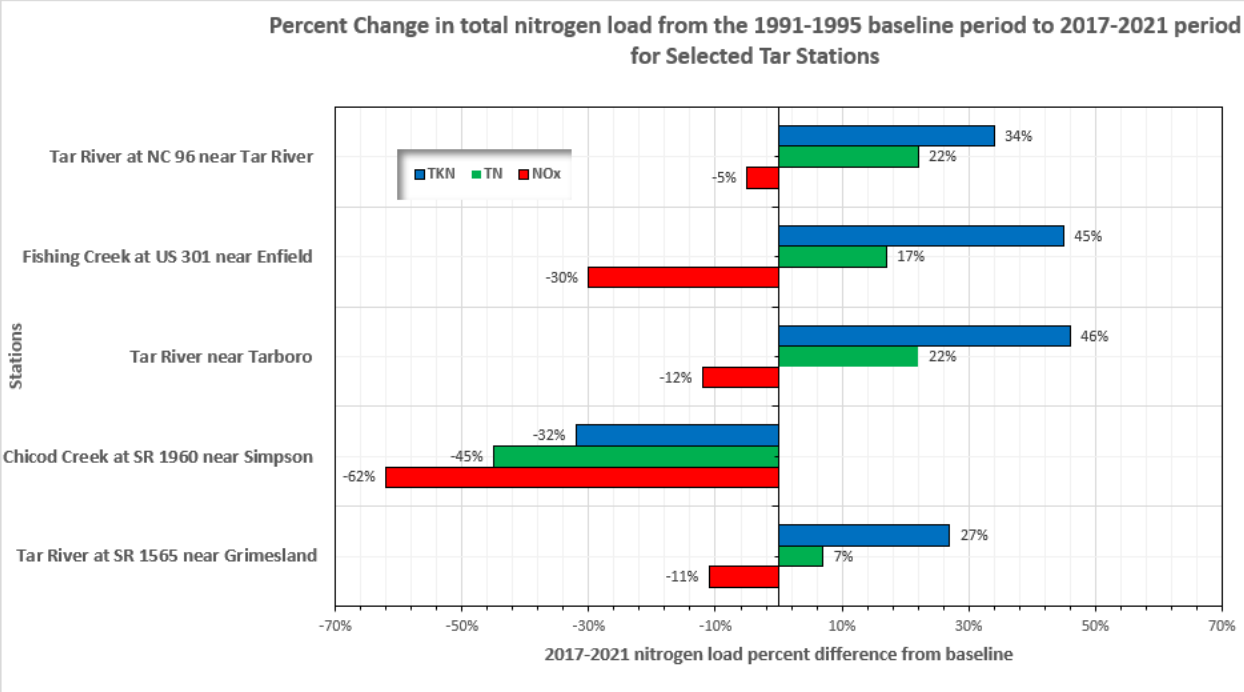
Over the course of the study period the flow-normalized total nitrogen loading has exhibited the combination of increasing patterns for NOx and TKN. Total nitrogen loading was consistently lower than the 1991-1995 loading through the 2004-2008 period and has been higher than the baseline loading levels ever since. The total nitrogen load was estimated to have its biggest drop to an estimated -14% in the 1994-1998 time period and has been gradually increasing ever since as it tracks increases in NOx and TKN in the basin over time. As in the Neuse, it is believed the large increases in TKN in the Tar-Pam are driven by organic nitrogen inputs. This increase in organic nitrogen loading is largely associated with high flow events suggesting that nonpoint sources and processes, including natural background organic nitrogen and runoff from both urban and agricultural sources.

FIGURE 18. PHOSPHORUS REDUCTION FOR AVERAGE FLOW CONDITION COMPARED TO 1991-1995 (GRIMESLAND)



Flow-normalized phosphorus loading at Grimesland has been consistently lower than the corresponding 1991-1995 loading until the 2009-2013 period when the load increased to approximately 30% greater than the 1991-1995 load (Figure 18). Since the peak in 2013, the phosphorus loading has decreased over the past 8 years to a minimum value of -12.0% in 2021. It is believed this dramatic increase in phosphorus loading during the 2009-2013 time period was the result of increases in the high flow intervals as well as the increases in phosphorus concentration during that time frame. More recent monitoring data indicate the phosphorus loading levels remain below baseline levels and are consistent with results observed prior to 2009.

FIGURE 19. UPSTREAM TO DOWNSTREAM: % CHANGE IN TAR-PAMLICO BASIN NITROGEN LOAD FROM 1991-1995

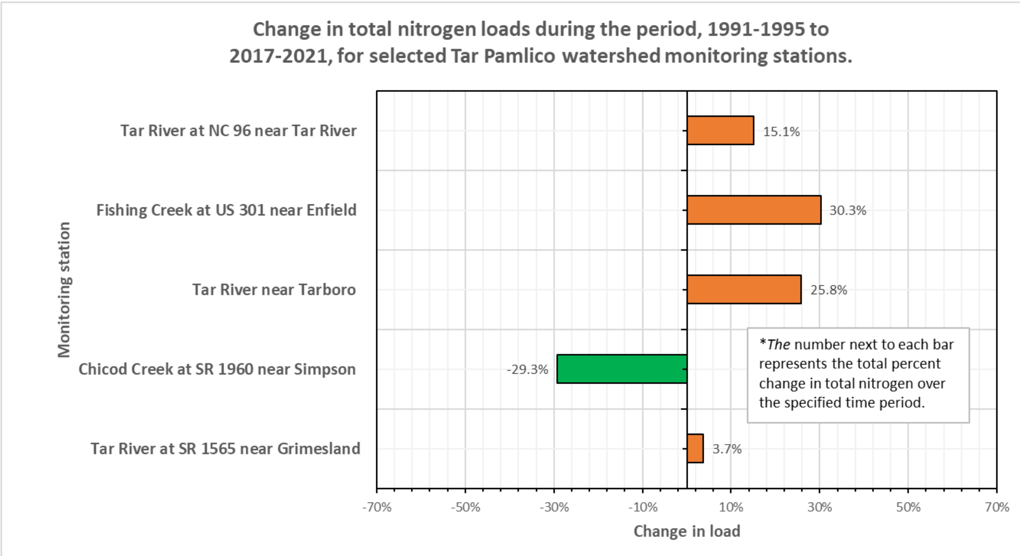


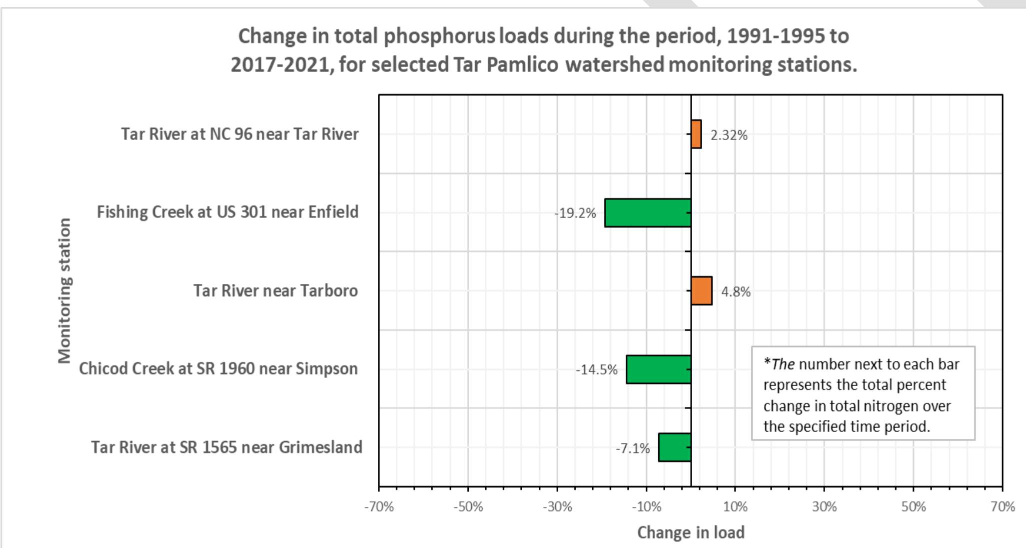
The results of the FN loading analysis indicate a decrease in flow normalized NOx loads at four of the five stations evaluated starting at the upper end of the basin at the Tar River at NC 96. These reductions then fluctuate as you move down the basin past Enfield and Tarboro and show an ever bigger 62% reduction at the Chicod Creek station followed by a more modest 11% reduction in NOx at the compliance point for the estuary at Grimesland at the lower end of the basin (Figure 19). This station at Grimesland has mixed results showing decrease in NOX along with a significant increase in TKN resulting in an overall slight 7% increase in total nitrogen loading relative to the 1991-1995 baseline period of the analysis.

Tar-Pam – WRTDS Method

The third method in this analysis takes another approach at addressing the influence of flow variability by calculating flow-normalized tributary loads and concentrations using the USGS Weighted Regressions on Time, Discharge, and Season (WRTDS) method. This method removes the effects of annual flow variations and is useful for observing changes in nutrient loads that occur as a result of management activities. The WRTDS method is a recently developed exploratory data analysis approach that provides insight about the characteristics of water quality data and can be used to evaluate changes in nutrient concentration and loads.

FIGURE 20. WRTDS NORMALIZED LOADING ANALYSIS FOR TAR-PAMLICO RIVER BASIN





The results in Figure 20 above show the change in flow normalized nitrogen and phosphorus loads for all five stations over the same time period using the WRTDS flow normalized method. As with the results using the Lebo method, the stations higher up in the watershed show increases in nitrogen loading while loading at Chicod creek shows a significant reduction in both nitrogen and phosphorus loading. The Grimesland station again exhibits mixed results with a decrease in phosphorus loading and slight increase in nitrogen loading relative to the 1991-1995 baseline period of the analysis.

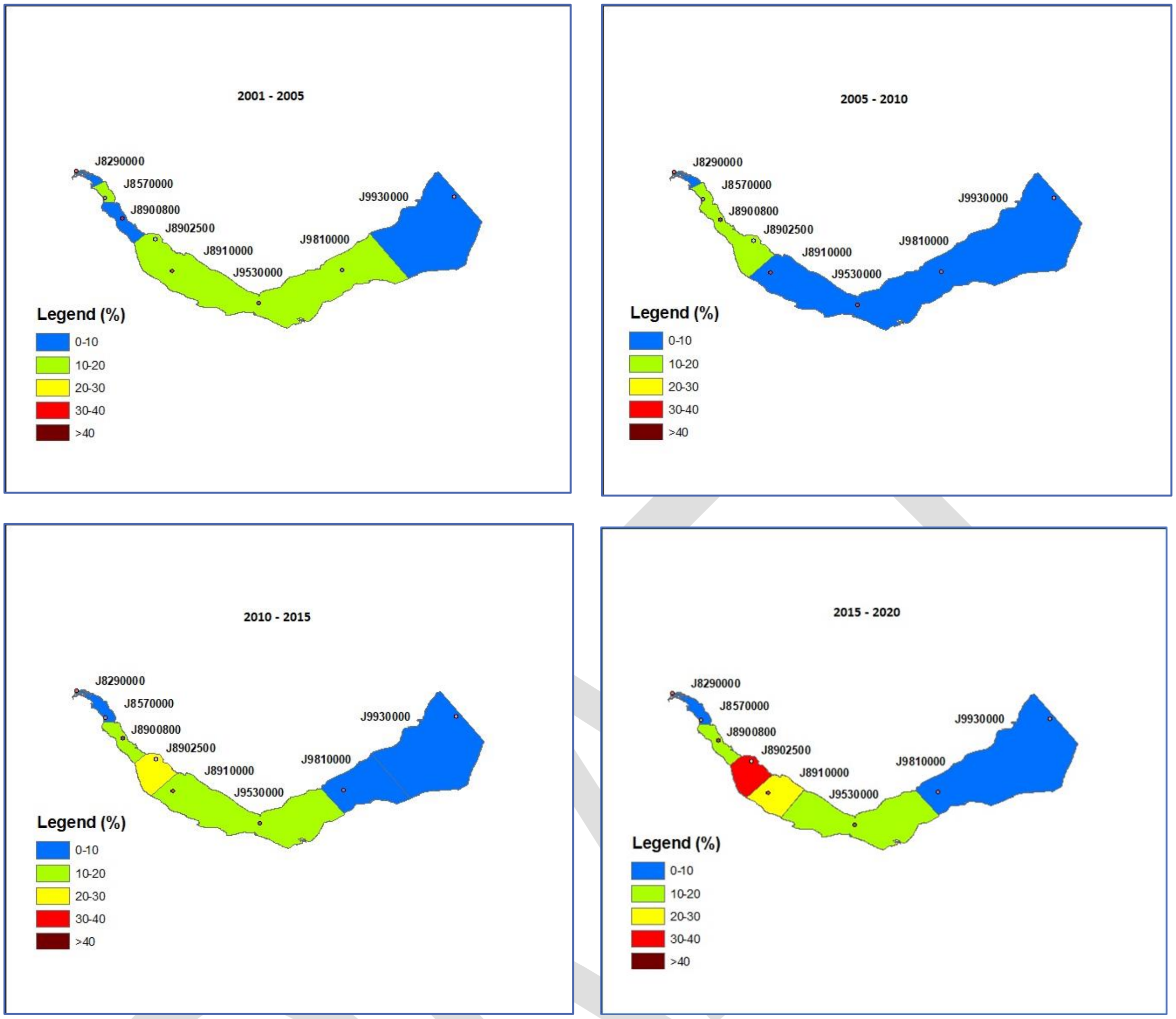
Estuary Chlorophyll *a* Concentrations

In addition to evaluating changes in nutrient loading, DWR also conducted an assessment of changes in chlorophyll *a* concentrations in the Neuse and Tar-Pamlico estuaries after the nutrient strategies went into effect. Two different analyses were performed using the chlorophyll *a* data collected from 2001 through 2020. The first is a percent exceedance analysis by station that determines the fraction of each station's samples exceeding the water quality standard 40 µg/L for given time periods. The second is a magnitude of exceedance analysis by station, characterizing the extent to which concentration values at a station ranged above the 40 µg/l standard. Four chlorophyll *a* datasets were used for analyzing percent exceedance and magnitude of exceedance over four five-year time periods. The first time period is 2001-2005, which is just after the management strategy rules were adopted. The second is for 2005-2010, the third for 2010-2015, and the fourth for 2015-2020. All three those later time periods coincide with full strategy implementation in both the Neuse and Tar-Pamlico. In both cases only DWR ambient data were used for this analysis.

Neuse Estuary – Chlorophyll *a*

Figure 21 illustrates the spatial distribution of chlorophyll *a* standard percent exceedance rates for the four time periods in the Neuse estuary. There are eight stations considered for evaluating exceedance rate. The stations J8290000, J8570000, and J8900800 represent the upper portion of the estuary; J8902500, J8910000 and J9530000 the middle portion; and J9810000 and J9930000 the lower portion. The exceedance rate is color coded. Green represents 0% to 10% samples exceeding the water quality standard 40 ug/L. Similarly, blue represents more than 10% to 20%, yellow more than 20% to 30%, red more than 30% to 40%, and dark red more than 40%.

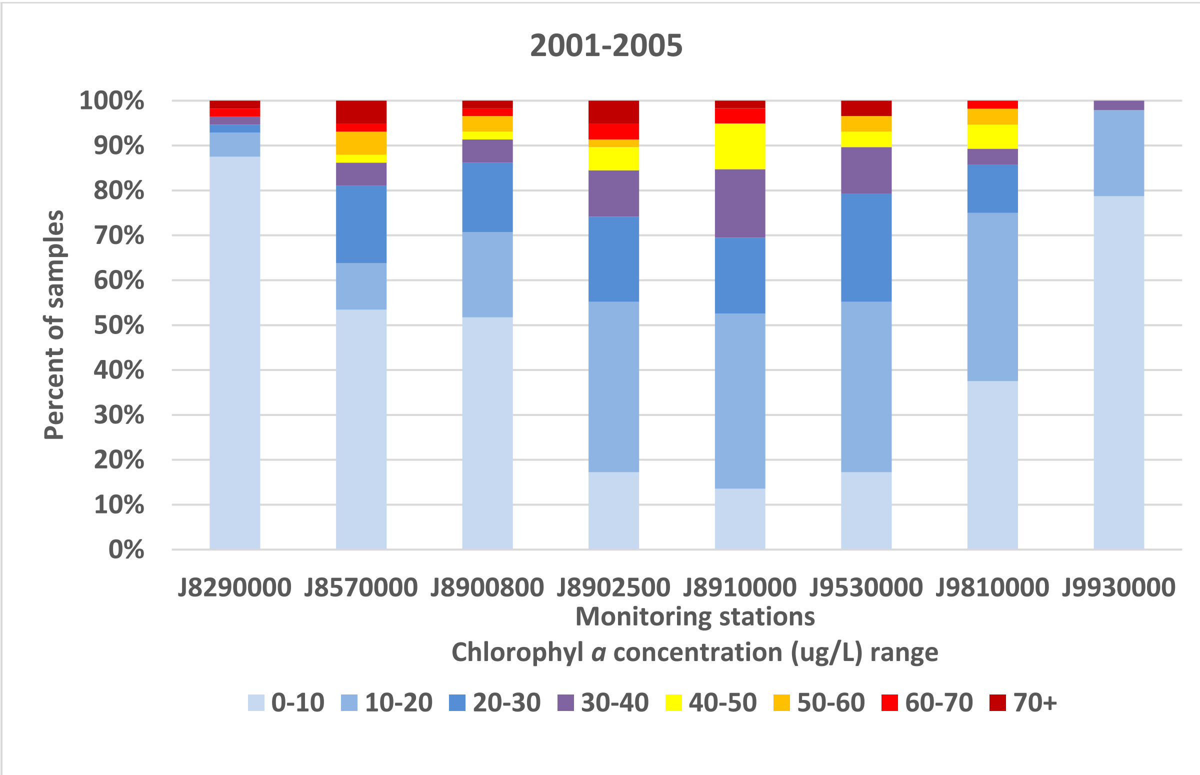
FIGURE 21. NEUSE - PERCENT OF SAMPLES EXCEEDING CHLOROPHYLL A STANDARD OF 40 µG/L FROM 2001 – 2020

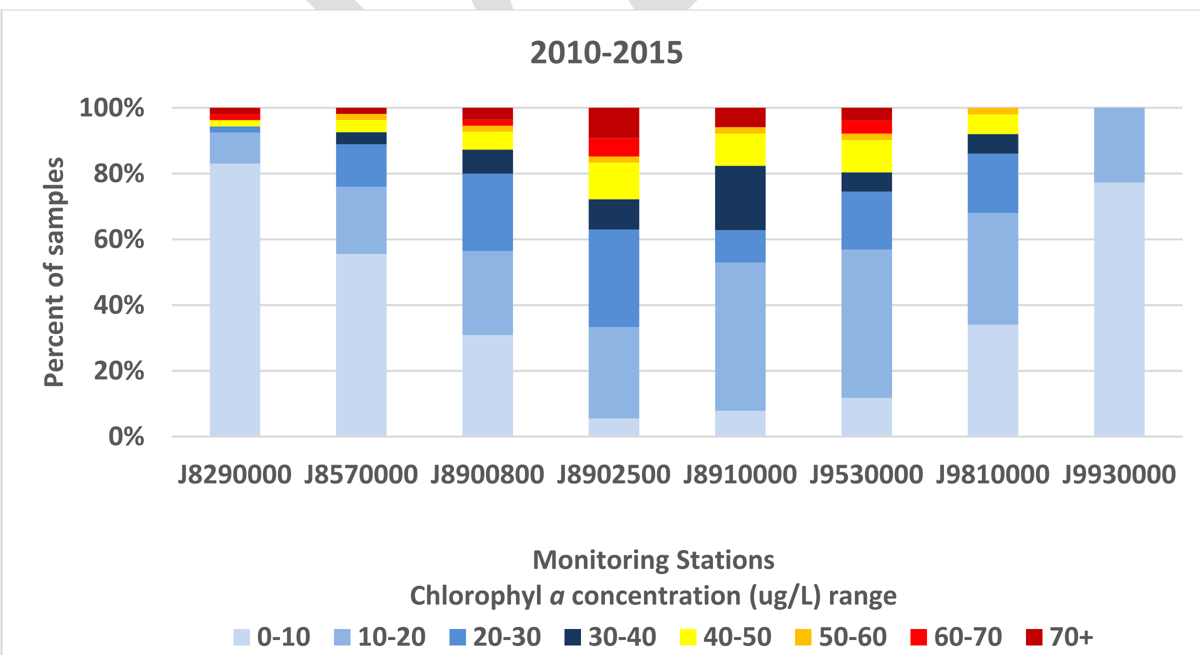


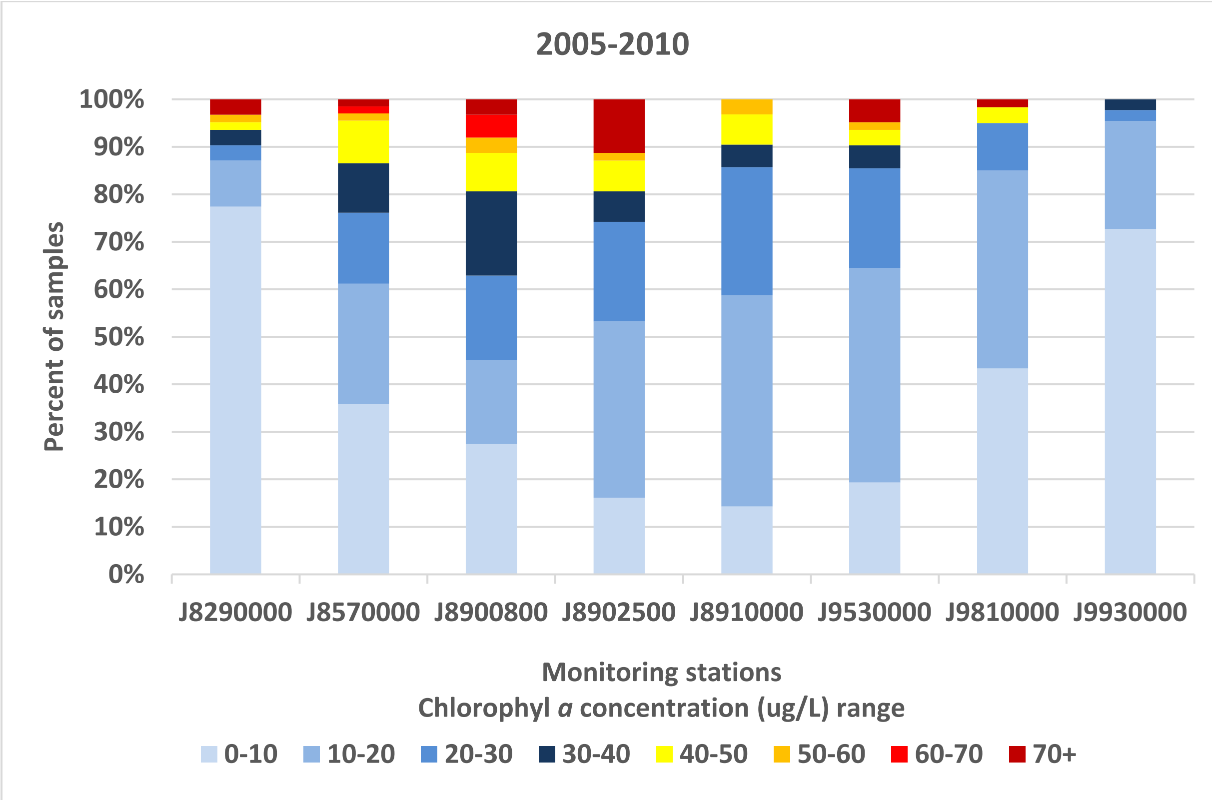
Exceedance rates of the chlorophyll *a* standard appear to be more stable in the upper and lower portions of the estuary and relatively sensitive in the middle portion. During the first period of this analysis (2001-2005), exceedance rates were moderately higher (10%-20%) in the mid-section of the estuary. This are showed some improvement during the second period (2005-2010), but the exceedance rate started going back up during the third and fourth five-year time periods between 2010 and 2020. Overall, the chlorophyll *a* exceedance rates were found to be consistently lower in the lower portion of the estuary throughout this 20 year period while at the same time moderately higher in the upper portion where between 10% and 20% of the samples at stations J8570000 and J8900800 measured chlorophyll *a* concentrations above the standard rate 40 µg/L during the study period.

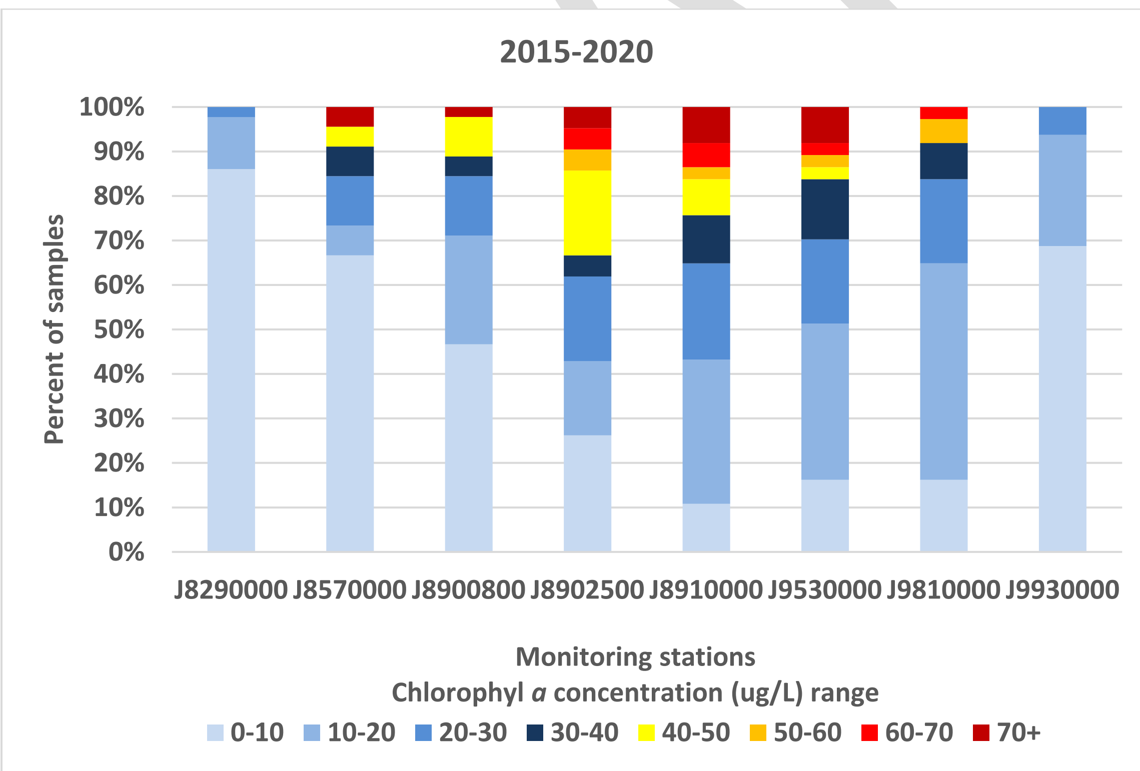
The higher rates of chlorophyll *a* exceedance in the middle portion of the Neuse estuary is further confirmed by the second part of the chlorophyll analysis (Figure 22), which illustrates the magnitude of chlorophyll *a* concentrations at each of the nine estuary monitoring stations for the same time periods as above. The "cooler" blue colors on the stacked bar charts below represent samples meeting the chlorophyll *a* standard of 40 µg/L. The “warmer” yellows, oranges, and red colors represent increasing magnitudes of exceedances of the standard.

FIGURE 22. CHLOROPHYLL-A CONCENTRATION RANGES - NEUSE RIVER BASIN






2005-2010
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of samples
J8290000 J8570000 J8900800 J8902500 J8910000 J9530000 J9810000 J9930000
Monitoring stations
Chlorophyl *a* concentration (ug/L) range
0-10 10-20 20-30 30-40 40-50 50-60 60-70 70+

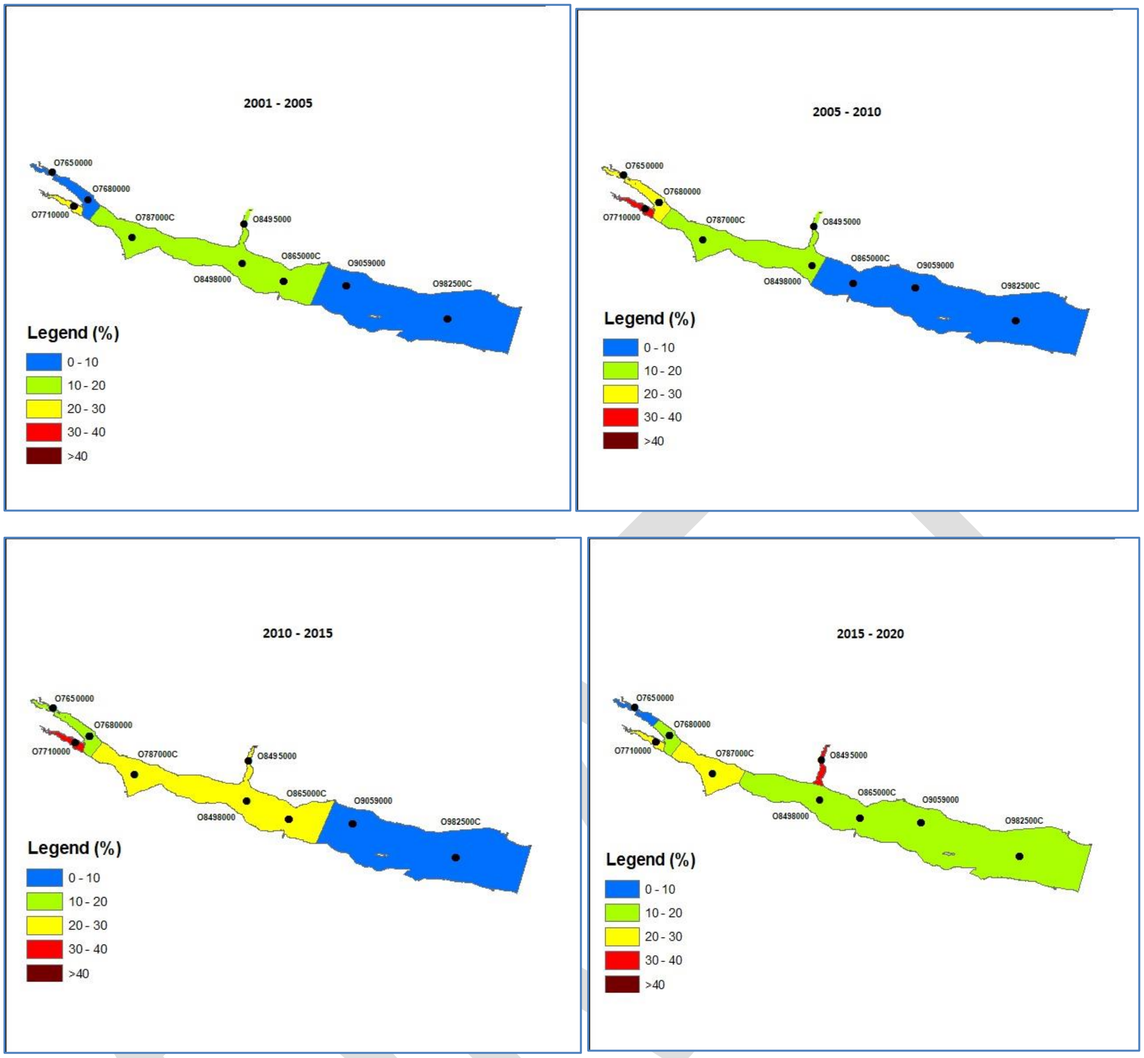

2015-2020
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of samples
J8290000 J8570000 J8900800 J8902500 J8910000 J9530000 J9810000 J9930000
Monitoring stations
Chlorophyl *a* concentration (ug/L) range
0-10 10-20 20-30 30-40 40-50 50-60 60-70 70+

A visual comparison of these stacked bar charts suggests that there is a higher magnitude of chlorophyll *a* exceedances in the middle portion of the Neuse estuary over time compared to the lower portion. These fluctuations in the magnitude of exceedances over time are influenced by biophysical interactions throughout the estuary, like the amount of water flowing from the river into the estuary during the different seasons and the quantity of nutrients that water carries. Higher flow periods typically carry higher nutrient loads through the estuary. Meanwhile, lower flow periods typically experienced in the dryer winter and early spring allows for organic matter to build up in the estuary, instead of flushing out as usual. Since the water in the middle portion of the estuary does not experience the stronger currents present in the upper and lower estuary it may be more susceptible to increased algal production during both the periodic higher nutrient inputs from high flow years and lack of "flushing" of organic matter in low flow years

Tar-Pamlico Estuary – Chlorophyll *a*

A similar chlorophyll *a* analysis was conducted for the Tar-Pamlico estuary. The spatial distribution of chlorophyll *a* standard percent exceedance rates for the four time periods is illustrated below in Figure 23. The exceedance rate was evaluated for nine estuary monitoring stations in the Tar-Pamlico. The stations O7650000, O7680000, and O787000C represent the upper portion of the estuary; O8498000, O865000C, and O9059000 the middle portion; and O9825000C the lower portion. The stations O7710000 and O8495000 represent the arms for the upper and middle portions of the estuary, respectively. The exceedance rate is color coded. Green represents 0% to 10% samples exceeding the water quality standard 40 ug/L. Similarly, blue represents more than 10% to 20%, yellow more than 20% to 30%, red more than 30% to 40%, and dark red more than 40%.

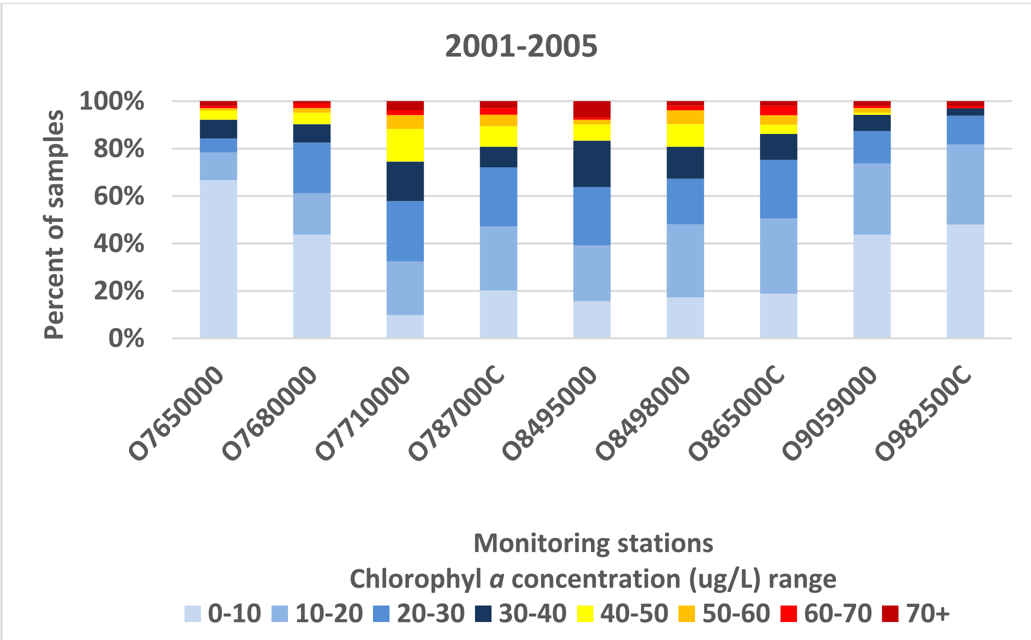
FIGURE 23. TAR-PAM - % OF SAMPLES EXCEEDING CHLOROPHYLL A STANDARD OF 40 μG/L FROM 2001 – 2020

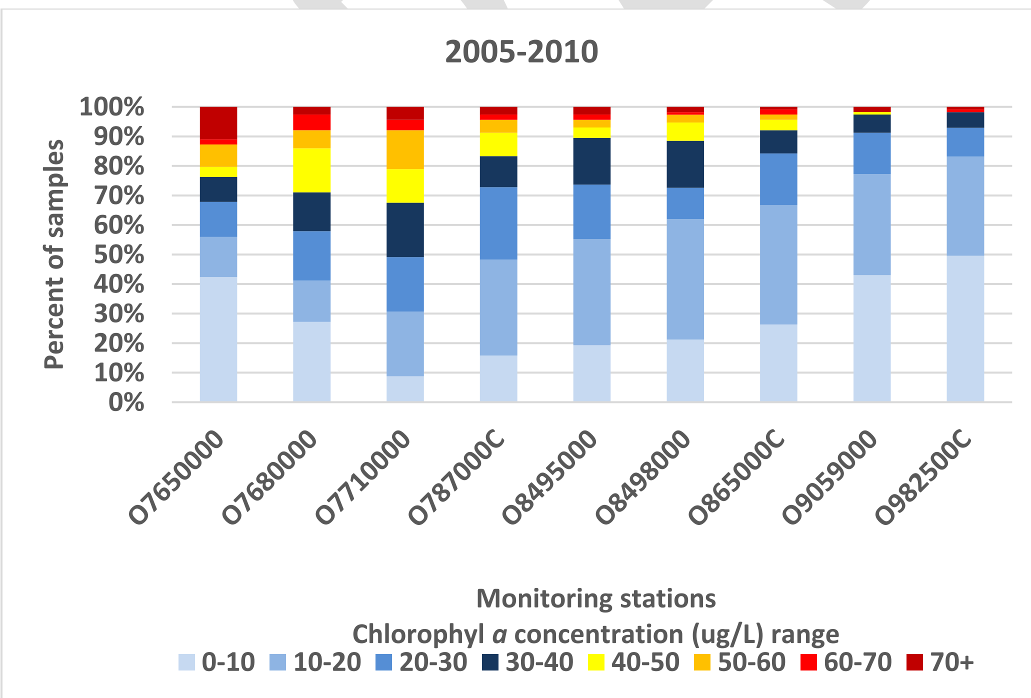


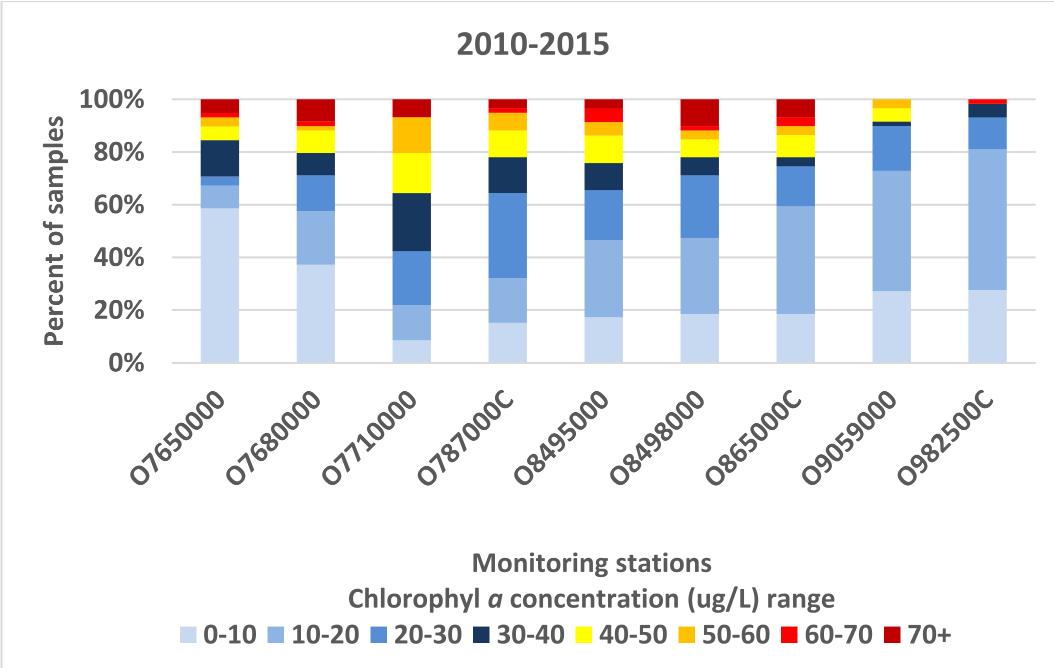
Unlike the Neuse, where the middle portion of the estuary was the most sensitive, in the Tar-Pamlico the majority of the estuary appears to be sensitive and prone to significant fluctuations in exceedance rates of the chlorophyll *a* standard between the 2001-2020 time period. Up until around 2010 the higher exceedance rates were limited to the upper and the middle portions of the estuary. However, the higher rates of exceedance were further extended to the lower portion of the estuary during the fourth period (2015-2020). Additionally, the rate remained higher (30%-40%) in the arms throughout the study period. The slightly different results in the Tar-Pam compared to the Neuse over the same time period may be partially due to the slight differences in the physical and hydrologic characteristics of the two estuaries. The Neuse is slightly longer and deeper and influenced by stronger currents in its upper and lower portions than the Tar-Pamlico.

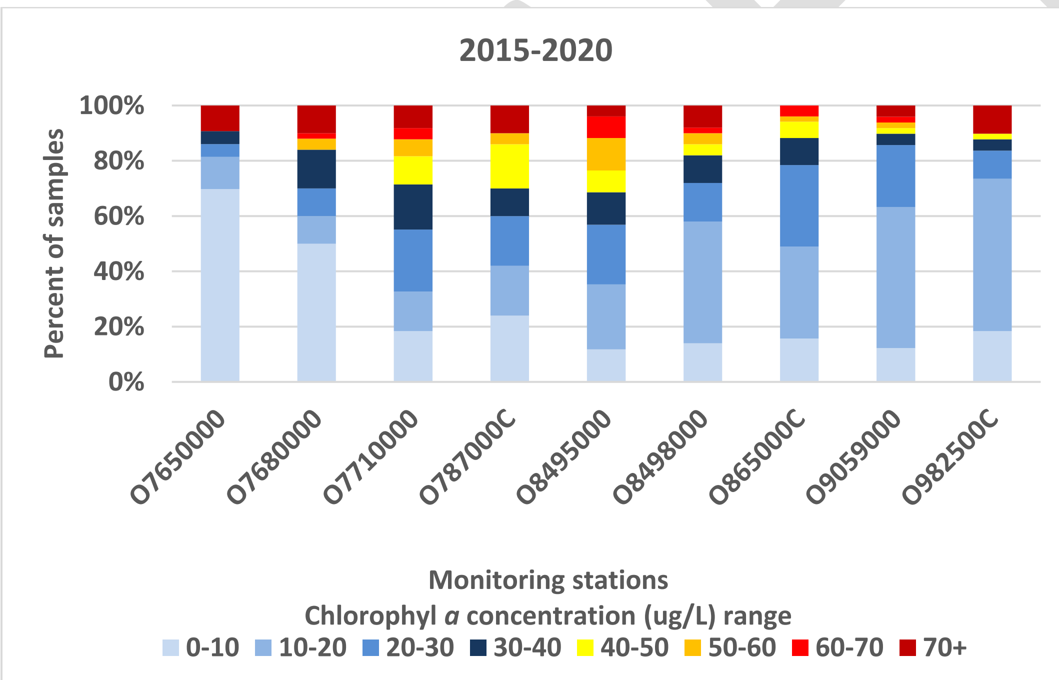
The above higher rates of chlorophyll *a* exceedance in the Tar estuary is further confirmed by the second part of the chlorophyll analysis (Figure 24). The magnitude of chlorophyll *a* concentrations were evaluated for the same time periods as above for each of the nine estuary monitoring stations. The "cooler" blue colors on the stacked bar charts below represent samples meeting the chlorophyll *a* standard of 40 µg/L. The "warmer" yellows, oranges, and red colors represent increasing magnitudes of exceedances of the standard. Visual comparison of the figures suggests that there is a higher magnitude in chlorophyll *a* exceedance in the upper and the middle portions of the Tar estuary with an increase in magnitude spreading into the lower portion of the estuary during the 2015-2020 time period.

FIGURE 24. CHLOROPHYLLY-A CONCENTRATION RANGES - TAR-PAMLICO RIVER BASIN






2010-2015
Percent of samples
100%
80%
60%
40%
20%
0%
07650000
07680000
07710000
0787000C
08495000
08498000
0865000C
09059000
0982500C
Monitoring stations
Chlorophyl a concentration (ug/L) range
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70+


2015-2020
Percent of samples
100%
80%
60%
40%
20%
0%
07650000
07680000
07710000
0787000C
08495000
08498000
0865000C
09059000
0982500C
Monitoring stations
Chlorophyl a concentration (ug/L) range
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70+

Fish Kill Events

The reporting of fish kill activity across North Carolina is based on protocols established by the North Carolina Division of Water Resources (DWR) in 1996. The protocols were developed with assistance from DWR Regional Office staff, North Carolina Wildlife Resources Commission biologists, and Division of Marine Fisheries personnel to improve the tracking and reporting of fish kill events throughout the state. Fish kill and fish health investigation data are recorded on a standardized form and sent to the DWR's Water Sciences Section (WSS) where the data are compiled and reviewed. Fish kill investigation forms, laboratory test results, and supplemental information regarding fish kill events are sent to the WSS and entered into a central database where the information can be managed and reported. The procedure also requires the notification of appropriate state officials and scientists associated with the investigation of such events. The protocols have proven successful in standardizing reporting methods and enhancing the quality and quantity of information reported from fish kill events.

During 2016 DWR staff developed a mobile app that can be used by the general public to report fish kill activity across the state. The app can be accessed through a smart phone, tablet, or PC running Android or iOS platforms. It was developed so that the public could easily report locational and anecdotal information to DWR.

While both the Neuse and Tar-Pamlico estuaries have seen an overall decline in the number of reported fish kill events over the past two decades they both experienced notable spikes in overall fish mortality during events between 2008-2009 and in 2013. The full history of fish kill events reported to the DWR between 2000 and 2020 is illustrated in Figures 25 and 26 below.

FIGURE 25. REPORTED FISH KILL EVENTS - NEUSE ESTUARY

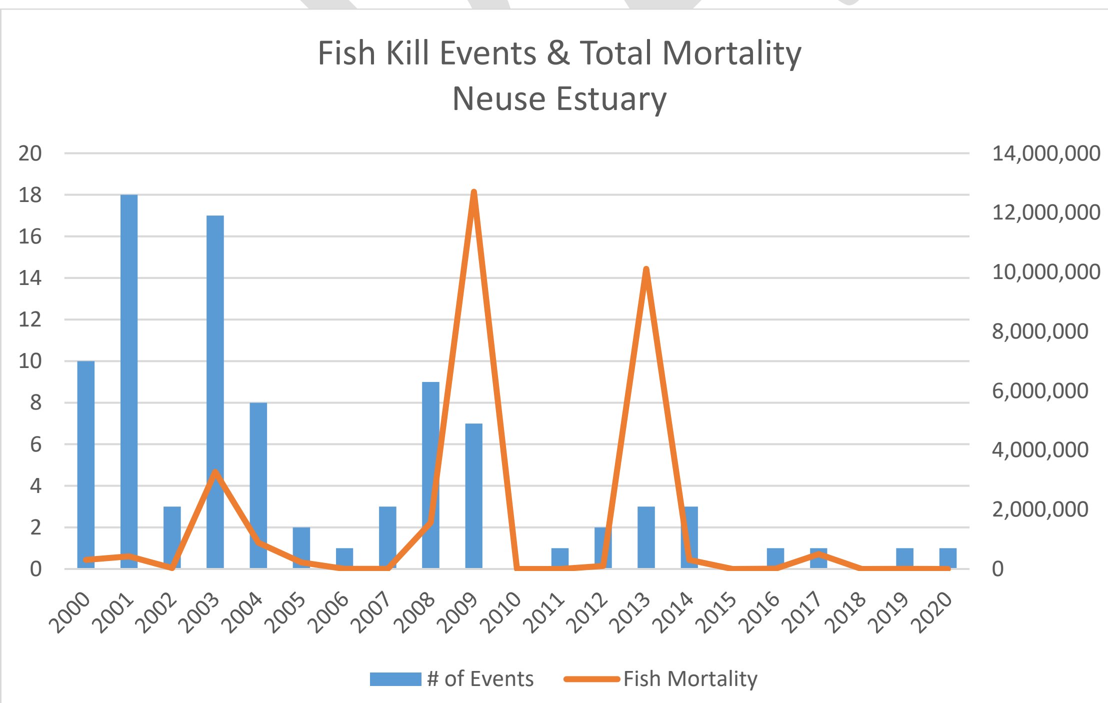
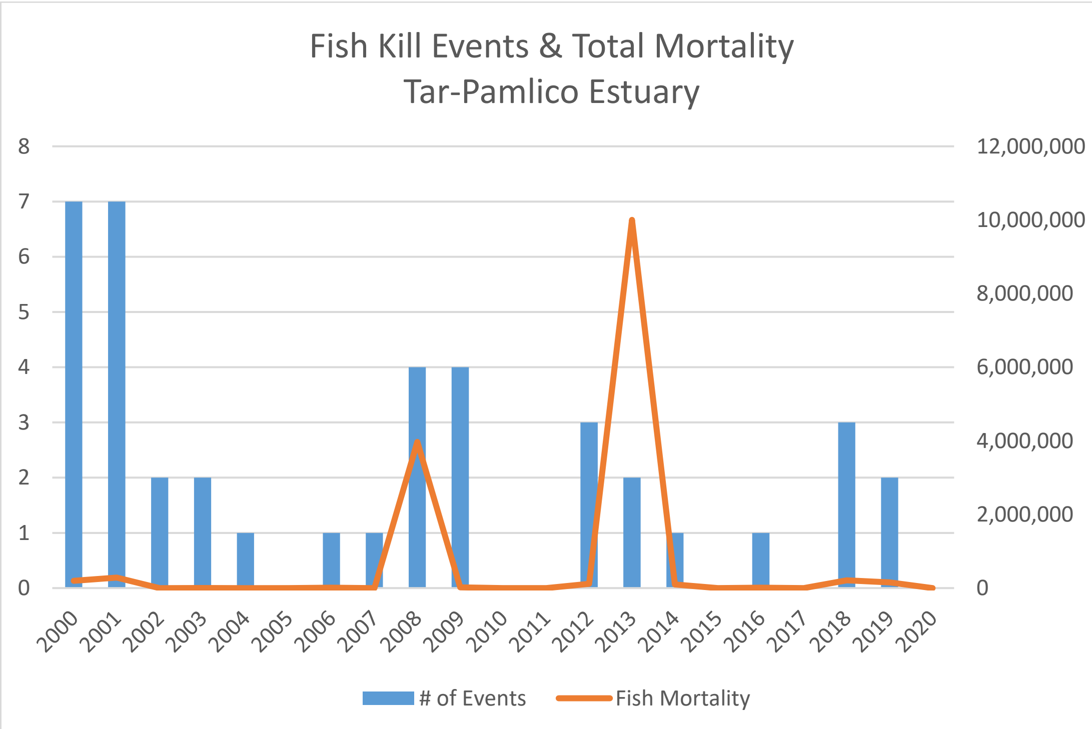


FIGURE 26. REPORTED FISH KILL EVENTS - TAR-PAMLICO ESTUARY

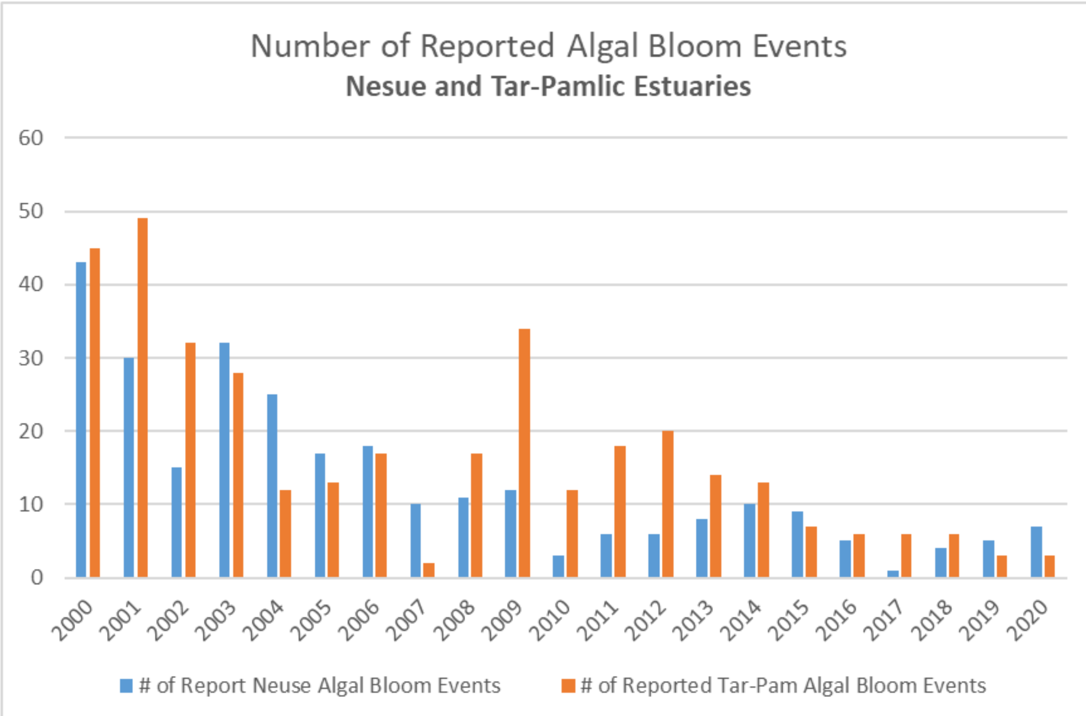


Algal Bloom Events

Algae are aquatic, microscopic plants, which respond to nutrients, temperature and light, and are an important food source for fish and other aquatic animals. Algae also contain pigments, including chlorophyll, which enable them to photosynthesize and produce oxygen. An algal bloom is a rapid increase in the density of algae in an aquatic system. Algal blooms sometimes are natural phenomena, but their frequency, duration and intensity are increased by nutrient pollution. These blooms, in turn, can deplete the water column of oxygen causing fish kills. When a site experiences dissolved oxygen concentrations >9 mg/l, DO percent saturation >110 percent, pH >8, or chlorophyll *a* concentrations exceed the state standard of 40 µg/l, the site is likely experiencing an algal bloom. When these algae die off or respire at night, dissolved oxygen can become very low; often resulting in fish kills.

The Division of Water Resources and other organizations have been monitoring the Neuse and Tar-Pamlico Estuaries for algal blooms for the past two decades. The figures below provide a summary of reported algal bloom events in both estuaries and a comparison of algal density observations in the two estuaries over time. While some years have been relatively mild in terms of algal blooms, there have been several significant events over the past two decades, but both estuaries have seen an overall decline in frequency of reported bloom events in recent years (Figure 27).

FIGURE 27. REPORTED ALGAL BLOOM EVENTS: NEUSE & TAR-PAMLICO ESTUARIES



A comparison of algal density concentrations over time (2000-2020) is provided below for selected "upstream" and "downstream" ambient monitoring stations in both estuaries (Figures 28 through 31). In addition to nutrients, other major factors that impact algal productivity in the estuaries includes are seasonal changes in water temperature, light availability, and changes to flow which influence nutrient concentrations and how quickly nutrients are transported into and out of a particular area of the estuary in question.

FIGURE 28. ALGAL DENSITY OVER TIME (MG/L) – STATION #J8902500 (UPPER NEUSE ESTUARY)

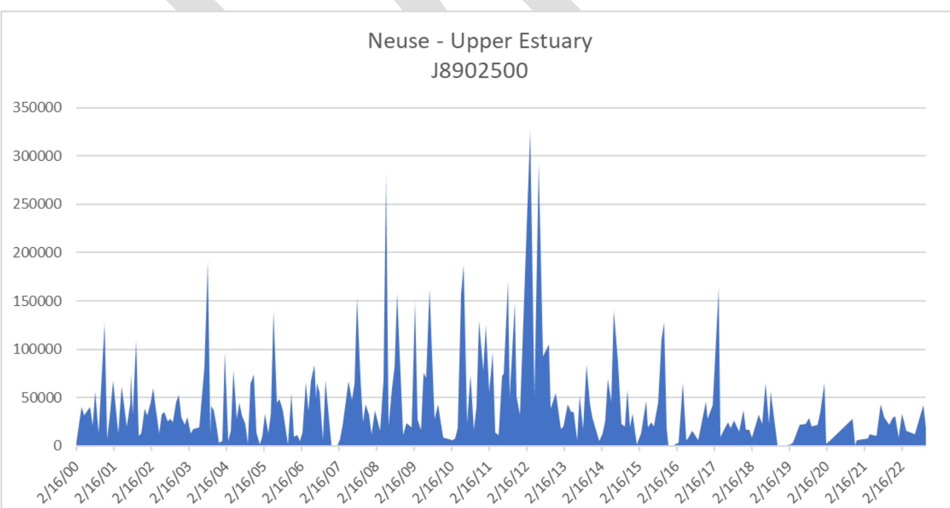


FIGURE 29. ALGAL DENSITY OVER TIME (MG/L) - STATION # J9810000 (LOWER NEUSE ESTUARY)

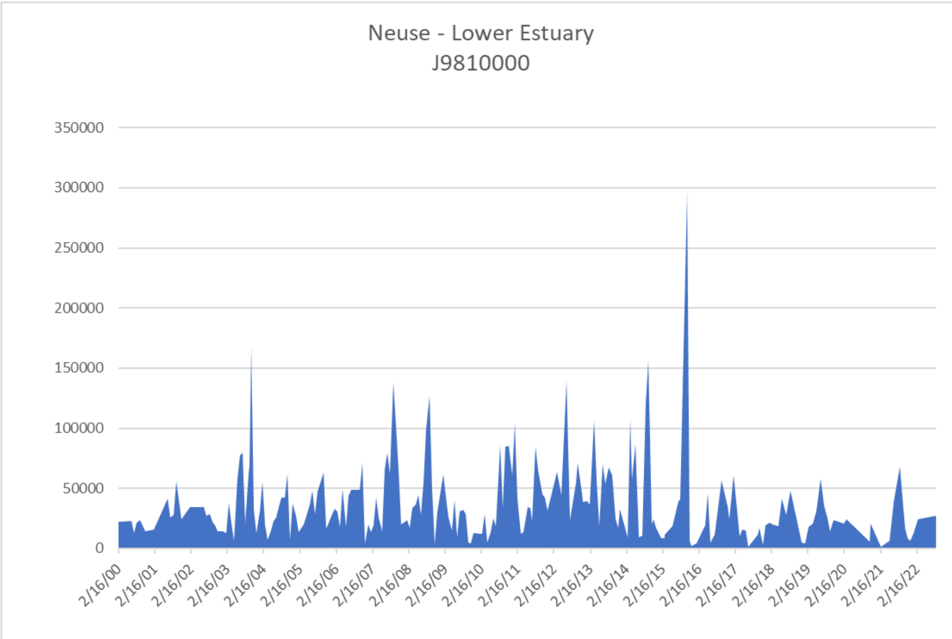


FIGURE 30. ALGAL DENSITY OVER TIME (MG/L) - STATION #O787000C (UPPER TAR-PAM ESTUARY)

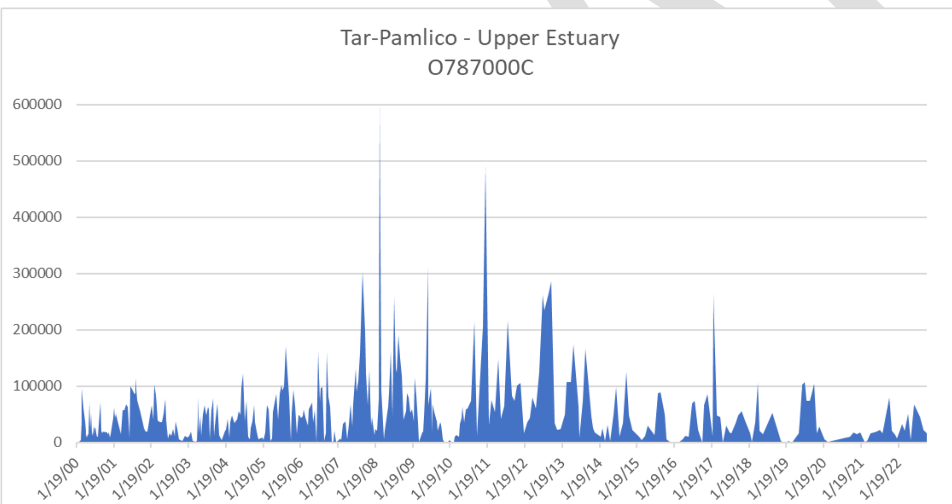
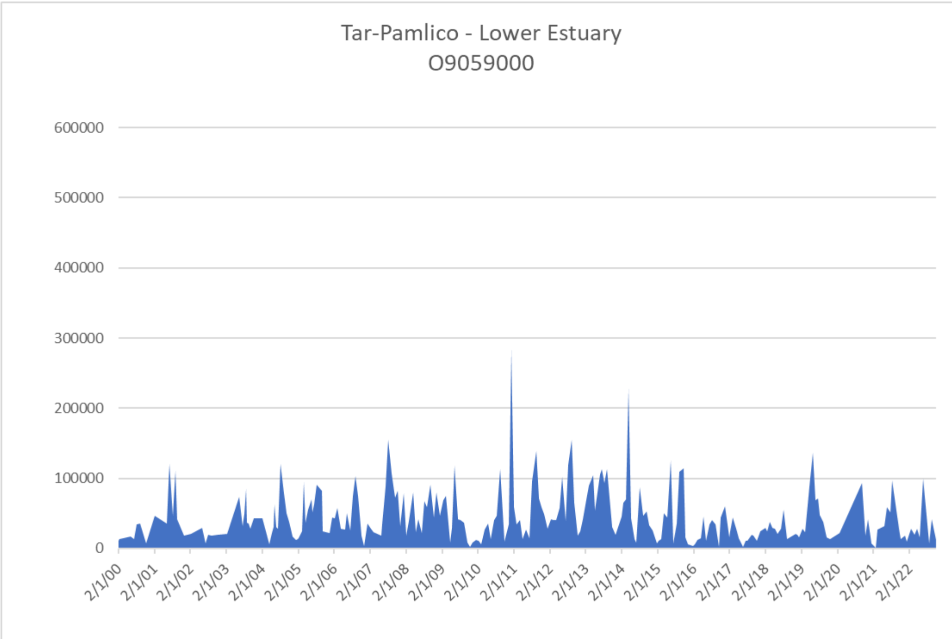


FIGURE 31. ALGAL DENSITY OVER TIME (MG/L) - STATION #O9059000 (LOWER TAR-PAM ESTUARY)



Watershed Changes

Land Use Changes

The Neuse and Tar-Pamlico River Basins are two of only four that lie entirely within the state. Both lie in eastern North Carolina, oriented northwest to southeast, with their upper halves in the Piedmont and lower portions spanning the Coastal Plain where their estuaries empty into Pamlico Sound. The Neuse River Basin is the third largest in the state with a land area covering 6,235 square miles. The headwaters drain smaller towns like Hillsborough and Creedmoor along with the north half of the City of Durham before flowing into Falls Lake, then continuing southeast past the municipalities of Raleigh, Smithfield, Goldsboro, Kinston, New Bern, and finally to the Pamlico Sound. The upper portion of the watershed below Falls Lake drains parts of metropolitan areas including the cities of Durham, Raleigh, and a number of growing Raleigh-adjacent communities including Cary.

The Tar-Pamlico River Basin is the fourth largest river basin in the state, resting atop the Neuse, and covers approximately 6,100 square miles. The Tar River originates in north central North Carolina in Person, Granville and Vance counties and flows southeasterly until it reaches tidal waters near Washington and becomes the Pamlico River and empties into Pamlico Sound.

The Neuse basin includes portions of 23 counties and 84 municipalities. The Tar-Pamlico basin is made up of portions of 18 counties and 55 municipalities. While both basins are similar in size, hydrology and overall land use composition relative to urban, agriculture, forested and grassland areas, they do differ in that the Tar-Pamlico basin is more rural with 5.6% of its land area developed as of 2019 compared to the rapidly developing Neuse Basin at 14.6% of its area developed. The Neuse' growth rate *by land area* of approximately 18% over the last twenty years was roughly double that of the Tar at 9%. These land area growth rates provide an interesting comparison to the population growth rates discussed below. Tables 3 and 4 detail changes in land cover acreage between 2001 and 2019. Development and population growth in the Neuse is concentrated in the Research Triangle area and select coastal communities, while population growth in the Tar-Pamlico Basin centers around Greenville, Rocky Mount and smaller municipalities within commuting distance to Raleigh, while other municipalities in the more rural areas have typically experienced negative growth over time (Figure 32).

FIGURE 32. NEUSE AND TAR-PAMLICO NATIONAL LAND COVER DATASET (2019)

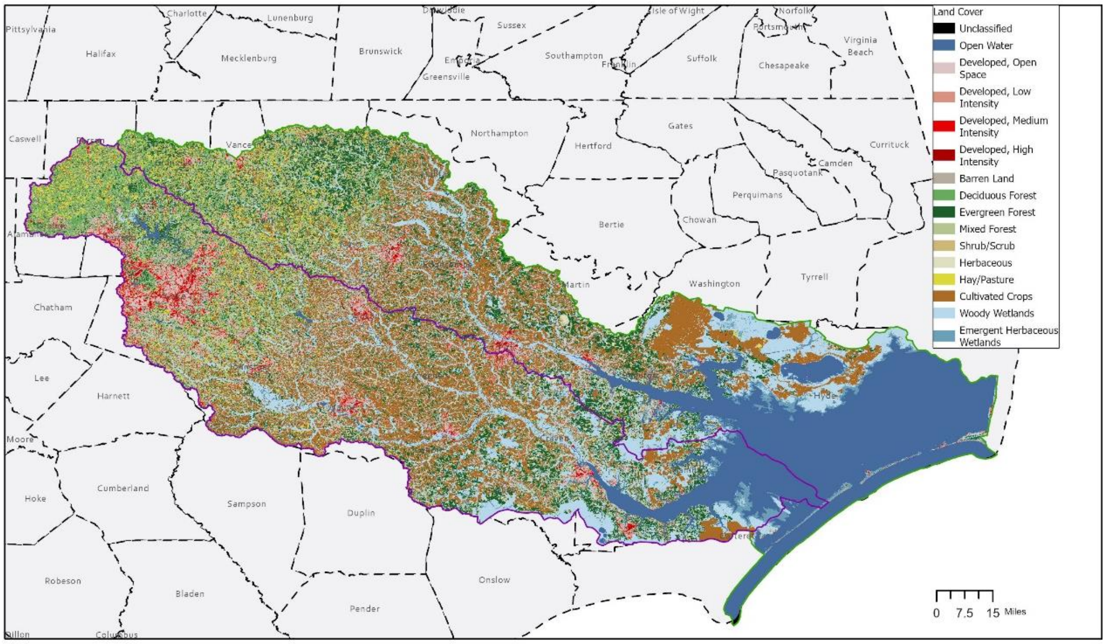


TABLE 3. CHANGES IN NEUSE RIVER BASIN LAND COVERS FROM 2001 TO 2019

Aggregated Land Cover Type	2001 (acres)	Percent of watershed	2019 (acres)	Percent of watershed	Change (acres)	Percent change
Agriculture	1,023,585	26.38%	987,646	25.45%	-35,939	-3.51%
Barren Land	5,072	0.13%	4,955	0.13%	-117	-2.30%
Developed	481,157	12.40%	566,461	14.60%	85,304	17.73%
Forest	1,061,188	27.35%	996,949	25.69%	-64,239	-6.05%
Grassland/Shrub	154,386	3.98%	169,918	4.38%	15,532	-10.06%
Wetlands	839,426	21.63%	837,828	21.59%	-1,598	-0.19%
Open Water	315,580	8.13%	316,636	8.16%	1,056	0.33%

TABLE 4. CHANGES IN TAR-PAMLICO RIVER BASIN LAND COVERS FROM 2001 TO 2019

Aggregated Land Cover Type	2001 (acres)	Percent of watershed	2019 (acres)	Percent of watershed	Change (acres)	Percent change
Agriculture	873,876	22.21%	853,070	21.68%	-20,805	-2.38%
Barren Land	13,550	0.34%	10,109	0.26%	-3,440	-25.39%
Developed	205,553	5.22%	223,159	5.67%	17,606	8.57%
Forest	938,158	23.84%	915,516	23.27%	-22,642	-2.41%
Grassland/Shrub	154,607	3.93%	179,669	4.57%	25,062	16.21%
Wetlands	767,567	19.51%	768,250	19.52%	682	0.09%
Open Water	981,711	24.95%	985,249	25.04%	3,538	0.36%

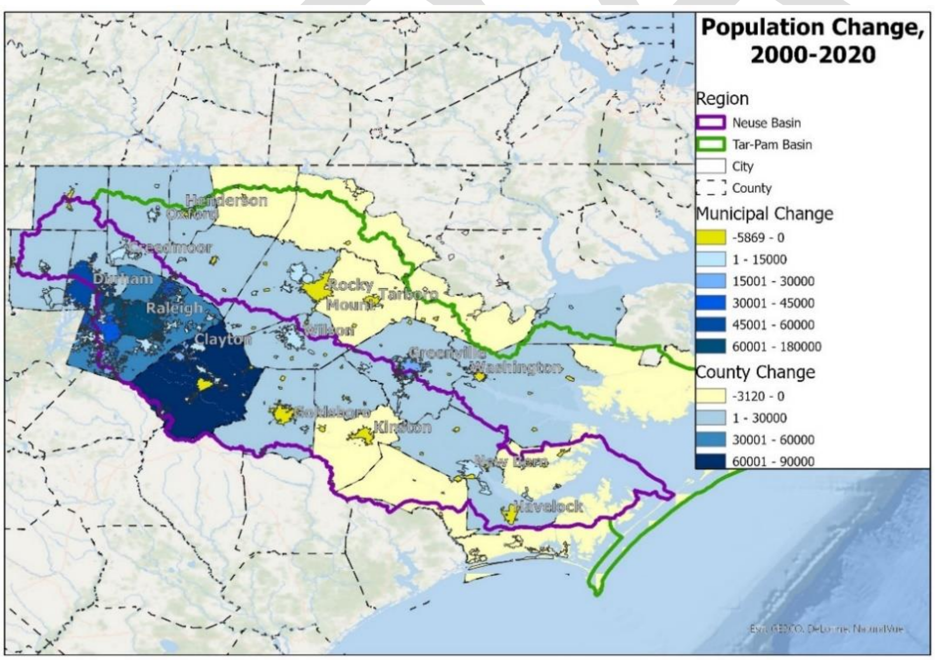
Population Growth

The Neuse and Tar-Pamlico River basins have both experienced population growth over the past two decades. However, the Neuse basin has grown at a much faster rate due to its larger urban centers with a resident population totaling more than 1.9 million people as of 2020, more than four times the size of the Tar-Pamlico at 430,000. According to the United States Census Bureau, the population of the Neuse basin has increased by about 46% between 2000 and 2020, while the Tar-Pamlico Basin grew by just 5% since 2000 (Figure 33). The map below in Figure 34 demonstrates these trends spatially with the total population change per municipality and county in the Neuse basin and Tar-Pamlico basin. Darker Shades indicate higher increase in population and yellow indicates a decrease in population.

As populations in both basins continue to grow, this will increase demand for community water resources and wastewater treatment plant expansions, as well as result in a loss of agricultural and forest land as pressure for more housing continues.

FIGURE 33. TOTAL POPULATION CHANGE OVER TIME – NEUSE & TAR-PAMLICO BASINS (2000 – 2020)

FIGURE 34. POPULATION CHANGE (2000-2020)



Agriculture: Changes in Total Crop Acreage and Changes by Crop

The Local Advisory Committees under the Agriculture rule (see Implementation section above) recalculate the cropland acreage annually by utilizing crop data reported by farmers to the Farm Service Agency. The number of cropland acres fluctuates every year in both watersheds. Each year, some cropland is permanently lost to development or converted to grass or trees. However, idle land is agricultural land that is currently out of production but could be brought back into production at any time. Cropland conversion and cropland lost to development is land taken out of agricultural production and is unlikely to be returned to production. The total crop acres are obtained from USDA-FSA and NC Agricultural Statistics annual reports; acres of idle land and conversion to other land uses comes from LAC members' best professional judgement, USDA-FSA records, and county planning departments.

Total reported crop acres for the Neuse watershed are presented in Figure 35, and the total for the Tar-Pamlico are presented in Figure 36. Overall crop acres have decreased by 20 to 25% in both watersheds compared to the baseline period. Reduction in total crop acres is included in the overall calculation of nitrogen loss reduction for each watershed.

FIGURE 35: TOTAL ACCOUNTED CROP ACRES IN THE NEUSE WATERSHED, BASELINE (1991-1995) AND SUBSEQUENT YEARS

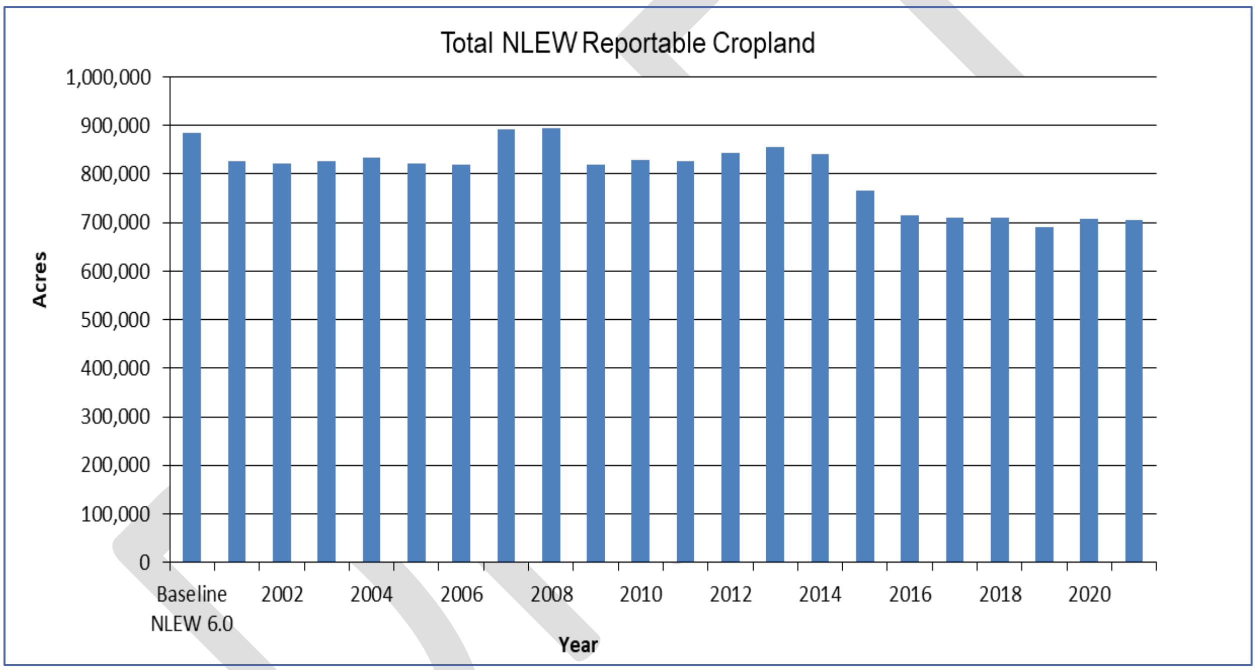
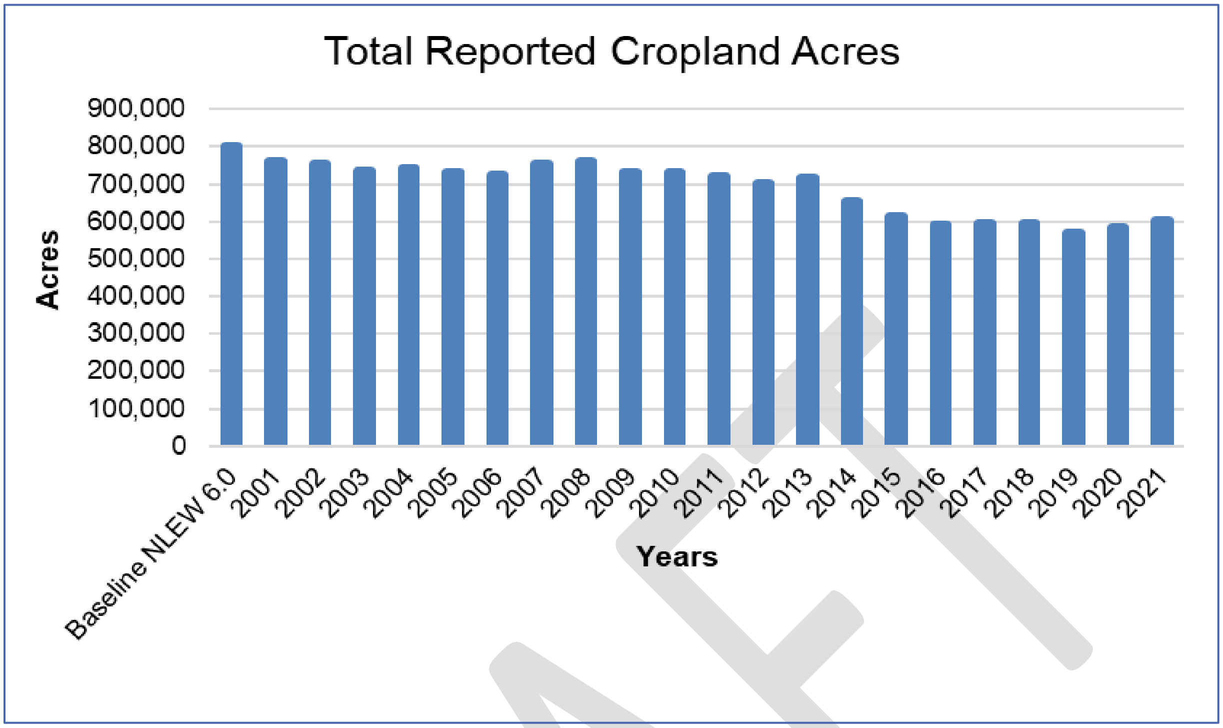


FIGURE 36: TOTAL ACCOUNTED CROP ACRES IN THE TAR-PAMLICO WATERSHED, BASELINE AND SUBSEQUENT YEARS



Crop Types and Fertilization Management

A host of factors from individual to global determine crop choices, including needs for fertilizer, ability to double-crop, weather patterns, and commodity prices. Some of this cropping shift is due to the need for regular rotations on agricultural operations. In order to minimize the threat of disease, the double-crop planting of wheat and soybeans is usually followed by a corn crop. This means that fluctuations within this rotation are to be expected from year to year even in the face of similar weather conditions. Because each crop type requires different amounts of nitrogen and utilizes applied nitrogen with a different efficiency rate, changes in the mix of crops grown can have significant impact on the cumulative yearly nitrogen loss reduction.

Figures 37 and 38 show the annual total acreage of seven major crop types tracked in the Neuse and Tar-Pamlico watersheds, respectively. Year-to-year variations within crop types are apparent, and similar relative crop magnitudes and overall temporal crop patterns are apparent between the two watersheds. While soybeans are the predominant crop acreage throughout the time period, they require minimal nitrogen application compared to other crop types.

FIGURE 37: TOTAL ACREAGE OF MAJOR CROPS IN THE NEUSE WATERSHED, BASELINE PERIOD AND SUBSEQUENT YEARS

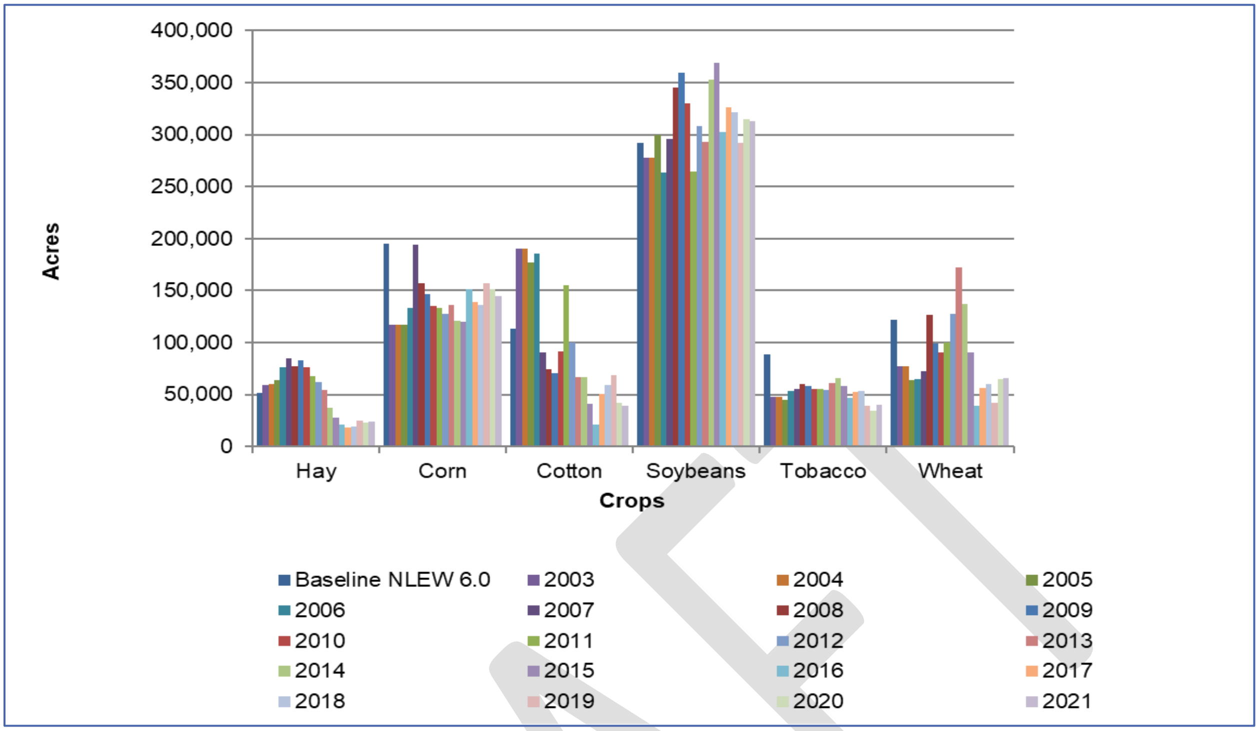
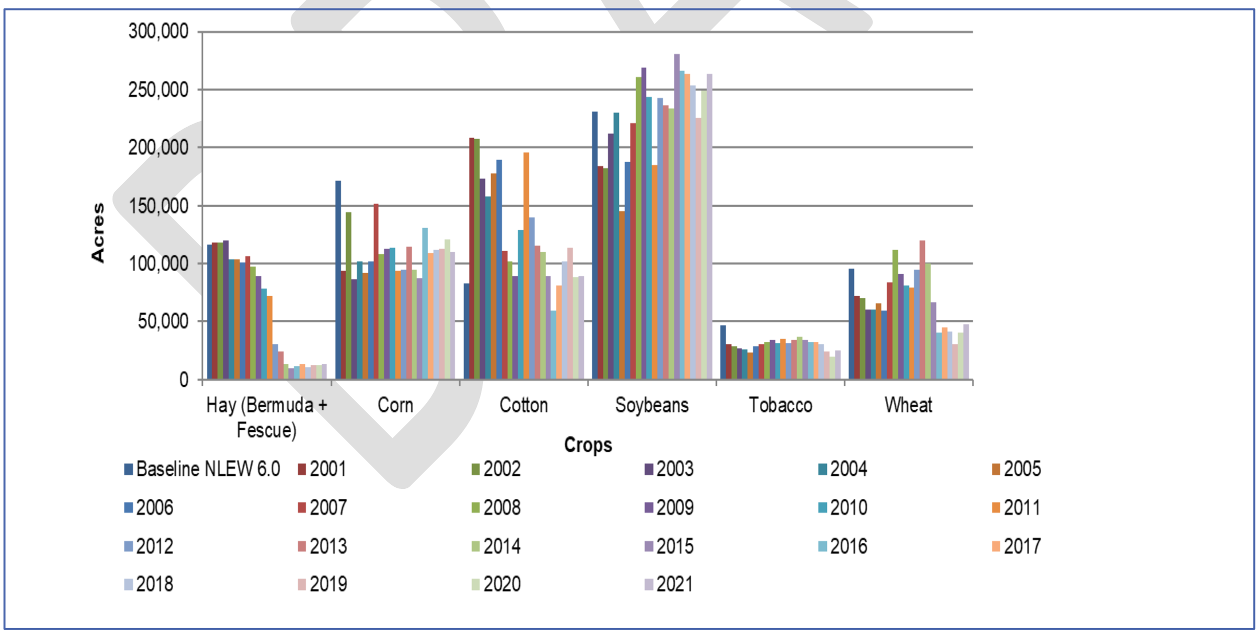


FIGURE 38: TOTAL ACREAGE OF MAJOR CROPS IN THE TAR-PAMLICO WATERSHED, BASELINE PERIOD AND SUBSEQUENT YEARS



Better nutrient management in both watersheds has resulted in a reduction of fertilizer application rates from baseline levels. Figures 39 and 40 show the nitrogen application rate used each year for the same major crops in the Neuse and Tar-Pamlico watersheds, respectively. With the exception of fertilizer for

Bermudagrass and Fescue (e.g. "hay"), fertilizer rates for each crop type are fairly stable year-to-year, but all crops show a decrease in application rate compared to the baseline period for both watersheds. Over time there has been an economic incentive for producers to improve nitrogen management. Factors identified by LACs that have contributed to reduced nitrogen application rates include mandatory animal waste management plans, increased education and outreach by NC Cooperative Extension, a federal government tobacco quota buy-out, economic decisions and fluctuating farm incomes. The phasing in of state AFO permitting programs occurred shortly after the baseline time period for these strategies, such that compliance with the regulations is believed to have driven notable reductions seen in N rates for the grasses.

FIGURE 39. NITROGEN APPLICATION RATES FOR MAJOR CROPS, NEUSE WATERSHED, BASELINE PERIOD & SUBSEQUENT YEARS

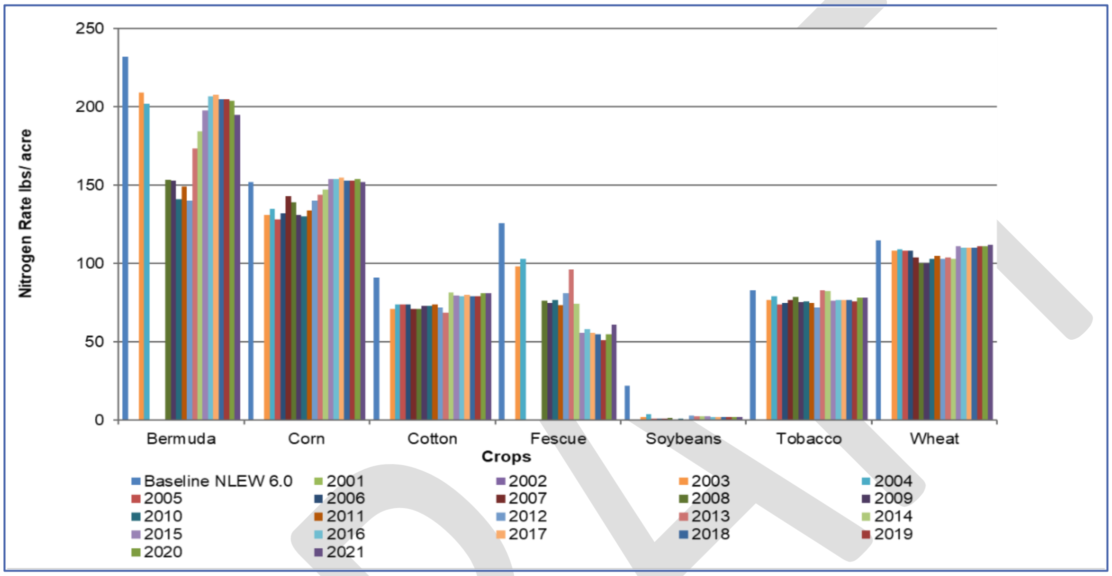
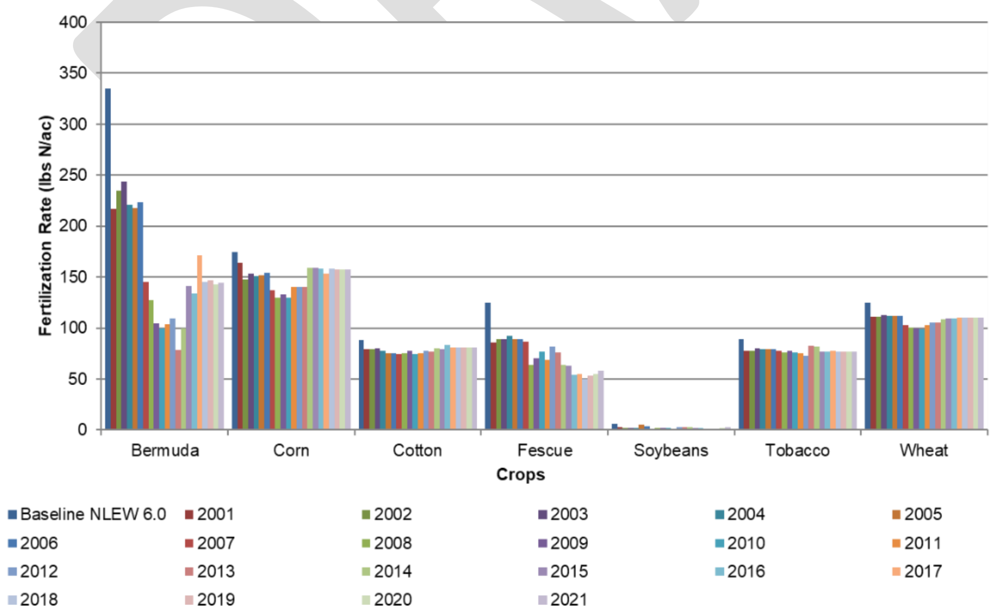


FIGURE 40: NITROGEN APPLICATION RATES FOR MAJOR CROPS, TAR-PAMLICO WATERSHED, BASELINE PERIOD AND SUBSEQUENT YEARS



Implementation of Agricultural Best Management Practices

BMP implementation is one factor, along with crop shifts, crop acreage changes and fertilizer rate changes, influencing nitrogen reduction on agricultural land. Key BMPs tracked by NLEW are riparian buffers of various widths (20’, 30’, 50’, 70’, and 100’), nutrient scavenger crops, and water management structures. Division of Soil and Water Conservation staff work with cost share records and LACs annually to tally BMP implementation.

Overall, total units of BMP implementation have increased since the baseline in both watersheds. Over half of all reported cropland in these basins receives some kind of BMP treatment, and this does not include farmer-installed BMPs that are not funded by cost share programs except in limited cases. Additionally, acreage treated by buffers is generally 5 to 10 times greater than the reported buffer footprint acres.

Figures 41 and 42 show cumulative stream buffer implementation in the Neuse and Tar-Pamlico watersheds, respectively. Apparent large changes in buffer acreages actually instead reflect changes in the way buffers were tracked over the implementation period. From 2001 through 2006, the NLEW program captured buffers 50’ and wider as one category. After the 2007 update, categories for 70’ and 100’ buffers were added. In CY2006 the buffers larger than 50’ were redistributed into these new categories. In CY2011 50’ and 70’ buffers were combined into a single category for everything larger than 50’ but less than 100’. Brieflyl summarizing buffer implementation, new buffer area was added over the first ten years of implementation and has remained relatively stable since.

In the most recent version of NLEW (starting in 2011), 20’ wide stream buffers are credited with reducing 20% of nitrogen lost from cropped areas and 100’ wide buffers are credited with reducing up to 35% of nitrogen lost from cropped areas, with proportional reductions for in-between buffer widths. No distinction in performance is made between buffer vegetation types (trees vs. shrubs vs. grass). Buffer performance is based on research conducted by NCSU.

FIGURE 41. CUMULATIVE ACRES OF STREAM BUFFERS IMPLEMENTED IN THE NEUSE WATERSHED

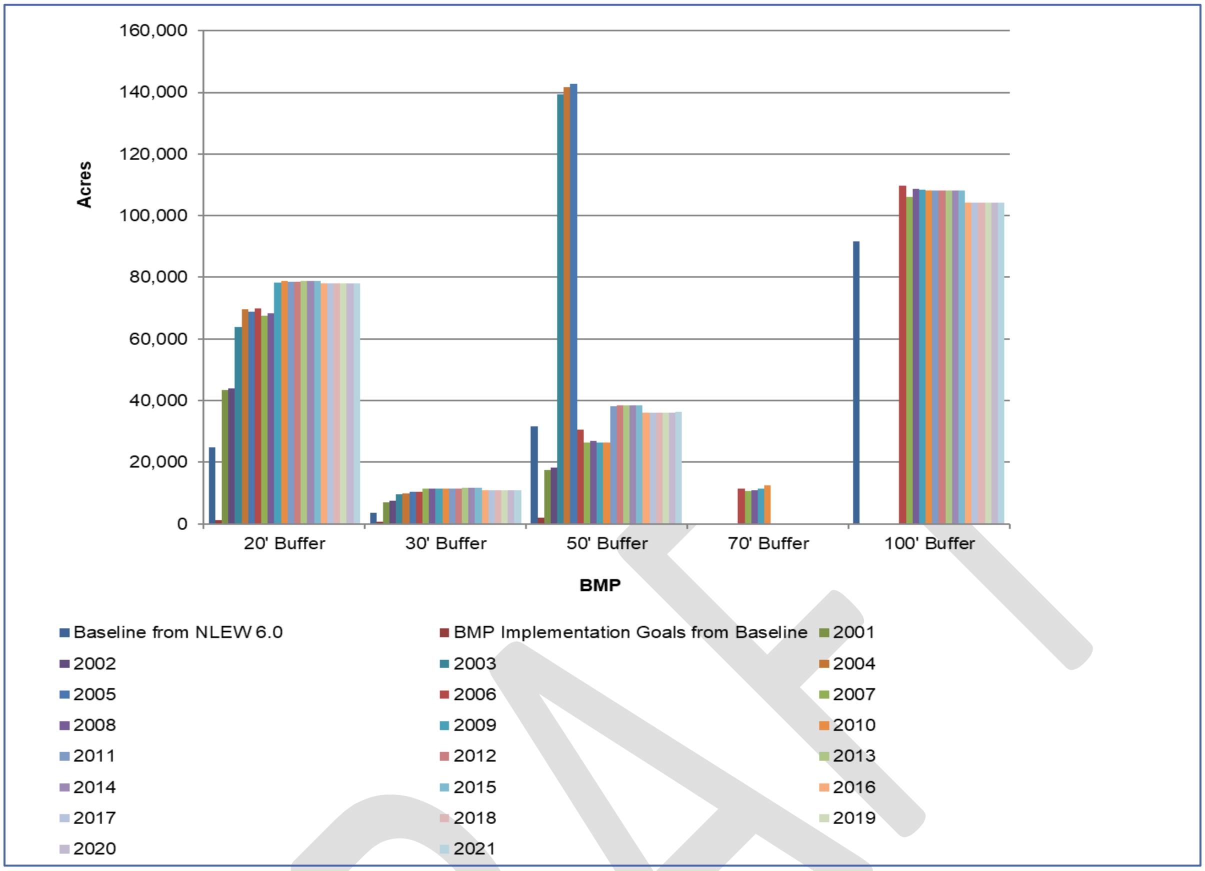
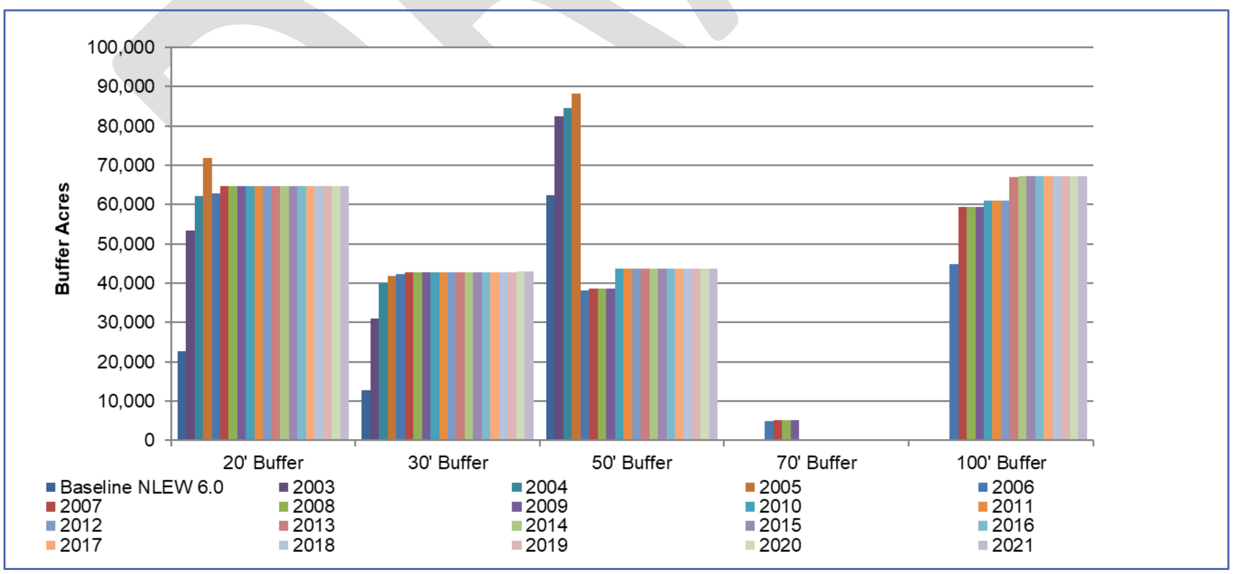


FIGURE 42. CUMULATIVE ACRES OF STREAM BUFFERS IMPLEMENTED IN THE TAR-PAMLICO WATERSHED



Figures 43 and 44 show annual acres of unfertilized cover crops in the Neuse watershed and Tar-Pamlico watershed, respectively. Unfertilized cover crops act to scavenge excess nitrogen from the soil.

FIGURE 43: ACRES OF UNFERTILIZED COVER CROPS, NEUSE WATERSHED

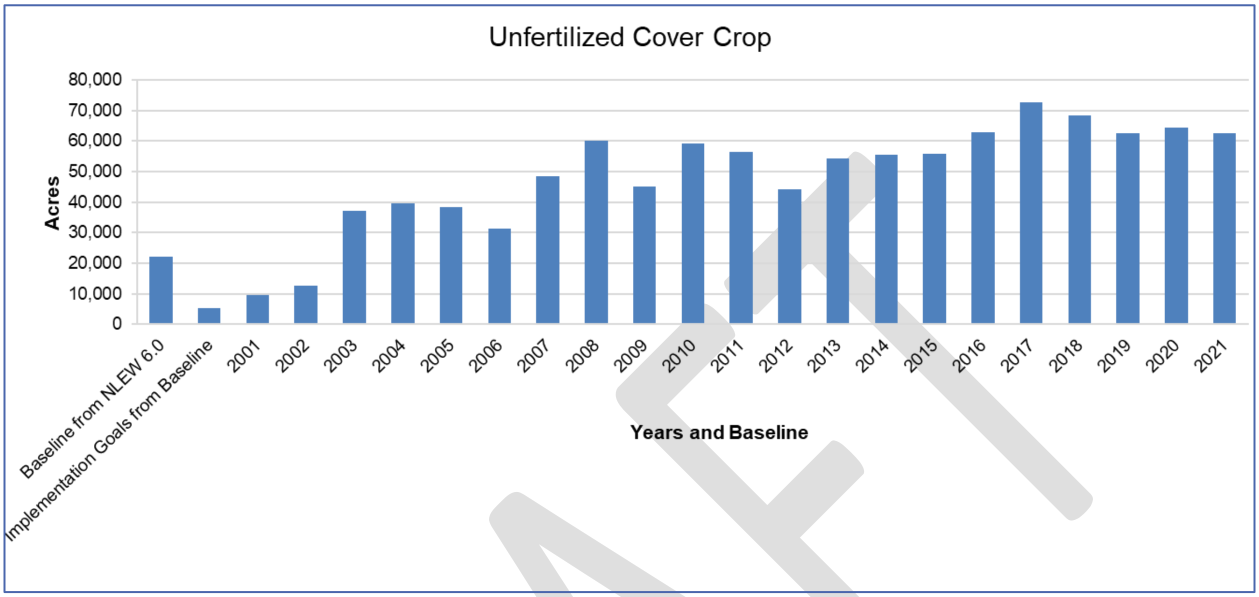
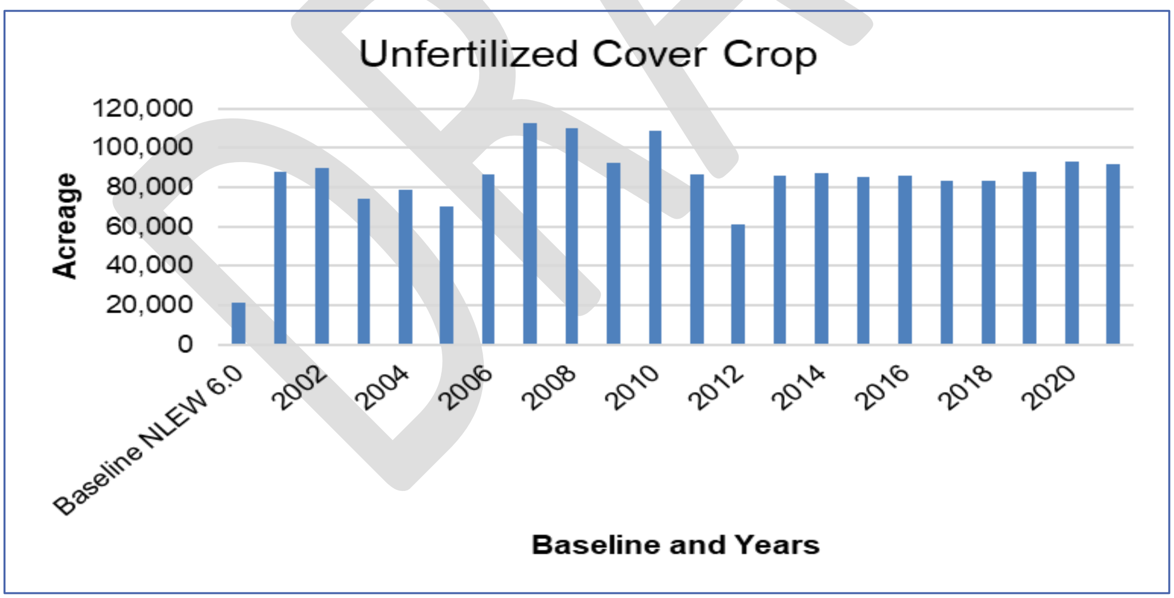


FIGURE 44: ACRES OF UNFERTILIZED COVER CROPS, TAR-PAMLICO WATERSHED



There have also been changes in how water control structures have been tracked over time. Every effort is made to ensure that reported BMPs continue to function as designed. Verification of this functionality requires site visits to individual farm owners who may or may not be under active contract. Coastal counties have reported that water control structures no longer under an operation and maintenance agreement that have been checked, are still being actively managed by producers despite contract expirations. Nevertheless, beginning with 2019 all acres affected by water control structures installed at least 10 years prior were manually removed from each county's total, and additional out-of-contract structures are removed each year on a rolling basis. Contracts which are re-enrolled in the Agriculture Cost Share Program or structures which are field-verified as still functioning are then re-added to the cumulative acre totals. Figures 45 and 46 show the cumulative total of all acres affected by water control structures since the baseline for the Neuse watershed and Tar-Pamlico watershed, respectively, as well as the adjusted total showing only active cost share contracts beginning in CY2019.

FIGURE 45. WATER CONTROL STRUCTURE IMPLEMENTATION IN THE NEUSE WATERSHED

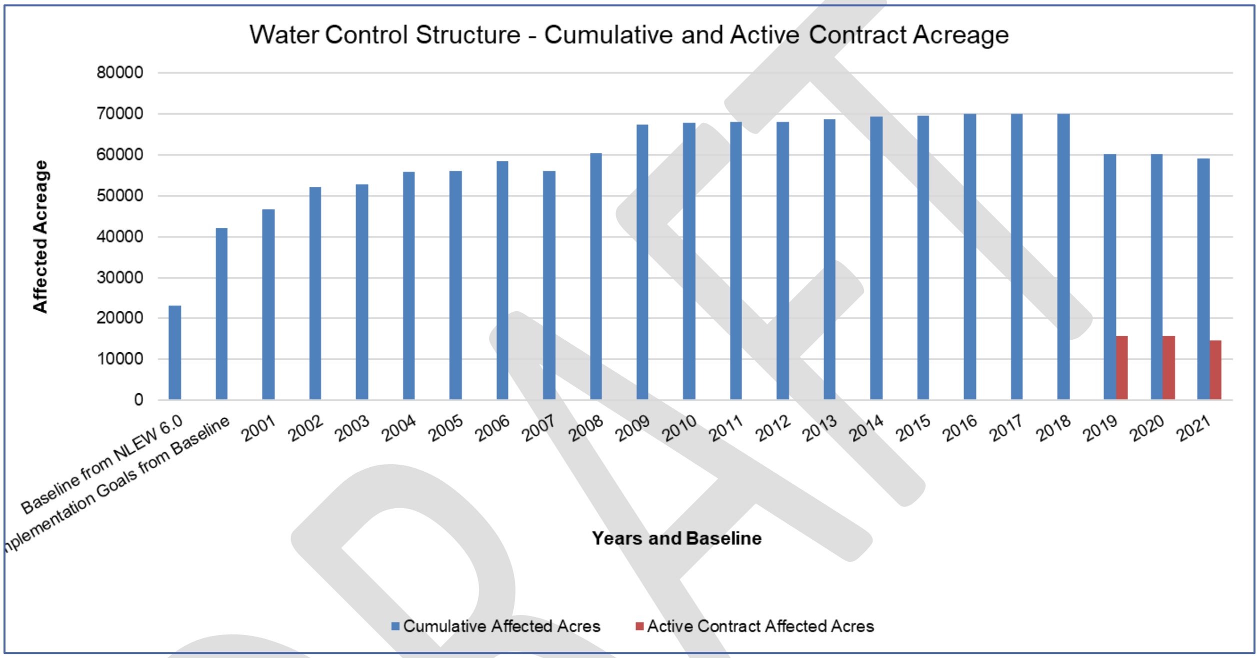
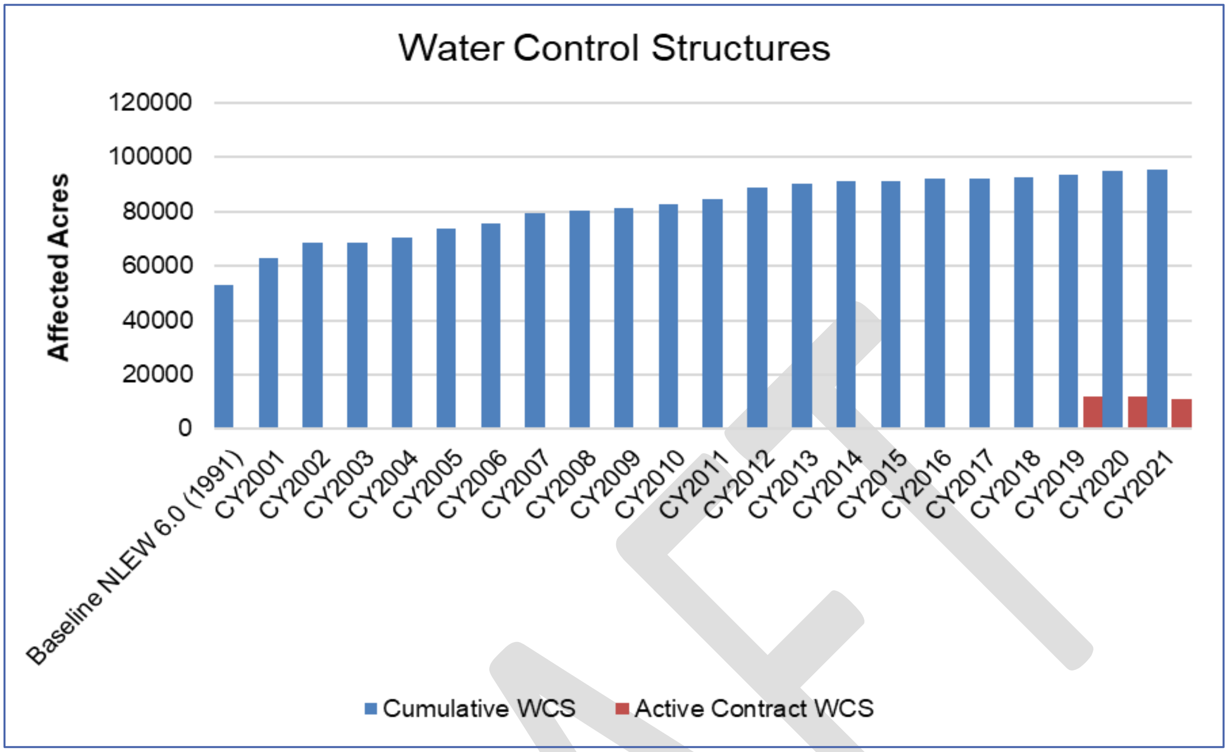


FIGURE 46. WATER CONTROL STRUCTURES IN THE TAR-PAMLICO WATERSHED



Not all types of nutrient-reducing BMPs are tracked by NLEW. These include livestock-related nitrogen and phosphorus reducing BMPs, BMPs that reduce soil and phosphorus loss, and BMPs that do not have enough scientific research to support a nitrogen reduction benefit. Figures 47 and 48 show nine additional types of BMPs that are not credited in NLEW that have some nitrogen reduction benefit in the Neuse watershed and Tar-Pamlico watershed, respectively. There has been a consistent increase in BMP implementation from 2001 to the present.

FIGURE 47: CUMULATIVE ACRES OF NON-NLEW-ACCOUNTED BMPS IN NEUSE WATERSHED

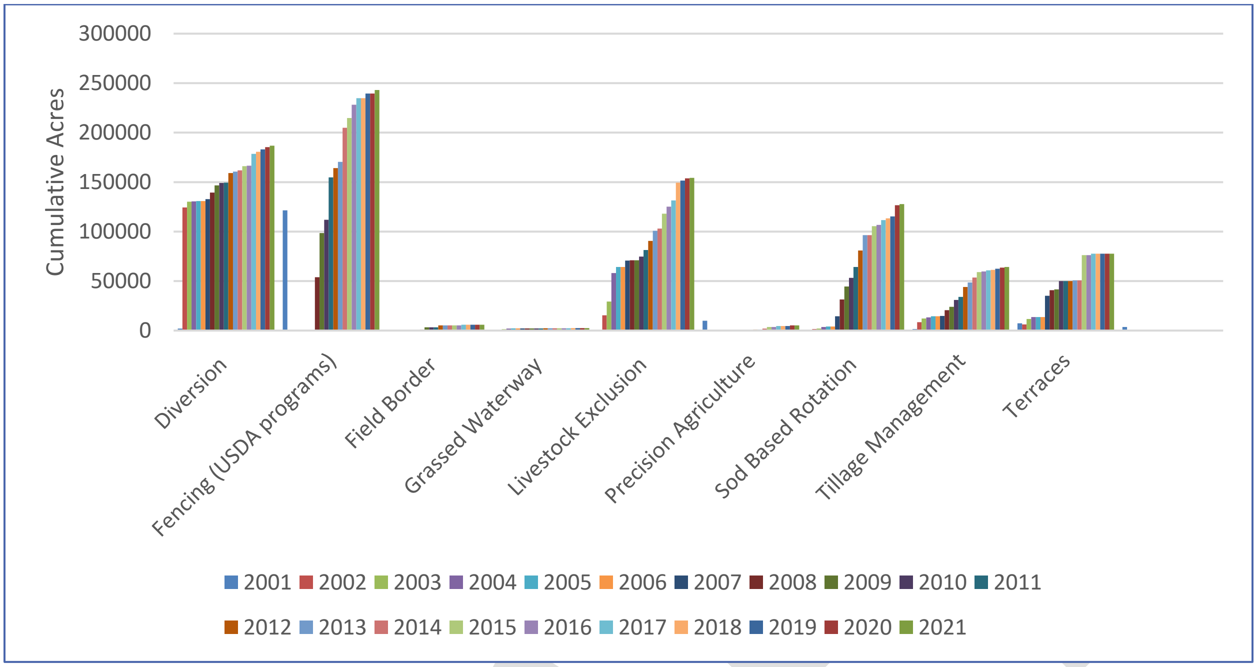
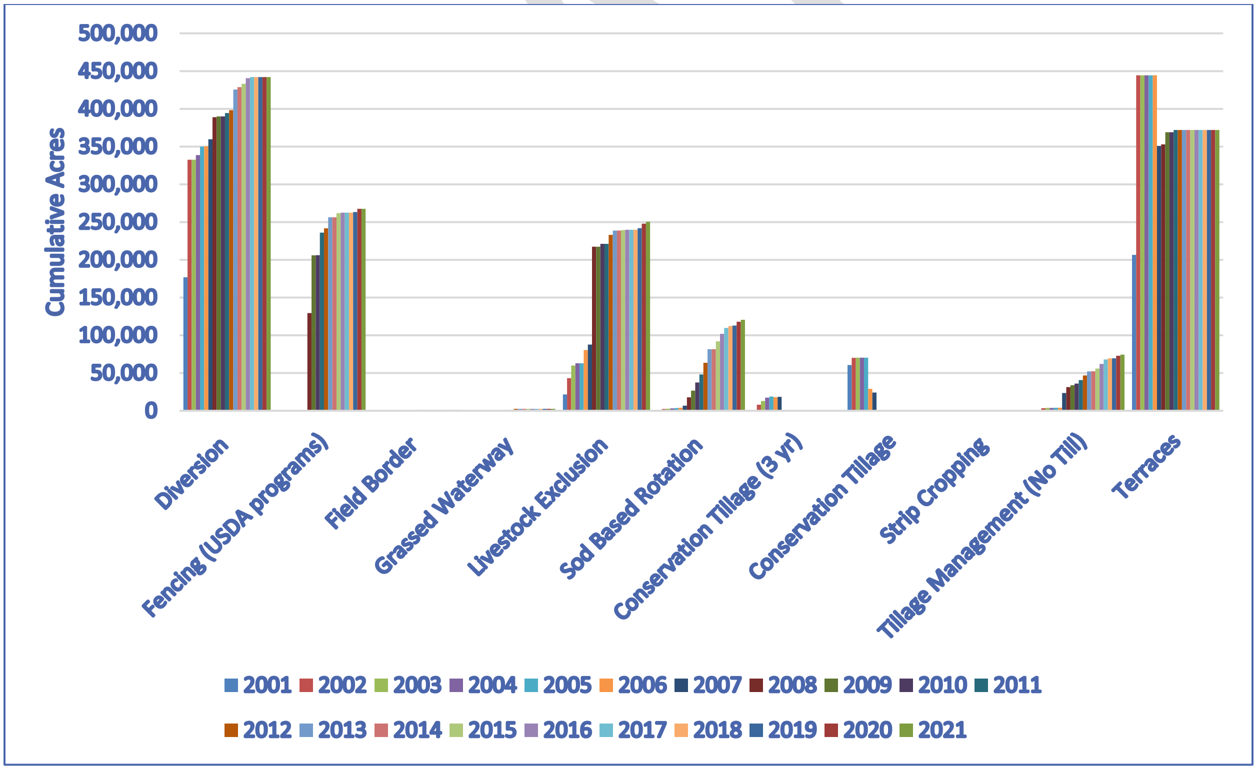


FIGURE 48. CUMULATIVE ACRES OF NON-NLEW-ACCOUNTED BMPS IN TAR-PAMLICO WATERSHED



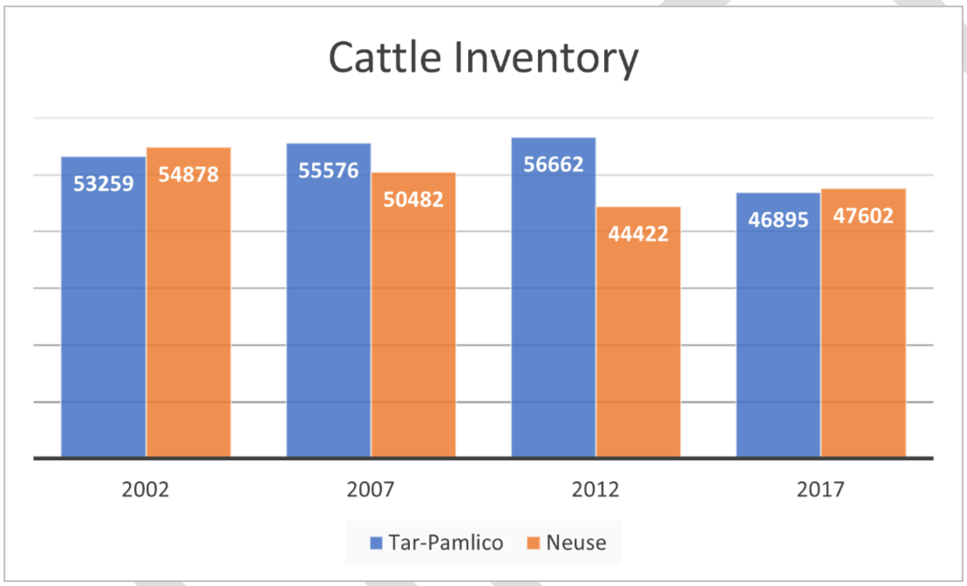
Livestock and Animal Feeding Operation Permitting

Animal numbers for this report were drawn from the national, 5-year frequency Census of Agriculture conducted by the USDA National Agricultural Statistical Service, for the span of 2002-2017 (2022 Census data are not available until 2024). The 5-year Census is generally considered the most reliable quantification of animal numbers publicly available, as it is based on a more rigorous survey of farms than the annual statistics provided by USDA. The Census provides a sequential snapshot of livestock dynamics across the two basins.

Cattle

Across the state, cattle numbers continue to decline, including modestly so in the Neuse and Tar-Pamlico. In 2017, there were about 47,600 Cattle in Neuse and 46,900 in Tar-Pamlico (Figure 48). The counties with the highest cattle numbers were Johnston (Neuse, 13,381) and Franklin (Tar-Pamlico, 13,522) (Figure 49.)

FIGURE 49. CATTLE, INCL CALVES, INVENTORY FOR THE COUNTIES WITHIN NEUSE AND TAR-PAMLICO RIVER BASINS, 2002-2017. SOURCE USDA NASS CENSUS, QUICKSTAT.



Swine

Hog inventories in the basins also fluctuated modestly from 2002-2017 with no apparent trend, as shown in Figure 50. In 2017, there were about 1,731,700 Hogs in Neuse and 544,660 in the Tar-Pamlico. The counties with the highest hog inventories were Wayne (Tar-Pamlico, 538,560) and Greene (Tar-Pamlico, 329,340). Figure 51 identifies the county with the highest animal inventory in each basin for each animal type, Cattle (Purple), Hog (Blue), and Poultry Broiler and Layer (Green).

FIGURE 50. HOG INVENTORY FOR COUNTIES WITHIN NEUSE AND TAR-PAMLICO RIVER BASINS, 2002-2017.

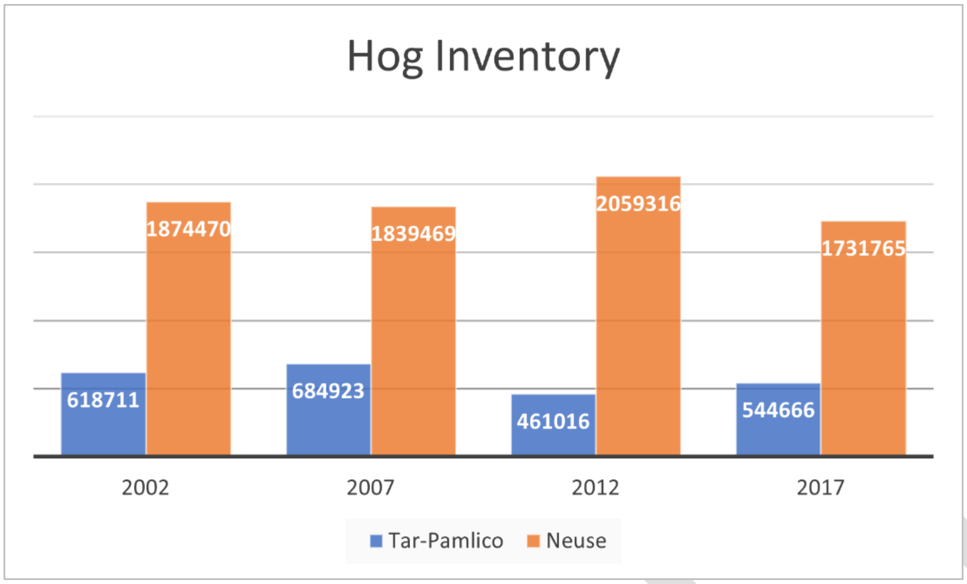
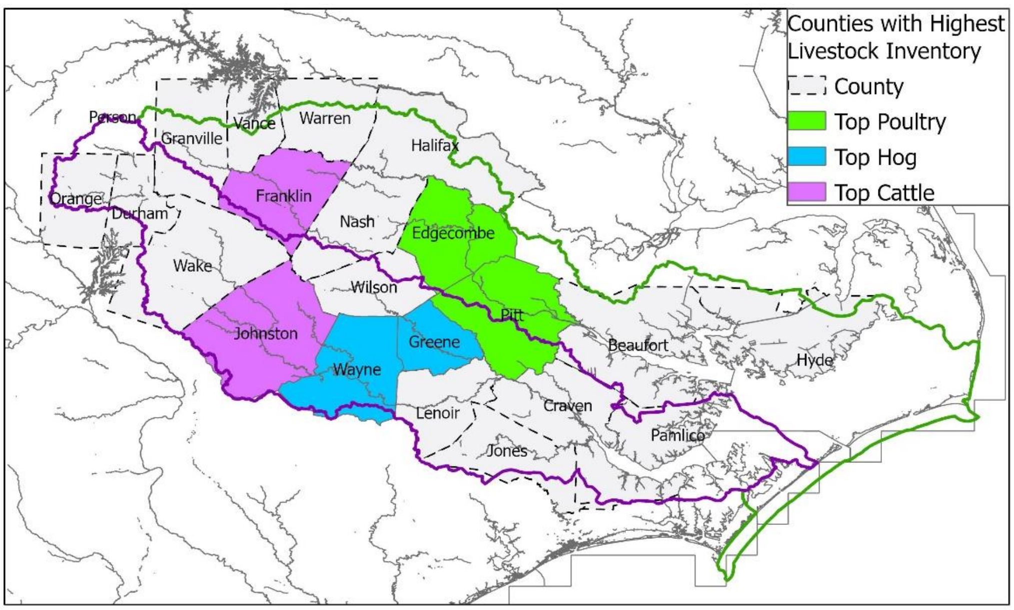


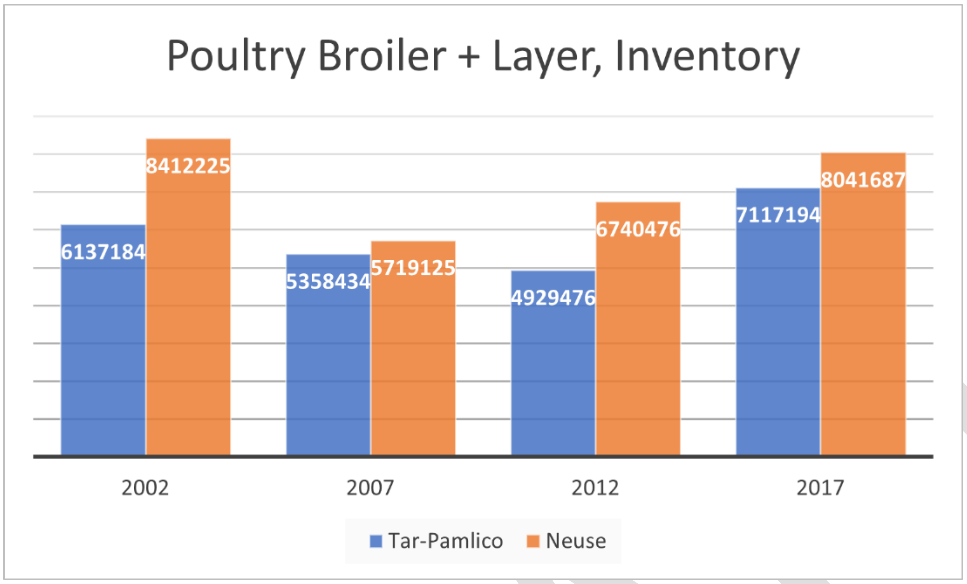
FIGURE 51. 2017 NEUSE AND TAR-PAMLICO BASINS, TOP ANIMAL INVENTORIES BY COUNTY.



Poultry

Across North Carolina, Broiler and Layer poultry inventories fluctuate but have generally increased since at least 2002. As of 2017 in Neuse and Tar-Pamlico, there were about 8,041,680 Poultry (Broiler + Layer) inventory in the Neuse and 7,117,290 in the Tar-Pamlico (qualifiers: the data presented in Figure 52 for poultry includes the USDA NASS Census categories of Broiler inventory and Layer inventory - it does not include Pullets, Roosters, Turkeys, or other poultry categories; inventory represents the number of birds in the county at any given time during the year, not the total produced over the year; and some counties report missing data in the Census and annual surveys, which potentially leaves out significant populations).

FIGURE 52. POULTRY BROILER WITH LAYER INVENTORY IN NEUSE AND TAR-PAMLICO RIVER BASINS, 2002-2017.



Among the various voluntary assistance programs available to producers in North Carolina and these Basins, one in particular - the Program to Acquire Conservation Easements On Swine Operations in the 100-Year Floodplain (aka Lagoon Buyout program) - may have significant bearing on nutrient loading to the estuaries. Created in November 1999 in the wake of devastation from Hurricanes Dennis, Floyd, and Irene, the Lagoon Buyout program is managed primarily by the DSWC. The objective of the program is to reduce the risk to water quality from future flood events. The DSWC solicits bids from interested on-going swine operations to relinquish their permit and establish a conservation easement on the property. The land can continue to be used for low-intensity agriculture but is prohibited from operating a feedlot associated with lagoons in a 100-yr floodplain or easement use as a spray field.

Since inception in 1999, the Land and Water Conservation Fund approved 4 grants (totaling $18,669,500 statewide) to the Division of Soil & Water Conservation to acquire conservation easements on swine operations in the 100-year floodplain. Within the Neuse and Tar-Pamlico, a total of 69 lagoons have gone through this program as detailed in Table 5.

TABLE 5. TOTAL NUMBER OF LAGOONS AND EASEMENT SPENDING BY THE NC LAGOON BUYOUT PROGRAM, 1999 TO PRESENT, NEUSE AND TAR-PAMLICO BASINS.

River Basin	Easement Cost	Number of Lagoons
Tar-Pamlico	$7,449,243	54
Neuse	$3,296,286	15

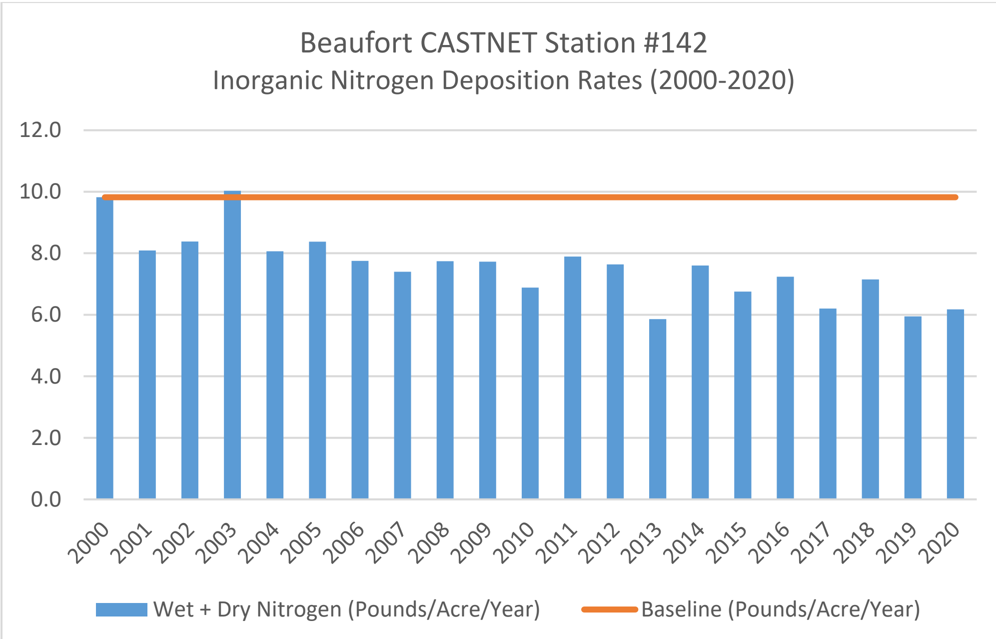
Changes in Atmospheric Deposition

Atmospheric deposition of nitrogen oxides (NOx) and ammonia (NH3) is a significant source of nitrogen input into North Carolina's coastal nutrient sensitive estuaries and sounds (Whitall and Paerl, 2001; Whitall et al., 2003; Costanza et al., 2008). During development of the Neuse and Tar-Pamlico TMDLs, contributions of atmospheric deposition were somewhat underestimated (Neuse) or overestimated (Tar-Pamlico) due to limited data availability and knowledge, as well as differing methods at the time. Both basin's TMDLs assigned open water a percentage of N and P loading based on direct atmospheric deposition to that water. The open water of the estuaries themselves had a large effect on the outcome, and inclusion of differing extents of estuary acreage yielded very different results, with the Neuse TMDL attributing about 5% of N loading to open water while the Tar-Pamlico assigned 33% to it. Regardless, neither TMDL proposed management actions for this portion of basin loading (actually the document officially recognized as the basis of the Tar-Pamlico TMDL, the 1994 Basinwide Plan, only budgeted nutrient sources and did not propose management actions; instead, Phase II of the point source dischargers' agreement with the state, established in 1995, provided the management plan), nor did they reassign it to other sources. They simply did not discuss its fate.

Ammonia can contribute a significant fraction to atmospheric nitrogen deposition, however its magnitudes are much more variable than those of NOx because its distribution is more localized than the much more regional, multi-state scale NOx mixing patterns. The majority of atmospheric ammonia in the coastal plain volatilizes from confined animal operations, but sewage treatment plants and fertilizers applied to the land also contribute small amounts (Whitall et al., 2003; Walker et al., 2004). In addition, a large single source of ammonia exists on the south side of the Pamlico estuary where the PCS Corporation operates a diammonium phosphate plant with significant ammonia emissions. In areas in the ammonia airshed of CAFO concentrations, ammonia can constitute up to approximately half of TN deposition.

Atmospheric N is delivered in two ways, wet and dry deposition. Dry is generally less easily measured and is thus less well-understood. A 2012 study conducted by the City of Durham that evaluated the contribution of organic Nitrogen to the total nitrogen load from atmospheric sources found that more than 95 percent of nitrogen deposited from the atmosphere is inorganic. (AMEC, 2012). With this in mind, deposition data from the EPA Clean Air Status and Trends Network (CASTNET) simulation of wet and dry inorganic deposition rates for the CASNET site #142 located in Beaufort, NC was used for this analysis to track the current trend in atmospheric deposition in the coastal plain area of NC (Figure 53).

FIGURE 53. INORGANIC NITROGEN ATMOSPHERIC DEPOSITION RATES AT BEAUFORT, NC



Results indicate a promising downward trend in long-term atmospheric nitrogen deposition in this coastal region of the Neuse and Tar-Pamlico basins, representing a 20 percent decline in the watershed since the 2000. Nitrate deposition reductions can be attributed to several state and federal air quality initiatives enacted in the early years of the 21st century, with overall decrease in inorganic nitrogen deposition attributable to regional and global reductions in emissions from vehicles and stationary sources like power plants.

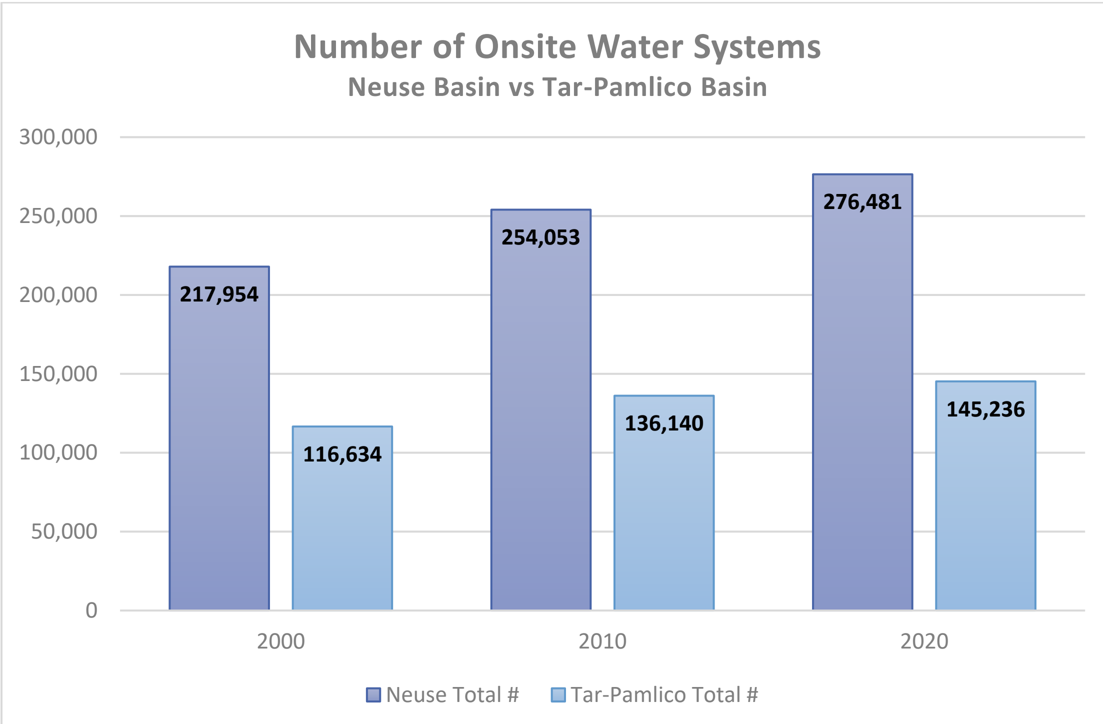
Inventory of Onsite Wastewater Systems

Onsite wastewater systems, also known as septic systems, remain a common method of wastewater treatment in the Neuse and Tar-Pamlico River Basins and other rural areas of North Carolina. These systems typically consist of a septic tank, which collects and treats wastewater from a home or building, and a drainfield, which disperses the treated wastewater into the surrounding soil.

These systems rely on nutrient removal through landscape processes, primarily denitrification, soil immobilization, and plant uptake. These treatment processes have been demonstrated to remove the great majority of nitrogen and phosphorus generated by the associated development before they reach surface waters when properly sited and maintained, with phosphorus removal at virtually 100% and nitrogen removal in the high 90 percent range. However, siting can be less than ideal at times, maintenance is known to be a weak point in performance, and landscape processes can be variable in nature and have the potential to contribute to nutrient loading and other water quality problems, especially in areas with high population densities or poorly drained soils.

More than 50% of the population in North Carolina rely on onsite wastewater systems to treat their household wastewater. As a result, the number of systems in the Neuse and Tar-Pamlico basins generally tracks with overall population growth in rural areas where connections to municipal wastewater systems are unavailable. The increase in onsite wastewater systems in the Neuse and Tar-Pamlico basins between 2000 and 2020 is illustrated below in Figure 54.

FIGURE 54. TOTAL NUMBER OF ONSITE SYSTEMS IN NEUSE AND TAR-PAMLICO RIVER BASINS



Sanitary Sewer Overflows

Aging community wastewater infrastructure may also be contributing to unaccounted nutrient inputs to surface waters. Upgrades and maintenance of wastewater infrastructure is important to protect human health, protect water quality and to prevent monetary fines and costs associated with a system overload. Sanitary sewer collection systems gather and transport domestic, commercial, and industrial wastewater, often along with limited amounts of infiltrated ground water, to treatment facilities for treatment. Occasionally, sanitary sewers will release raw sewage due to blockages, line breaks or rainfall-driven inflow and infiltration where lines have deteriorated allowing stormwater or groundwater to overload the system. These types of releases are called dry weather or wet weather sanitary sewer overflows (SSOs), respectively. SSOs that reach waters of the U.S. are point source discharges.

SSOs are prohibited and permittees are required to report them to the appropriate DWR Regional office staff within 24 hours of discovering an overflow if the spill or overflow is more than 1,000 gallons to the ground and any overflow, regardless of volume, that reaches surface water.

The DWR Collection System Permitting program, working with the DWR Regional Offices, receives and tracks SSO reports either from the facilities or complaints. Based on DWR records, annual numbers of SSO events and volumes spilled in gallons, from 2002-2020, for the Neuse and Tar-Pamlico Basin counties are provided in Figures 55 & 56 below. No particular trend in number of events or discharge volumes is apparent over these timeframes.

FIGURE 55. SANITARY SEWER OVERFLOWS - NEUSE BASIN

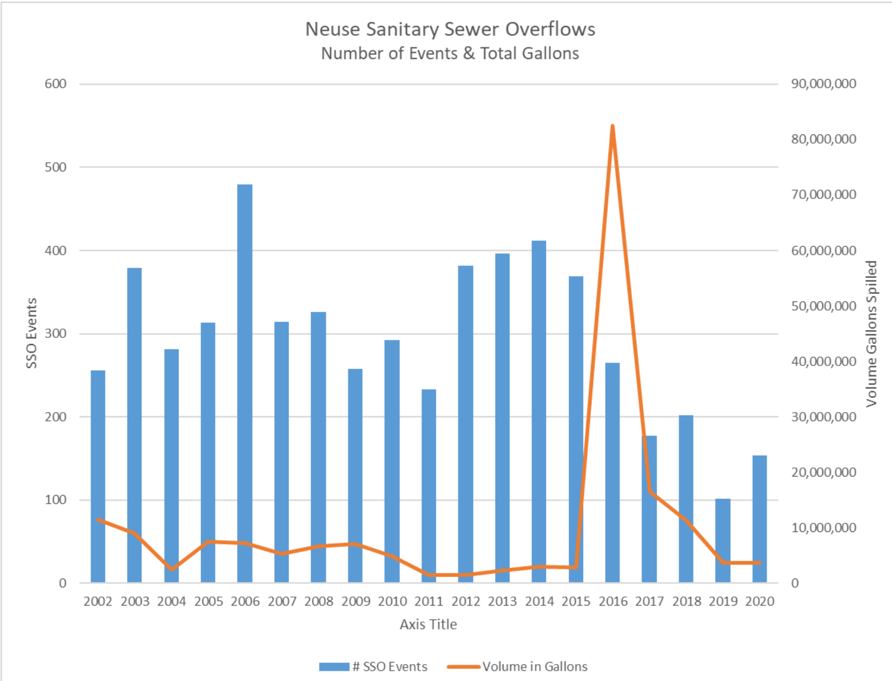
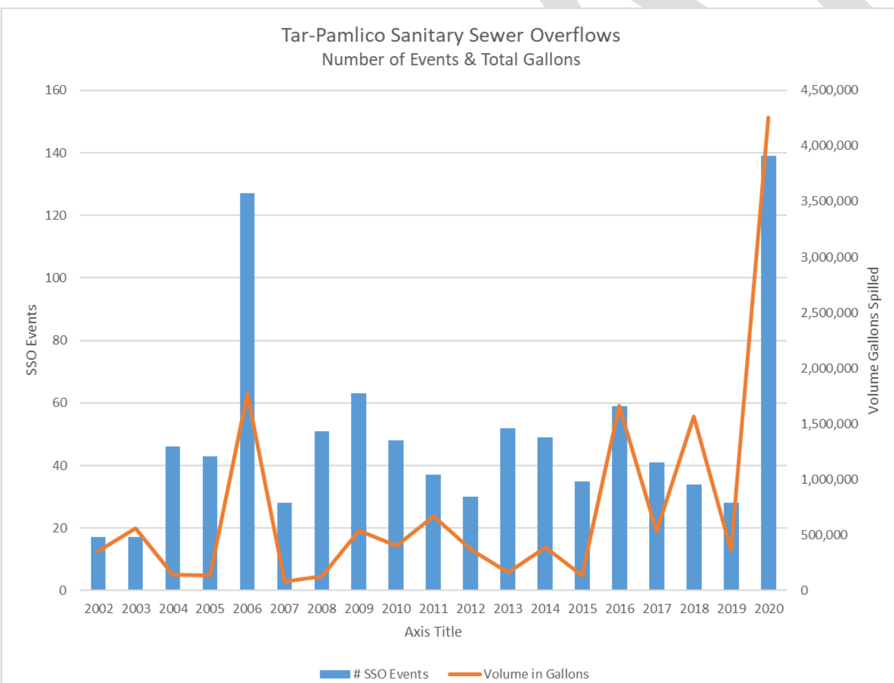


FIGURE 56. SANITARY SEWER OVERFLOWS - TAR-PAMLICO BASIN



Non-Discharge Permits: Residuals and Wastewater Effluent Land Application

Non-discharge permits include residual and wastewater effluent land application facilities as well as beneficial use of reclaimed water for the purpose of conserving the state's potable water, surface water, and groundwater resources. DWR must permit wastewater treatment systems under General Statue 143-215.1 Control of Sources of Water Pollution; Permits required, and under several Administrative Codes:

- 15A NCAC 02T - Waste Not Discharged to Surface Waters
- 15A NCAC 02U – Reclaimed Water
- 15A NCAC 02L – Groundwater Classification & Standards
- 15A NCAC 18A .1900 – Sewage Treatment & Disposal Systems
- 15A NCAC 02B - Surface Water & Wetland Standards
- 15A NCAC 01C – North Carolina Environmental Policy Act
- 15A NCAC 02H .0400 – Coastal Waste Treatment Disposal

Non-discharge permitting allows wastewater treatment and disposal while avoiding discharge to surface waters and may reuse waste as a beneficial product. Non-Discharge is NOT the discharge to surface waters of the state or utilization of a sub-surface disposal system (i.e. septic system with leach field – see Septic System section).

TABLE 6. TYPES OF NON-DISCHARGE PERMITS

Types of Non-Discharge Permits:	Non-Discharge Disposal Methods	Domestic, Commercial and Industrial Facilities that Need a Non-Discharge System
• Wastewater Irrigation • Single-Family Residence Wastewater Irrigation • High-Rate Infiltration • Other Wastewater • Closed-Loop Recycle • Reclaimed Water • Residuals Management	• Spray/Drip Irrigation • High-Rate Spray/Drip Infiltration • High-Rate Basin Infiltration • High-Rate Rotary Infiltration • Closed-Loop Recycle • Reclaimed Water Reuse • Reclaimed Water Irrigation • Non-Discharge Disposal Methods	• Unable to connect to local sewer system • Unable to obtain subsurface system permit • Unable to obtain discharge permit (NPDES) • Utilize reclaimed water to replace potable water • Recycle systems to reduce overall water usage

The NC DWR Non-discharge branch permits are available to the public on Laserfiche and generally demonstrated on the Online GIS map, Non Discharge Permits (View) | NC DEQ GIS Data (arcgis.com).

Within the Neuse River Basin there are about 11 land application of residual permits (503 and 503 except), totally about 18,800 permitted dry tonnage. Within the Tar-Pam there are about 12 of the same active permits, and 12,790 dry tonnage. Residuals, or sometimes referred to as biosolids, are sludge that has been treated to ensure that it can be safely applied to land as a fertilizer or soil amendment (these are called beneficial reuses). Agronomic rates are considered when permitting dry tonnage of residuals for land application: 40 CFR Part 503.14 requires that biosolids must be applied to land at the appropriate agronomic rate which is the sludge application rate designed to provide the amount of nitrogen needed by the crop or vegetation grown on the land.

FIGURE 57. PERMITTED DRY TONNAGE FOR LAND APPLICATION OF RESIDUALS PER COUNTY: NEUSE

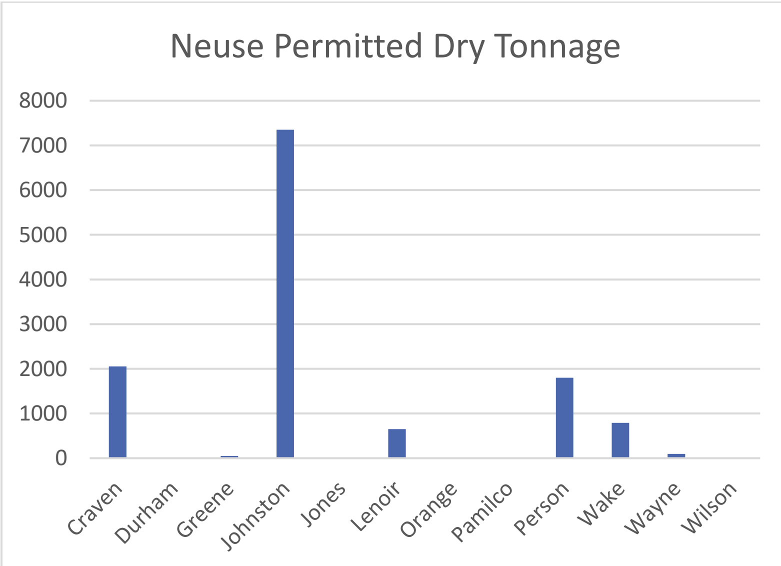
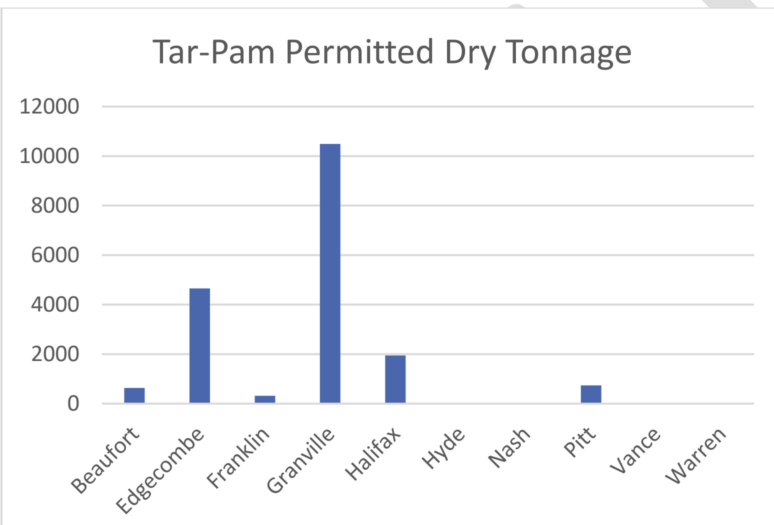
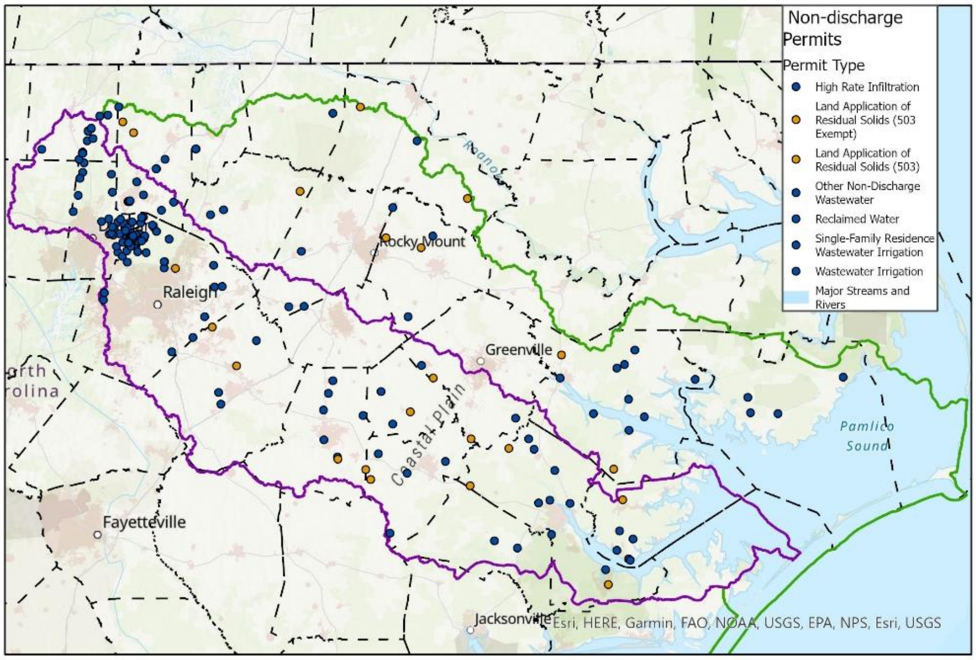


FIGURE 58. PERMITTED DRY TONNAGE FOR LAND APPLICATION OF RESIDUALS PER COUNTY: TAR-PAM



The land application of wastewater effluent is permitted by flow (GPD) under wastewater irrigation, single-family residence wastewater irrigation, and high-rate infiltration, and other non-discharge wastewater. Within the Neuse River Basin has about 1,430,000 GPD permitted flow and the Tar-Pam as about 15,560,000 GDP permitted flow. Figure 59 shows the approximate location (distribution) of the land application of effluent and residuals in both basins.

FIGURE 59. LOCATION OF NON-DISCHARGE SITES – NEUSE & TAR-PAMLICO RIVER BASINS



Environmental Changes

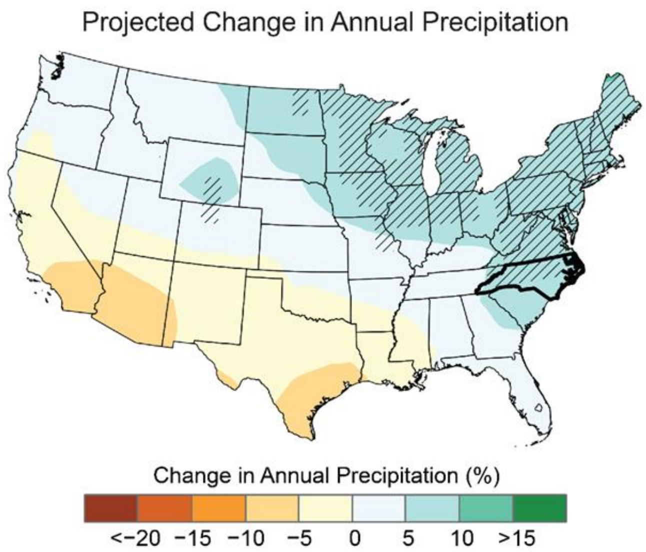
Climatic Trends

Recent studies have suggested that climate-driven increases in the frequency and intensity of tropical storms may be a significant factor in organic nitrogen increases in the Neuse and Tar-Pamlico River Basins. Over the past two decades, North Carolina has experienced a number of impacts from climate change. Some of the most significant impacts include:

- **Increased frequency and severity of hurricanes:** North Carolina is particularly vulnerable to hurricanes, and climate change has led to an increase in both the frequency and severity of these storms. This has led to widespread damage and disruption, particularly in coastal areas.
- **Increased temperatures:** North Carolina has experienced a steady increase in temperatures over the past two decades, which has led to more frequent heatwaves and droughts. This has had a significant impact on agriculture and has increased the risk of wildfires.
- **Changes in precipitation patterns:** Climate change has led to changes in precipitation patterns in North Carolina, with some areas experiencing more frequent and intense rainfall events, while others experience droughts. This has also affected the state's agriculture and water resources.

Overall, the impact of climate change in North Carolina has been significant, affecting everything from the state's economy to its natural resources and infrastructure. It is likely that these impacts will continue to increase in the coming years unless significant action is taken to mitigate and adapt to climate change.

FIGURE 60. PROJECTED CHANGE IN ANNUAL PRECIPITATION IN THE US AND NORTH CAROLINA. (CITATION NOAA).



North Carolina's projected increase in temperature and rainfall may impact freshwater export to the ocean and reduce capture by reservoirs and groundwater recharge. Rising sea levels also pose risk for saltwater intrusion.

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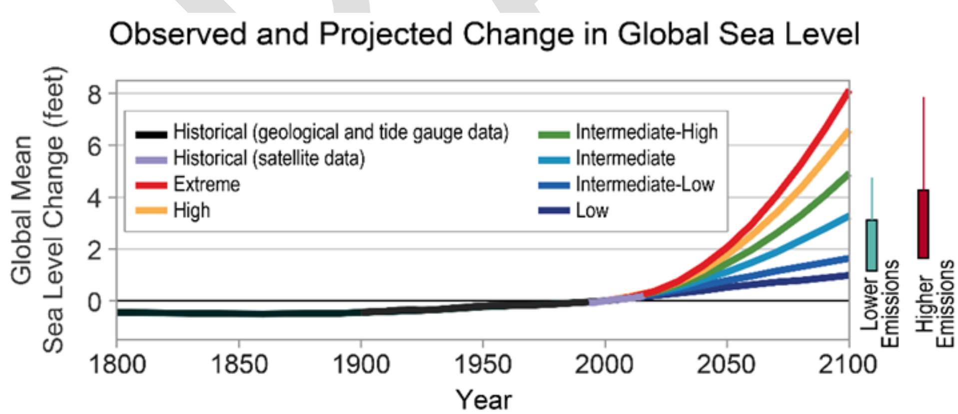
FIGURE 61. CHANGE IN GLOBAL SEA LEVEL RISE, NOAA PREDICTIONS.



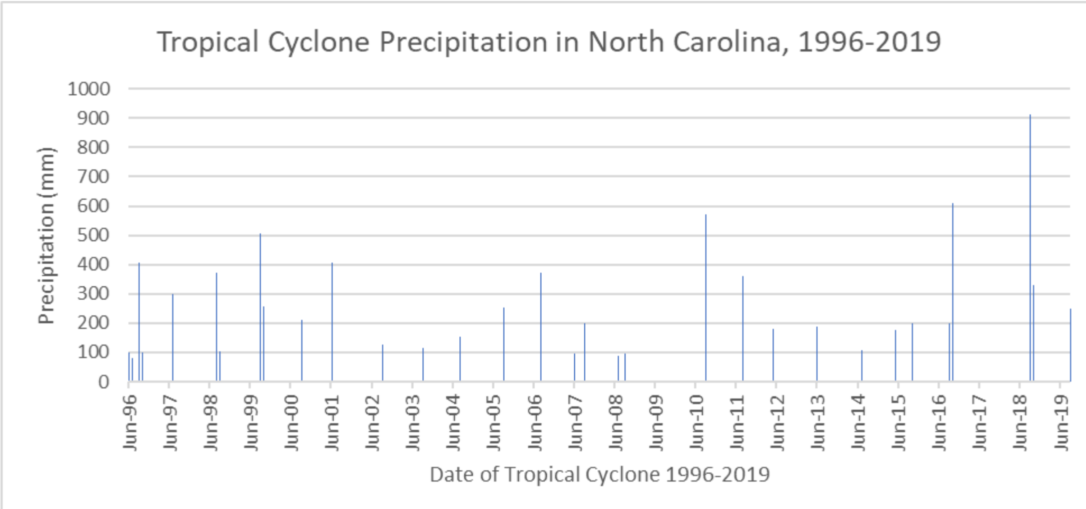
Frankson, R., K.E. Kunkel, L.E. Stevens, D.R. Easterling, W. Sweet, A. Wootten, H. Aldridge, R. Boyles, and S. Rayne, 2022: North Carolina State Climate Summary 2022. NOAA Technical Report NESDIS 150-NC. NOAA/NESDIS, Silver Spring, MD, 5 pp. https://statesummaries.ncics.org/chapter/nc/

Hurricanes & Extreme Weather Events

Coastal North Carolina experienced 36 tropical cyclones, including three floods of historical significance in the past two decades (Hurricanes Floyd-1999, Matthew-2016 and Florence-2018). Continuous rainfall records for coastal NC since 1898 reveal a period of unprecedented high precipitation storm events since the late-1990s.

Six of seven of the "wettest" storm events in this > 120-year record occurred in the past two decades, identifying a period of elevated precipitation and flooding associated with recent TCs (Paerl et al, 2020).

FIGURE 62. TROPICAL CYCLONE PRECIPITATION – ADAPTED FROM PAERL ET AL. (2020)



The annual precipitation for NOAA Climate Divisions Climate Division 7, Central Coastal Plain, and Division 4, Peidmont, contain the Neuse and Tar-Pamilco Basins. Within these regions, precipitation has increased over time in the alternating periods of relatively wet years to more dry years. Monthly average precipitation throughout the basins are usually higher during the summer months than the rest of the year. However, summer is also the time when vegetation uses more water and high temperatures increase evaporation. The combination of these two factors produces lower streamflows in the summer months when demands for water are usually the highest.

Annual Rainfall & Flows

Precipitation and annual stream flows are closely related and play a major role influencing the year-to-year variability of nutrient loads delivered to the Neuse and Tar-Pamlico estuaries. Precipitation and runoff mobilize and transport nutrients and also transport eroded sediment from upland sources. However, the relationship between precipitation and stream flows can be complex and is by more than just how often and how much it rains. It can also be affected by factors such as the amount of water that is already stored in the soil and land use land use changes as well as timing and intensity of precipitation events.

Figures 63 and 64 below compare the average annual flows measured at Fort Barnwell in the Neuse and Grimesland in the Tar-Pamlico basin to annual rainfall measurements at the Greenville precipitation station located in the central coastal plain. This side-by-side comparison shows how stream flows at these two monitoring stations generally correspond with the year-to-year variability of high and low rainfall years which strongly correlates with the annual raw loading to the two estuaries as show in the water quality trend analysis discussed earlier in this report.

FIGURE 63. ANNUAL FLOW AT FORT BARNWELL, NEUSE BASIN VS. ANNUAL RAINFALL (GREENVILLE)

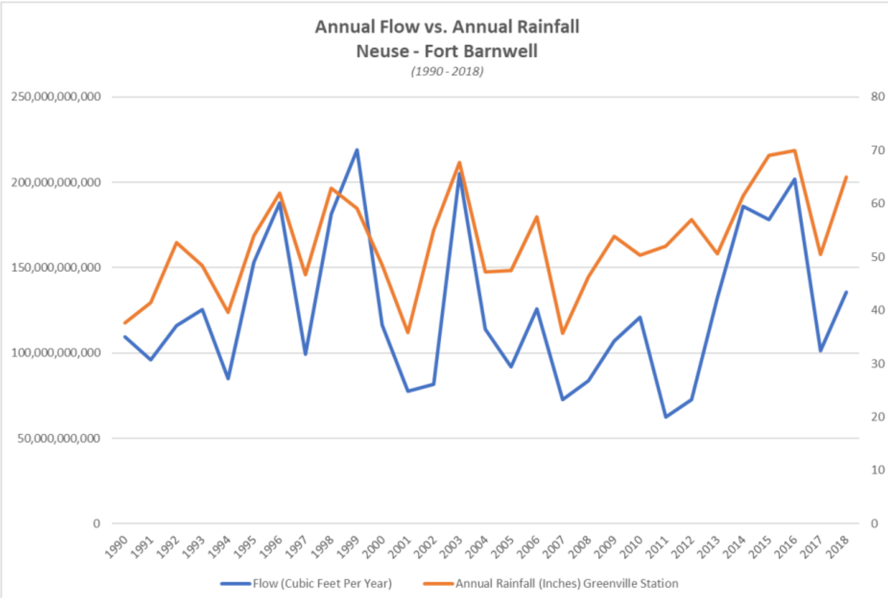
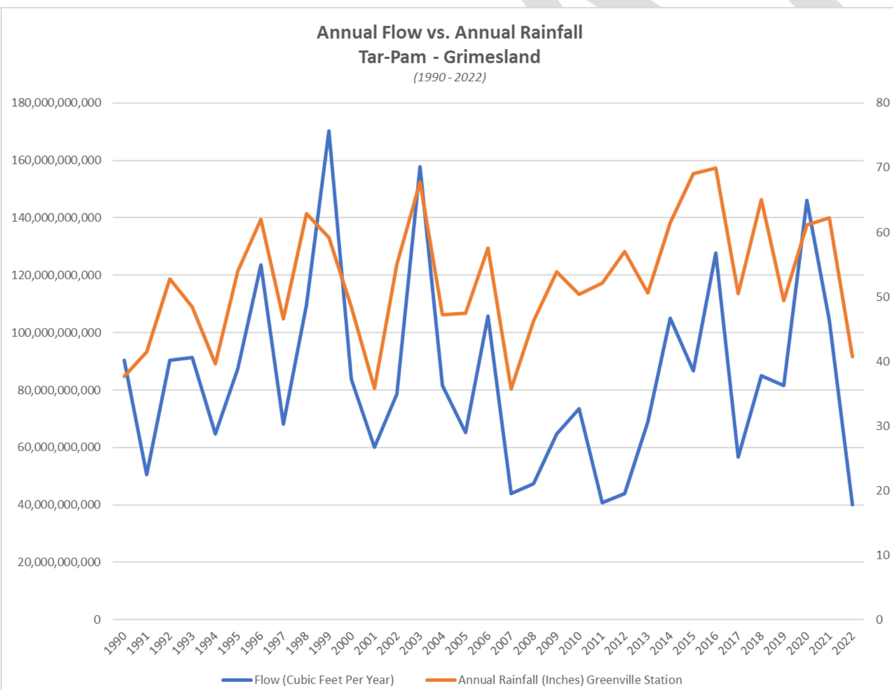


FIGURE 64. ANNUAL FLOW AT GRIMESLAND, TAR-PAMLICO BASIN VS ANNUAL RAINFALL (GREENVILLE)



Other Water Quality Improvement Efforts

319 Grant Program

Through Section 319(h) of the Clean Water Act, the U.S. Environmental Protection Agency provides states with funding to reduce nonpoint source pollution. North Carolina typically receives around $1 million every year for competitive funding of watershed restoration projects and has previously allocated just under $5 million for projects in the Neuse and Tar-Pamlico basins combined since 2012. Funds may be used to conduct watershed restoration projects such as stormwater and agricultural best management practices and restoration of impaired streams. Section 319 grant projects must be used to help restore water bodies currently impaired by nonpoint source pollution in areas with approved watershed restoration plans.

State and local governments, interstate and intrastate agencies, public and private nonprofit organizations, and educational institutions are all eligible to apply for 319 funding. An interagency workgroup reviews the proposals and selects those of merit to be funded.

205J Grant Program

Through the Section 205(j) Grant program, the U.S. Environmental Protection Agency provides states with funding to do water quality planning. North Carolina typically receives around $150,000 for competitive funding of water quality planning projects and has awarded approximately $45,000 for projects in the Neuse and Tar-Pamlico basins since 2012. These projects can involve identifying the nature, extent and cause of water quality problems or doing planning work to address those problems. Projects can include but are not limited to the development of EPA 9-Element Watershed Restoration Plans for a 12-digit or smaller USGS HUC, mapping stormwater infrastructure, conducting engineering designs for stormwater best management practices, and watershed assessments of pollutant sources.

205(j) grants are eligible to regional Councils of Government; COGs may partner with any public sector organization to implement projects. A match is preferred, but not required. Once contracted, projects can run for a maximum of 18 months. Funds are dispersed on a quarterly reimbursement basis, with any invoice to be accompanied by a report of the work performed. The request for proposals is released annually in summer and projects are selected in fall.

WRD Grant Program

The purpose of the Water Resources Development Grant Program is to provide cost-share grants and technical assistance to local governments throughout the state. Applications for grants are accepted for seven eligible project types: general navigation, recreational navigation, water management, stream restoration, water-based recreation, Natural Resources Conservation Service Environmental Quality Incentives Program (EQIP) stream restoration projects and feasibility/engineering studies. The navigation and coastal storm damage mitigation projects are collectively referred to as Coastal Infrastructure projects. The non-navigation projects are collectively referred to as State and Local Projects. Approximately $7.28 million has been allocated to WRD projects in the Neuse and Tar-Pamlico basins since 2016.

Assessment & Adaptive Recommendations

This three-year report provides a snapshot of the current state of rule implementation activities in both the Neuse and Tar-Pamlico River Basins as well as changes in nutrient loading and estuary water quality. It highlights both the challenges in achieving the water quality goals of the nutrient management strategy and the need for additional information to inform the adaptive management of the estuary and ongoing rules reexamination process. All the while, the regulated community continues to work constructively and collaboratively with the Division to improve water quality in the Neuse Estuary. The partnership between DWR and stakeholders has been essential and invaluable in addressing the formidable challenges inherent in sustaining the resources and designated in the Neuse River Basin and estuary.

Analysis of Key Findings

Given that both Neuse and Pamlico estuaries remain roughly as impaired today as they were at the outset of these strategies, a reasonable first question is, how much progress has been made in nutrient loading to the estuaries, and by what sources? The first section below recaps answers to the estuary loading part of the question drawing on content from the Status and Trends chapter above and bringing in important research findings that speak to the source part of the question for the unexpected increases seen in TKN loading. Subsequent sections shed light on progress by regulated sources.

Estuary Temporal Nutrient Loading Trends

In recent years, instream analyses of flow-normalized loading (FNL) trends in nitrogen species in Neuse and Tar-Pamlico basins over the course of nutrient strategy history have increasingly identified a pair of important common phenomena. First is the initial strategy years' decrease in TN loading driven mainly by the NOx-N fraction. Second is a common general trend of increasing TKN since approximately the turn of the century. In both basins, this increase has acted as a counterforce to NOx loading decreases being achieved through nutrient strategy implementation. As shown in the following figures, the most recent trend analyses developed at the head of the estuaries by DWR's Modeling and Assessment Branch (detailed in the Status and Trends section) show no meaningful initial change in TKN through the 1990's, after which it increases almost every year for 10 to 15 years. The result in the Neuse has been that an initial 20% TN reduction reached in 2000 was eventually negated by about 2012, and it has since hovered around no net TN reduction. In the Tar-Pamlico, an approximately 10% initial TN reduction was negated by 2009, continuing into net increase territory in all years since. It should be noted that the patterns of TKN increase vary considerably between monitoring sites in these basins (see Appendix D), but all stations have shown a general increase since 2001 or earlier. TKN in the Neuse Basin was composed of about 90% organic N and 10% NH_3-N (Lebo et al, 2012).

FIGURE 65. NEUSE NITROGEN REDUCTION FOR AVERAGE FLOW CONDITION VS. 1991-1995 (FORT BARNWELL)

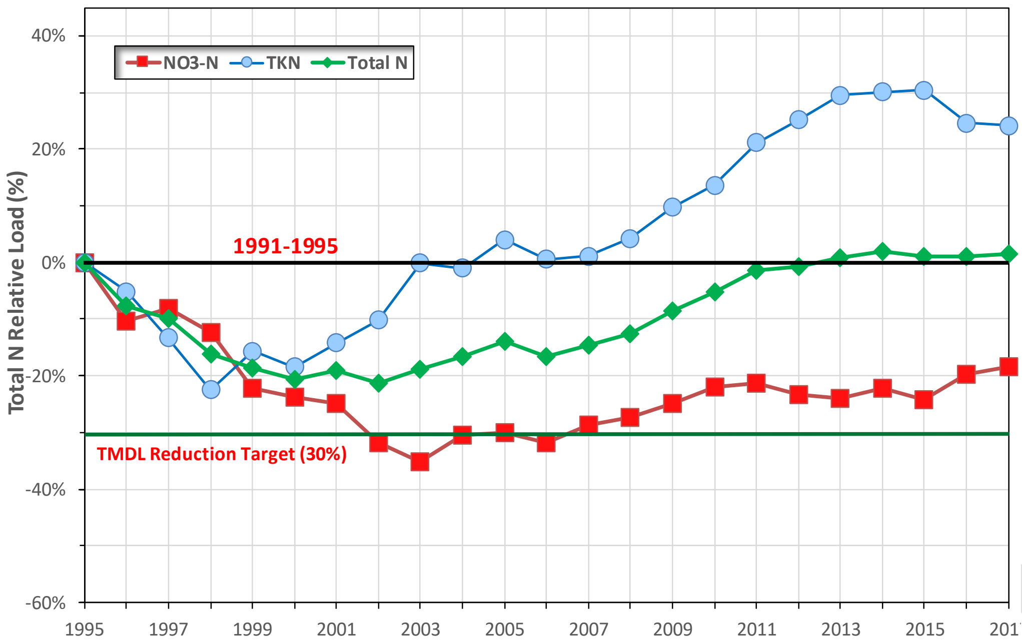
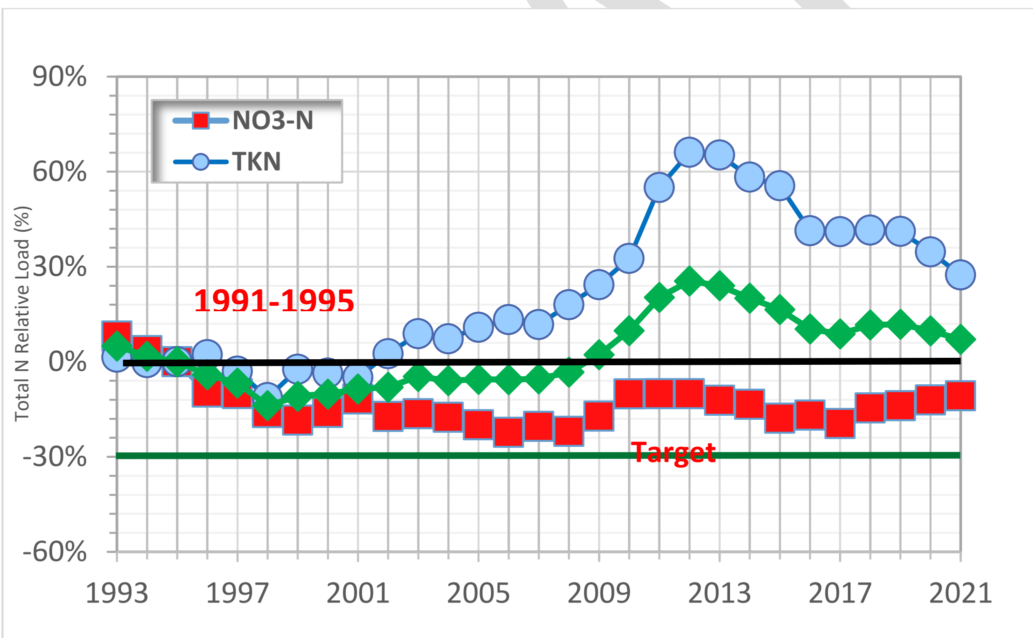


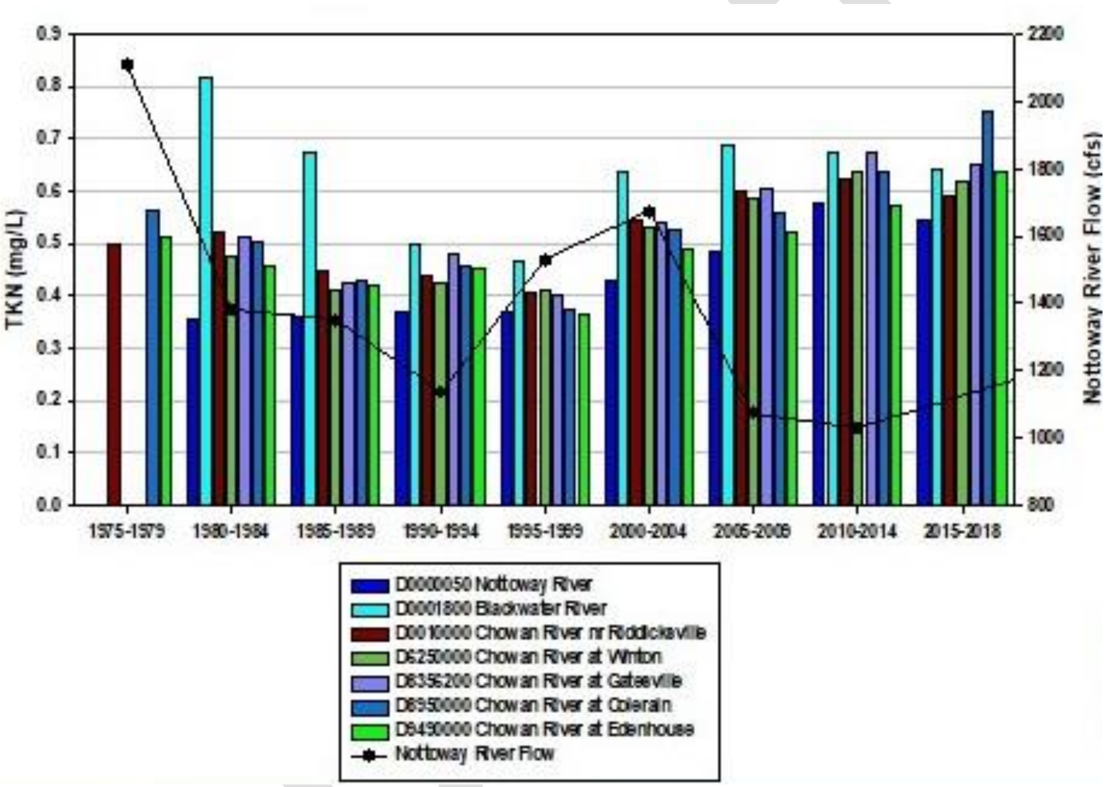
FIGURE 66. TAR-PAMLICO NITROGEN REDUCTION FOR AVERAGE FLOW CONDITION VS. 1991-1995 (GRIMESLAND)



As these trends have emerged, Paerl and colleagues have built a compelling case (Paerl et al, 2020; Paerl et al, 2019; Paerl et al, 2018) that distinct increases have occurred in coastal NC rainfall and flooding from intensified tropical cyclone activity since the late 1990's, and they have, among other things, mobilized large amounts dissolved organic carbon from freshwater wetlands, and increased N and P loading, including dissolved organic nitrogen, and have delivered them to the estuaries.

Paerl et al (2020) also recognized that a similar rainfall-driven freshwater C-N-P loading increase pattern has occurred in the Chowan and other Albemarle Sound tributaries. Figure 67 illustrates this pattern for the Chowan River, with TKN increases since about 2000 across the mainstem and tributaries, contrasted against a decreasing overall flow pattern in that timeframe. These TKN values are concentrations rather than percent changes, and they are not flow-normalized, however the combination of a distinctly decreasing flow pattern since the 1995-1999 period with steadily increasing concentrations over that same period provides clear support for the case that organic N has been increasing significantly here since the turn of the century, and even moreso with flow factored out. It is also noteworthy that this trend is occurring in the Nottoway and Blackwater Rivers in addition to the Chowan, adding evidence of a larger phenomenon.

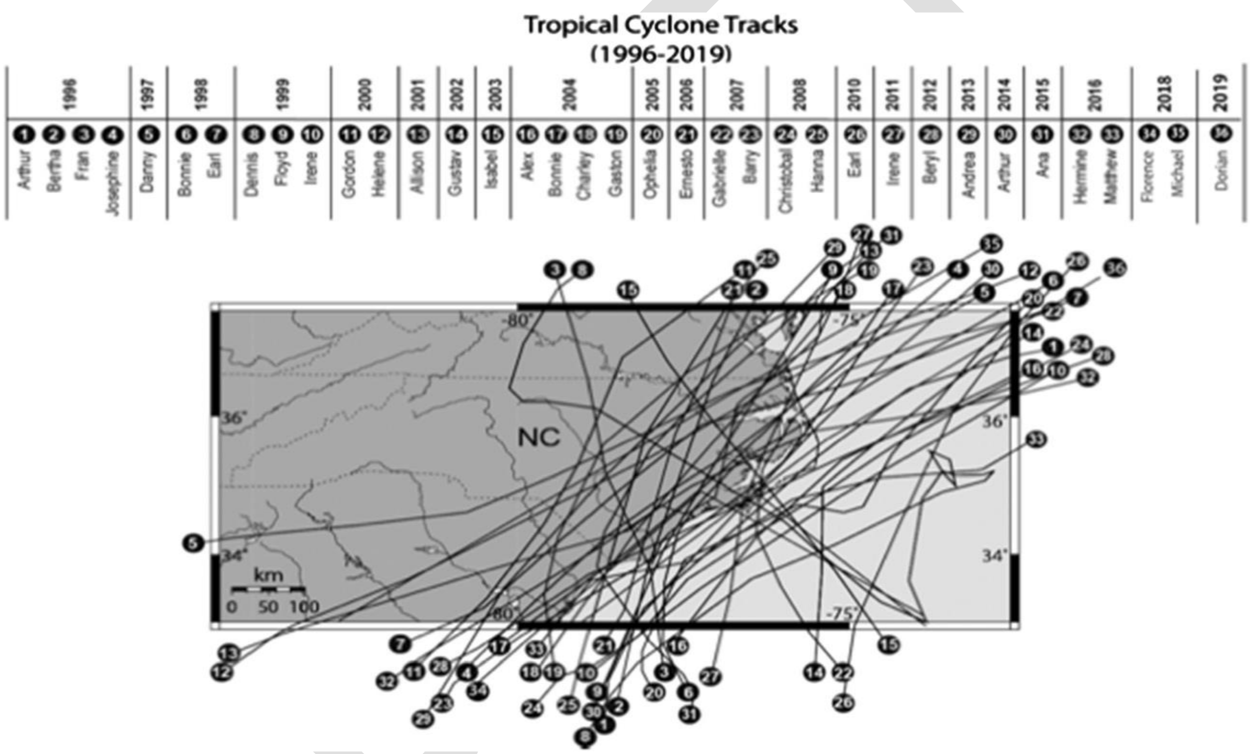
FIGURE 67. CHOWAN RIVER AND TRIBUTARY STATIONS 5-YEAR AVERAGE TKN CONCENTRATIONS, 1975 -2018 (SOURCE: NC DWR CHOWAN RIVER BASIN WATER RESOURCES PLAN, 2021)



More specifically, Paerl et al documented that coastal North Carolina has experienced 36 tropical cyclones in the last 2 decades, including 6 of the 7 wettest storms in the last 120 years, involving unprecedentedly high precipitation events and three extreme tropical cyclone-driven flood events since 1999, leading to major alterations of water quality. Large amounts of mobilized, previously accumulated terrigenous carbon (C) was determined through flourescence tracking to originate from flooded freshwater wetlands. Floodwaters contained extremely high loads of organic matter, dominated by dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) as well as other nutrients. Major storms caused up to a doubling of annual nitrogen and tripling of phosphorus loading compared to non-storm years. Depending on the magnitude of freshwater discharge, the Neuse estuary acted as either a ‘‘processor’’ to partially assimilate and metabolize the loads or acted as a ‘‘pipeline’’ to transport the loads to the Albemarle-Pamlico Sound and coastal Atlantic Ocean. When the estuary processed these increased loads, there were associated increases in: harmful algal blooms; CO_2 release to the atmosphere; fish and shellfish kills; fish disease rates; freshening of the estuary; and hypoxia and anoxia conditions. When the estuary acted as a pipeline to Pamlico Sound, the Sound saw increased large blooms and CO_2 atmospheric efflux. During large storm years, the system switched from a net carbon sink to a net carbon source. The authors concluded that,

> *“We appear to have entered a new climatic regime characterized by more frequent extreme precipitaion events, with major ramificaions for hydrology, cycling of C, N and P, water quality and habitat conditions in estuarine and coastal waters.” (Paerl et al, 2020)*

FIGURE 68. TROPICAL CYCLONE PATHS THROUGH NC FOR ELEVATED PERIOD, MID-1990’S – 2019 (FROM PAERL ET AL, BIOGEOCHEMISTRY, 2020)



It appears clear from this work that most or a large portion of the TKN upswing being delivered to these estuaries can be attributed to climatically driven shifts in rainfall. Beyond that, two related questions for this analysis are: how effective have the nutrient strategies been apart from the organic N additions?; and, have loadings from watershed nutrient sources been impacted by the climatic shift characterized by Paerl et al? While we may not be able to answer these questions separately, the next section evaluates basin nutrient source changes over the last twenty plus years, drawing on the content of the Watershed Changes section above and on relevant research.

Trends in Basin Nutrient Sources

Strategy implementation timeframes are provided first as a reference for the ensuing discussions. Following that, source loading trend reviews seek to address the extent to which loading has been reduced from regulated nutrient sources in the basin, starting with wastewater.

Nutrient Rules Implementation Timeframes: The Neuse nutrient rules went into effect in August 1998, while the Tar-Pamlico rules went into effect in 2000 and 2001. One of two exceptions to these initiation timeframes was implementation of riparian buffer protections, which were enacted by temporary rule for both basins in advance of the main rule packages, going into effect in 1997 and early 2000 respectively. The second, more important exception to these initiation timeframes was the implementation of Tar-Pamlico wastewater discharge requirements, which began as early as 1990 under a signed agreement between an association of dischargers, the Tar-Pamlico Basin Association, or TPBA, and the state. TPBA dischargers remain under this agreement until June 2025, while the substantive existing discharge requirements of the agreement were incorporated into individual permits and an overlying group watershed permit in 2014. All new management actions required by the Neuse rules were in place by 2004, and likewise for the Tar-Pamlico rules by 2007.

Wastewater Rules Implementation and Accounting: The management area involving the least uncertainty for achieving load reductions is clearly point source regulations, including the ability to quantify rule compliance and instream progress with good confidence. Neuse and Tar wastewater compliance accounting has documented to-stream loading reductions with easily the highest degree of certainty of any source due to the discrete nature of the source and the ability to monitor end-of-pipe discharges directly to state waters, along with having conducted sufficient baseline nutrient and flow monitoring to have established baseline loading estimates. As illustrated in the Implementation section, dischargers in both basins have met and significantly exceeded load reduction requirements, and continue to do so consistently. Both the NRCA and the TPBA have achieved and maintain annual loads in the range of 60-70% of their collective caps for both N and P.

FIGURE 69. NEUSE RIVER COMPLIANCE ASSOCIATION ANNUAL NITROGEN LOADS (1995-2021)

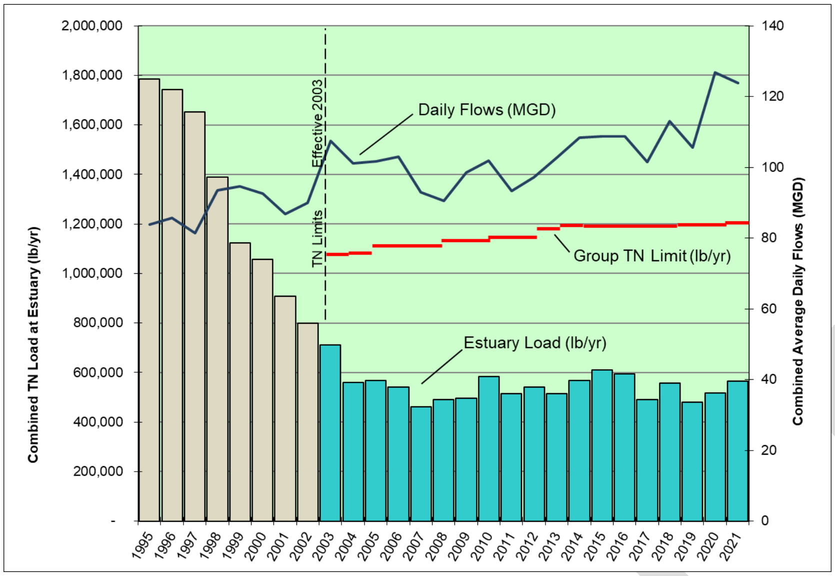
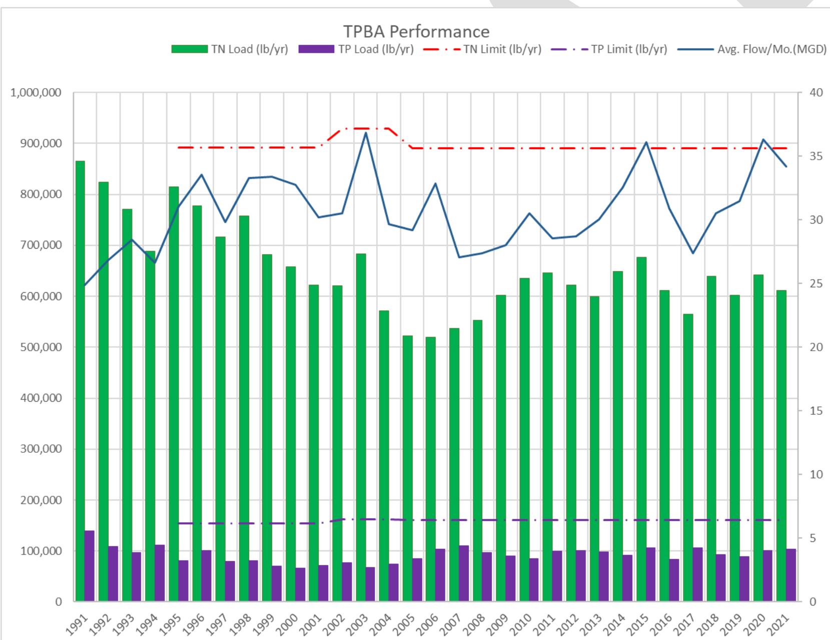


FIGURE 70. TAR-PAMLICO BASIN ASSOCIATION ANNUAL NITROGEN AND PHOSPHORUS LOADS (1991-2021)



One qualifier on Tar-Pamlico wastewater performance is that certain assumptions used in the calculation of the TPBA 30% N load reduction allocation were later determined to be inaccurate, resulting in a cap that equated to less than a 30% reduction from baseline, and more in the range of a 15-20% reduction. Dischargers' representatives made the case that reductions were also achieved prior to the 1991 baseline year, making the cap a fair target. While this concern was not addressed further, it is worth noting that average facility performance levels needed to meet the current caps are notably less rigorous than either Neuse discharger requirements or limits of technology.

Wastewater Instream Trends: At least two instream analyses corroborate point source achievements in the two basins. First, as illustrated in Fig. 4 of the trend analysis in the Status and Trends section above, reproduced below, NOx reductions for the 2013-2017 period relative to baseline track urban areas and discharge points, peaking at 57% reduction near Clayton downstream of Raleigh and satellite communities' discharges. Proceeding downstream, NOx reduction percentage wanes to 18% by Ft. Barnwell. This pattern is highly likely to be driven by wastewater discharges. Second, watershed modeling conducted by Strickling and Obenour (2018) found for the period of 1994-2012 that point source N load decreased in the Neuse by 61%, while it showed essentially no change in the Tar-Pamlico basin, where dischargers had already largely achieved much of their reductions by 1994.

FIGURE 71. UPSTREAM TO DOWNSTREAM % CHANGE IN NEUSE BASIN NITROGEN LOAD VS. 1991-1995 BASELINE

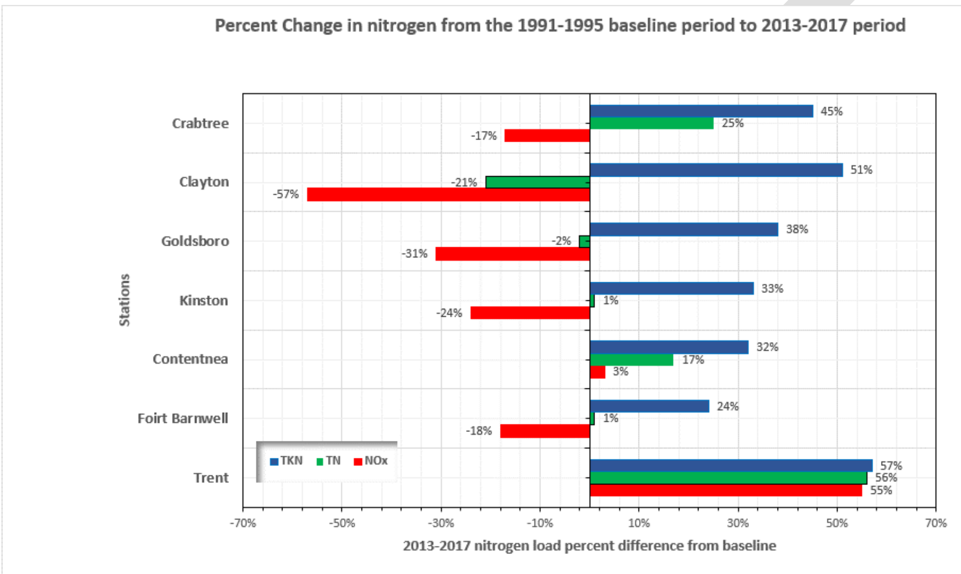
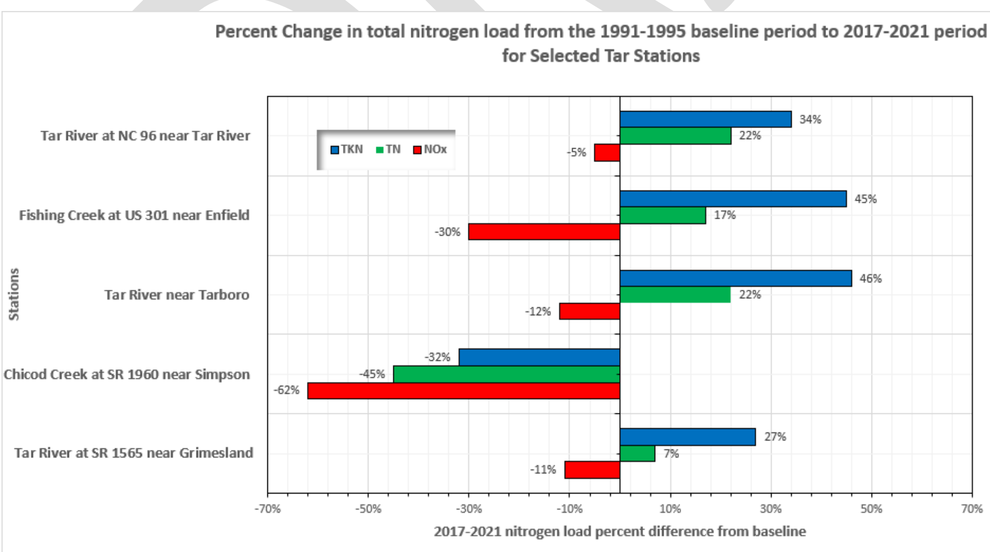
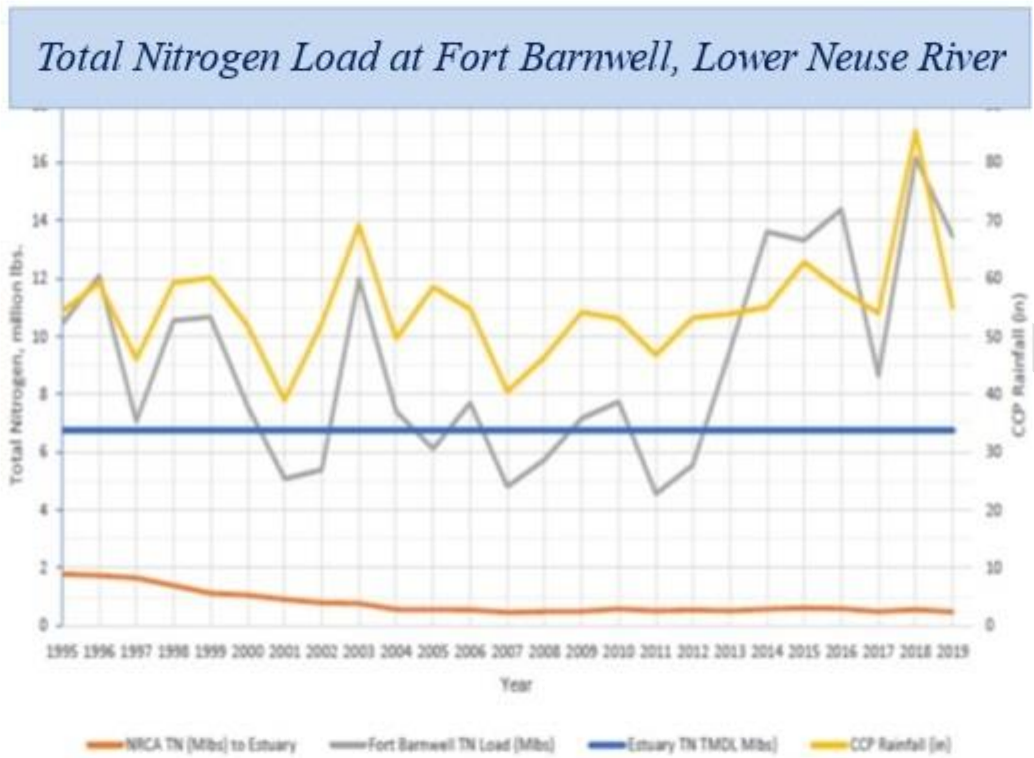


FIGURE 72. UPSTREAM TO DOWNSTREAM % CHANGE IN TAR-PAMLICO BASIN NITROGEN LOAD VS. 1991-1995 BASELINE



Nonpoint Source Loading: Speaking first to nonpoint source loading in general, the following graphic developed by the Neuse River Compliance Association illustrates the rainfall-driven character of most of the nitrogen loading in the Neuse Basin, and the relative magnitude of point source loading compared to that of nonpoint, in addition to the striking reductions achieved in discharge loading by the Association.

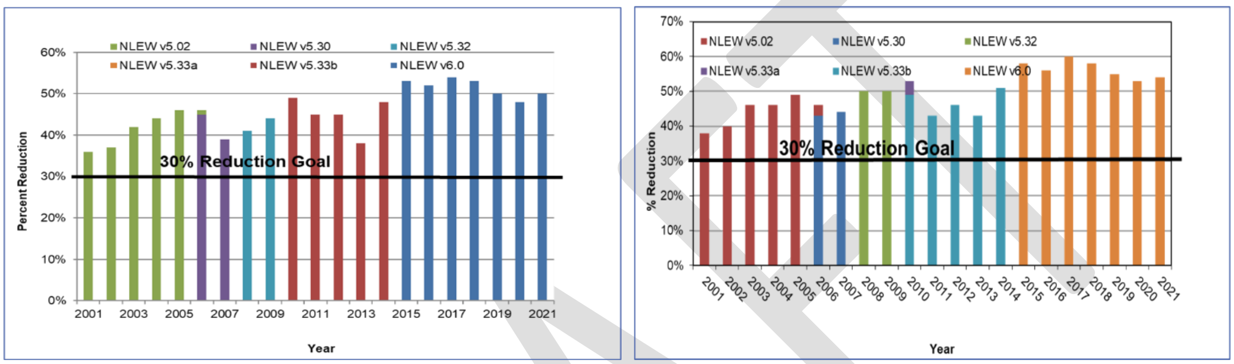
FIGURE 72. NEUSE BASIN POINT AND NONPOINT SOURCE LOADING AT FT. BARNWELL, 1995-2019 (SOURCE: NEUSE RIVER COMPLIANCE ASSOCIATION)



Agriculture Rule Compliance: The Agriculture rules used a novel collective compliance approach and nominally called for all agricultural operations to collectively achieve the 30% N load reduction goal. However, rule structural limitations included limited enforceability and deferral of important specifics on how various challenging elements might be implemented to processes called for by the rules. Ultimately, implementation did not address certain aspects of the ambitious charge. It did not address loading from AFO facilities, a sector for which separate state regulations were being rolled out at the time. It was statutorily barred from addressing dry litter poultry facilities and their waste management practices. The science was found insufficient to account for nutrient dynamics and loading from grazed pasture agriculture. To the extent that nutrient loading to surface waters from these unaddressed agricultural sectors did not decrease or increased, overall progress would be undercut.

Regarding rule compliance accounting, lacking watershed modeling for the basin at the time (the development of which was, if nothing else, not feasible within the timeframes provided for implementation), the accounting system developed through the leadership of subject matter experts used a relatively uncomplicated empirically based accounting structure to estimate reductions in N loss from edge of management unit rather than reductions in N loading to streams. The NLEW program (see Implementation section) has estimated collective annual reductions in N loss from basin croplands ranging between 35-55% over the last 20 years. Reductions are attributed to a combination of: a net loss of cropland acreage (the decrease ranging from 20-25% in Fig.'s 35 and 36); reductions in N application rates (Fig.'s 39 and 40, most significant for fescue and bermuda); crop shifts (increase in low-no N soy and decreases in most other major crops); and BMP implementation.

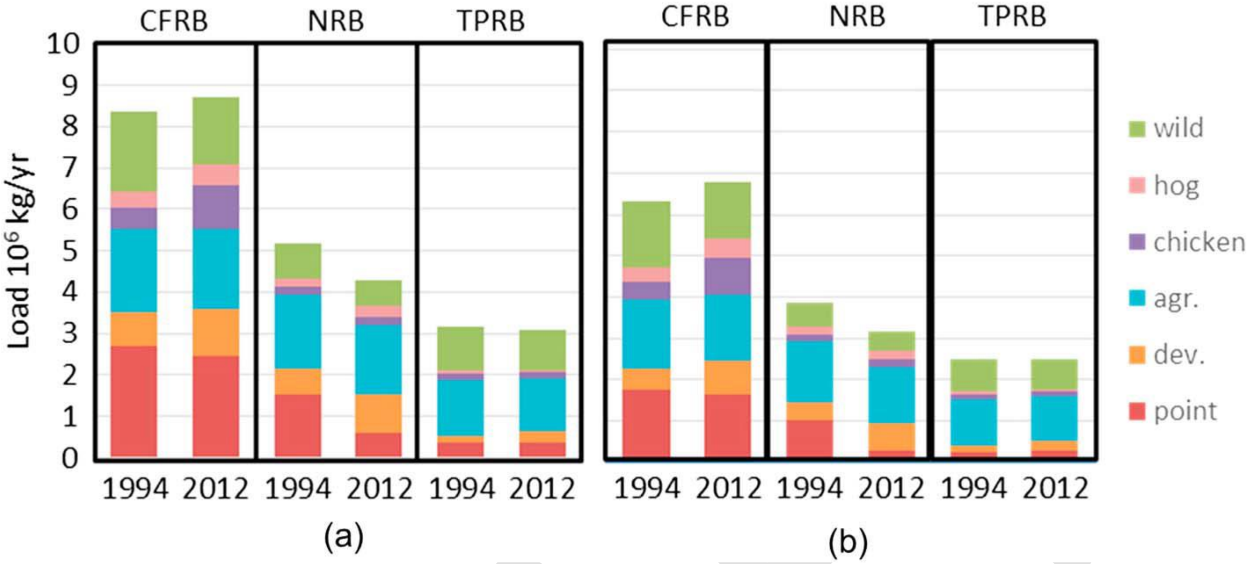
FIGURE 73. ESTIMATED COLLECTIVE ANNUAL BASIN CROPLAND AGRICULTURAL REDUCTIONS IN NITROGEN LOSS FROM NEUSE (LEFT) AND TAR-PAMLICO (RIGHT) BASINS, 2001-2021



AFO Trends: While the Agriculture rules do not regulate AFOs, these operations can potentially have effects on nutrient loading. As seen in the Watershed Changes section, according to the Agricultural Census for 2002 through 2017, cattle inventories fluctuated and overall showed a modest decrease in these basins. Hogs also fluctuated somewhat but stayed roughly the same. Poultry showed a decreasing followed by increasing trend, finishing close to starting population for this time period. It will be worthwhile to add the preceding 10 years of this tracking to understand the entire trend back from baseline.

Agriculture Instream Trends: At least one watershed-scale study estimated changes in agricultural nutrient loading over time in the basins. Watershed modeling conducted by Strickling and Obenour (2018) used a "hybrid" formulation similar to USGS SPARROW, but considering inter-annual variability related to precipitation and land-use change. It also used Bayesian inference for rate estimation and uncertainty quantification. The model found no appreciable change to stream N loading from agriculture between 1994 and 2012 in either basin. This modeling analyzed loading from hog and chicken waste separately, and for the same time period estimated a 35% increase in hog N export in the Neuse (from 9% to 12% of total N loading) compared to a 14% decrease in the Tar-Pamlico, with no meaningful change in chicken N export in either basin. Spatially, the model estimated greater unit-area loading rates from the mostly agricultural lower-basin watersheds. It also found increases in those loading rates in lower basin watersheds over the study period, perhaps due at least in part to a greater impact from increased precipitation in the coastal part of the basins. One potentially significant note is that the downstream spatial extent of this modeling did not capture the Trent River watershed, which enters the estuary at New Bern below Ft. Barnwell. This watershed's poultry contributions are discussed in the Organic Nitrogen Sources section below.

FIGURE 74. SOURCE-SPECIFIC TN LOADS (A) ENTERING AND (B) AT DOWNSTREAM BASIN OUTLETS OF CAPE FEAR (KELLY), NEUSE (FT. BARNWELL), AND TAR-PAMLICO (WASHINGTON) RIVER BASINS, 1994 VS 2012



Considering the many differences between edge-of-field nitrogen loss estimation and stream loading and watershed delivery modeling, one potential factor that could contribute to the disparities seen in these results may lie in the groundwater to surface water landscape linkage given that most agriculturally applied N goes to either plant uptake or shallow groundwater. The groundwater flow path involves the potential for a lag effect for fertilization reductions to register in stream loading as nitrogen moves through varying-aged groundwater flowpaths and makes its way to surface waters. The modeling study's time period precedes and only partially overlaps with Agriculture rule reporting, adding to the potential for a lag effect to register after the modeling period.

Another potential factor could be more recent climate-driven changes in nutrient export behavior. The watershed modeling conducted by Strickling and Obenour (2018) found precipitation to have a larger influence on unit-area N export rates for agricultural than for developed lands, creating a system dominated by agricultural total nitrogen during high precipitation years and by developed (urban) regions during low precipitation years. In high precipitation years, agricultural N export rates are approximately twice those of urban, while in low precipitation years, dominance swings in the other direction and urban N export rates are approximately 1.8 those of agriculture. Findings also suggested that increased precipitation patterns in the lower basins may have contributed to increases in unit-area N loading found from lower basin watersheds over the study period of 1994-2012. Thus, the increase in frequency of extreme storms in coastal NC since the late 1990's identified by Paerl et al (2020) could be increasing surface and subsurface losses of nitrogen from the agricultural landscape relative to assumptions made in the agriculture rule accounting tool in the late 1990's. Also, the increasing relative proportin of soil organic nitrogen yield in the down-basin progression reported by Osburn et al (2016) in the Neuse basin may suggest a significant linkage to agricultural contributions.

While Strickling and Obenour (above) found no meaningful change in poultry TN loading to either estuary over their study time period (1994-2012), Osburn et al (2016) in a single-timespan DON source typing study

(Aug 2011 – May 2013) found that at Ft. Barnwell poultry had the highest poultry DON yields, roughly 3 times greater than urban sources comprised of wastewater influent and effluent, septic and street runoff (see Organic Nitrogen Sources below for further details). These findings together might suggest that poultry loading may not have changed much over the first dozen years of strategy implementation, yet it may have comprised a large fraction of the organic N loading to the estuary at that point. This outcome on its face would not seem to help explain the increase in estuary TKN delivery since 2000 documented by DWR's trend analyses. However, one possibility is that the intersection of climate-driven rainfall increases and organic N sources that are more available on the landscape, potentially such as poultry waste, resulted in increased wash-off and delivery of nutrients from those sources. This could help explain DWR's and others' trend analyses showing large increases in TKN from e.g. the Trent River watershed and at lower mainstem stations in both basins. In any case the differing result between these increases and Strickling and Obenour's model results remains unexplained.

Development Rules: Basin stormwater rules included programmatic elements for local governments to implement, some of which - illicit discharge detection and elimination programs and education - could potentially help reduce loads from existing developed lands. The rules did not mandate any quantitative requirements for existing development nor tracking of activities to reduce loading from these lands.

The main focus of the rules was requirements for local regulation of post-construction stormwater runoff. Their intent was to achieve strategy percent nutrient reduction goals on a project-by-project basis by establishing uniform unit-area loading rate requirements for developers that reflected the strategy percent reductions applied to assumed average pre-development loading conditions.

As implementation played out, certain aspects of the post-construction design proved to limit its effectiveness. Due to time and resource limitations, load accounting tools were not developed until after the rules went into effect, while the loading rate targets were set in rule using literature-based export coefficients. Ultimately, differences in methods between targets and compliance calculators introduced uncertainty around whether the numeric objective was being achieved. Also, later studies funded by the UNC Collaboratory indicate that development in Jordan and Falls watersheds has come disproportionately from forest lands rather than in even proportions from forest, crop and pasture. If true for Neuse and Tar Basins in general, this outcome undercuts that key assumption used to set the loading rate targets, with the result being they were not sufficiently stringent.

More importantly, the rules also set certain loading rate thresholds below which onsite treatment was not required and developers could simply pay an in-lieu fee to offset their loading levels in excess of the rate targets. Once accounting tools were established, the offsite thresholds of 6 lbs TN/ac/yr for residential and 10 lbs TN/ac/yr for commercial/industrial development projects were found to equate to approximately 36% BUA and 57% BUA respectively. These unintentionally loose treatment thresholds, combined with what became established as the comparatively low cost of the prevailing offsite offset option, resulted in virtually exclusive use of the offsite option by any development below the thresholds. As a result, most residential and a significant portion of commercial/industrial development has likely occurred without water quality volume capture controls that would provide basic protection to receiving streams from erosive post-construction stormwater flows as well as providing general water quality treatment protection for receiving waters. While this unintentional loophole was eliminated in the rules readoption that became effective in 2020, local program revisions are only now going into effect, and this allowance existed for the entire history of these strategies as reviewed in this report.

Compounding this loophole, it has become increasingly apparent over time that the nutrient credit assigned to the practice used virtually exclusively by developers paying in-lieu fees, riparian buffer restoration on rural lands, was significantly over-credited when it was established in the late 1990's by a factor of approximately 3 to 4 for nitrogen. Revision of this credit is a priority, but it too has been in place for the full history of these strategies to date.

Development Trends: As illustrated in the Watershed Changes section above, the vast majority of population growth in the last 20 years has occurred in the upper Neuse Basin in Raleigh and surrounding communities. Consistent with statewide trends, many upper Coastal Plain cities and counties actually saw population decreases. Tables 3 and 4 show that developed land covers increased 18% and 9% in Neuse and Tar respectively, while population increased by 45% and 5% respectively, suggesting that Tar growth was much more in the low density residential direction while Triangle growth was much denser urban in nature. Following the population trends, nitrogen offset purchases in the Neuse were over an order of magnitude greater than those in the Tar, and 86% of Neuse offsets occurred in the upper basin's 01 8-digit HU. By contrast, 62% of Tar basin offsets occurred in the lower basin's 03 HU encompassing Greenville with most of the rest in the upper basin probably associated with Raleigh commuter growth.

Development Instream Loading Trends: The watershed modeling conducted by Strickling and Obenour (2018), described above, estimated that nitrogen loading from developed lands in both Neuse and Tar-Pamlico basins increased by approximately 50% between 1994 and 2012. Aside from the Neuse 61% point source loading reduction, this was the most significant change in loading estimated in either basin.

Interestingly, in DWR's trend analyses, TKN showed the largest percentage increases in the upper, more urban Neuse basin, decreasing its proportion traveling downstream, as seen in Figures 71 and 72 above, which provide an upstream to downstream progression of flow-adjusted nitrogen species' percent changes. A similar, weaker trend appears in the Tar TKN trends.

Organic Nitrogen Sources

Osburn et al (2016) conducted a study using flourescence technology to track dissolved organic nitrogen (DON) source loads to the Neuse estuary. Dissolved organic nitrogen (DON) from eight watershed sources was modeled for its flourescence characteristics, which were then used as a reference set against which to compare surface water samples taken between August 2011 and May 2013 from stations in the Neuse River. DON is the nitrogen component of dissolved organic matter and is part of the biologically reactive nitrogen pool that can degrade water quality. Results were generally consistent with changes in land use from the urbanized Raleigh metropolitan area to the largely agricultural Southeastern coastal plain. The study found that while >70% of DON was attributed to natural background sources, nonpoint sources, such as soil and poultry litter leachates and street runoff, accounted for the remaining 30%. Interestingly, virtually no swine contribution, one of two agricultural sources typed, was measured in streams of the basin.

Instead, at Ft. Barnwell poultry had the highest yields, roughly 3 times greater than urban sources comprised of wastewater influent and effluent, septic and street runoff. The poultry yield equated to the total permitted wastewater discharge organic nitrogen load for the basin, which was one quarter of the permitted total nitrogen discharge load for the basin. In addition, poultry DON yield at the Trenton gauging station capturing less than one third of the Trent River watershed, which enters the mainstem below Ft. Barnwell, was half again the Ft. Barnwell poultry yield, suggesting that the entire Trent watershed yield could potentially rival that at Ft. Barnwell.

Soil DON had the largest signal other than natural background, with a yield at Ft. Barnwell three times greater than the next largest, poultry. While soil may be considered a "natural" source, it may be an anthropogenically influenced source important for the increasing N load to the Neuse River Estuary. The authors noted that the Maillard humification reaction could transform a poultry or swine signal into a soil signal, and they recognized that resolution of this question is an important unaddressed information need to the understanding of DON loading to the estuaries.

Review of Strategy Allocation Designs

The goal of these nutrient strategies, as stated in the original Neuse Goal rule, 15A NCAC 2B .0232, and in the 1994 Phase II TPBA Agreement, was a 30% reduction in nitrogen loading to the respective estuaries from point and nonpoint sources of nutrients, relative to their baseline loading periods of 1991-1995 and 1991 respectively. The Tar-Pamlico Agreement had the additional goal of returning phosphorus loading to its baseline level. On its face, neither strategy was explicitly designed to fully meet these goals, since neither attempted to address inputs from forest lands (estimated at 20% of N loading in the 1999 Neuse TMDL and 10% of N loading in the 1994 Tar-Pamlico Basin Plan), from existing developed lands (8% and 2% of N loading respectively), or from atmospheric sources (5% and 33% of N loading respectively) in any quantitative or arguably meaningful way. Together, one third or more of major source nitrogen loading was not explicitly addressed in these strategies. Managers may have anticipated potential strengthening of air quality regulations that could reduce atmospheric N deposition and may have considered education and illicit discharge program requirements in the stormwater rules, along with the Nutrient Management rules' requirement for professional fertilizer applicators to either follow an approved nutrient management plan or take basin-specific nutrient management training, to have potential for reducing existing development loads. It should be recognized that these were novel management strategies, certainly for the state, that were testing the efficacy of a new suite of requirements toward remedying overproductive estuaries in the context of significant uncertainties about how the estuaries would respond. Both the Phase II Tar-Pamlico Agreement and the 1999 and 2001 Neuse TMDLs described various modeling uncertainties, and discussed the potential need for greater ultimate reductions in loading, establishing an adaptive management mindset from the start.

Potential Adaptive Management Actions Going Forward

While the findings in this analysis highlight a set of challenges, they also provide a basis for considering adaptive management and knowledge acquisition needs. Planning staff offer initial thoughts for the next iteration of basin nutrient strategies. While DWR nutrient strategy planning priorities are currently focused on other watersheds, this report provides a sound start for consideration of adaptive management needs and possibilities, as well as knowledge and policy areas in which to build our understanding to better support improvements in the design of the next iteration of these important management initiatives.

Reassess Estuary Needs

Now over twenty (Neuse) to over thirty (Tar) years since estuary response modeling was developed for these systems, modernization of these strategies, when it is undertaken, would likely benefit from a reassessment of estuary nutrient loading reduction needs. This evaluation should probably consider not only the chl-a standard, but also the draft clarity standard currently being developed by DWR's Classifications and Standards program for protection and recovery of SAV habitat. Another argument in favor of this action would seem to be the compelling evidence assembled by Paerl et al (2020) of a major climatic shift in the last twenty or so years that is affecting estuary dynamics. If nothing else, increases in variability of riverine inputs might affect projections of reduction needs. Practical counter-arguments to this notion would include that as long as the original reduction goal has not been achieved, remodeling is not yet needed, particularly considering the substantial time and resources required for that effort, in addition to the implications for strategy restructuring.

Reallocate Load Reduction Responsibilities

Once estuary nutrient loading needs are reestablished, or alternatively continuing under the current TMDLs, strategy modernization would benefit from a fuller allocation of load reduction needs. If current approaches are followed, forest loading reductions would be redistributed across regulated sources, and local governments would be called on to take long-term responsibility for making progress on reducing loads from existing developed lands.

Another unaddressed "source" category is atmospheric deposition. Atmospheric deposition of nitrogen has shown a promising downward trend in the coastal region of the Neuse and Tar-Pamlico basins, representing a 20 percent decline in the watershed since 2000. Nitrate deposition reductions were the bulk of this improvement, attributed to several state and federal air quality initiatives enacted in the early years of the 21st century. Looking forward, the expected maturation of prior air emissions regulatory initiatives, both stationary sources and mobile, along with new ones in progress together suggest further reductions are likely. As the population grows in the airshed of the Neuse and Tar-Pamlico River Basins, the sheer increase in numbers of vehicles on the road will likely dampen a downward trend in NOx emissions, while the growing popularity of electric vehicles will likely act in the opposing direction, helping to minimize the increasing effect of vehicle numbers over time. At a minimum, for the near future the Division should consult with DAQ on forecasting of future trends and should continue to track and include annual deposition data in future reports to follow changes in atmospheric deposition in the Neuse and Tar-Pamlico River Basins.

Address Existing Development

As described in the Nutrient Sources evaluation above, the Neuse and Tar-Pamlico rules do not include requirements for quantitative reductions in nutrient loading from existing developed lands. According to land cover data collected by the National Resources Inventory (NRI), as of 1997 there were 481,000 acres of urban and built-up land cover in the Neuse Basin, or approximately 13% of the entire basin. While in the Tar-Pamlico approximately 200,000 acres (7% of the basin) were already developed by that time. Since the current nutrient strategies in both basins didn't addresses stormwater from new development until 2001 (Neuse) and 2006 (Tar-Pam), the stormwater runoff from these 481,000 developed acres in the Neuse and 200,000 acres in the Tar-Pam, plus any lands developed between 1997 and the implementation of the new development rules in both basins has probably not been subject to post-construction control requirements. As further described above, much of the post-rule development also did not require treatment as a result of the unintended offsite threshold loophole. Altogether, most developed lands in the basin probably lack detention and treatment.

Treating nutrient runoff from existing development through stormwater retrofit SCMs and other load reducing measures, both structural and management oriented, represents a real opportunity to further reduce existing nutrient loads to the basin from this significant source. A rule to address nutrient contributions from stormwater runoff from existing development could provide municipalities opportunities to receive nutrient reduction through practices such as removing existing impervious cover, buffer restoration, street sweeping, and removal of illicit discharges, in addition to structural retrofits.

Climate and Existing Development

Adapting to the impacts of climatic shifts appears important. One area of focus should involve expanding the set of management tools for local compliance with an Existing Development mandate with ecosystem restoration-focused or "nature based" management actions such as stream restoration, floodplain reconnection, regenerative stormwater conveyances, and renovation of hardened urban watercourses. Where quantitative nutrient crediting is not established, a compliance structure should be considered that will allow practices nonetheless recognized as beneficial for nutrients and water quality to be used, particularly if they provide adaptive benefits to more extreme precipitation conditions.

Post-Construction Stormwater

It would appear important to address several sources of "leakage" in post-construction stormwater requirements, likely including treatment thresholds, offset crediting and hydrologic impacts to receiving streams.

Post-Construction Site Controls: Neutralizing the water quality impacts of new development has proven difficult to date in this state, including protection of receiving streams from degradation via hydrologic impacts. As climate change increases the challenges of protecting streams, one aspect of improved stormwater management in these watersheds would seem to be lowering the development intensity threshold at which some level of stormwater capture and treatment is required. For the same reasons, attention should be given to needs for updating post-construction stormwater treatment requirements to better minimize hydrologic impacts.

Revise Buffer Restoration Nutrient Offset Credit: Protection of existing intact riparian buffers and restoration of buffers remain important elements of the strategies to improve water quality in the Neuse and Tar-Pamlico basins. However, as recognized in the Nutrient Sources analysis above, it has become clear based on more recent science and evidence that the riparian buffer restoration practice established in the late 1990's provided significant over-crediting based on several assumptions included in the calculation and is in need of revision. Buffer restoration as currently regulated involves converting an active use of the riparian zone such as cropping or pasture to an unfertilized, undisturbed zone of woody vegetation. The nutrient loading benefits of this conversion include.

Agricultural Improvements

Another need would appear to involve revisiting agricultural practices toward improving nutrient retention in the face of more challenging climatic conditions. One appropriate agricultural objective would seem to be increased implementation of livestock exclusion from streams. Another would be seeking to increase funds and assistance to the Lagoon Floodplain Buyout program. It would also appear important to establish greater transparency on poultry waste management practices to determine where improvement opportunities may exist.

Livestock Exclusion: Livestock exclusion is the practice of restricting or prohibiting livestock access to streams, rivers, and other water bodies. This is typically achieved by building fences or other barriers and providing alternative water sources. As described in the Nutrient Sources evaluation above, the Neuse and Tar-Pamlico rules do not address loading from grazed pasture agriculture as the science was found to be insufficient at the time. Further compounding this gap in the nutrient managemetn strategy is the Strickling and Obenour (2018) finding that estimated agriculture loading rates appear to be greater in lower-basin watersheds, which is where the vast majority of animal operations are located in both basins.

Study evaluating the environmental impact of unrestricted livestock access to streams has improved over the past twenty years. Recent efforts to beter quanitfy and understand the nutrient dynamics and loading of this activity provide further support for management measures addressing stream protection from animals. Preventing animals from entering open water and degrading streambanks has been shown to reduce cattle-induced erosion and in turn reduces nitrogen, phosphorus, and sediment export from pasture (Line et al. 2016).

The development of recommendations for limiting livestock from streams will benefit from ongoing discussion in other watersheds that are currently developing nutrient management strategies attempting to address this topic. Current proposed management concepts being discussed involve calling for the agricultural community to commit to exclude an agreed upon percent over overall stream miles with participating farms over a certain size and providing for flexibility over qualifying exclusion “barriers” and allowing stream crossing access point and emergency exemptions.

Ultimately any proposed approach for addressing this source of nutrient in the Neuse and Tar-Pamlico River basins would be developed in cooperation with the Agricultural Basin Oversight Committees with input from agriculture stakeholders so that basin-specific factors can be considered in the development of requirements, accounting, and goals appropriate for both river basins.

Lagoon Buyout Program: An obvious program to seek to accelerate in the face of increasing climate-driven flooding is the Program to Acquire Conservation Easements on Swine Operations in the 100-Year Floodplain. The program was created in November 1999 in the wake of devastation from Hurricanes Dennis, Floyd, and Irene. The objective of the program is to reduce the risk to water quality from future flood events. The DSWC solicits bids from interested on-going swine operations to relinquish their permit and establish a conservation easement on the property. The land can continue to be used for low-intensity agriculture but is prohibited from operating a feedlot associated with lagoons in a 100-yr floodplain or easement use as a spray field.

Recently the DSWC was awarded a $2.5 million Regional Conservation Partnership Program grant from USDA and another to $319,342 grant from Land and Water Conservation Fund to offer a fifth phase of the program. The Division has received excellent cooperation from the NC Pork Council, Cooperative Extension, the Farm Bureau, the Conservation Council, and the Land and Water Conservation Fund. Members of the General Assembly have expressed interest and support for this voluntary initiative.

Waste Application at Phosphorus Agronomic Rates: When biosolids, animal manures, and other organic residuals are land-applied to fertilize crops, current North Carolina requirements call for these waste streams to be applied at agronomic rates based on the nitrogen need of the receiving crop. The N:P ratios in the waste result in phosphorus application at several times higher than phosphorus agronomic rate. The over application of phosphorus can then lead to excessive legacy phosphorus in the soil which can result in its loss from the soil by leaching or erosion into surrounding waterbodies over time (Doydora et al. 2020). Under a more extreme rainfall climate regime, increases in soil loss through runoff are likely, increasing the potential for P movement into streams.

To address this concern, measures should be considered calling for land application of biosolids, animal manures, and other organic residuals to be based on agronomic rates for phosphorus. Establishing such a requirement will need to be informed through additional input from entities currently engaged in land application activities as well as in consultation with subject matter experts, including a detailed review of the most current research available in order to craft the appropriate requirements for these two specific nutrient sensitive river basins.

Management of Poultry Litter: Given the apparent significant contributions of organic nitrogen loading from poultry waste described in the Analysis section, it would also appear important to establish a better understanding of poultry dry litter management practices to determine where management improvement opportunities may exist. Improved understanding would be facilitated by greater transparency. Currently, inspections of dry litter poultry operations are mostly complaint-driven, and information is only available to the public if it is determined that the operation has impacted water quality and a violation is issued. A possible next step to move the issue forward could be an interagency committee that seeks to develop recommendations for litter management and oversight improvement needs for legislative consideration.

To inform a discussion on dry litter management, the following side-by-side comparison information is provided between dry litter and permitted AFO's. Cattle, swine, and wet poultry AFOs above threshold numbers across the State are regulated by DWR's Animal Feeding Operations Branch, which in concert with DWR Regional Offices is responsible for permitting and compliance activities on these operations. The land application of manure is managed and must be applied at agronomic rates. Statute has established the specific requirements for dry litter poultry operations, which are deemed permitted with certain associated requirements. A brief side-by-side comparison of regulations between dry litter poultry and other AFO types is provided in Table 7. This is not a complete list of requirements; for more information, visit the DWR AFO webpage or federal and state regulatory code.

TABLE 7. BRIEF COMPARISON OF REGULATORY CODE BETWEEN DRY LITTER POULTRY AND OTHER AFO'S (SWINE, CATTLE, WET POULTRY).

Federal	Dry Litter Poultry	AFO (swine, cattle, wet poultry)
40 CFR 122 NPDES requirement: CAFOs require an NPDES permit if discharge to waters of the US	15A NCAC 02T .1305: NPDES permit if discharge to waters of the state	15A NCAC 02T .1305: NPDES permit if discharge to waters of the state
State has the Authority to permit AFOs	143-215.10C 15A NCAC 02T .1303: Deemed Permitted If over 30,000: Must do following:	143-215.10C 15A NCAC 02T .1304 State or Individual permit required, If over thresholds: 250 or more swine, 100 or more confined cattle, 75 or more horses, 1,000 or more sheep, 30,000 wet poultry Must do following:
	No routine inspections	Annual inspections, self-report
	Not mandatory for Technical Specialist to develop Waste Utilization Plan, and not submitted to DEQ for review	Waste Utilization Plan developed by Certified Technical Specialist, and submitted to DEQ
	Soil test once every 3 years	Soil test once every 3 years
	Apply at agronomic rates	Apply at agronomic rates
	25-ft setback from streams for land application	25-ft setback from streams for land application
	100-ft setback from a well for land application	100-ft setback from a well for land application
	Manure stockpiles must not be uncovered more than 15-days; manure may be stockpiled on uncovered ground	Manure storage has specific requirements and management usually within inspected lined lagoons
	Representative waste analysis within 60 days of land application	Representative waste analysis within 60 days of land application

Domestic Wastewater

Interestingly, between 2010 and 2020, when total population in the Tar-Pamlico decreased by 18,970 people, the number of new onsite wastewater installations increased by 9,000 units, albeit at about half the pace of new installs from 2000 to 2010. This suggests that the net population decline in the basin in those ten years came entirely from municipalities on a net basis, and enough to also offset the increase in more rural population. Overall, given the highly effective nutrient removal from septic systems as compared to publicly owned treatment works, this evidence would suggest a net decrease in total wastewater nutrient loading to the Tar-Pamlico basin from human sources in the last ten years assuming consistent POTW performance.

With over 50% of basin populations relying on septic systems and recognizing that maintenance is generally recognized as the weak link in sustaining good performance, homeowner and business owner education and technical assistance should be advanced as a useful management improvement action.

Recognizing that a certain fraction of septic systems are malfunctioning at any point, and that local resources to detect them and to facilitate remedial actions are often deficient, improvements to the delivery of remedial support to system owners is another potentially valuable management improvement. Resources for this kind of work could potentially be improved under an Existing Development rule construct.

Small Municipal Wastewater Discharges

Under the Neuse Wastewater rule, municipal wastewater dischargers in the basin with daily flows less than 0.5 MGD (minor facilities) were originally assigned a collective annual discharge nitrogen allocation of 138,000 pounds when the Rule was first adopted but were not assigned individual limits in their NPDES permits. As a result, these facilities are not currently required to reduce their total nitrogen loads. Over time several of these smaller facilities have entered into agreements and connected with major facilities to treat their wastewater. However, a preliminary review of the facility monitoring data for the remaining 45 minor facilities indicates these smaller facilities, as a group, are not meeting their collective assigned total nitrogen allocation. Putting limits into the permits of facilities with flows greater than 100,000 GPD could represent a significant source of nitrogen loading to the estuary that can provide relatively very cost-effective loading reduction opportunities. While there are significantly fewer minor wastewater discharge facilities in the Tar-Pamlico basin compared to the Neuse, consideration for assigning limits for those smaller facilities in the Tar-Pam should be evaluated as well. These smaller dischargers are largely public utilities. The Utilities Commission will likely not authorize them to include the cost of upgrades of their plants to reduce nutrient loads in any future rate requests unless State law mandates the upgrade by putting limits in their permits.

Appendices

Appendix A - Research Paper Summaries

A sample of relevant literature is summarized below. We collected peer reviewed research papers and reports related to nutrient flows in the Neuse River Basin and Tar-Pamlico River Basin. Research below focuses on modeling on nutrient and carbon dynamics and sources. A comprehensive literature review was not conducted due to NC DWR limited funding to access research publications.

Bowen, J., & Harrigan, N. B. (2017). *Comparing the impact of organic versus inorganic nitrogen loading to the Neuse River Estuary with a mechanistic eutrophication model*. NC WRRI. Report No. 470.

This study aims to advance Bayesian methods for modeling daily eutrophication dynamics – they include more environmental factors into the model to try to better represent the real-world algal growth dynamics. Researchers try to improve these environmental models to help guide reduction targets – the modeling studies developed for the Neuse River Estuary TMDL in the past had limitations. Improved computing power as well as long term decadal and fine resolution data can advance the models – the authors developed a process-based eutrophication model that simulates chl-*a* and nutrient dynamics at a daily time scale over multiple decades. They compared empirical and mechanistic phytoplankton modeling approaches. As a data source, it is important to note that measurements of nutrients, chl-*a*, salinity, temperature, and light extinction spanning almost 22 years, 1997–2018, were collected approximately biweekly (twice per month) along the NRE by the Modeling and Monitoring Program - ModMon, 2019. The models are compared and the mechanistic models were considered most useful for hypothetical nutrient loading scenarios. The model results suggest that achievement of the current nutrient reduction goal (30% TN reduction) will most likely facilitate compliance with NC criteria, based on the frequency of exceeding high chl-*a* (40 µg/L) concentrations. A 10% change in nitrogen loading (flow held constant) could produce an approximate 4.3% change in estuary chl-*a* concentration, while the statistical model suggests a larger (10%) effect.

Models that represent the natural environment are advancing which can help predict nutrient management scenarios. The current 30% TN reduction goal will help reduce chl-a concentrations in the Neuse River Estuary.

Byrnes, D. K., Van Meter, K. J., & Basu, N. B. (2020). Long-term shifts in US nitrogen sources and sinks revealed by the new TREND-nitrogen data set (1930–2017). Global Biogeochemical Cycles, 34(9), e2020GB006626. https://doi.org/10.1029/2020GB006626

This authors have developed the TREND-nitrogen data set, which, for the first time, provides a comprehensive, 88-year (1930–2017) data set of county-scale N inputs (fertilizer, manure, biological N fixation, human waste, and atmospheric deposition) and nonhydrologic outputs (crop uptake) across the contiguous United States. The TREND-nitrogen data set used in this research is available at https://doi.org/10.1594/PANGAEA.917583. A cluster analysis was completed with the new dataset – they found that similarities in N surplus trajectories across climatically diverse regions identified are indicative of a widespread functional homogenization of human-dominated landscapes; very generally, urban and rural/agriculture areas are each becoming more uniform and intensified.

Cha, Y., Alameddine, I., Qian, S. S., & Stow, C. A. (2016). A cross-scale view of N and P limitation using a Bayesian hierarchical model. *Limnology and Oceanography*, *61*(6), 2276-2285. https://doi.org/10.1002/lno.10375

This paper uses a bivariate Bayesian hierarchical model to review multiple aspects of N-P relationships-N and P concentration variability, ratio, and correlation. Understanding N and P dynamic in freshwater require models to allow for seasonal and spatial variation. The authors look at three case studies, including the Neuse

River Estuary. They found that the Neuse River Estuary exhibits a wide variation in within-group N:P correlation. The correlation is highest in the spring and at the upstream stations, probably reflecting spring precipitation and associated watershed inputs as the main driver of N and P concentrations. Moving downstream, and during lower flow conditions, internal processes, which differentially influence N and P concentrations appear to dominate resulting in a decoupling of N and P. future research should link this model to biological components, such as phytoplankton abundance, or toxin concentrations, so that relevant eutrophication ecosystem response indicators are probabilistically predicted as a function of covarying N and P, while also accounting for temporal and spatial dimensions.

Neuse River Estuary has seasonal and spatial gradients for N and P distributions – the riverine N input in important and summer sediment release is important in seasonal P.

Cira, E. K., Paerl, H. W., & Wetz, M. S. (2016). Effects of nitrogen availability and form on phytoplankton growth in a eutrophied estuary (Neuse River Estuary, NC, USA). PLoS One, 11(8), e0160663. https://doi.org/10.1371/journal.pone.0160663

This study experimentally determined the influence of urea and nitrate additions on phytoplankton growth throughout the growing season (March 2012, June 2011, August 2011) in the Neuse River Estuary. Different types of phytoplankton (taxa-specific) react slightly differently to levels of nitrogen availability - and N form may influence phytoplankton community structure by favoring the growth of certain taxa over others. Urea is a major component of fertilizers, and the urea may prompt harmful taxa. Some seasonal differences were also recorded in the phytoplankton response to N form – In March, the phytoplankton community was dominated by Gyrodinium instriatum and only fucoxanthin-based growth rates were stimulated by nitrogen addition. The limited response to nitrogen suggests other factors may control phytoplankton growth and community composition in early spring. In June, inorganic nitrogen concentrations were low and stimulatory effects of both nitrogen forms were observed for chlorophyll a- and diagnostic photopigment-based growth rates. In contrast, cell counts showed that only cryptophyte and dinoflagellate (Heterocapsa rotundata) growth were stimulated. Responses of other photopigments may have been due to an increase in pigment per cell or growth of plankton too small to be counted with the microscopic methods used. Despite high nitrate concentrations in August, growth rates were elevated in response to urea and/or nitrate addition for all photopigments except peridinin. However, this response was not observed in cell counts, again suggesting that pigment-based growth responses may not always be indicative of a true community and/or taxa-specific growth response. The researchers stress the importance of continued use of microscopic identification/enumeration in phytoplankton research due to the ability to differentiate among more types of taxa (i.e. Chlorophyll a, Alloxanthin, Chlorophyll b, Fucoxanthin, Peridinin, Zeaxanthin).

Urea is a major component of fertilizers, and the urea may prompt harmful phytoplankton taxa.

Harris, K. E., & Haring, C. P. (2022). Tar-Pamlico and Neuse River Basins, North Carolina, Geomorphic Summary Report. Engineer Research and Development Center (US).

This paper primarily reviews the management of woody debris in rivers large woody debris (LWD) – the authors compiled existing research. The cities within the Tar-Pamlico River Basin have faced recurring flooding due to several hurricanes in the past 2 decades and with reported channel buildup of woody debris within the river, causing concern that the debris is exacerbating flooding problems. The flooding raises concern for emergency access, spilling of waste ponds, and increased riverbank erosion. There appears to be concentrated sites of debris accumulation in the meander bends of the river surrounding the city of Tarboro and at bridge crossings. Also, The Neuse River Basin, based on rating curve analyses, appears to have more geomorphic instabilities and areas of degradation compared to the Tar-Pamlico. There are currently no data on the extent of debris within the basin. The authors highlight several findings from the literature on LWD: 1) the role of LWD in flooding has been overstated in cases of mild to moderate debris accumulation within the rivers, 2) LWD is valuable infrastructure could be modified to allow LWD to pass downstream while preserving areas of LWD storage to maintain its presence and ecological benefit, 3) LWD removal is expensive and is still manual removal; Structures such as piles and debris dams retain LWD in more optimal locations and gate structures capture LWD at the banks for more convenient removal, 4) USACE has recently developed a geomorphic watershed assessment approach with the FluvialGeomorph (FG) toolkit which can aid with LWD issues. The authors propose managing LWD to stabilize the river system to decrease bank erosion and debris supply, therefore reducing the supply of LWD that comes from trees falling in from bank erosion and caving.

LDW is an important issue to address for flooding, although manual removal is expensive and not always required – stabilizing river systems is proactive management option.

Hounshell, A., & Paerl, H. (2017). *Role of organic nitrogen to eutrophication dynamics along the Neuse River Estuary, NC*. NC Water Resources Research Institute. Report No. 479.

A year-long environmental survey (July 2015 – July 2016) was completed to collect dissolved organic matter and particulate organic matter samples. They were analyzed for fluorescence spectroscopy using Excitation Emission Matrices (EEMs). The researchers suggest there are bio-reactive parts of the organic material, which might be contributing to algal blooms. Future research should review the source of these biologically active components – organic nitrogen sources.

Katin, A., Del Giudice, D., & Obenour, D. R. (2019). Modeling biophysical controls on hypoxia in a shallow estuary using a Bayesian mechanistic approach. Environmental Modelling & Software, 120, 104491. https://doi.org/10.1016/j.envsoft.2019.07.016

Hypoxia is a major issue for the Neuse River Estuary; usually defined by DO concentrations of less than 2 g/m3 (2 mg/L). It occurs due to excessive nutrient inputs and ecological dynamics; when dissolved oxygen (DO) in the bottom layer of a stratified water body is consumed due to organic matter (OM) decomposition faster than it can be replenished from the surface waters. Understanding how changes in meteorology, hydrology, and nutrient loads interact to control eutrophication and hypoxia development is critical for assessing progress toward meeting water quality improvement objectives. The TMDL for the Neuse River Estuary was based on three different water quality models published in 2003. Since then, models have advanced – this paper focuses on developing a hybrid mechanistic-Bayesian model for simulating estuary hypoxia. This model is the first to first study to simulate hypoxia based on a numerical solution to a series of mass balance differential equations within a Bayesian framework. Overall, from a management perspective, the results demonstrate that seasonal loading reductions will reduce short term oxygen demand and the intensity and duration of summer hypoxia. For instance, a 30% loading reduction would increase the average July–August bottom layer (subpycnocline) dissolved oxygen concentration by 11% and decrease the amount of hypoxic days by 25%. Further reductions in hypoxia could be achieved if long-term oxygen demand can also be ameliorated, potentially by reducing rates of organic matter accumulation in sediments over the long term.

The model emphasizes the importance of managing nutrient loadings depending on the seasons.

Keith, D. J. (2014). Satellite remote sensing of chlorophyll a in support of nutrient management in the Neuse and Tar–Pamlico River (North Carolina) estuaries. *Remote Sensing of Environment*, *153*, 61-78. https://doi.org/10.1016/j.rse.2014.05.019

In this study, the MERIS chlorophyll a data product was used to conduct a retrospective analysis of the NC standard for water quality and Total Maximum Daily Load (TMDL) for total nitrogen in the Neuse and Tar–Pamlico River estuaries from 2006 to 2009. This data product successfully collected information on the chlorophyll a levels from past images of the Neuse River Basin – images collected by EPA National Exposure Research Laboratory (NERL) Landscape Characterization Branch, derived from 206 atmospherically corrected, MERIS full resolution (FR) (300 × 260 m pixel size) images subset for the Albemarle–Pamlico area. The relationship between TN and chlorophyll was examined using linear regression analysis and datasets from1995 to 2004. From these relationships, a chlorophyll-based TMDL for total nitrogen can be estimated using the NC Chl a standard as a guide. Of the four year dataset, the period from January to May 2007 in both the Neuse River Basin and Pamlico River estuaries exhibited the largest phytoplankton blooms. The MERIS time series, when combined with hydrologic data for the study period, suggested that increased freshwater discharge and nutrient loadings caused by tropical storm Ernesto and a late fall 2006 Nor'easter were responsible for pushing the chlorophyll maximum downstream to the lower sections of the NRE. In comparison, from May to November 2007, the NRE showed a dramatic reduction in water quality exceedances. The decline in exceedances and the increased water quality could be attributed the onset of abnormally dry to severe drought conditions upstream in the Neuse River Basin during much of summer and fall 2007. During this period, the PRE and adjoining creeks and rivers were also impacted by increased rainfall and nutrient loadings associated with tropical storm Ernesto and the 2006 Nor'easter. The MERIS data used in this study strongly support the conclusion of previous research publications (e.g., Paerl, 2009; Paerl et al., 2010) that hydrologic variability which occurs in response to large climatic events plays an important role in the mobilization, processing and delivery of nutrients to sounds and bays in the Neuse and Pamlico estuarine systems. The MERIS data indicated there were 12 times between March 2006 and June 2009 when the 10/40 criterion was exceeded in the Neuse River Basin (Table 1). For the Pamlico River, the data indicated the 10/40 criterion had been exceeded 14 times during the same time period. This paper also provides background on the establishment of the Neuse TMDL.

The data product was successfully used to conduct an analysis of the chlorophyll-based TMDL for total nitrogen - TMDL standard for total nitrogen for the Neuse and Pamlico River basins has not been met (per 2014 publication). Large climatic events play an important role in nutrient loading to the estuaries and the coast.

Lebo, M. E., Paerl, H. W., & Peierls, B. L. (2012). Evaluation of progress in achieving TMDL mandated nitrogen reductions in the Neuse River Basin, North Carolina. Environmental management, 49, 253-266. https://doi.org/10.1007/s00267-011-9774-5

The study provides an evaluation of trends in flow-normalized nutrient loading to provide feedback on effectiveness of implemented actions to reduce N loading to estuarine waters in Neuse River Basin. This is a trend analysis, not a Bayesian model. They found that decreases in nitrate-nitrite (NO3–N) concentrations occurred throughout the basin and were largest just downstream of the Raleigh metropolitan area. Conversely, concentrations of total Kjeldahl N (TKN) increased at many stations, particularly under high flow conditions. This indicates a relative increase in organic N (Org-N) inputs since the mid-1990s. Basically, nitrate-nitrate concentrations, most likely from Raleigh urban areas, are decreasing in the upper reaches, likely due to TMDL implementation in upper estuary. The concentrations are not progressing in the lower reaches likely because settled particle bound N may be remineralized when they are deposited from high river flows (i.e. more precipitation or storms). TKN, organic N, concentrations are getting worse.

Montefiore, L. R., Nelson, N. G., Staudinger, M. D., & Terando, A. (2023). Vulnerability of estuarine systems in the contiguous United States to water quality change under future climate and land-use. Earth's Future, 11, e2022EF002884. https://doi.org/10.1029/2022EF002884

This study developed a social and technical framework for identifying estuarine systems at risk of suffering from water quality degradation—specifically through increases in nutrients—due to climate and land-use and land cover (LULC) change. Many factors capturing biological, physical, ecological, and social aspects of estuarine vulnerability to water quality change were analyzed in the framework, which was used to assess the vulnerability of 112 estuarine systems across the contiguous US to future increases in nutrients. Study findings revealed that the largest increases in future estuarine nutrient loads are expected along the Atlantic and eastern Gulf of Mexico, and the lowest increases are expected along the Pacific and western Gulf of Mexico. However, the North Atlantic and the South Pacific were associated with the greatest access to resources for mitigating ecological degradation (e.g., access to local knowledge, legislative and governmental actions), which could help estuaries in these regions better cope with the effects of LULC and climate on nutrient loads, making them potentially less vulnerable.

Osburn, C. L., Rudolph, J. C., Paerl, H. W., Hounshell, A. G., & Van Dam, B. R. (2019). Lingering carbon cycle effects of Hurricane Matthew in North Carolina's coastal waters. Geophysical Research Letters, 46, 2654–2661. https://doi.org/10.1029/2019GL082014

This study focused on extreme weather event impacts (Hurricane Matthew, characterized as a 500-year flooding event) to wetland and coastal water export of organic matter. Biweekly records were used for the 3 months following Hurricane Matthew in 2016. Surface water samples were collected from a bridge over the Neuse River at Ft. Barnwell and from a network of estuarine stations throughout the Neuse River Estuary and Pamlico Sound, and processed. Sample results were compared to 20-year mean averages measured during the ModMon sampling program. Results from the extreme weather event flooding showed that land and wetland derived dissolved organic carbon flushed into receiving waters can have persistent effects on carbon cycling processes, which linger for months afterward. Non-tidal wetlands were confirmed as the predominant source of labile, dissolved organic carbon to the estuary, enhancing primary production following the storm. Its degradation and release as $CO2$ resulted in the estuary serving as a source of atmospheric carbon rather than a sink for months following the storm.

In 2016, Hurricane Matthew accounted for 25% of the annual riverine C loading to the Neuse River Estuary Pamlico Sound.

Osburn, C. L., Handsel, L. T., Peierls, B. L., & Paerl, H. W. (2016). Predicting sources of dissolved organic nitrogen to an estuary from an agro-urban coastal watershed. Environmental science & technology, 50(16), 8473-8484. https://doi.org/10.1021/acs.est.6b00053

In this study, samples of dissolved organic nitrogen (DON) from eight watershed sources were analyzed and modeled for their flourescence characteristics, which were then used as a reference set against which to compare surface water samples taken between August 2011 and May 2013 from stations in the Neuse River. DON is the nitrogen component of dissolved organic matter and is part of the biologically reactive nitrogen pool that can degrade water quality. The application of FluorMod (the authors' model that uses parallel factor analysis) to surface waters of streams within the Neuse River Estuary showed that while >70% of DON was attributed to natural background sources, nonpoint sources, such as soil and poultry litter leachates and street runoff, accounted for the remaining 30%. While the results were generally consistent with changes in land use from the urbanized Raleigh metropolitan area to the largely agricultural Southeastern coastal plain, virtually no swine contribution, the other agricultural source, was measured in streams of the basin. Instead, at Ft. Barnwell poultry had the highest yields, roughly 3 times greater than urban sources of wastewater influent and effluent, septic and street runoff. The poultry yield equated to the total permitted wastewater discharge organic nitrogen load for the basin, which was one quarter of the permitted total nitrogen discharge load for the basin. In addition, poultry DON yield at the Trenton gauging station capturing less than one third of the Trent River watershed, which enters the mainstem below Ft. Barnwell, was half again the Ft. Barnwell poultry yield, suggesting that the entire Trent watershed yield could potentially rival that at Ft. Barnwell. Overall, the total predicted fraction of nonpoint DON sources was consistent with previous reports of increased organic N inputs in this river basin, which are suspected of impacting the water quality of its estuary.

Soil DON had the largest signal other than natural background, with a yield at Ft. Barnwell three times greater than the next largest, poultry. While soil may be considered a "natural" source, it may be an anthropogenically influenced source important for the increasing N load to the Neuse River Estuary. The authors note that the Maillard humification reaction could transform a poultry or swine signal into a soil signal, and they recognize that resolution of this question is an important unaddressed information need to the understanding of DON loading to the estuaries.

Osburn, C. L., Handsel, L. T., Mikan, M. P., Paerl, H. W., & Montgomery, M. T. (2012). Fluorescence tracking of dissolved and particulate organic matter quality in a river-dominated estuary. Environmental science & technology, 46(16), 8628-8636. https://doi.org/10.1021/es3007723

This study tested a method, excitation−emission matrix (EEM) fluorescence, to model particulate (POM) and dissolved (DOM) organic matter quality in the Neuse River Estuary. Surface water samples from the Neuse River Estuary were collected during August 24−September 17, 2011, before and after passage of Hurricane Irene on August 27, 2011. Sampling site data, details of BEOM extraction for POM fluorescence and more is available via the Internet at http://pubs.acs.org/. They found base-extraction of fluorescent POM is a rapid approach for simultaneously evaluating POM and DOM in estuarine waters and is can use used in other freshwater and marine environments. The authors found OM is degraded by sunlight exposure, the watershed contributes to organic nitrogen to the Neuse River Estuary, and a phase transfer of organic matter from POM to DOM pools in the water column and sediments.

Osmond, D. L., Hoag, D. L., Luloff, A. E., Meals, D. W., & Neas, K. (2015). Farmers' use of nutrient management: Lessons from watershed case studies. Journal of environmental quality, 44(2), 382-390. https://doi.org/10.2134/jeq2014.02.0091

This paper evaluates two case studies involving farmer surveys and conservation adoption practices: (i) a synthesis of the National Institute of Food and Agriculture, the Conservation Effects Assessment Project; and (ii) field surveys from three nutrient-impaired river basins/watersheds in North Carolina (Neuse, Tar-Pamlico, and Jordan Lake drainage areas). Nutrient management planning is the primary tool recommended to reduce nutrient losses from agricultural fields. Its effectiveness requires nutrient management plans be used by farmers. Results indicate farmers generally did not fully apply nutrient management plans or follow basic soil test recommendations even when they had them. Farmers were found to be hesitant to apply N at university-recommended rates because they did not trust the recommendations, viewed abundant N as insurance, or used recommendations made by fertilizer dealers. Exceptions were noted when watershed education, technical support, and funding resources focused on nutrient management that included easing management demands, actively and consistently working directly with a small group of farmers, and providing significant resource allocations to fund agency personnel and cost-share funds to farmers. Without better dialogue with farmers and meaningful investment in strategies that reward farmers for taking what they perceive as risks relative to nutrient reduction, the authors believe little progress in true adoption of nutrient management will be made.

The farmers in these surveys generally did not use nutrient management plans or follow soil test recommendations, viewed abundant N as insurance, used recommendations made by fertilizer dealers, and were hesitant to apply N at university-recommended rates because they did not trust the recommendations.

Paerl, H. W., Otten, T. G., & Kudela, R. (2018). Mitigating the expansion of harmful algal blooms across the freshwater-to-marine continuum. Environ. Sci. Technol. 2018, 52, 5519−5529 pubs.acs.org/est. https://doi.org/10.1021/acs.est.7b05950

This article provides an updated overview, considering links between P and N and climatic changes, of freshwater-marine nutrient interactions as well as a discussion on different points of intervention along the watershed gradient. P reductions have been traditionally prescribed exclusively for freshwater systems, while N reductions were mainly stressed for brackish and coastal waters. However, because most systems are hydrologically interconnected, single nutrient (e.g., P only) reductions upstream may not necessarily reduce HAB impacts downstream. Reducing both N and P inputs is the only viable nutrient management solution for long-term control of HABs along the continuum. Another observation suggesting that controlling for both nutrients is important was that bloom occurrences tend to be more severe when both N and P are present in excess than when only one is. Positive feedback loops between rising temperatures and increased CyanoHAB potentials are also emphasized. Most management responses to eutrophication issues involve interventions aimed at treating individual segments of the freshwater-marine continuum and frequently focus on the problem (blooms) rather than the underlying causes that often take place upstream of the bloom itself. Various HAB mitigation strategies are highlighted in the paper such as reducing nutrient inputs, increasing dilution with increased flow, ultrasonic treatment, and introduce top-down biological controls.

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Paerl, H. W., Crosswell, J. R., Van Dam, B., Hall, N. S., Rossignol, K. L., Osburn, C. L., & Harding, L. W. (2018). Two decades of tropical cyclone impacts on North Carolina's estuarine carbon, nutrient and phytoplankton dynamics: implications for biogeochemical cycling and water quality in a stormier world. Biogeochemistry, 141, 307-332. https://doi.org/10.1007/s10533-018-0438-x

Paerl, H. W., Hall, N. S., Hounshell, A. G., Luettich Jr, R. A., Rossignol, K. L., Osburn, C. L., & Bales, J. (2019). Recent increase in catastrophic tropical cyclone flooding in coastal North Carolina, USA: Long-term observations suggest a regime shift. Scientific reports, 9(1), 10620. https://doi.org/10.1038/s41598-019-46928-9

Paerl, H. W., Hall, N. S., Hounshell, A. G., Rossignol, K. L., Barnard, M. A., Luettich, R. A., & Harding, L. W. (2020). Recent increases of rainfall and flooding from tropical cyclones (TCs) in North Carolina (USA): implications for organic matter and nutrient cycling in coastal watersheds. Biogeochemistry, 150, 197-216. https://doi.org/10.1007/s10533-020-00693-4

These three papers, Pearl et al., 2018, Paerl et al., 2019, Paerl et al., 2020, provide evidence that we have entered a new climatic regime characterized by more frequent extreme precipitation events, with major ramifications for hydrology, cycling of C, N and P, water quality and habitat conditions in estuarine and coastal waters.

These studies used data collection from National Oceanic and Atmospheric Administration Cooperative Observer Network sites, ModMon (https://paerllab.web.unc.edu/projects/modmon/), USGS (i.e. daily discharge Fort Barnwell, 02091814), and North Carolina Department of Environmental Quality to study trends in the Albemarle-Pamlico Sound and Neuse River Estuary; data was collected for several indicators such as freshwater discharge, nutrient (focusing on the algal growth-limiting nutrient, nitrogen) and organic carbon inputs as well as water column salinity, pH and dissolved oxygen over time (i.e., daily material loadings of C, N and P were calculated using Weighted Regressions on Time Discharge and Season using daily average river flow and material concentrations at the head of the estuary by ModMon).

North Carolina, and primarily coastal NC, has experienced 36 tropical cyclones in the last 2 decades, including 6 of the 7 wettest storms in the last 120 years, involving unprecedentedly high precipitation events and three extreme tropical cyclone-driven flood events since 1999, leading to major alterations of water quality: Hurricane Floyd (1999), Hurricane Florence (2018), Hurricane Matthew (2016). There is evidence that large storms have mobilized large amounts of previously accumulated terrigenous C in the watershed, mainly as dissolved organic carbon, and extreme winds rapidly released CO_2 to the atmosphere - leading to sustained CO_2 efflux for months. Floodwaters contained extremely high loads of organic matter, dominated by dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) as well as other nutrients. Major storms caused up to a doubling of annual nitrogen and tripling of phosphorus loading compared to non-storm years. Depending on the magnitude of freshwater discharge, the NRE either acted as a ‘‘processor’’ to partially assimilate and metabolize the loads or acted as a ‘‘pipeline’’ to transport the loads to the APS and coastal Atlantic Ocean. When the estuary had to process these increased loads via increased primary production, there were associated increases in: harmful algal blooms; CO_2 release to the atmosphere; fish and shellfish kills; fish disease rates; freshening of the estuary; and hypoxia and anoxia conditions. When the estuary acted as a pipeline to Pamlico Sound, the Sound saw increased large blooms and CO_2 atmospheric efflux. During large storm years, the system switched from a net carbon sink to a net carbon source. The source of much of the increase in DOC was identified as freshwater wetlands that were flooded by large storms. Overall, short-term impacts of the climatic shift described here have been established by these studies, while more difficult to determine longer-term impacts are also likely.

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Rudolph, J. C., Arendt, C. A., Hounshell, A. G., Paerl, H. W., & Osburn, C. L. (2020). Use of geospatial, hydrologic, and geochemical modeling to determine the influence of wetland-derived organic matter in coastal waters in response to extreme weather events. Frontiers in Marine Science, 7, 18. https://doi.org/10.3389/fmars.2020.00018

This study provided evidence that flooded wetlands contribute to dissolved organic matter (DOM) export in the Neuse River Estuary-Pamlico Sound. The authors used a geographic information system (GIS) based flood model, validated with a Bayesian Monte Carlo mixing model, and data primarily collected through ModMon (https://paerllab.web.unc.edu/projects/modmon/). This study, similar to Pearl et al., 2018, Paerl et al., 2019, Paerl et al., 2020, emphasize the importance of considering large storms (or extreme weather events) in nutrient and carbon cycling dynamics – the authors looked at DOM exports related to Hurricane Matthew. Results were consistent with prior studies in this system, and other coastal ecosystems, that attributed a high reactivity of DOM as the underlying reason for large CO_2 releases following extreme weather events.

Strickling, H. L., & Obenour, D. R. (2018). Leveraging spatial and temporal variability to probabilistically characterize nutrient sources and export rates in a developing watershed. Water Resources Research, 54(7), 5143-5162. https://doi.org/10.1029/2017WR022220

In this study, the authors develop a hybrid watershed model to better understand and quantify how different source types (cities, cropland, hogs and chicken livestock operations, and wildland) contribute to overall nitrogen loading in Tar Pamlico, Neuse, and Cape Fear. This study is primarily about the model's development, considering it is one of the first to incorporate temporal variability in either source distributions or climate – this is important since there is evidence that precipitation is the primary driver in interannual variability in loading rates, and it is important to understand changes in nutrient source contributions over time and particularly during management implementation timeframes. The "hybrid" model formulation is similar to USGS SPARROW, but considers inter-annual variability related to precipitation and land-use change. It also uses Bayesian inference for rate estimation and uncertainty quantification. The model was calibrated to nutrient loading estimates at 21 river monitoring sites around the study area. Results include nutrient source apportionments, estimates of how nutrient loading has changed over time, and estimates of instream retention (e.g., Figure S8). In the model an understanding of the importance of each source type is developed based on the amount of nitrogen observed in various streams across the study area. When leveraging data over a large area and over multiple decades the authors quantify loading rates from different source types with increased confidence (interannual variability substantially constrains uncertainties in nutrient export and delivery coefficients). They can also predict how much of this nitrogen reaches sensitive downstream estuaries.

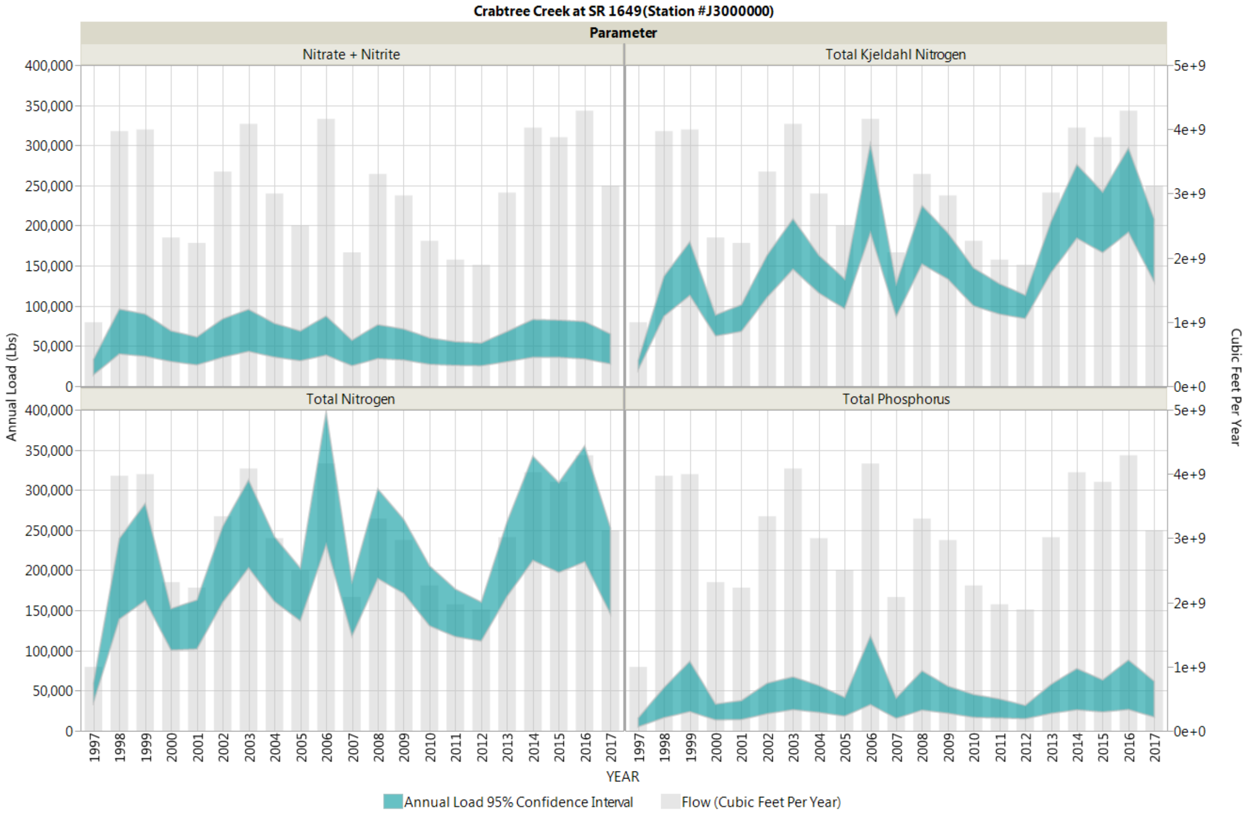
While the study found that the most significantly increasing source contributions of nitrogen during the 1994 to 2012 study period occurred in the Cape Fear Basin due to increasing hog and chicken numbers, the Cape Fear differed noticeably from the other two basins in this regard, and the remainder of this discussion will focus on Neuse and Tar-Pamlico results. The most dramatic change in these two basins during the period was a 61% decrease in point source nitrogen loading (generally consistent with dischargers' reported results). Point source nitrogen loads in the Tar-Pamlico showed virtually no change during this period. The second largest change in the two basins was a 50% increase in loads from development in the Neuse. In fact, all three basins showed the same 50% increase, however the initial development contribution in the Tar-Pamlico was a small fraction of the total. This was the most notable change for the Tar-Pamlico, with a commensurate decrease from the "wild" lands category; otherwise, source contributions in this basin registered minimal change.

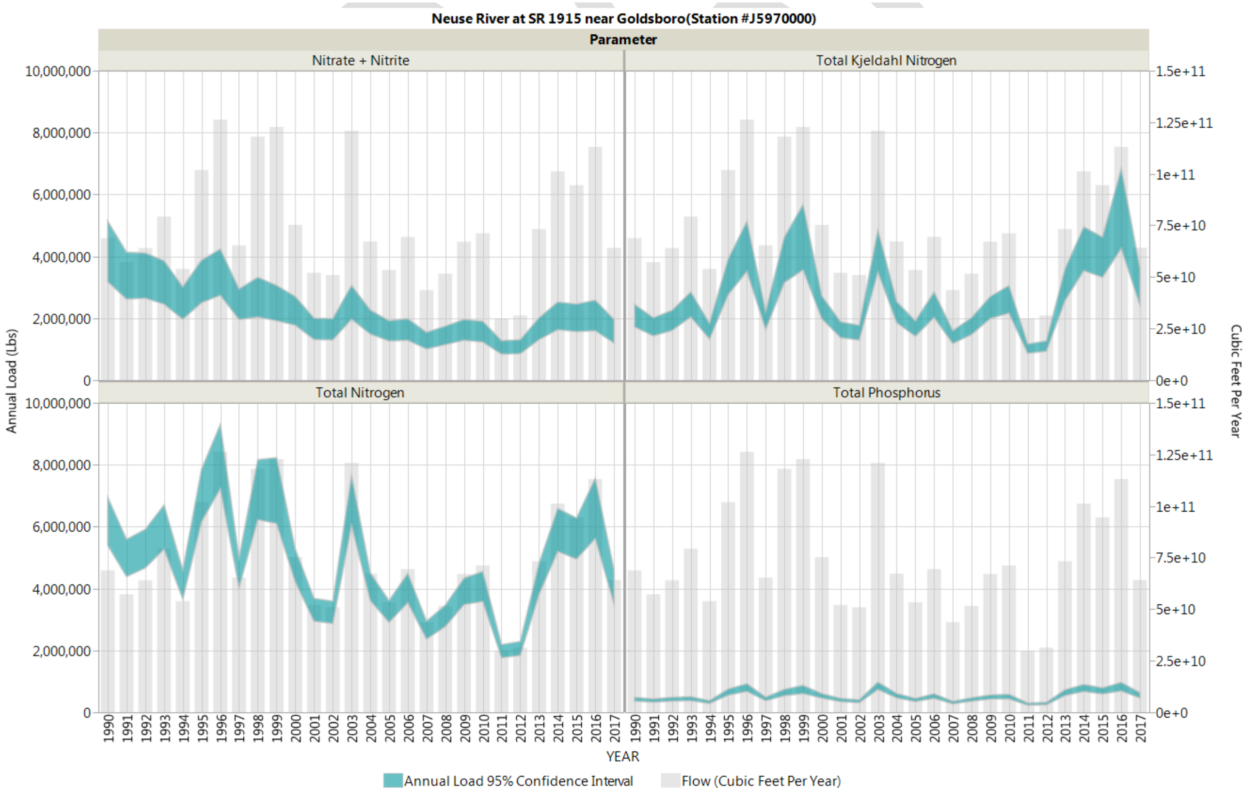
Agricultural lands, separate from hog and chicken waste, were the largest nitrogen sources by percentage in both basins in both 1994 and 2012, and changed very little in either basin between start and end years. However, hog waste nitrogen loading in the Neuse increased by 35%, from 9 to 12% of total source loading. Chicken waste loading was a smaller percentage and showed negligible change in this time period in either basin. These CAFO results appear consistent with inventory numbers as illustrated in the paper, which remained stable throughout the period other than an initial hog inventory upswing in the Neuse in the mid-1990's.

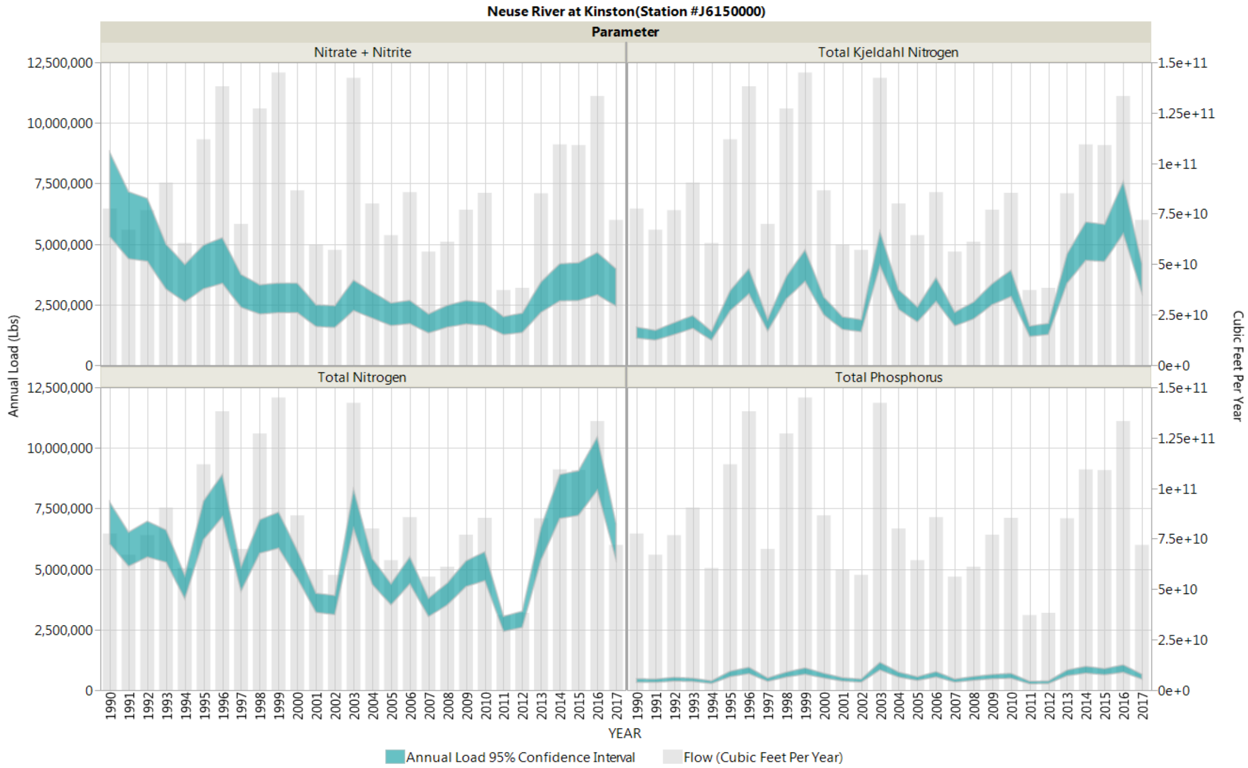
In terms of estuary loading, the study found a decline in flow-normalized total nitrogen loading in both basins until around 2000, thereafter shifting to increasing in both basins through 2012, with loading estimates suggesting larger unit-area contributions from the mostly agricultural lower-basin watersheds. Also, precipitation is shown to have a larger influence on unit-area export rates for agricultural than for developed lands, creating a system dominated by agricultural total nitrogen during high precipitation years and by developed (urban) regions during low precipitation years. In high precipitation years, agricultural export rates are approximately twice those of urban, while in low precipitation years, dominance swings in the other direction and urban export rates are approximately 1.8 those of agriculture.

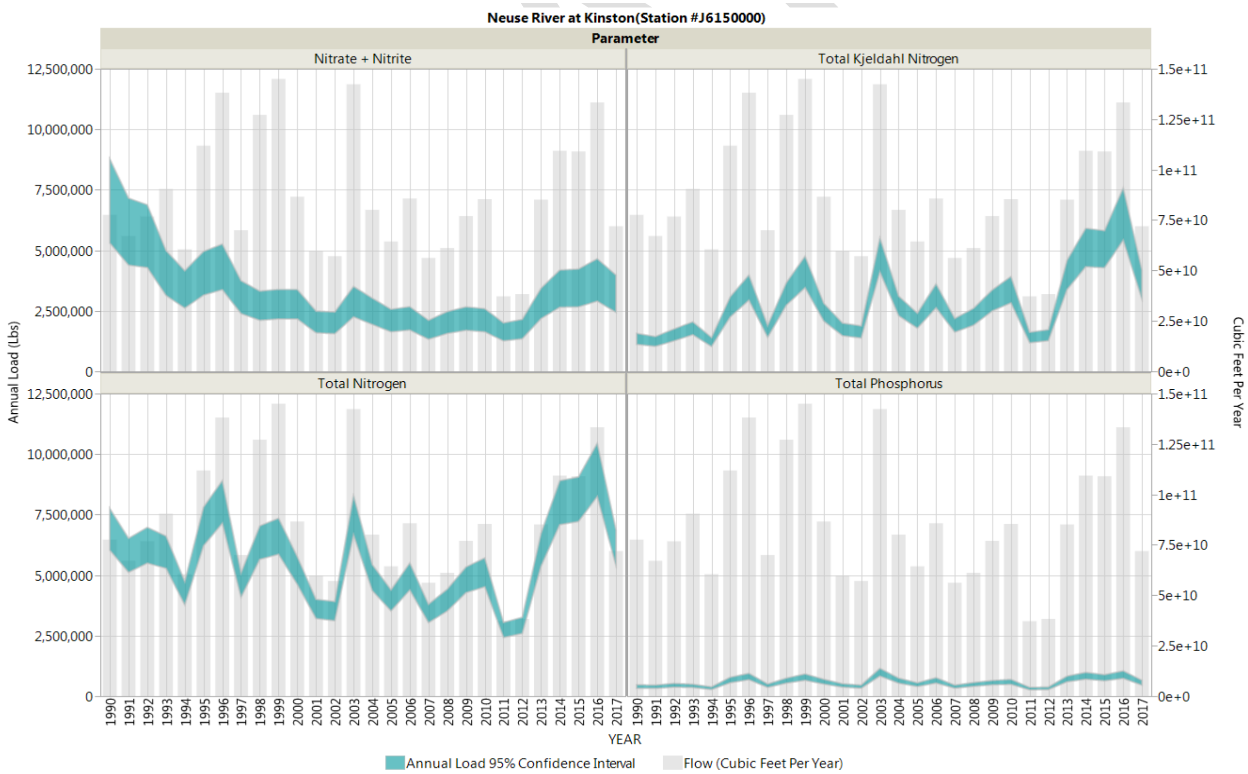
Appendix B – Additional Water Quality Trend Figures

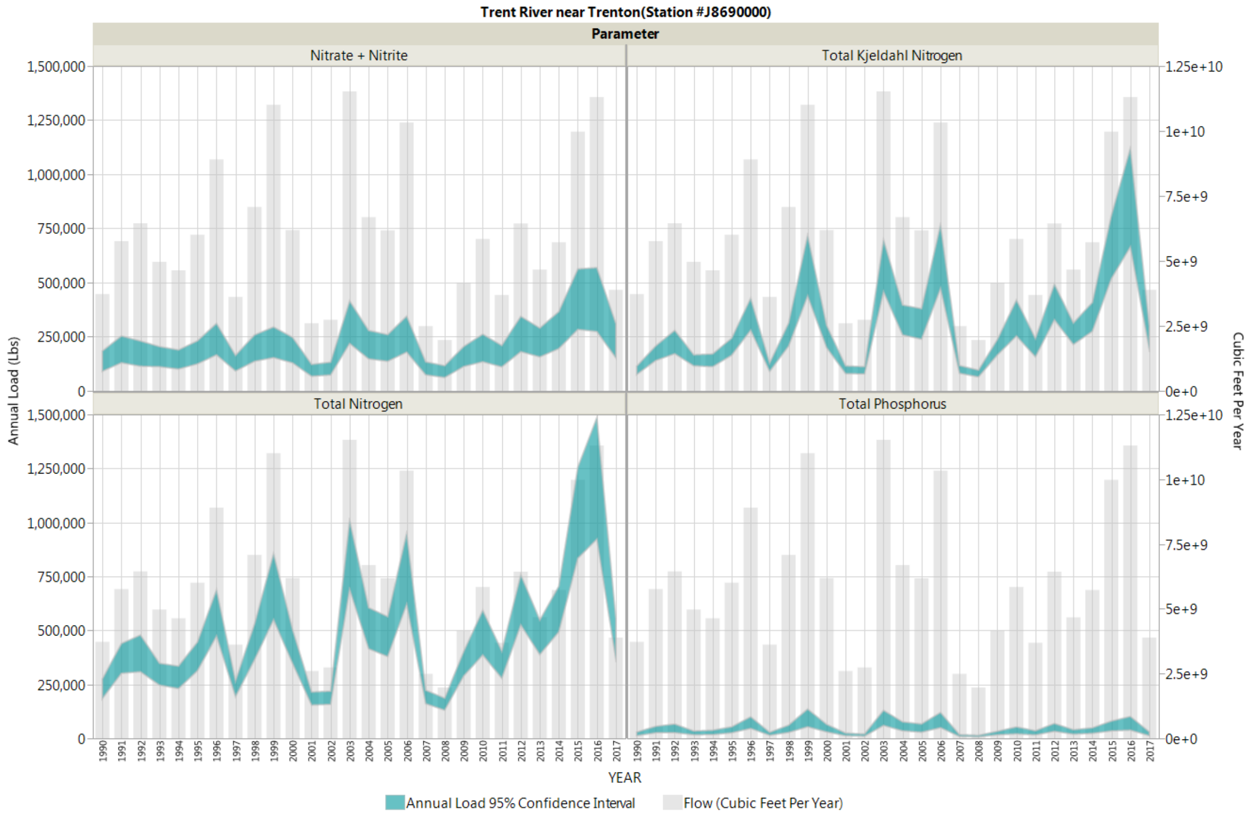
Neuse River Basin LOADEST Loading Estimates at Select Stations



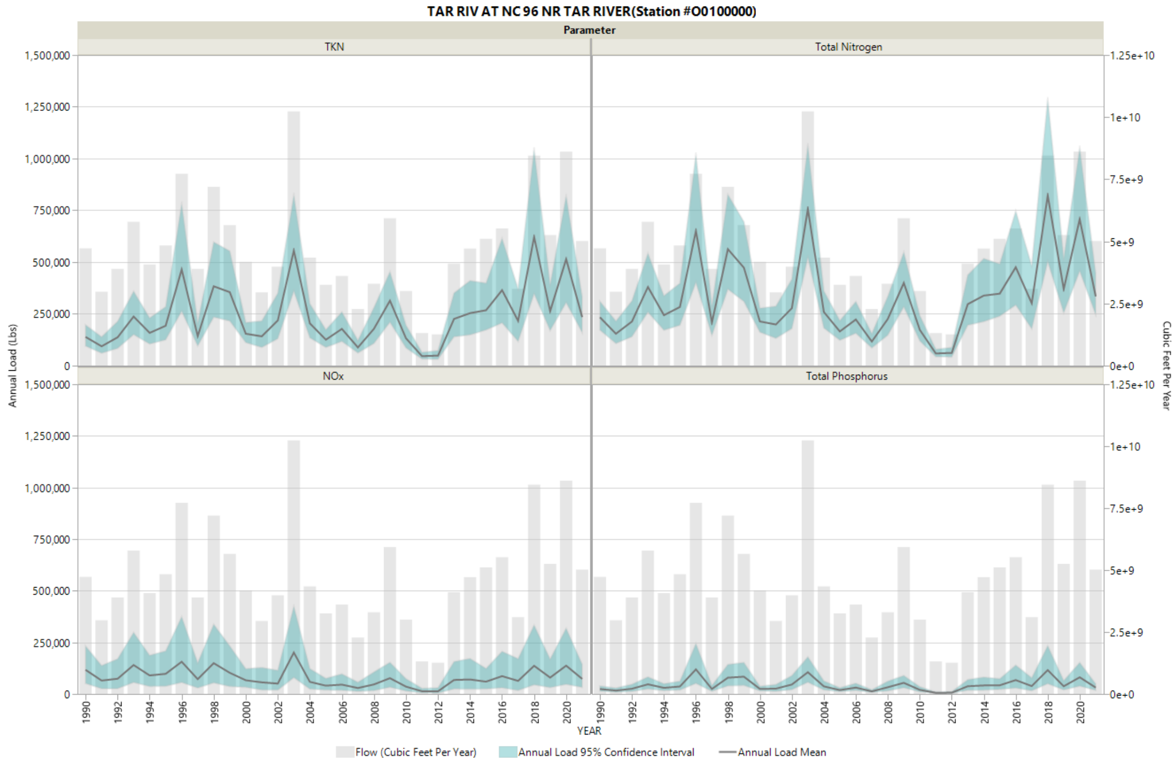



Neuse River at Kinston(Station #J6150000)
Parameter
Nitrate + Nitrite
Total Kjeldahl Nitrogen
Total Nitrogen
Total Phosphorus
Annual Load (Lbs)
Cubic Feet Per Year
YEAR
Annual Load 95% Confidence Interval
Flow (Cubic Feet Per Year)

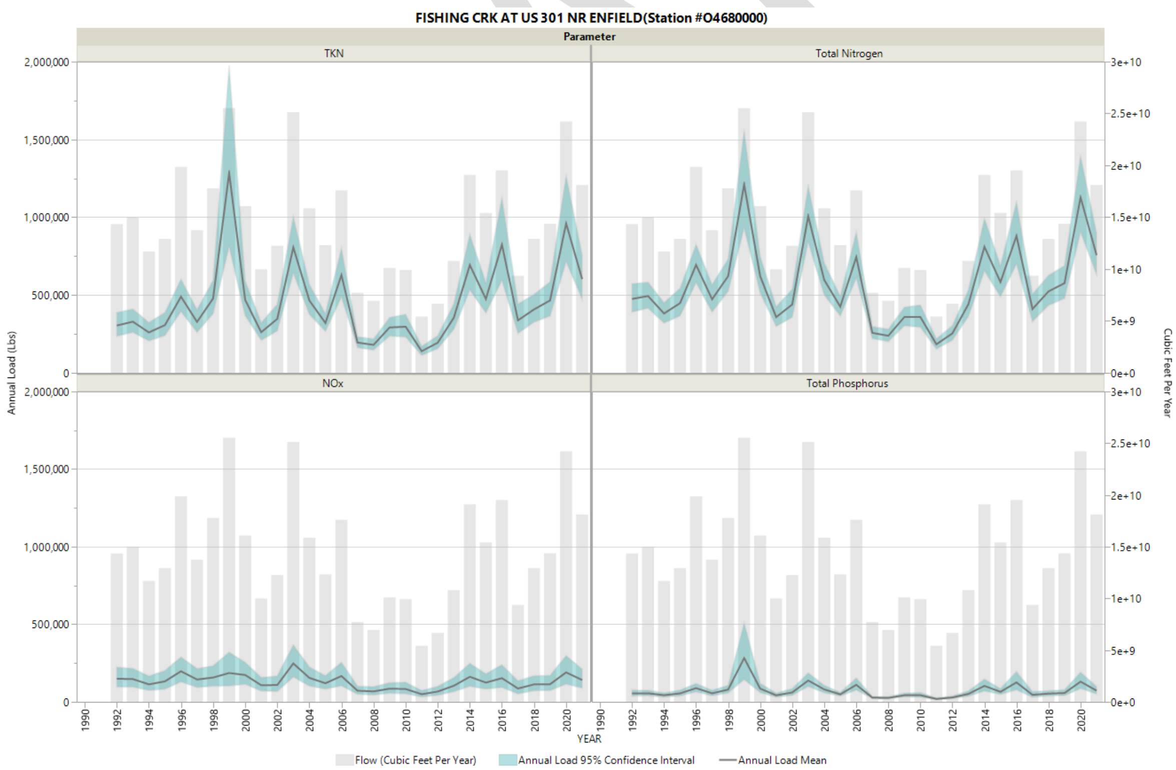

Neuse River at Kinston(Station #J6150000)
Parameter
Nitrate + Nitrite
Total Kjeldahl Nitrogen
Total Nitrogen
Total Phosphorus
Annual Load (Lbs)
Cubic Feet Per Year
YEAR
Annual Load 95% Confidence Interval
Flow (Cubic Feet Per Year)



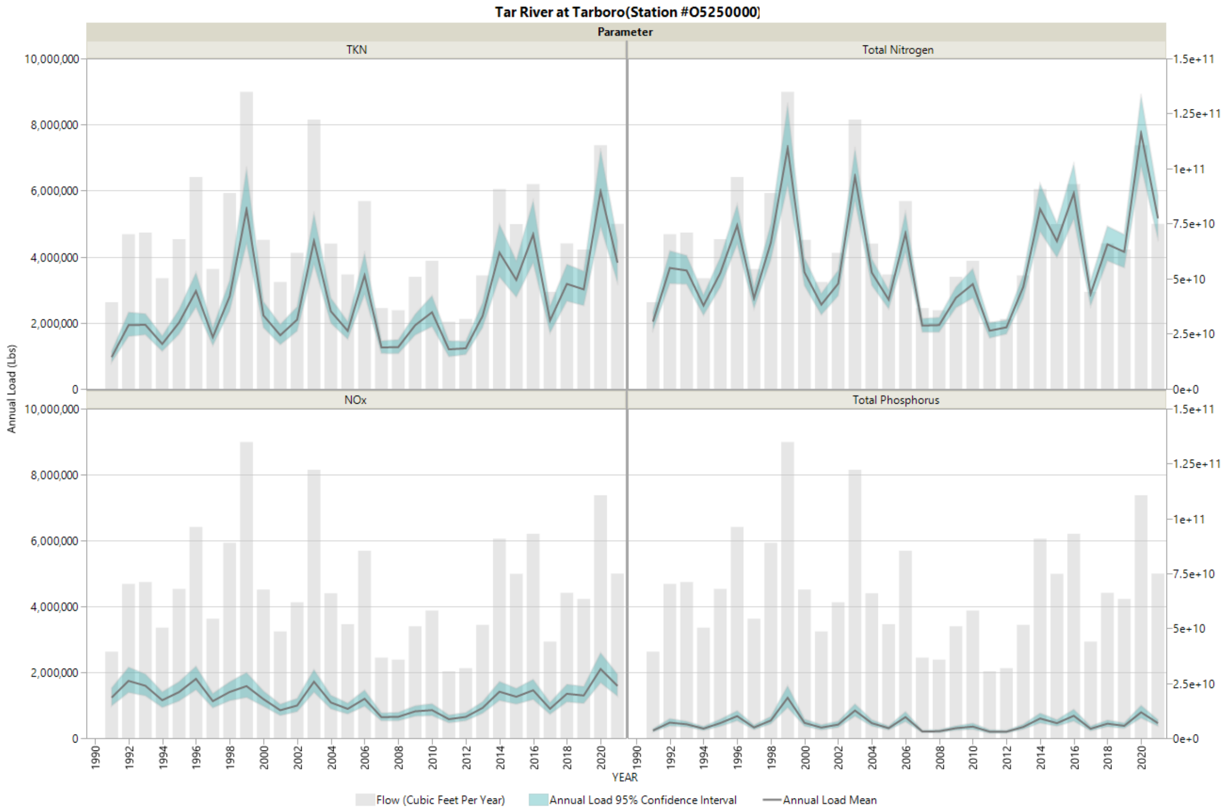
Tar-Pamlico River Basin LOADEST Loading Estimates at Select Stations



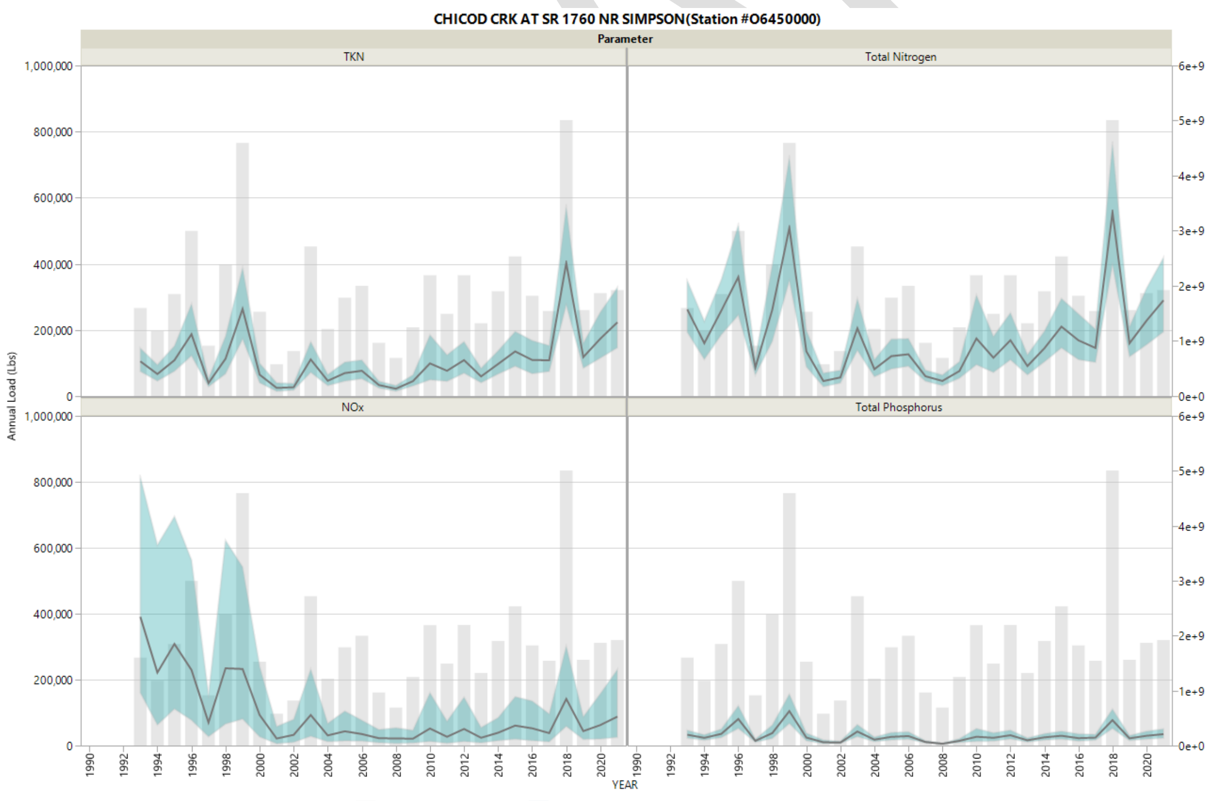
TAR RIV AT NC 96 NR TAR RIVER(Station #O0100000)
Parameter
TKN
Total Nitrogen
NOx
Total Phosphorus
Annual Load (Lbs)
Cubic Feet Per Year
YEAR
Flow (Cubic Feet Per Year)
Annual Load 95% Confidence Interval
Annual Load Mean



FISHING CRK AT US 301 NR ENFIELD(Station #O4680000)
Parameter
TKN
Total Nitrogen
NOx
Total Phosphorus
Annual Load (Lbs)
Cubic Feet Per Year
YEAR
Flow (Cubic Feet Per Year)
Annual Load 95% Confidence Interval
Annual Load Mean



Tar River at Tarboro(Station #O5250000)
Parameter
TKN
Total Nitrogen
NOx
Total Phosphorus
Annual Load (Lbs)
Cubic Feet Per Year
YEAR
Flow (Cubic Feet Per Year)
Annual Load 95% Confidence Interval
Annual Load Mean



CHICOD CRK AT SR 1760 NR SIMPSON(Station #O6450000)
Parameter
TKN
Total Nitrogen
NOx
Total Phosphorus
Annual Load (Lbs)
Cubic Feet Per Year
YEAR
Flow (Cubic Feet Per Year)
Annual Load 95% Confidence Interval
Annual Load Mean

Tar-Pamlico Flow Normalized Nitrogen Loading Analysis at Select Stations

FIGURE 75. TAR-PAMLICO STATION #O010000 – TAR-RIVER

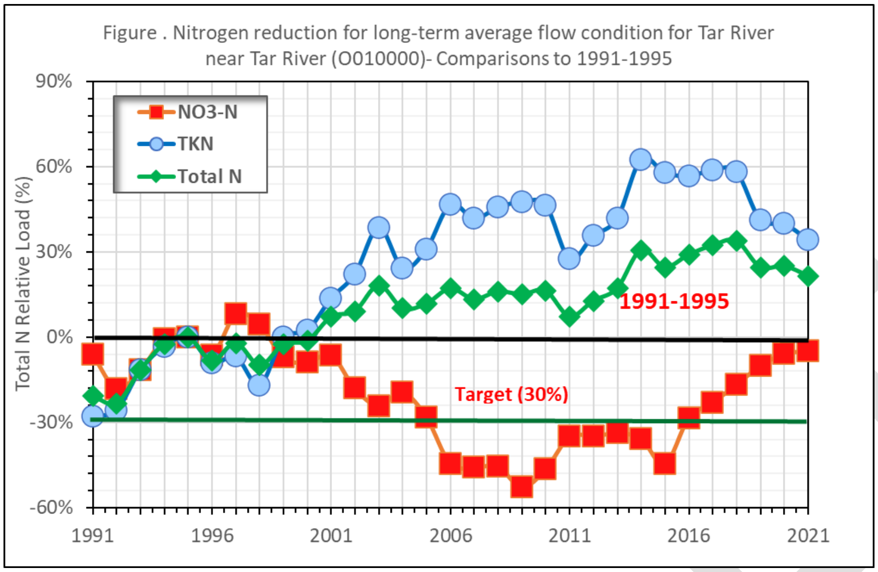


FIGURE 76. TAR-PAMLICO STATION #O4680000 – FISHING CREEK

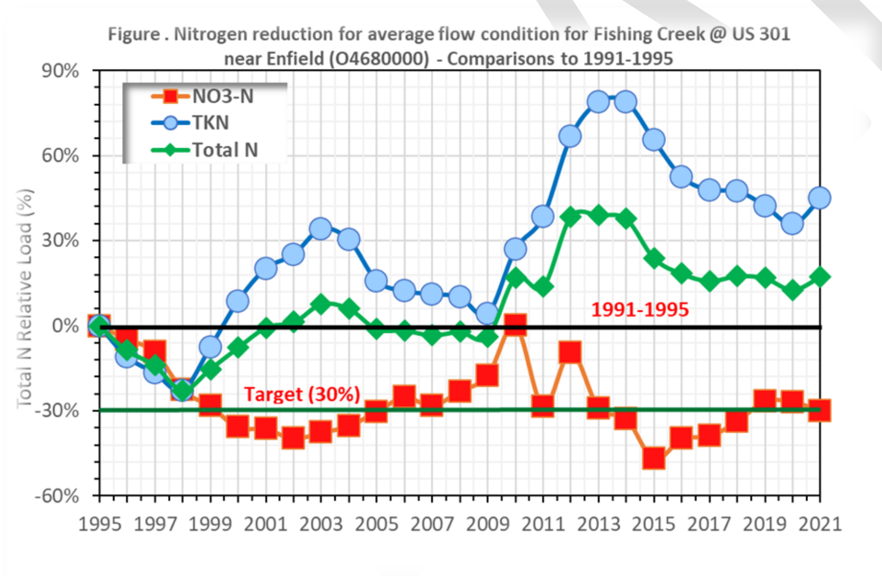


FIGURE 77. TAR-PAMLICO STATION #O5250000 - TARBORO

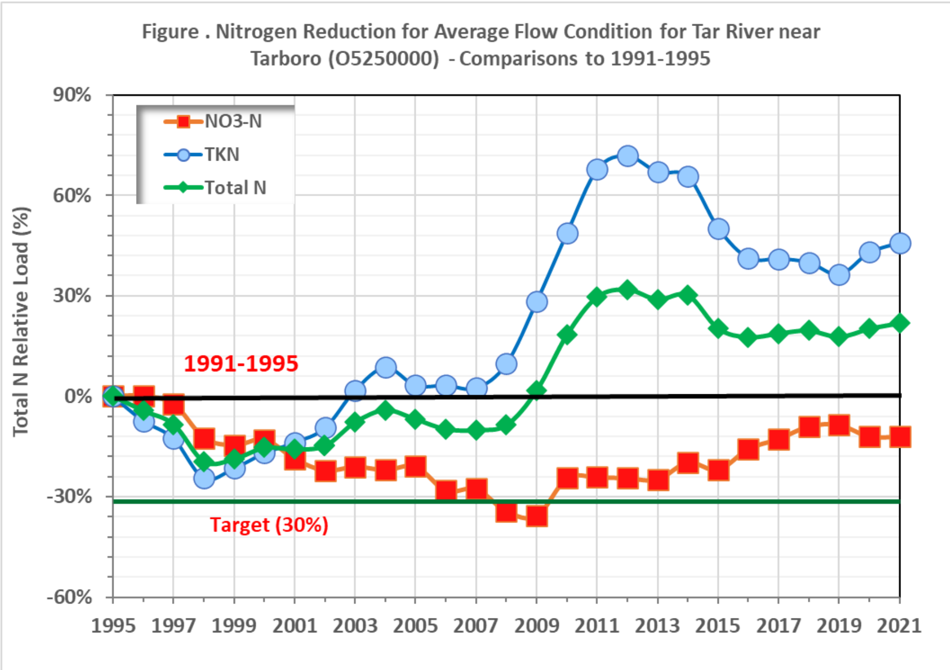
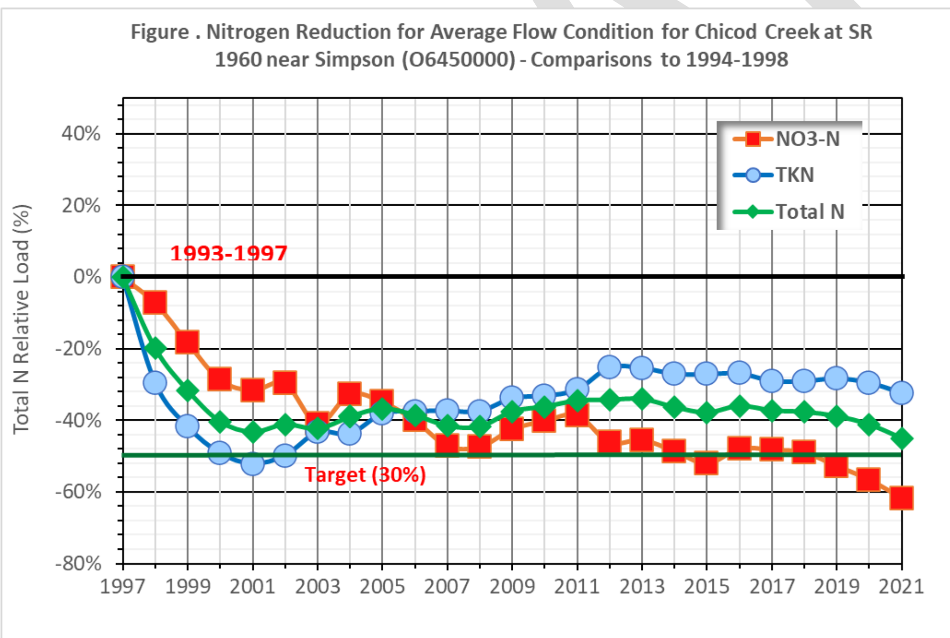


FIGURE 78. TAR-PAMLICO STATION #O6450000 – CHICOD CREEK



Tar-Pam Flow Normalized Phosphorus Loading Analysis at Select Stations

FIGURE 79. TAR-PAMLICO STATION #O010000 – TAR-RIVER

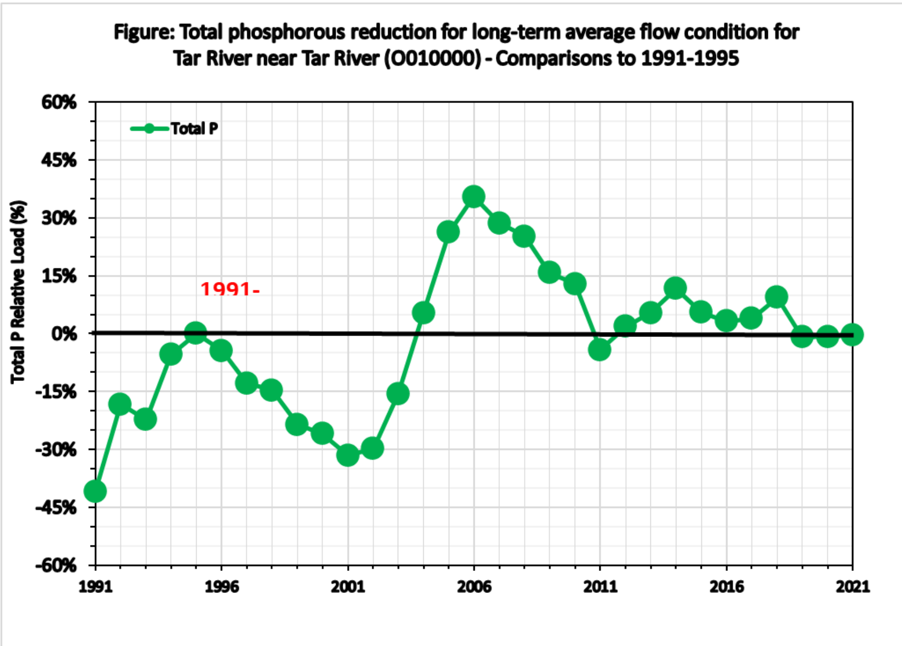


FIGURE 80. TAR-PAMLICO STATION #O4680000 – FISHING CREEK

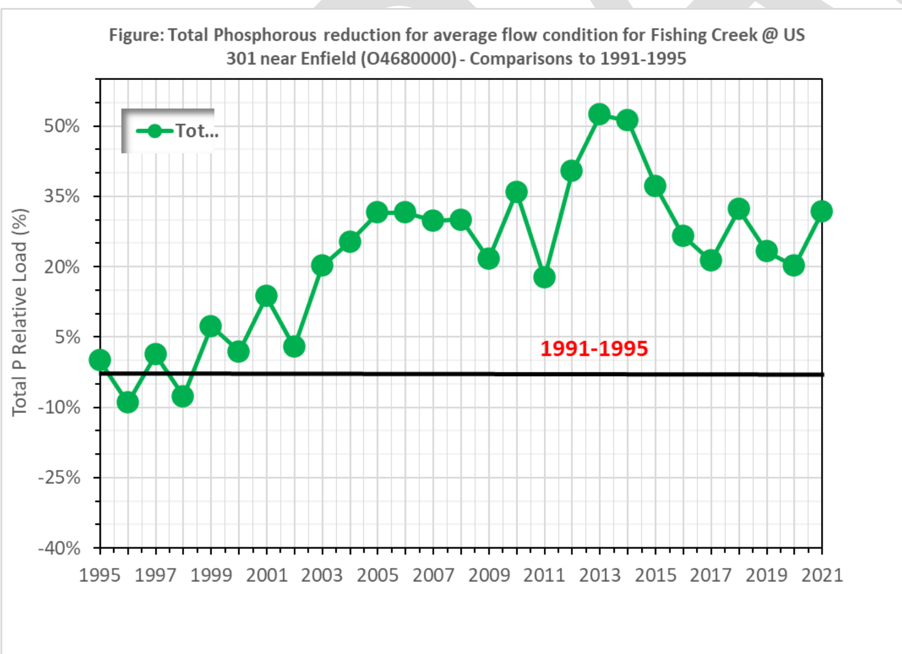


FIGURE 81. TAR-PAMLICO STATION #O5250000 - TARBORO

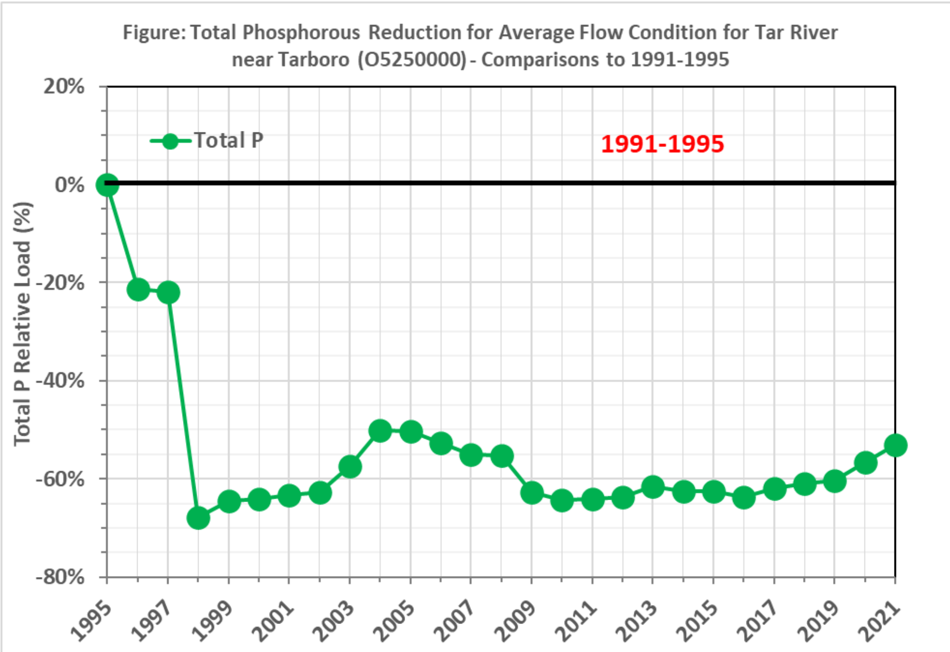
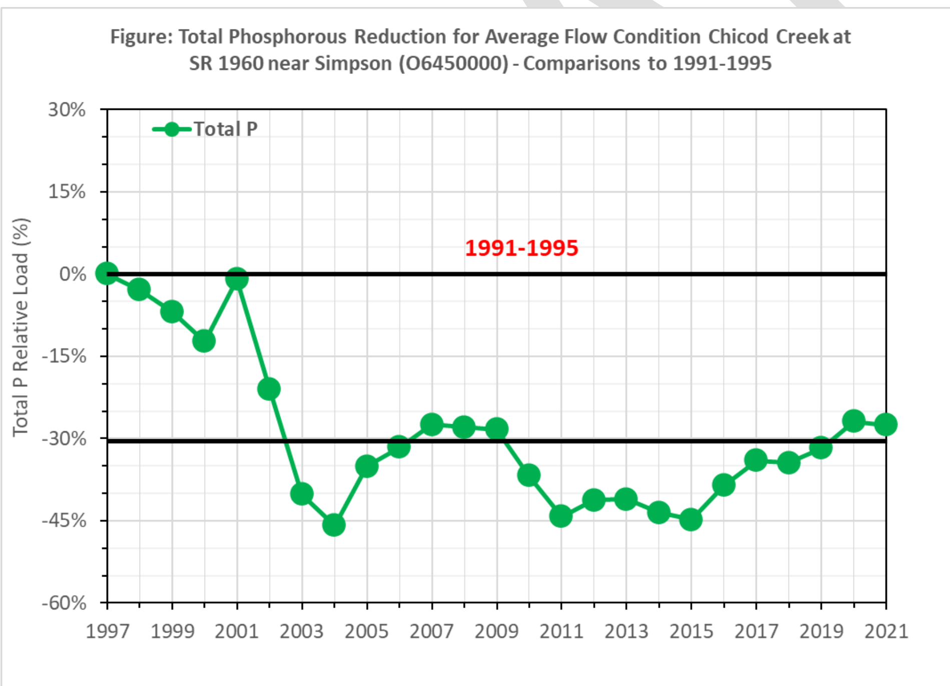


FIGURE 82. TAR-PAMLICO STATION #O6450000 – CHICOD CREEK



Neuse Flow Normalized Nitrogen Loading Analysis at Select Stations

FIGURE 83. NEUSE STATION # J3000000 – CRABTREE CREEK

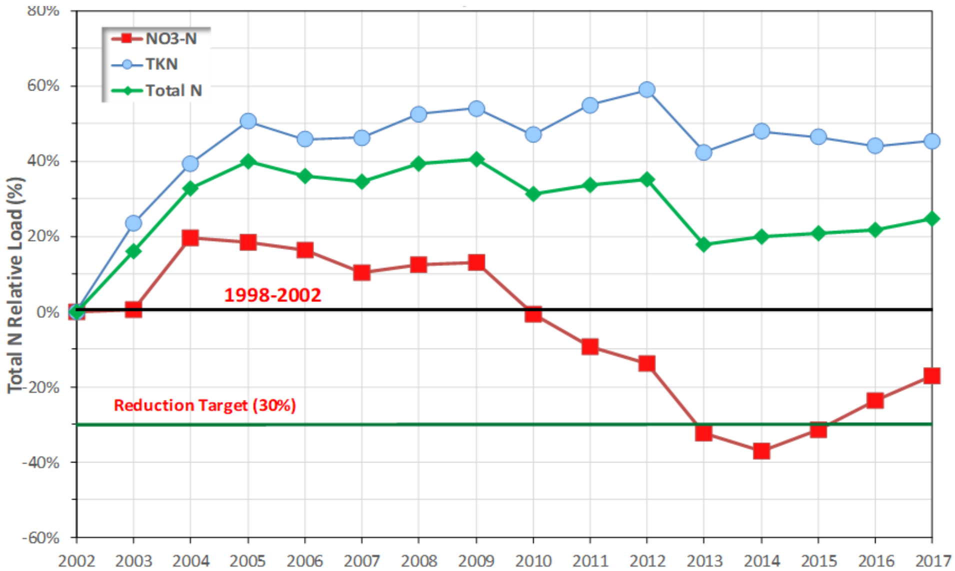


FIGURE 84. NEUSE STATION # J5970000 - GOLDSBORO

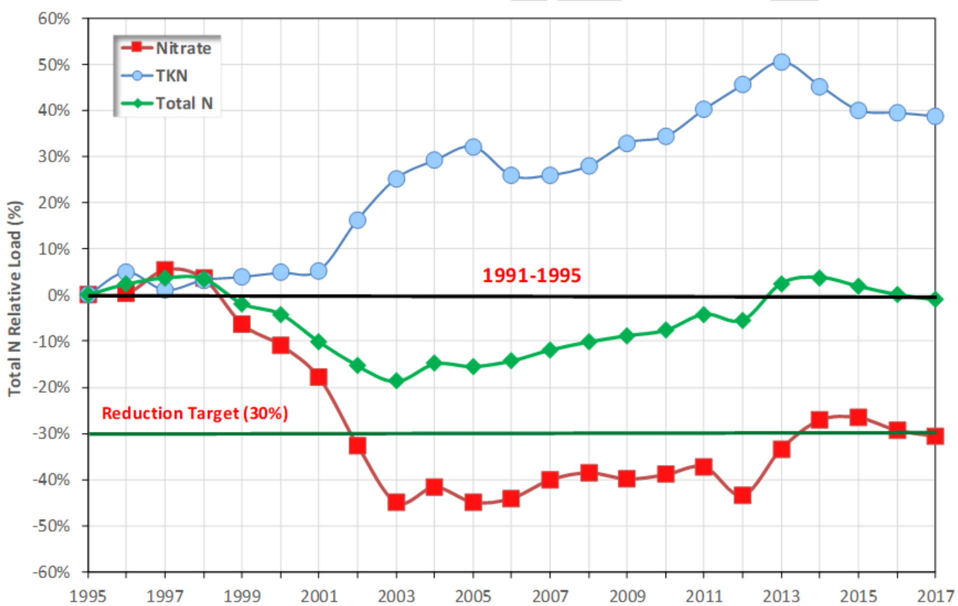


FIGURE 85. NEUSE STATION # J6150000 - KINSTON

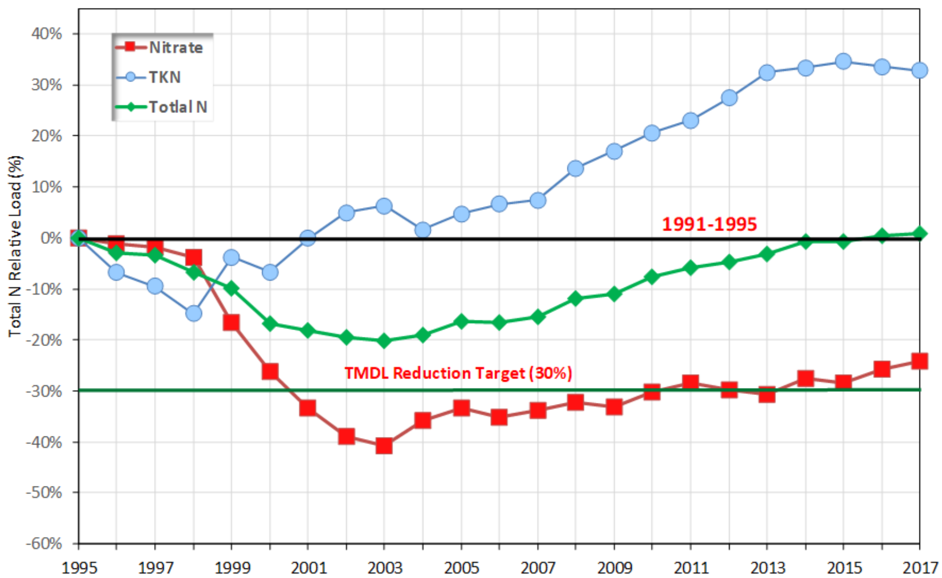


FIGURE 86. NEUSE STATION # J7450000 - HOOKERTON

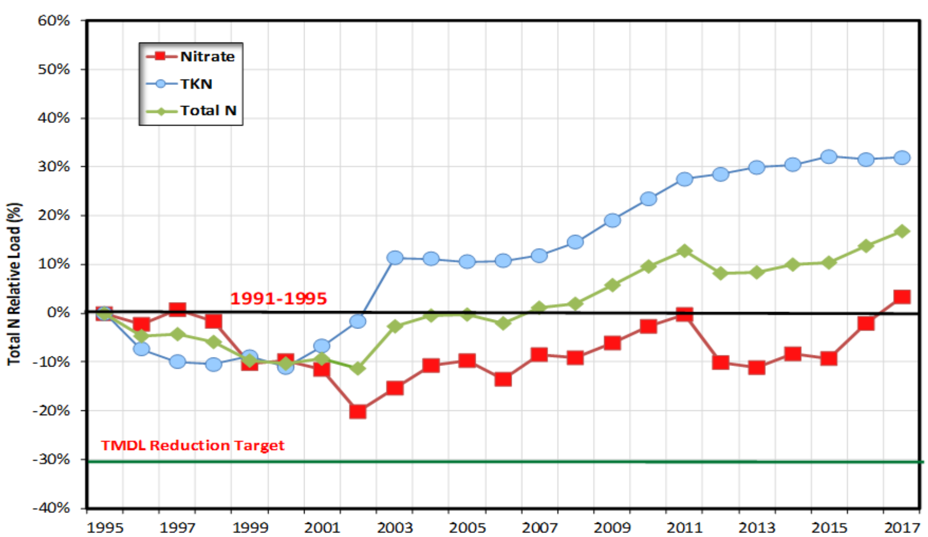
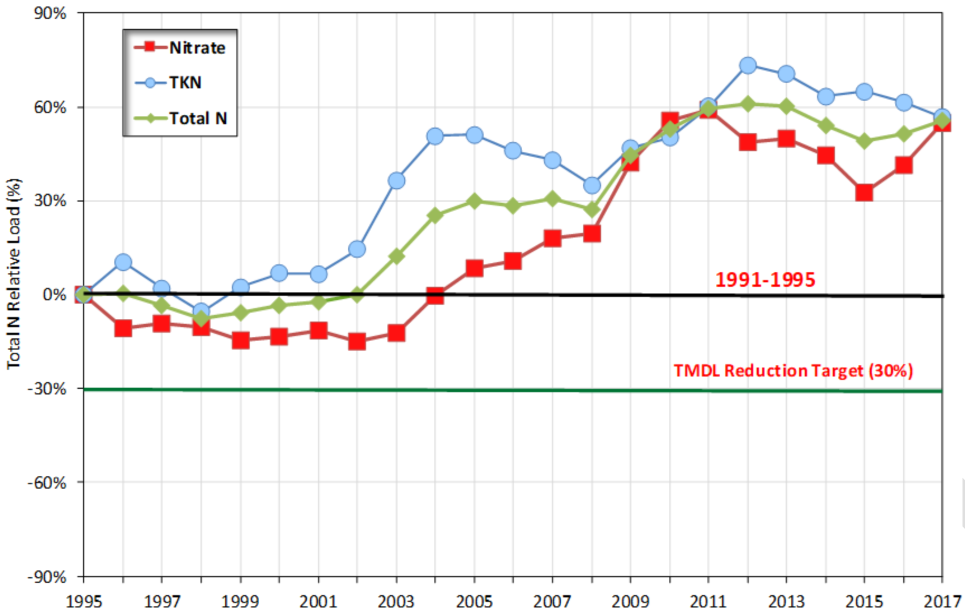


FIGURE 87. NEUSE STATION # J8690000 - TRENT RIVER



Neuse Flow Normalized Phosphorus Loading Analysis at Select Stations

FIGURE 88. NEUSE STATION # J3000000 - CRABTREE CREEK

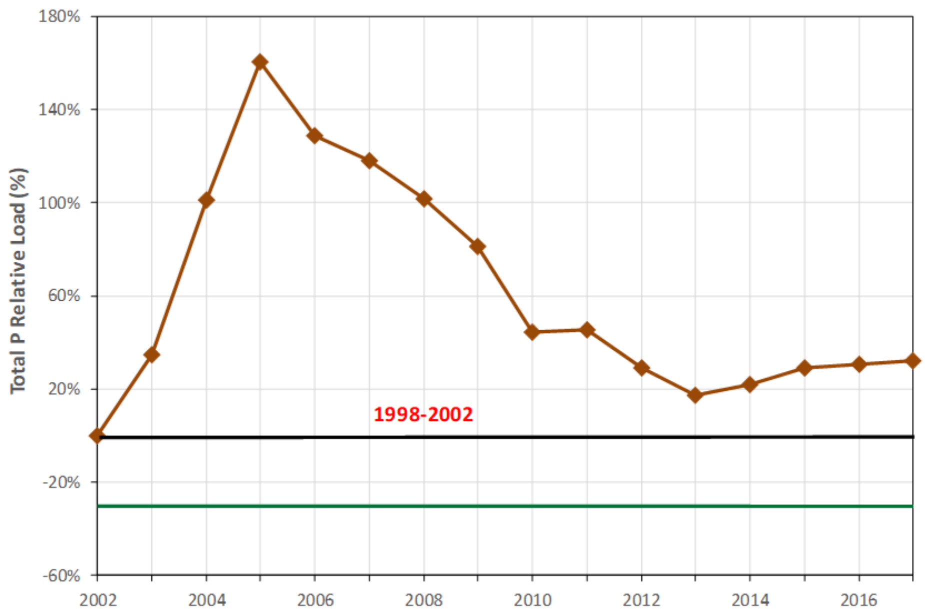


FIGURE 89. NEUSE STATION # J5970000 - GOLDSBORO

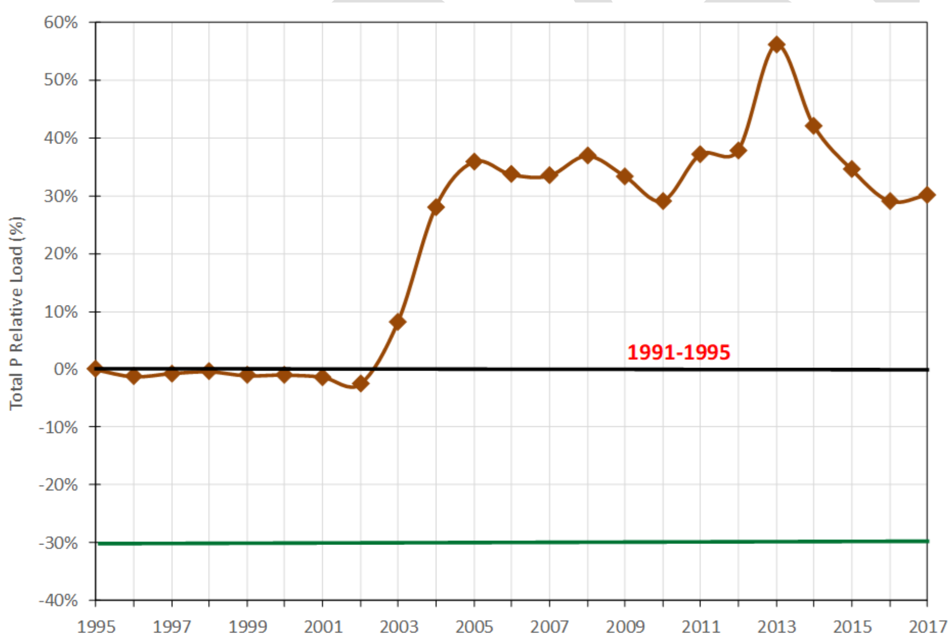


FIGURE 90. NEUSE STATION # J6150000 - KINSTON

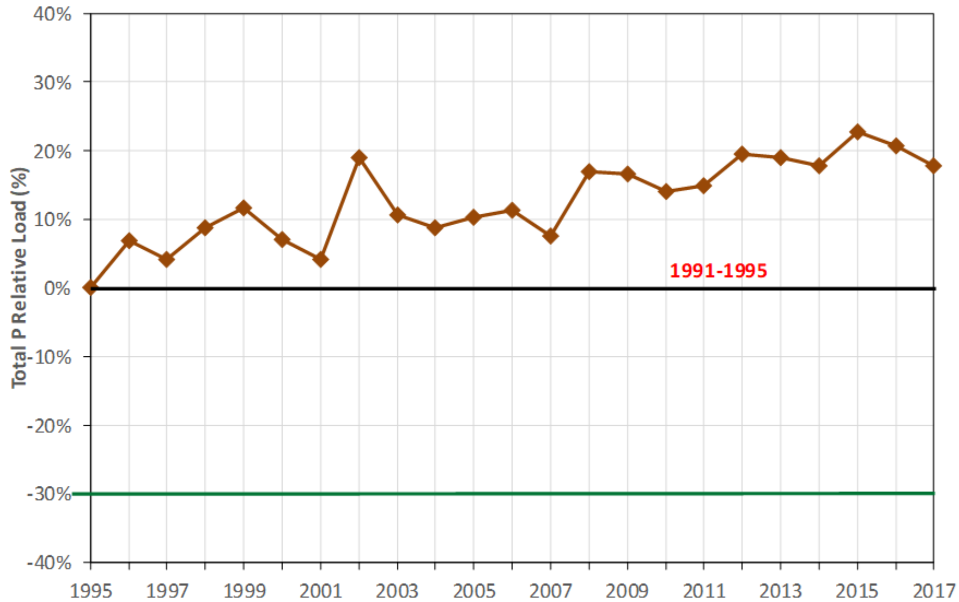


FIGURE 91. NEUSE STATION # J7540000 - HOOKERTON

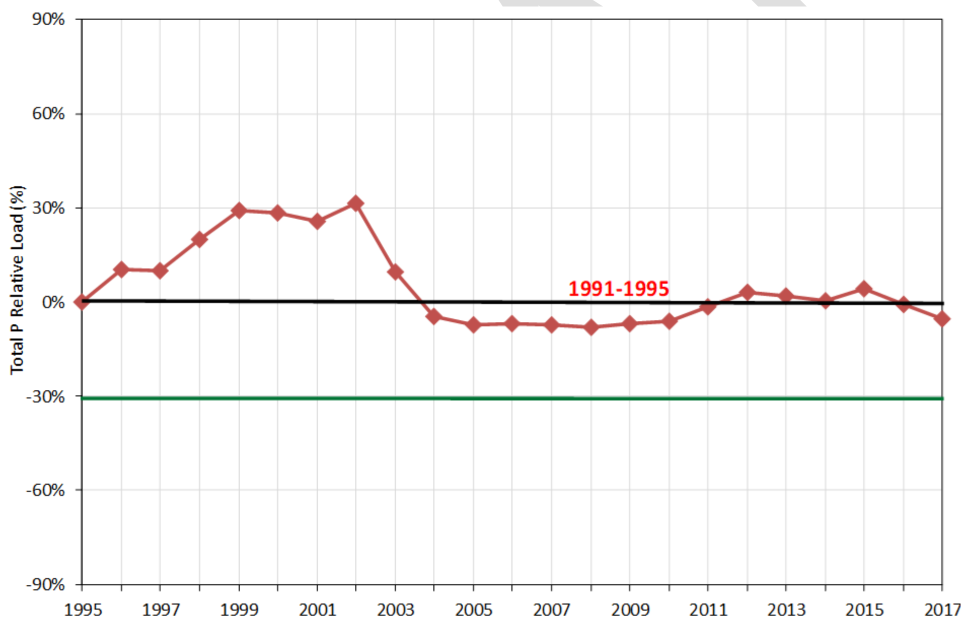
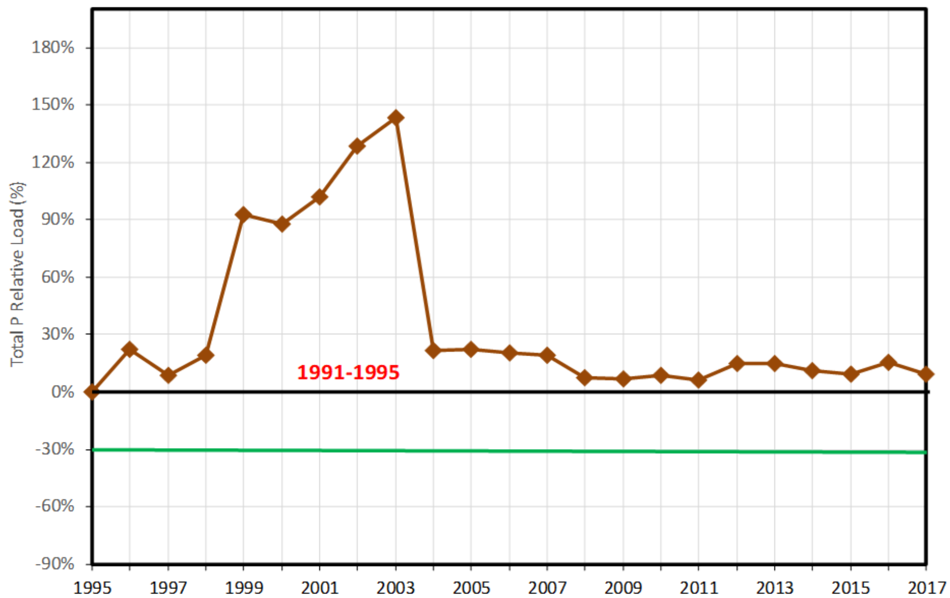


FIGURE 92. NEUSE STATION # J8690000 - TRENT RIVER



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implications for organic matter and nutrient cycling in coastal watersheds. Biogeochemistry, 150, 197-216. https://doi.org/10.1007/s10533-020-00693-4

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