NC Division of Water Resources
Planning Section
Modeling and Assessment Branch

Memorandum

April 15, 2019

To: Basinwide Planning Branch

From: Modeling and Assessment Branch

Subject: Trend Analysis of Nutrients for Selected Stations in the Neuse River Basin

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Introduction

In 2007, the Modeling and Assessment Branch (MAB) performed a trend analysis of nutrient concentrations and loads to examine the status of nitrogen and phosphorus loading at the ambient station J7850000 near Fort Barnwell for the 1991-2006 timeframe. Similar analysis was carried out in 2013 for the 1991-2011 timeframe. The objective of the analyses was to evaluate the progress in achieving the Phase II Neuse Estuary TMDL reduction goal relative to the baseline period, 1991-1995. The TMDL requires a 30% reduction in TN by the year 2001.

The 2007 trend analysis indicated that there was a statistically significant decreasing trend in total nitrogen (TN), nitrate/nitrite (NOx), and total phosphorus (TP) concentrations and statistically significant increasing trend for total Kjeldahl nitrogen (TKN) concentration at an $\alpha = 0.05$ level of significance. There was a statistically significant increasing trend in TKN load, but trends in TN, TP, and NOx loads were not statistically significant. The 2013 nutrient trends study showed that statistically significant decreases in TN, TP, ammonia, and NOx concentrations occurred at Fort Barnwell. In contrast, TKN concentrations showed statistically significant increase over the same time-period. There was statistically significant downward trend in NOx and ammonia loads, but trends in TN, TP, and TKN loads were not statistically significant.

The current analysis is designed to update the 2013 trend analysis by extending the study period through 2017 and including additional stations in the Neuse River Basin (Table 1). Trend analysis was performed for TN, TP, TKN, ammonia (NH3), and NOx concentrations.

The first part of the report presents the results of the Seasonal Kendall trend analysis performed on the nutrient data from selected water quality monitoring stations in the Neuse River Basin. The analysis was performed for three different time-periods (1991-2001, 2002-2017, and 1991-2017). The different time periods were chosen to evaluate changes in pre and post Nutrient Sensitive Waters (NSW) implementation periods.

The second part of the report presents a flow-normalized (FN) analysis to evaluate annual nutrient loading trends using a simplified approach (Lebo et al. 2011). The simplified FN loading analysis allows evaluation of changes under various flow regimes (low, medium, and high flow) and provides feedback on effectiveness of point and nonpoint source nutrient management actions.

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The third part includes a nutrient loading estimation for multiple stations in the basin using the USGS LOADEST tool.

Site Description

The Neuse River Basin is located in eastern North Carolina and covers 6,235 square miles. The headwaters drain portions of the City of Durham, flow into Falls Lake and continue as the Neuse River as it flows southeast past the municipalities of Raleigh, Smithfield, Goldsboro, Kinston, New Bern, and finally to the Pamlico Sound. The upper portion of the watershed drains parts of metropolitan areas including the cities of Durham, Raleigh, and Cary. The lower portion of the watershed is dominated by agricultural areas including row crops and animal operations.

Fort Barnwell station (J7850000) is the downstream most mainstem station for this analysis and also the compliance point for the TMDL. The Neuse River at this station drains approximately 63% of the Neuse River Basin and both long-term DWR monitoring data and USGS flow data are available here. Four monitoring stations in this analysis are located at various locations upstream of the Fort Barnwell station. The Trent River drains a watershed south of Fort Barnwell and flows directly into the Neuse River Estuary (Figure 1). The drainage areas for each station and 2011 National Landcover Database (NLCD) percentages are shown for each watershed in Table 1.

Table 1. Drainage area and 2011 NLCD landcover distribution for selected sites

Location	Drainage Area (SQMI)	2011 NLCD Landcover Distribution Percentage							
		Barren Land	Crop/ Pasture	Developed	Forest	Grassland/ Herbaceous	Scrub/ Shrub	Open Water	Wetland
CRABTREE CRK AT SR 1649 NR RALEIGH	76.6	0.7	3.2	56.4	32.8	2.9	0.8	2.0	1.3
NEUSE RIV AT SR 1915 NR GOLDSBORO	2,401.7	0.4	24.0	20.2	35.1	5.8	3.8	1.7	9.0
NEUSE RIV AT NC 11 AT KINSTON	2,707.0	0.3	26.1	19.4	32.6	5.5	4.3	1.7	10.1
CONTENTNEA CRK AT NC 123 AT HOOKERTON	734.2	0.2	43.2	9.8	20.0	4.5	4.2	1.2	17.0
NEUSE RIV AT SR 1470 NR FORT BARNWELL	3,950.0	0.3	31.3	16.0	28.0	5.0	4.7	1.5	13.2
TRENT RIV AT SR 1129 NR TRENTON	167.6	0.1	25.7	3.4	24.1	4.4	12.2	0.2	30.0

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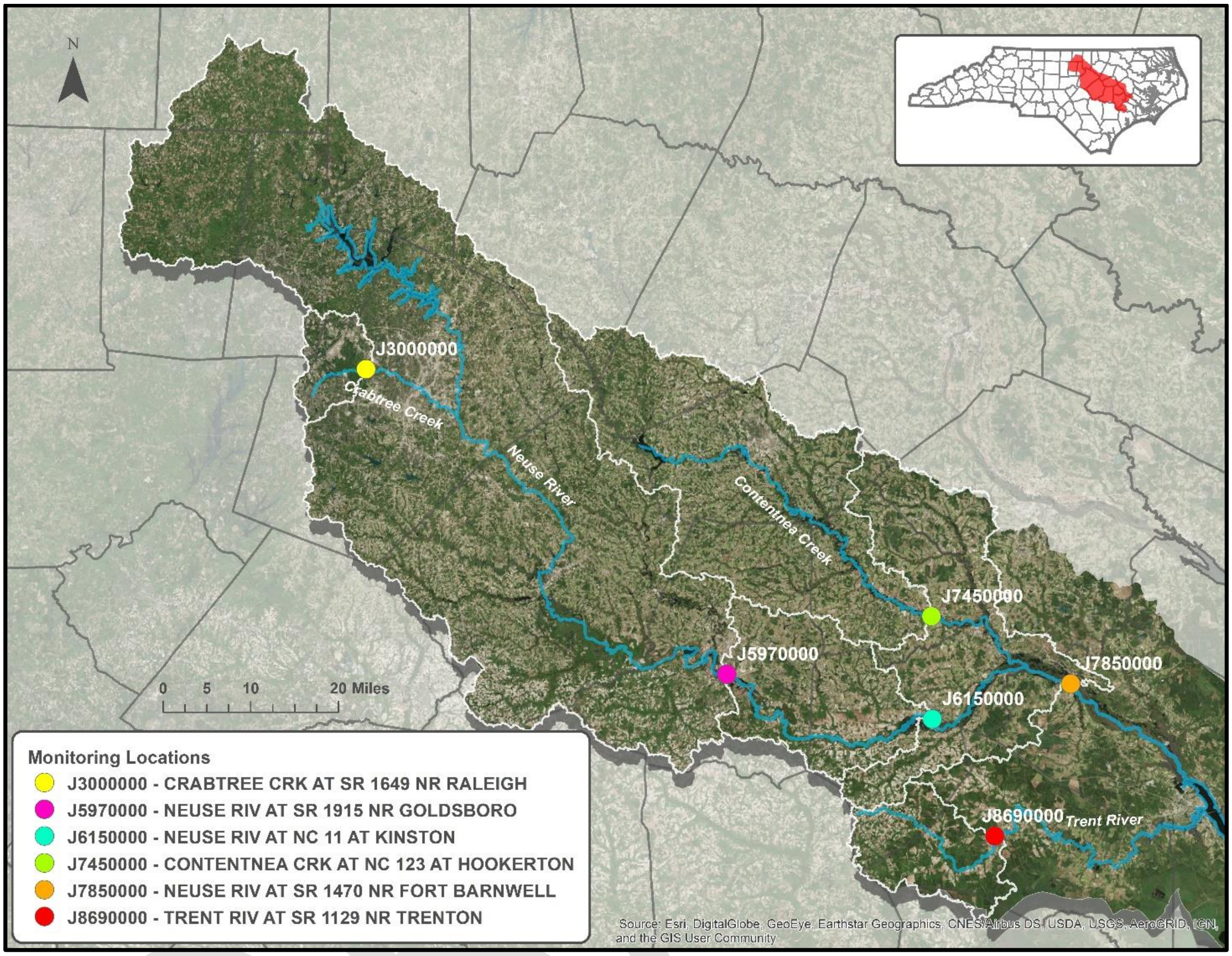

Figure 1. Selected Neuse River Basin Water Quality Stations

Data Compilation and Management

Water quality data collected at selected DWR ambient monitoring stations (AMS) between 1990 and 2016 were retrieved from the Environmental Protection Agency's (EPA's) STOrage and RETrieval (STORET) and AMS data for 2017 was obtained internally from DWR's Water Sciences Section. Additional Lower Neuse Basin Association (LNBA) data from 1990 through 2011 was obtained through STORET, while 2012 through 2017 data was obtained from the Water Sciences Section. All USGS data was obtained through STORET. Figure 1 shows the location of the DWR ambient monitoring stations.

Nutrient fractions compiled for this study included ammonia, NOx, TKN, TN, and TP. Total Nitrogen was computed as TKN plus NOx. Organic Nitrogen (Org-N) is computed as TKN minus ammonia. The monitoring records for some of the stations vary over time and include data collected at monthly, daily, or weekly time intervals. While routine monthly sampling was conducted before 1996, the frequency of sampling increased to almost daily from 1996 to 2002 and was reduced to weekly monitoring after 2002.

Flow data for the selected stations were obtained from USGS for each collocated USGS gage station. Long term daily flows have been measured at these locations. The selected ambient monitoring stations and the collocated USGS gages are shown in Table 1 and Figure 1. For the Fort Barnwell station, daily flow before October 1996 was estimated using flow data from the upstream stations on the Neuse River at Kinston and on Contentnea Creek at Hookerton with a regression model like the one that was developed by Stow and Borsuk (2003). Flow has been measured by USGS at Kinston since 1928 and at Hookerton since 1930. The final flow dataset for the Fort Barnwell station included estimated flow values for the period before October 1996 and observed flow values from October 1996 to December 2018. Flow data for the Crabtree Creek gage at SR1649 near Raleigh station was not recorded from 2/19/1993 to 5/31/1997. As a result, flow data from 6/1/1997 to 12/31/2017 was used for the analysis. Missing USGS flow value(s) were replaced with the average of the flow value from the day before and day after the missing value(s). Long term flow averages and the flow record used for the selected USGS sites are given in Table 4. The average given in Table 2 represent the average of 0-33% of flows (Low), the average of 34-66% flows (Middle), and the average of 67-100% flows (High). Additional information on annual flow statistics is provided in Appendix A.

Table 2. Summary of long-term average flows from USGS flow gages at selected AMS stations

Location	USGS ID	Data Record	Flow Average(cfs)			DWR AMS
			Low	Middle	High	
Fort Barnwell	02091814	1996-2017	899	2628	8855	J7850000
Kinston	02089500	1970-2017	650	1736	5933	J6150000
Contentnea Creek @ Hookerton	02091500	1970-2017	126	459	1754	J7450000
Trent River @ Trenton	02092500	1970-2017	16	86	469	J8690000
Goldsboro	02089000	1970-2017	491	1392	5338	J5970000
Crabtree Creek @ Raleigh	208726005	1997-2017	15	42	237	J3000000

Notes: (1) The flow record at Fort Barnwell (02091814) was from 1996 to 2017 and flows for earlier time-period (1970 - 1996) were estimated from daily flows from Kinston and Hookerton; (2) Flow for Crabtree Creek was missing from 2/19/1993 to 1997 and available data from 6/1/1997 to 12/31/2017 was used.

I. Seasonal Kendall Test

Various parametric and nonparametric statistical methods have been developed to determine trends in water quality parameters, all of which have certain assumptions that must be met for the analysis to be valid. One method for determining if a given parameter is changing over time is the Seasonal Kendall test (Hirsch et al., 1982). The nonparametric Seasonal Kendall test is appropriate where data sets are commonly non-normal, vary seasonally, and contain outliers and censored values (Helsel and Hirsch 1995).

Multiple factors contribute to variability in water quality over time and may prevent the detection of trends. Changes in water quality brought about by human activity will usually be superimposed on natural sources of variation such as flow and season. Identification and separation of these components is one of the most important tasks in trend analysis. Nutrient concentrations most commonly exhibit seasonal patterns resulting from biological activities and changes in land uses and practices, while nutrient loads exhibit variation that is mostly a result of changes in flow. Therefore, trend in nutrient concentration rather than load is tested using the Seasonal Kendall test to account for seasonality.

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Seasonal Kendall Trend Test – Summary

Trend analyses using the Seasonal Kendall test on the flow adjusted residual concentrations were performed for ammonia, NOx, TN, TKN, and TP concentrations based on data from selected NC ambient monitoring stations (Table 2) for the 1991-2017, 1991-2001, and 2002-2017 timeframes. The WQHYDRO software was used for the analysis. All statistical tests were performed at an α = 0.05 level of significance to test the null hypothesis of no trend over the analysis period. The summary of the results of the trend analysis are provided in Table 3.

Table 3. Summary of trend analysis results for nutrient concentrations for selected stations

Constituent	Neuse River near Fort Barnwell			Neuse River near NC 11 at Kinston		
	Concentration Trend			Concentration Trend		
	1991-2017	1991-2001	2002-2017	1991-2017	1991-2001	2002-2017
NH3 -N	Decreasing	No trend†	Increasing	Decreasing	No trend†	Increasing
NOx	Decreasing	Decreasing	No trend†	Decreasing	Decreasing	No trend†
TKN	Increasing	No trend†	Increasing	Increasing	No trend†	Increasing
TN	No trend†	Decreasing	Increasing	No trend†	Decreasing	Increasing
TP	Decreasing	Decreasing	No trend†	No trend†	Decreasing	No trend†
	Trent River near Trenton			**Contentnea Creek near Hookerton**		
NH3 -N	Decreasing	No trend†	Decreasing	Decreasing	Decreasing	No trend†
NOx	Increasing	Decreasing	No trend†	No trend†	Decreasing	No trend†
TKN	Increasing	No trend†	Increasing	Increasing	No trend†	Increasing
TN	Increasing	No trend†	No trend†	Increasing	Decreasing	Increasing
TP	Increasing	No trend†	Increasing	Decreasing	No trend†	No trend†
	Neuse River near Goldsboro			**Crabtree Creek near Raleigh***		
NH3 -N	Decreasing	No trend†	No trend†	No trend†		No trend†
NOx	Decreasing	Decreasing	No trend†	No trend†		Decreasing
TKN	Increasing	Decreasing	No trend†	Increasing		No trend†
TN	Decreasing	Decreasing	No trend†	No trend†		No trend†
TP	Increasing	No trend†	No trend†	No trend†		No trend†

† not significant at α = 0.05 level, * the period of analysis for Crabtree Creek was 1997-2017

Evaluations of the nutrient trends for the 1991-2017 period show that statistically significant decreases in NOx concentrations occurred at the Fort Barnwell, Kinston, and Goldsboro sites, while statistically significant increasing trends were observed at the Trent River site near Trenton. For the 1991-2001 period, statistically significant downward trends were observed at all stations except for Crabtree Creek near Raleigh. Statistically significant trends in NOx were not detected at all stations for the 2002-2017 period, except for a significant decreasing trend for Crabtree Creek near Raleigh.

In contrast, TKN concentrations show a statistically significant increase over the 1991-2017 period at all stations (1997-2017 for the Crabtree Creek station). Statistically significant trends in TKN were not detected at all stations over the 1991-2001 period except the Neuse River at Goldsboro which showed a significant decreasing trend. For the 2002-2017 period, significant increasing trends were detected for Neuse River at Fort Barnwell and Kinston, Trent River at Trenton, and Contentnea Creek at Hookerton.

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Significant trends were not detected for Neuse River at Goldsboro and Crabtree Creek near Raleigh for the 2002-2017 period.

Total nitrogen results followed the combinations of patterns of NOx and TKN trends. For the 1991-2017 period, statistically significant increasing trends were observed for Trent River at Trenton and Contentnea Creek at Hookerton and a decreasing trend for Neuse River at Goldsboro. The results were not statistically significant for Neuse River at Fort Barnwell and Kinston and Crabtree Creek near Raleigh (1997-2017 period). The results for Neuse River at Kinston, Fort Barnwell and Goldsboro and Contentnea Creek at Hookerton show a statistically significant downward trend for the 1991-2001 period while no trend was detected for Trent River at Trenton. For the 2002-2017 period, significantly increasing trends were observed at Fort Barnwell, Kinston and Hookerton. Significant trends were not detected for Trenton, Goldsboro, and Crabtree Creek near Raleigh for the 2002-2017 period.

Ammonia generally showed no trend or a decreasing trend except for Neuse River at Fort Barnwell and Kinston where there was a significant increase for the 2002-2017 period. Likewise, Total Phosphorus generally showed no trend or a decreasing trend except for Neuse River at Goldsboro and Trent River where there was a significant increase for the 1991-2017 period.

The Seasonal Kendall test used in this analysis provides useful information to identify direction of trends and estimate the median rate of change over time. Further investigations should focus on identification of the causes of trends, contributing sources, and nutrient loading processes and mechanisms.

Seasonal Kendall Trend Test - Method

The Water Quality / Hydrology Graphics / Analysis System (WQHYDRO) software was used to perform the Seasonal Kendall test (Aroner, 2012). For monitoring records where the sampling frequency has changed over time, the selection of a single value for a season provides a more constant variance in seasonal values which in turn will produce more accurate statistical tests (Schertz et al. 1991). The monitoring records for the selected Neuse River basin stations have changed over time and include data collected at monthly, daily, and weekly time intervals. It is necessary to have comparable number of samples for all years and to maintain constant variance; therefore, data collected at daily time interval is subsampled by selecting only one sample per month (closest to the middle of the month).

For the Seasonal Kendall test, observations are first ranked by date order and the difference between each value and subsequent data values are computed and the sum of the signs of the differences is evaluated as the Kendall sum statistic (S). The process is repeated until all successive differences have been evaluated. The Kendall S statistics is then the difference between the number of positive values and the number of negative values (Gilbert 1987). The Kendal S is then compared to a critical value to test the null hypothesis (H_o) of no trend. The Kendall S statistics is given by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

Where: sign ($x_j - x_k$) = 1 if $x_j - x_k > 0$
sign ($x_j - x_k$) =-1 if $x_j - x_k < 0$
sign ($x_j - x_k$) = 0 if $x_j - x_k = 0$

The WQHYDRO tool computes the Seasonal Kendall test with and without correction for serial correlation. A fundamental assumption of statistical procedures is that observations within or between samples are independent of one another and are from the same statistical distribution. Water quality time series commonly exhibit serial correlation and appropriate adjustment is required to minimize the effect of autocorrelation. Therefore, the data are checked for log-1 autocorrelation and when significant autocorrelation is detected, an autocorrelation corrected version of the Seasonal Kendall test is used. The WQHYDRO tool has an automatic provision for removing the serial correlation problem using an autocorrelation-corrected version of the Seasonal Kendall test.

The effect of natural and anthropogenic changes on nutrient concentration trends can be separated by performing trend analysis for flow-adjusted concentration. Decreasing flow-related variability in nutrient concentrations increases the chance of detecting a trend resulting from influences other than flow (Schertz et al., 1991). In the data record, there was a substantial effect of flow on nutrient concentrations; therefore, flow-adjusted concentration was used in the trend analysis. Flow-adjusted concentrations were calculated from LOcally WEighted Scatterplot Smoothing (LOWESS) of nutrient concentrations on flow.

For this study, nutrient data including ammonia, NOx, TKN, TN, and TP from the Neuse River near Fort Barnwell and five other stations were analyzed using the Seasonal Kendall test on the flow-adjusted concentrations for trend. Statistical tests for temporal trends were considered significant for p-values less than or equal to 0.05 ($\alpha \leq 0.05$). The null hypothesis of no trend over time for selected parameters was tested. If the analysis indicated a significant trend, the null hypothesis was rejected, and the trend slope or percent change a parameter exhibits over the study time-period is calculated. This value can be either negative (decreasing) or positive (increasing). For nutrients, upward trend (positive slope) indicates degradation of water quality, whereas downward trend (negative slope) indicates improvement of water quality.

It is important to note that the nonparametric trend hypothesis tests for trend are not tests of significance of the estimated trend slope magnitude. Therefore, the magnitude of the trend slope should be interpreted with care and only the values reported for statistically significant trends should be used to evaluate progress in achieving reduction goals in general. Also, more than 9% of the ammonia record contains observations that are below laboratory detection limits for all the stations. While the sign of the slope is resistant to the presence of nondetected values, the estimate of the magnitude of the slope can be influenced by the values selected for nondetected observations (Schertz et al., 1991).

Seasonal Kendall Trend Test - Results

Neuse River at Fort Barnwell

The results of the Seasonal Kendall test for concentrations of TN, TKN, ammonia, NOx, and TP are provided in Table 5. Assessment of nutrient trends for the 1991-2017 time-period showed that significant decreases in ammonia, TP, and NOx concentrations occurred at Fort Barnwell. Conversely, TKN concentration showed a statistically significant ($\alpha \leq 0.05$) increasing trend. TKN is comprised of ammonia and Org-N and the proportion of ammonia calculated from the Fort Barnwell data record is approximately 12% of TKN. Because the proportion of ammonia is small and there is a significant downward trend observed for ammonia, the increase in TKN is due to the increase in Org-N. There was no statistically significant trend for TN.

Table 5. Flow adjusted nutrient concentration trends at the Fort Barnwell station

Constituent	1991-2017			1991-2001			2002-2017		
	Slope	Trend	%change	Slope	Trend	%change	Slope	Trend	%change
NH_3 -N	-0.001	YES	-30		No		0.001	YES	52
NOx	-0.011	YES	-30	-0.047	YES	-54		No	
TKN	0.009	YES	49		No		0.010	YES	30
TN		No		-0.053	YES	-39	0.016	YES	25
TP	-0.0008	YES	-12	-0.005	YES	-34		No	

For the 1991-2001 time-period, only NOx, TN and TP showed statistically significant ($\alpha \leq 0.05$) downward trend. For the 2002-2017 time-period only TKN, TN and ammonia showed a statistically significant ($\alpha \leq 0.05$) increasing trend.

Evaluation of nutrient concentrations relative to the baseline was done by computing percent change relative to the 1991-1995 baseline period. Trend slope (seasonal Sen trend slope) given in Table 5 represents the median rate of change in concentrations for each parameter with a statistically significant trend. For example, the statistically significant decreasing trend of NOx for the 1991-2017 time-period suggests that the average decrease in median NOx concentration per year was 0.01059 mg/L during the study period, representing a 30% decrease in the average NOx concentration (based on the median values of the 1991-1995 baseline period) over the 27 years of the study period. The results show 30, 30, and 12% decrease in the baseline period median concentrations of ammonia, NOx, and TP, respectively, over the 27 years ending in 2017. Total Kjeldahl Nitrogen concentration, in contrast, increased by 49% over the same period.

<u>Contentnea Creek at Hookerton</u>

The results of the Seasonal Kendall test for concentrations of TN, TKN, ammonia, NOx, and TP at the Contentnea Creek site near Hookerton are provided in Table 6. The trend analysis results for the 1991-2017 time-period showed that significant decreases in ammonia and TP concentrations occurred at the Contentnea Creek site at Hookerton. Conversely, TKN and TN concentration showed a statistically significant increasing trend ($\alpha \leq 0.05$). TKN is comprised of ammonia and Org-N and the proportion of ammonia calculated from the Contentnea Creek data record is approximately 13% of the TKN. A statistically significant trend was not detected for NOx. The results show 46 and 21% decrease in the baseline period median concentrations of ammonia and TP, respectively, over the 27 years ending in 2017. Total Kjeldahl nitrogen and TN concentrations, in contrast, increased by 54% and 20%, respectively, over the same period.

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Table 6. Flow adjusted nutrient concentration trends at the Contentnea Creek site at Hookerton

Constituent	1991-2017			1991-2001			2002-2017		
	Slope	Trend	%change	Slope	Trend	%change	Slope	Trend	%change
NH3 -N	-0.002	YES	-46	-0.008	YES	-75		No	
NOx		No		-0.016	YES	-25		No	
TKN	0.010	YES	54		No		0.009	YES	23
TN	0.009	YES	20	-0.012	YES	-11	0.017	YES	24
TP	-0.001	YES	-21		No			No	

For the 1991-2001 time-period, ammonia, NOx, and TN concentrations showed statistically decreasing trends (α ≤ 0.05). Total Kjeldahl nitrogen concentration did not show a statistically significant trend.

For the 2002-2017 time-period, only TKN and TN showed statistically significant positive trend (α ≤ 0.05). There was no statistically significant trend for ammonia, NOx and TP concentration for the same time-period.

<u>Trent River near Trenton</u>

The results of the Seasonal Kendall test for the Trent River near Trenton site are provided in Table 7. The trend analysis results for the 1991-2017 time-period showed that significant decreases in ammonia concentrations occurred at the Trent River. Conversely, NOx, TKN, TN and TP concentrations showed statistically significant (α ≤ 0.05) increasing trends for the same period. TKN is comprised of ammonia and Org-N and the proportion of ammonia calculated from the Trent River data record is approximately 10% of TKN. The results show 50, 85, 68, and 14% increase in the baseline period median concentrations of NOx, TKN, TN, and TP, respectively, over the 27 years ending in 2017. Ammonia concentrations, in contrast, decreased by 47% over the same period. It should be noted that increases in all constituents except ammonia were observed for the Trent River near Trenton.

Table 7. Flow adjusted nutrient concentration trends at the Trent River site near Trenton

Constituent	1991-2017			1991-2001			2002-2017		
	Slope	Trend	%change	Slope	Trend	%change	Slope	Trend	%change
NH3 -N	-0.001	YES	-47		NO		0.000	YES	-18
NOx	0.010	YES	50	-0.017	YES	-35		NO	
TKN	0.016	YES	85		NO		0.011	YES	28
TN	0.026	YES	68		NO			NO	
TP	0.000	YES	14		NO		0.001	YES	20

For the 1991-2001 time-period only NOx concentrations showed statistically decreasing trends (α ≤ 0.05). The trend results were not statistically significant for ammonia, TKN, TN, and TP concentrations.

For the 2002-2017 time-period, ammonia, TKN and TP showed statistically significant positive trend (α ≤ 0.05). Total Nitrogen and NOx concentrations did not show a statistically significant trend for the same time-period.

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Neuse River at Kinston

The results of the Seasonal Kendall test at the Neuse River site near Kinston are provided in Table 8. The results for the 1991-2017 time-period showed that significant decreases in ammonia and NOx concentrations occurred at the Neuse River site at Kinston. Conversely, TKN concentrations showed a statistically significant ($\alpha < 0.05$) increasing trend. TKN is comprised of ammonia and Org-N and the proportion of ammonia calculated from the Kinston data record is approximately 9% of TKN. The results for TN and TP were not statistically significant. The results show 41% and 38% decrease in the baseline period median concentrations of ammonia and NOx, respectively, over the 27 years ending in 2017. Total Kjeldahl nitrogen concentrations, in contrast, increased by 39 % over the same period.

Table 8. Flow adjusted nutrient concentration trends at the Neuse River site at Kinston

	1991-2017			**1991-2001**			**2002-2017**		
Constituent	**Slope**	**Trend**	**%change**	**Slope**	**Trend**	**%change**	**Slope**	**Trend**	**%change**
NH3 -N	-0.001	YES	-41		NO		0.001	YES	51
NOx	-0.013	YES	-38	-0.052	YES	-61		NO	
TKN	0.007	YES	39		NO		0.009	YES	28
TN		NO		-0.054	YES	-43	0.014	YES	21
TP		NO		-0.003	YES	-27		NO	

For the 1991-2001 time-period, NOx, TN, and TP concentrations showed statistically decreasing trends ($\alpha \leq 0.05$). Total Kjeldahl nitrogen and ammonia concentrations results were not statistically significant.

For the 2002-2017 time-period, ammonia, TKN and TN showed statistically significant positive trend ($\alpha \leq 0.05$). The trends were not statistically significant for NOx and TP.

Neuse River at Goldsboro

The results of the Seasonal Kendall test for the Neuse River site near Goldsboro are provided in Table 9. The results for the 1991-2017 time-period showed that significant decreases in ammonia, NOx, and TN concentrations occurred at the Neuse River site near Goldsboro. Conversely, TKN and TP concentrations showed statistically significant ($\alpha \leq 0.05$) increasing trends. TKN is comprised of ammonia and Org-N and the proportion of ammonia calculated from the Goldsboro creek data record is approximately 14% of the TKN. The results showed 58%, 54%, and 25% decrease in the baseline period median concentrations of ammonia, NOx and TN, respectively, over the 27 years ending in 2017. Total Kjeldahl nitrogen and TP concentrations, in contrast, increased by 45% and 31%, respectively, over the same period.

For the 1991-2001 time-period, NOx, TKN, and TN concentrations showed statistically significant decreasing trends ($\alpha \leq 0.05$). Ammonia and TP concentration did not show a statistically significant trend. For the 2002-2017 time-period, no significant change was detected for all constituents.

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Table 9. Flow adjusted nutrient concentration trends at the Neuse River Site near Goldsboro

	1991-2017			1991-2001			2002-2017		
Constituent	**Slope**	**Trend**	**%change**	**Slope**	**Trend**	**%change**	**Slope**	**Trend**	**%change**
NH3 -N	-0.002	YES	-58		NO			NO	
NOx	-0.020	YES	-54	-0.047	YES	-52		NO	
TKN	0.007	YES	45	-0.012	YES	-33		NO	
TN	-0.013	YES	-25	-0.048	YES	-37		NO	
TP	0.001	YES	31		NO			NO	

<u>Crabtree Creek near Raleigh</u>

The results of the Seasonal Kendall test for the Crabtree Creek site near Raleigh are provided in Table 10. The Crabtree Creek data record started in 1997 and the analysis time-period covers a 20-year period ending in 2017. The results for the 1997-2017 time-period showed that significant increases in TKN concentrations occurred at the Crabtree Creek site near Raleigh. Ammonia, NOx, TN, and TP results were not statistically significant. TKN is comprised of ammonia and Org-N and the proportion of ammonia calculated from the Crabtree creek data record is approximately 10% of the TKN.
For Crabtree creek, a comparison of data relative to the baseline was done by computing percent change relative to the 1997-2001 baseline period. The results show 89% increase in the baseline period median TKN concentrations, over the 20 years ending in 2017 and 39% decrease for NOx for the 2002-2007 period.

Table 10. Flow adjusted nutrient concentration trends at the Crabtree Creek site near Raleigh

	1997-2017			1997-2001	2002-2017		
Constituent	**Slope**	**Trend**	**%change**		**Slope**	**Trend**	**%change**
NH3 -N		NO				NO	
NOx		NO			-0.011	YES	-39
TKN	0.017	YES	89			NO	
TN		NO				NO	
TP		NO				NO	

There was limited amount of data for the 1997-2001 time-period and the seasonal Kendall Test was not conducted for Crabtree Creek. For the 2002-2017 time-period, a statistically significant decrease in NOx concentrations was observed. The results for ammonia, TN and TP were not statistically significant.

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II. Flow-Normalized Loading Analysis

In 2013, the Modeling and Assessment Branch (MAB) performed FN loading analysis at the Fort Barnwell station for the 1991-2011 timeframe. The present study covers the time-period from 1991 to 2017 and includes multiple stations in the Neuse River Basin. The analysis was performed to evaluate annual nutrient loading trends and the progress made to meet the nutrient loading reduction relative to the 1991-1995 baseline period. The results of the analysis are presented in this section.

Summary

The focus of the current study was to update the 2013 trend analysis, extend the study period through 2017, and include other stations in the Neuse River Basin. In addition, flow-normalized (FN) loading was performed to evaluate annual nutrient loading trends using a simplified approach (Lebo et al. 2011). Flow-normalized loading analysis provides useful insights on changes in annual nutrient loading including changes associated with different flow regimes and nutrient constituents. Flow-normalized estimates can be used in the evaluation of progress towards nutrient reduction goals and provide additional insight on the relative effectiveness of nutrient management measures implemented in the watershed. Lebo et al. (2011) and AquAeter (2016) used this approach to evaluate progress in achieving the Neuse TMDL reduction goal as well as changes in N fractions associated with different flow regimes.

The simplified FN loading analysis allows evaluation of changes under various flow regimes which includes a low flow interval (0-33% of flows), medium flow internal (34-66% flows), and high flow interval (67-100% flows) and provides feedback on effectiveness of point and nonpoint source nutrient management actions. The analysis was conducted for the available data record from 1990 to 2017 (1997-2017 for Crabtree Creek near Raleigh) from selected Neuse River Basin stations. Nutrient concentrations were estimated from the mean of available data and flow-weighted average concentrations. Nutrient loads for the long-term flow distribution were 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.

Evaluation of TN and TP concentrations at stations along the Neuse River showed differences in response to the overall set of control actions implemented for FN loads. On the average, flow normalized TP loading showed increases at five of the selected stations and decreases for the Fort Barnwell station relative to the 1991-1995 baseline period (1997-2002 for Crabtree Creek). Flow normalized TN loading showed decreases on the average at the Fort Barnwell, Kinston, and Goldsboro stations and increases at the Contentnea, Trent, and Crabtree stations (relative to the 1991-1995 baseline). The largest average increase in TN was observed at the Crabtree station (16-41%) followed by the Trent station (-8-61%). On the average, similar reductions in TN were observed at Goldsboro (-4 - 19%), Kinston (-1-20%), and Fort Barnwell (-2-21%), respectively.

In general, the NOx concentration decreased at all of the selected locations except the Trent River station where it showed an increase. In contrast, increases in flow normalized TKN loading were observed at all locations. Similar results were also reported for the period ending in 2015 in a recent study by AquAeTer (AquAeTer, 2016). A summary of the percent reduction achieved for the 2013-2017 period relative to the 1991-1995 baseline period for the selected stations is shown in figure s-1. The results show that some progress has been achieved in NOx reduction at the Neuse River mainstem sites, but NOx loads increased at downstream tributary stations. With the increase in TKN loads at all stations, little progress has been made in meeting the TN reduction goal of 30%.

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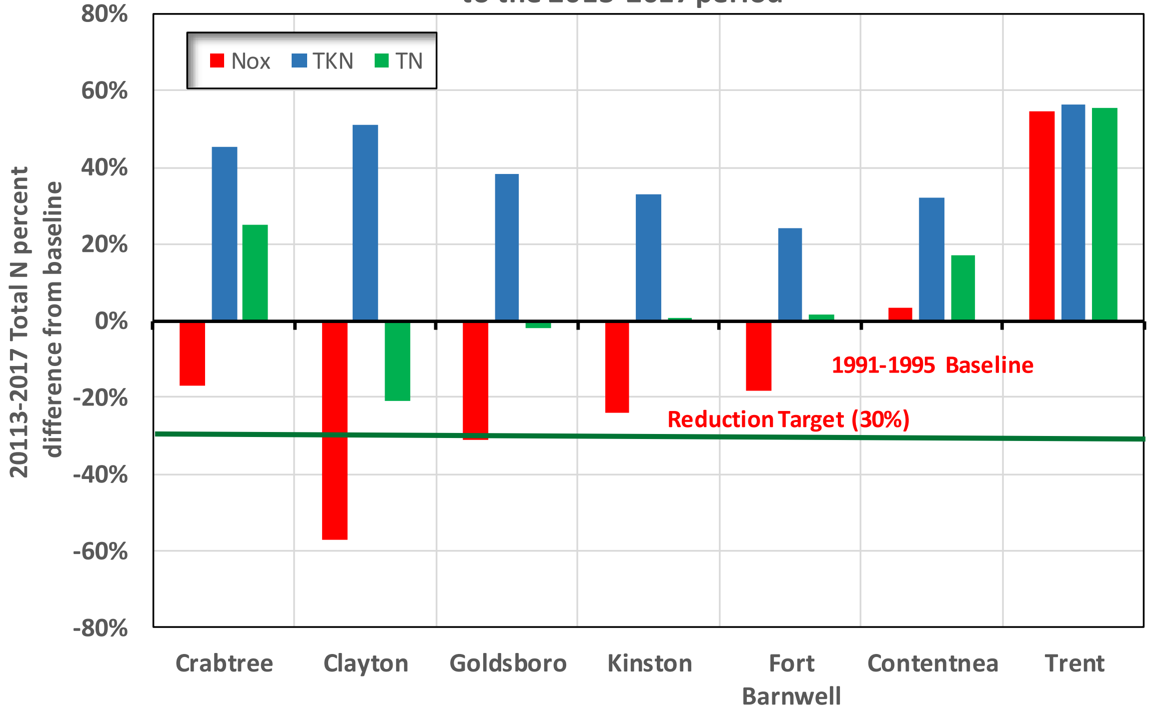
Figure s-1. Percent change from the 1991-1995 baseline period to the 2013-2017 period



Overall, the current analysis indicates that significant reductions in NOx loads were achieved in the early 1990s, but the loadings have shown increases in the 2000s. In contrast, the TKN loads have continued to increase steadily over the years. 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 are consistent with the nutrient loading trends and increased Org-N inputs in the Neuse River Basin reported in recent studies (Alameddine et al., 2011, AquAeTer, 2016, Lebo et al., 2011, and Osburn, et al., 2016).

Method

Assessment of trends in annual nutrient loads at Fort Barnwell was done using FN concentrations and loads computed for flow intervals representing low, medium, and high flows. The description of the site and the data used for this analysis are provided in Part I. A spreadsheet-based tool was used for this analysis.

Flow-normalized estimates are designed to remove the effect of random stream flow-driven variations and are ideal for evaluating progress towards nutrient reduction goals (Sprague et al., 2011). Recent studies have demonstrated the use of FN loading assessments to evaluate effectiveness of management actions to reduce nutrients (Hirsch, 2012; Hirsch et al., 2010; Hirsch, 2011; Lebo et al., 2011; and Sprague et al., 2011). While some of these studies employed rigorous statistical methods for their analyses, the approach proposed by Lebo et al.; (2011) used a simpler method and was selected for the current study. Lebo et al. (2011) used this approach to evaluate progress in achieving the Neuse TMDL reduction goal as well as changes in N fractions associated with different flow regimes. Their 2001 study evaluated nutrient loads at Clayton, Hookerton, Trenton, and Streets Ferry Stations in the Neuse River

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Basin. Recently, the same tool was used by AquAeter to evaluate effectiveness of management actions using data through 2015 from multiple Neuse River Basin stations (AquAeTer, 2016).

The current analysis was designed to replicate the same approach used by Lebo et al. (2011) for the available data record from 1990 to 2017 from selected Neuse River Basin stations. Nutrient concentrations were estimated from the mean of available data and flow-weighted average concentrations. Nutrient loads for the long-term flow distribution were 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 detailed description of this approach is presented in a published peer-reviewed article (Lebo et al., 2011).

Flow-Normalized Loading Analysis Results – Fort Barnwell

Figure 2 shows annual TN loading at Fort Barnwell. The results show that annual TN loading at Fort Barnwell ranged from 4.8 to 15.4 x 10^6 lbs/year for the 1990–2017 timeframe, with a median value of 8.3 x 10^6 lbs/year. Average contributions of ammonia, NOx, and Org-N to the TN load for 1990–2017 period were 5%, 51%, and 44%, respectively. Organic Nitrogen was computed as TKN minus ammonia. There was an increase in the contribution of the Org-N fraction and a decrease in that of the NOx fraction to TN loading at Fort Barnwell after 1998. The average Org-N contribution increased from 34% of TN for 1990–1998 period to 49% of TN for 1999–2017 period. The NOx contribution decreased from 61% of TN for 1990-1998 period to 46% of TN for 1999-2017 period. Figure 3 shows annual TN loading at Fort Barnwell by flow interval. The average TN contributions from low, middle, and high flow interval were 8%, 24% and 68%, respectively. The annual TP loading at Fort Barnwell ranged from 0.50 to 2.2 x 10^6 lbs/year, with a median value of 0.90 x 10^6 lbs/year. The average TP contributions from low, middle, and high flows were 9%, 26% and 65%, respectively (Figure 4).

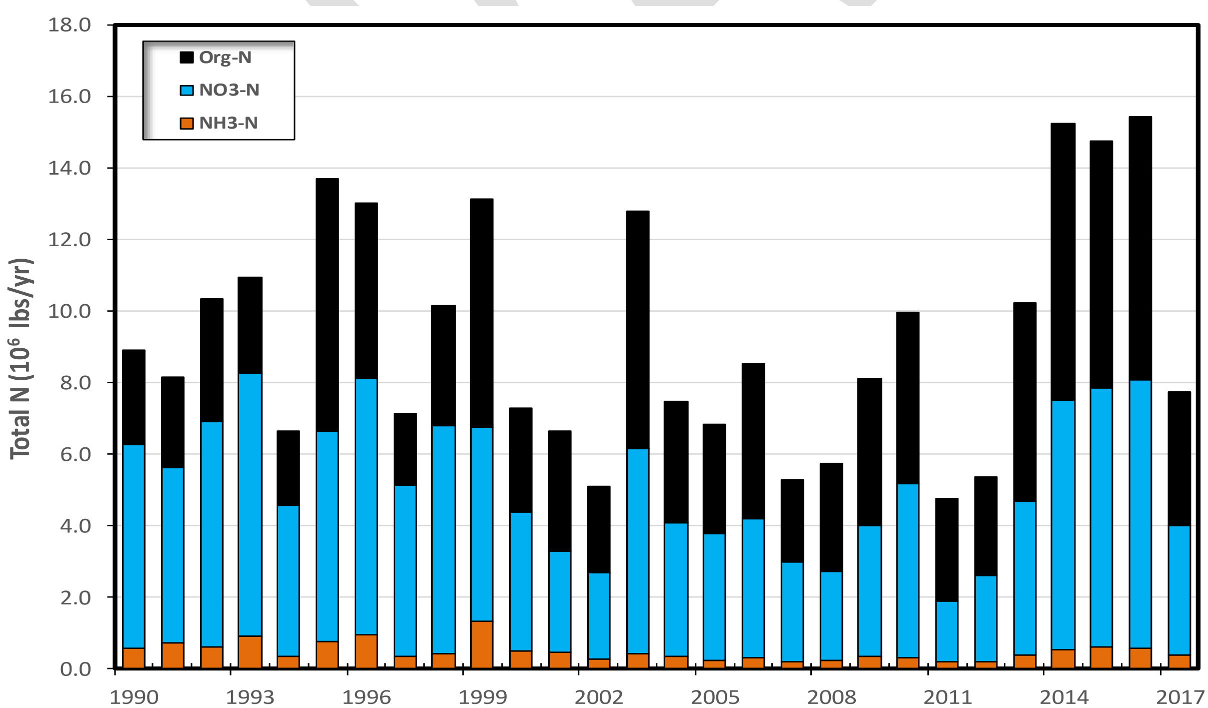

Figure 2 – Annual total N load by constituents for Neuse River at Fort Barnwell

These results show that high flow events contribute substantially large amounts of nutrients in this watershed, especially organic nitrogen. This suggests that high flow events deliver more TKN possibly from sediments and other nonpoint source products and processes.

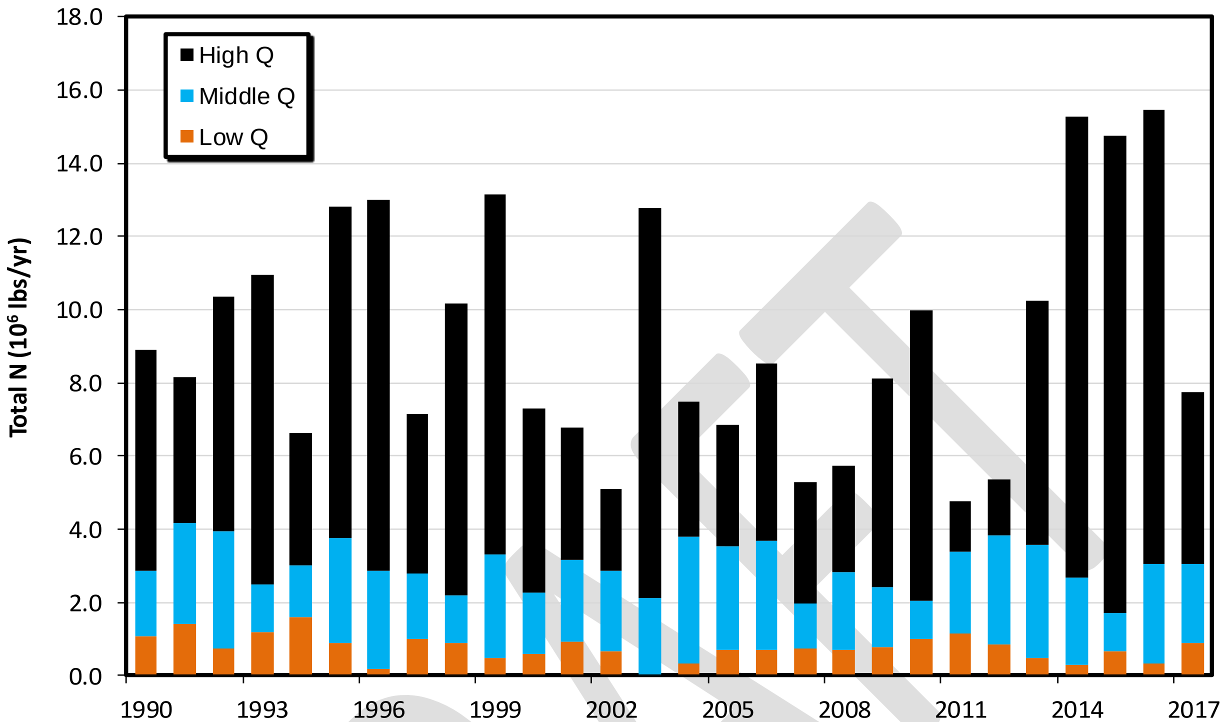

Figure 3. Annual total N load by flow bin for Neuse River at Fort Barnwell

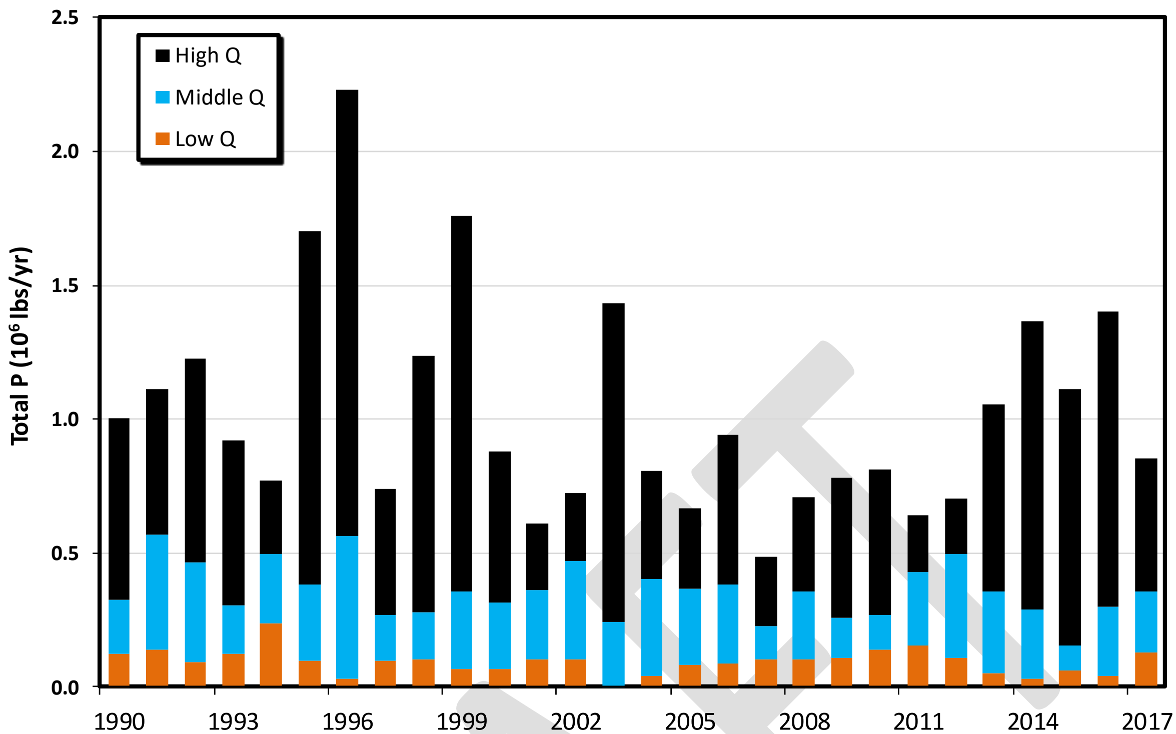

Figure 4. Annual total P load by flow bin for Neuse River at Fort Barnwell

At the Fort Barnwell location, flow normalized NOx predicted loads based on the long-term flow average steadily decreased from the1990-1994 period through 1999-2003. This decrease was followed by an increase from 2004-2007 through 2013-2017. The flow normalized loads increased from 3.7 x 10^6 lbs/yr in 1999-2003 to 4.7 x 10^6 lbs/yr in 2013-2017. The recent increase in the NO3-N load observed at Kinston and Goldsboro stations was also observed at Fort Barnwell. A steady increase in TKN loads was observed at Fort Barnwell for the 1994-1998 through 2011-2015 periods from 3.5 x 10^6 to 5.9 x 10^6 lbs/yr and a slight decrease to 5.7 x 10^6 lbs/yr through the 2013-2017 period. Overall, a large fraction of NOx and TKN loads occurred during middle and high flow conditions. Predicted FN loads for long-term average hydrology for the selected stations are provided in Appendix B.

Changes in flow normalized TN load exhibited the combination of pattern of the decrease in the NOx load in the 2000s and the variable pattern observed for TKN load. The TN load for long-term average flow conditions steadily decreased until the 1998-2002 period and steadily increased through the 2010 - 2014 periods and then slightly decreased through the 2013-2017 period. Flow normalized TP loads at the Fort Barnwell station generally declined over the study period.

In order to evaluate progress in achieving the 30% reduction goal set by the Neuse Estuary TMDL, FN load estimated under long-term average flow conditions were compared to the average load for the 1991-1995 baseline period (Figure 4 and 5). In the plots, a value of 0% indicates the predicted load is the same as derived for 1991-1995 while negative numbers denote reductions relative to 1991-1995. The target level of reduction of 30% is indicated in each plot with a solid green line.

The results of the FN loading analysis indicate reduction in FN NOx loading, but an increase in TKN loading. The flow-normalized NOx loading decreased beginning in the 1992–1996 period and reached a minimum value of -35% in the 1999–2003 time-period relative to the 1991-1995 baseline loading. The average reduction achieved was approximately 24% for all periods beginning with 1992–1996 (Figure 5). Flow-normalized TKN loading at Fort Barnwell decreased from the baseline period and reached the minimum values of -22% in the 1994-1998 period and increased gradually afterwards. Flow-normalized TKN loading has been consistently higher than the 1991–1995 baseline period throughout the past 18 years and increased by about 16% during this period. Since ammonia loading declined by 48% over the same time-period, the increase in TKN loading was primarily due to an increase in the Org-N fraction during mid and high flow events. The recent increase in NOx and TKN flow normalized loadings is mainly due to increases for the high flow intervals.

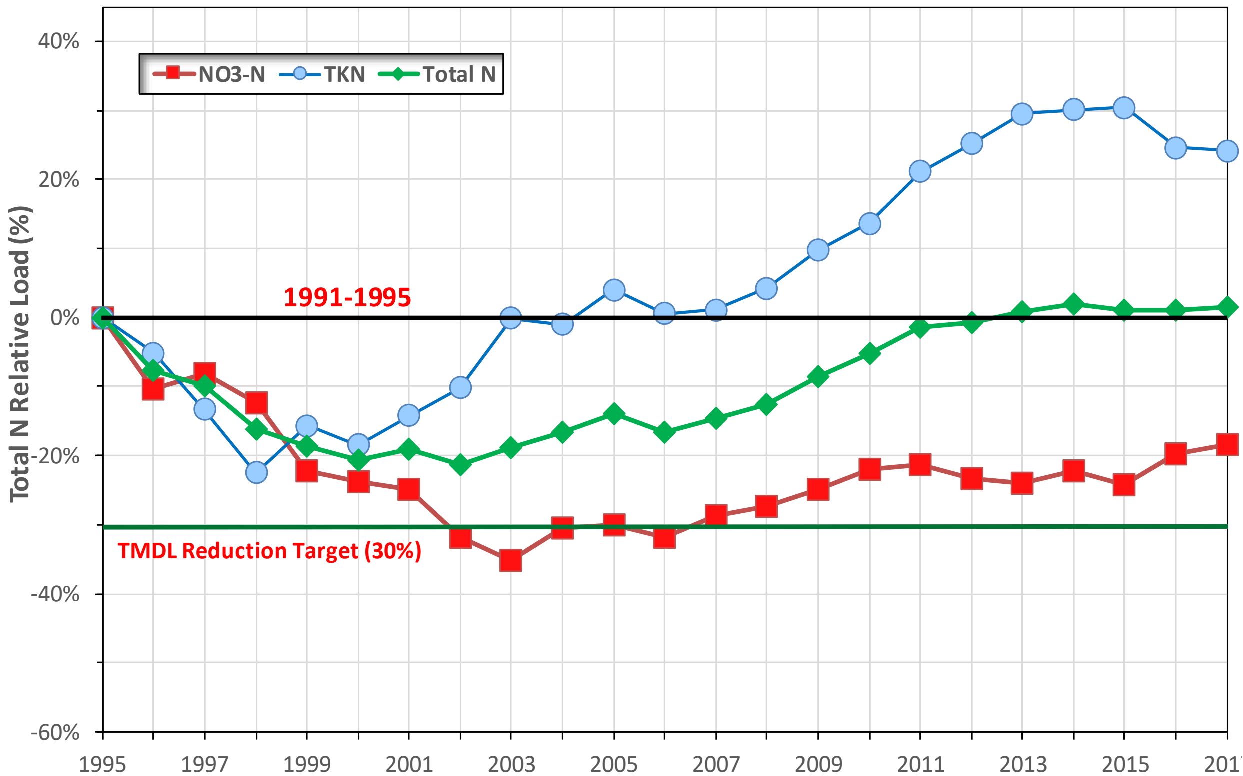

Figure 5. Nitrogen reduction for average flow condition compared to the 1991-1995 baseline for Neuse River at Fort Barnwell

Flow-normalized TN loading exhibited the combination of the patterns for NOx and TKN and has been consistently lower than the corresponding 1991-1995 baseline loading until the 2008-2012 period. The TN reduction percentage started to increase during the 2009-2013 period. The flow-normalized TN loading reduction decreased to a minimum value of -21% in the 1998-2002 period and increased gradually afterwards. The average reduction in flow-normalized TN loading for the periods ending in 1998-2011 was approximately 13%. Overall, the FN nutrient loading patterns at Fort Barnwell followed similar patterns reported for Clayton and Kinston stations (Lebo et al., 2011 and AquAeTer, 2016). The reduction in TP relative to the 1991-1995 period ranges from 4 to 25% for the periods starting in 1994-1998 and ending in 2013-2017 (Figure 6). Similar results are reported for the Fort Barnwell station for the period ending in 2015 (AquAeTer, 2016).

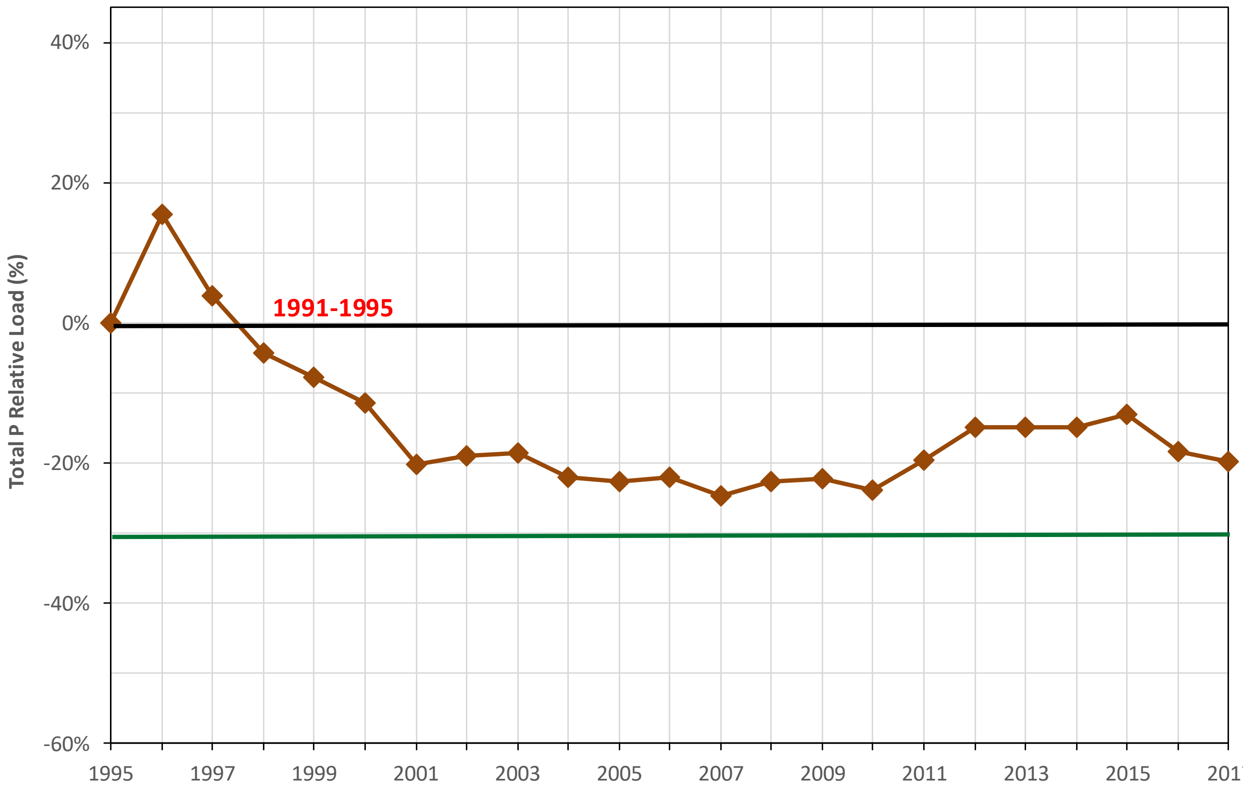

Figure 6. TP reduction for average flow condition compared to the 1991-1995 baseline for Neuse River at Fort Barnwell

<u>Changes in Concentration</u>

Table 11 shows average concentrations of N fractions and P by flow interval at Fort Barnwell. The results show that changes in N fractions exhibited marked differences for the different flow intervals. While the average concentrations of the NOx fraction decreased more for the low and middle flow intervals than for high flows, the average concentrations of the TKN fraction increased more for the middle and high flow intervals. For example, reductions in NOx for the 2013–2017 period from corresponding values for 1991–1995 were 46%, 35%, and 5%, respectively, for the low, middle, and high flow interval. Conversely, the changes in TKN concentrations for 2013-2017 from the corresponding values for 1991-1995 were -2%, 29%, and 25%, respectively, for the low, middle, and high flow interval. TN concentrations decreased for low flow and middle flow intervals by 33 and 12%, respectively and increased by 12% for the high flow interval. The decrease in concentrations for NOx when flow is increased could indicate that dilution is a factor, while the increase in TKN concentrations over the same flow intervals could indicate that high flow events deliver more TKN from sediments and other NPS landscape processes. Total Phosphorus concentrations for 2013-2017 decreased by 36%, 26%, and 15% for low, middle, and high flow intervals, respectively, from corresponding values for 1991-1995.

Table 11. Average nutrient concentrations at Fort Barnwell by 5-year period and flow interval

Period	Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
1980-1984	0.980	0.875	0.762	0.61	0.52	0.50	1.57	1.39	1.26
1981-1985	0.984	0.854	0.775	0.49	0.53	0.51	1.48	1.38	1.28
1986-1990	1.083	0.902	0.669	0.51	0.46	0.44	1.60	1.36	1.11
1991-1995	1.197	0.955	0.587	0.53	0.52	0.57	1.74	1.48	1.14
1996-2000	0.777	0.707	0.467	0.38	0.47	0.46	1.15	1.18	0.93
2001-2005	0.537	0.600	0.462	0.52	0.53	0.60	1.05	1.13	1.07
2006-2010	0.497	0.596	0.547	0.56	0.60	0.65	1.06	1.20	1.20
2011-2015	0.565	0.558	0.529	0.57	0.70	0.76	1.13	1.26	1.28
2012-2016	0.617	0.590	0.559	0.54	0.68	0.72	1.15	1.27	1.28
2013-2017	0.650	0.619	0.559	0.52	0.68	0.72	1.17	1.29	1.28

	Ammonia (mg/L)			Total P (mg/L)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
1980-1984	0.063	0.129	0.060	0.303	0.268	0.151
1981-1985	0.070	0.127	0.073	0.321	0.273	0.155
1986-1990	0.129	0.114	0.065	0.318	0.236	0.156
1991-1995	0.116	0.108	0.074	0.209	0.179	0.135
1996-2000	0.052	0.082	0.072	0.135	0.155	0.126
2001-2005	0.049	0.060	0.037	0.138	0.133	0.109
2006-2010	0.053	0.046	0.041	0.145	0.126	0.108
2011-2015	0.045	0.056	0.044	0.136	0.146	0.125
2012-2016	0.045	0.055	0.044	0.129	0.140	0.117
2013-2017	0.050	0.058	0.046	0.134	0.133	0.115

Flow-Normalized Loading Analysis Results - Kinston

Figure 7 shows annual TN loading for the Neuse River at Kinston. The results show that annual TN loading at Kinston ranged from 2.6 to 10.6 x 10^6 lbs/year for the 1990–2017 timeframe, with a median value of 5.6 x 10^6 lbs/year. Average contributions of ammonia, NOx, and Org-N to the TN load for 1990–2017 period were 5%, 52% and 43%, respectively. The Org-N fraction and the NOx fraction of TN loading ranged from 23% to 55% and 35% to 72%, respectively. Figure 8 shows annual TN loading at Neuse River at Kinston by flow interval. The average TN contributions from low, middle, and high flow interval were 9%, 27% and 64%, respectively. The annual TP loading ranged from 0.30 to 1.0 x 10^6 lbs/year, with a median value of 0.55 x 10^6 lbs/year. The average TP contributions from low, middle, and high flows were 11%, 31% and 58%, respectively (Figure 9).

These results show that high flow events contribute substantially large amount of nutrients in this watershed, especially nitrogen, suggesting that high flow events deliver more nitrogen possibly from sediments and other nonpoint source products and processes.

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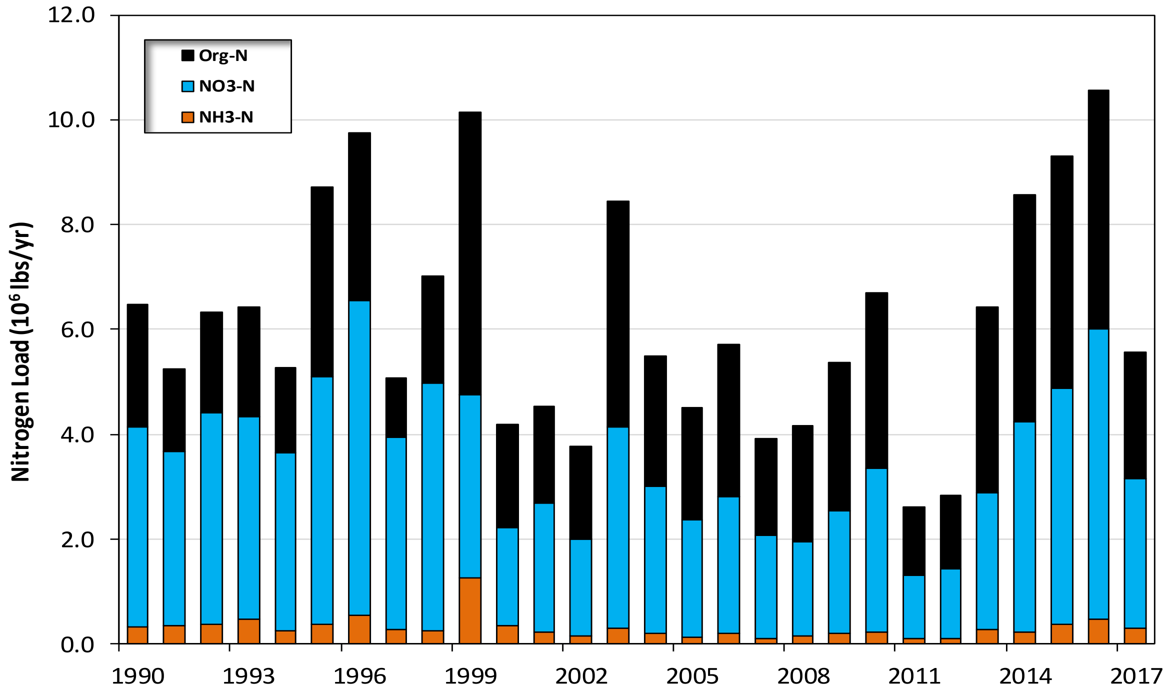

Figure 7 – Annual total N load by constituents for Neuse River at Kinston

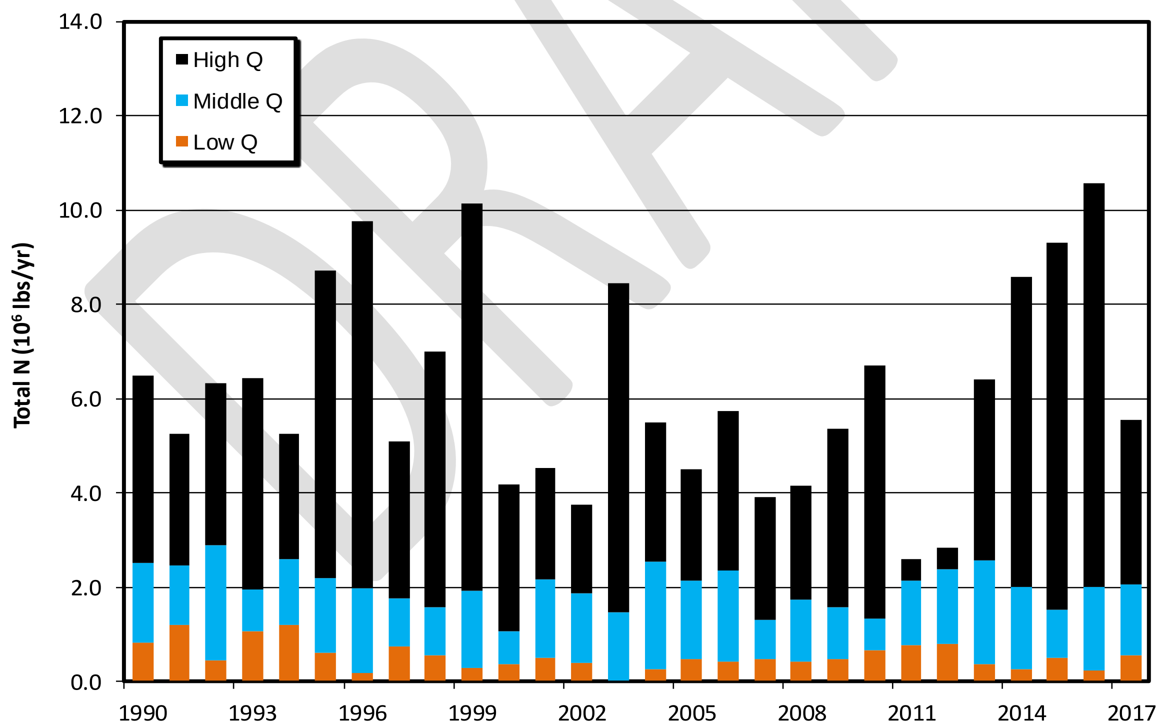

Figure 8. Annual total N load by flow bin for Neuse River at Kinston

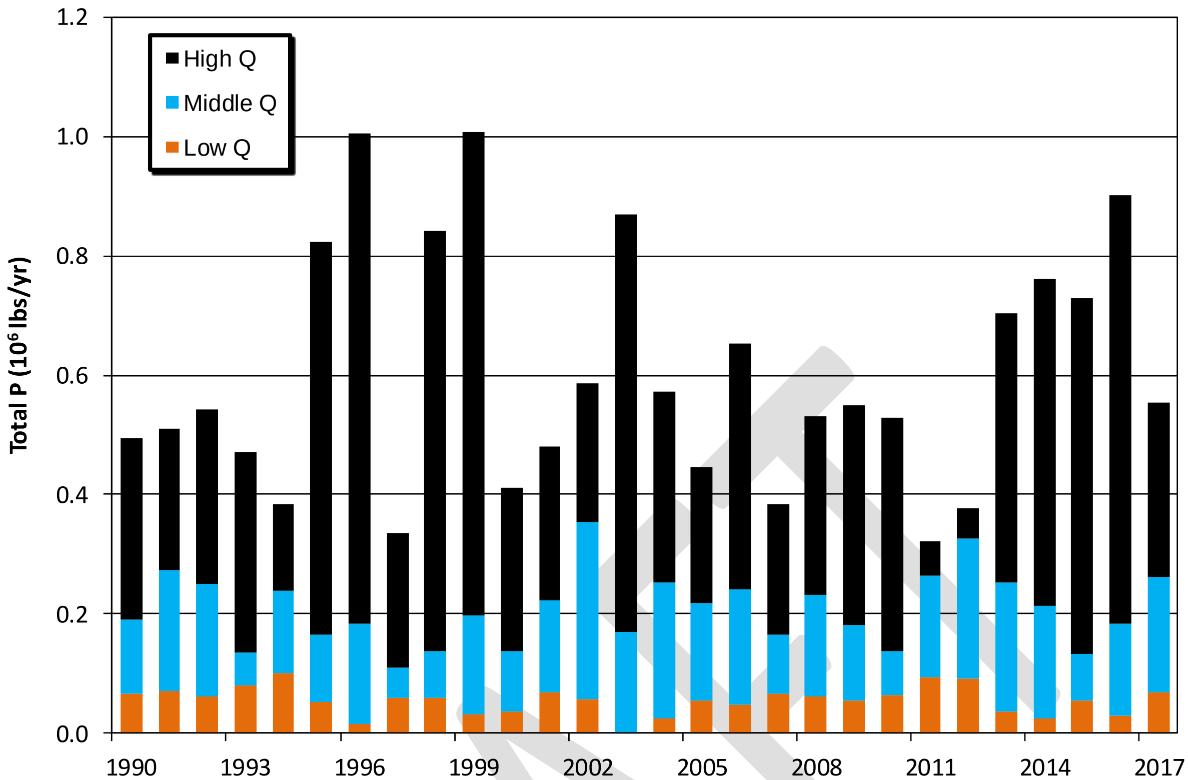

Figure 9. Annual total P load by flow bin for Neuse River at Kinston

At the Kinston location, flow normalized NOx predicted loads based on the long-term flow average steadily decreased for 1991-1995 through 1999-2003. This decrease was followed by a slight increase from 2004-2007 through 2013-2017. The flow normalized loads increased from 2.5 x 10^6 lbs/yr in 1999-2003 to 3.2 x 10^6 lbs/yr in 2013-2017. A steady increase in TKN loads was observed at Kinston for the 1994-1998 through 2013-2017 periods from 2.5 x 10^6 to 3.9 x 10^6 lbs/yr. Overall, a large fraction of NOx and TKN loads occurred during middle and high flow conditions. Predicted FN loads for long-term average hydrology for the selected stations are provided in Appendix B.

Changes in TN load exhibited the combination of pattern of the decrease in the NOx load in the 2000s and the variable pattern observed for TKN load. The TN load for long-term average flow conditions steadily decreased until the 1999-2003 period and steadily increased through the 2013 -2017 period. The flow normalized loads decreased from 6.9 x 10^6 lbs/yr in 1991-1995 to 5.5 x 10^6 lbs/yr in 1999-2013 and increased from 5.6 x 10^6 lbs/yr in 2000-2004 to 6.9 x 10^6 lbs/yr in 2013-2017. Flow normalized TP loads at the Kinston station generally increased over the study period.

The results of the FN loading analysis indicate a reduction in NOx loading, but an increase in TKN loading (Figure 10). Flow-normalized NOx loading decreased beginning in the 1992–1996 period and reached a minimum value of -40 % in the 1999–2003 time-period relative to the 1991-1995 baseline loading and increased slightly afterwards, but remained below the 1991-1995 baseline values. The average reduction achieved was approximately 27% for all periods beginning with 1992–1996 (Figure 10). Flow-normalized TKN loading for Neuse River at Kinston decreased from the baseline period and reached the minimum values of -15% in the 1994-1998 period and increased gradually afterwards and reached a maximum of 35% in the 2011-2015 period. Flow-normalized TKN loading has been consistently higher than the 1991–1995 baseline period throughout the past 19 years starting from the 1998-2002 period and increased by an average 19% during this period. Since ammonia loading declined by about 36% over the same time-period, the increase in TKN loading was primarily due to an increase in the Org-N fraction during mid and high flow events. The recent increase in NOx and TKN flow normalized loadings is mainly due to increases for the high flow intervals.

Flow-normalized TN loading exhibited the combination of the patterns for NOx and TKN and has been consistently lower than the corresponding 1991-1995 baseline loading until the 2011-2015 period. The flow-normalized TN loading decreased to a minimum value of -20% in the 1999-2003 period and increased gradually afterwards. The average reduction in flow-normalized TN loading for the periods ending in 2011-2015 was approximately 11%. TP loading was consistently higher than the 1991-1995 loading for all periods ending in 2013-2017 (Figure 11). The increase in TP loading relative to the 1991-1995 period ranges from 4 to 23%. Similar results are reported for the Neuse River at Kinston station for the period ending in 2015 (AquAeTer, 2016).

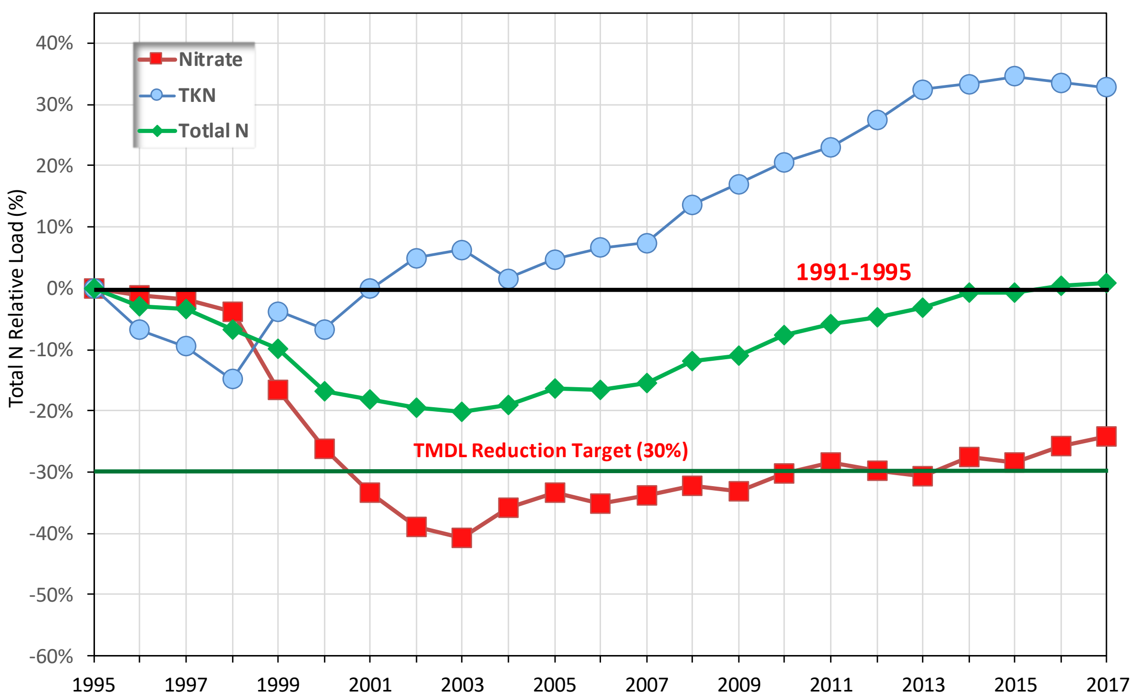

Figure 10. Nitrogen reduction for average flow condition compared to the 1991-1995 baseline for Neuse River at Kinston

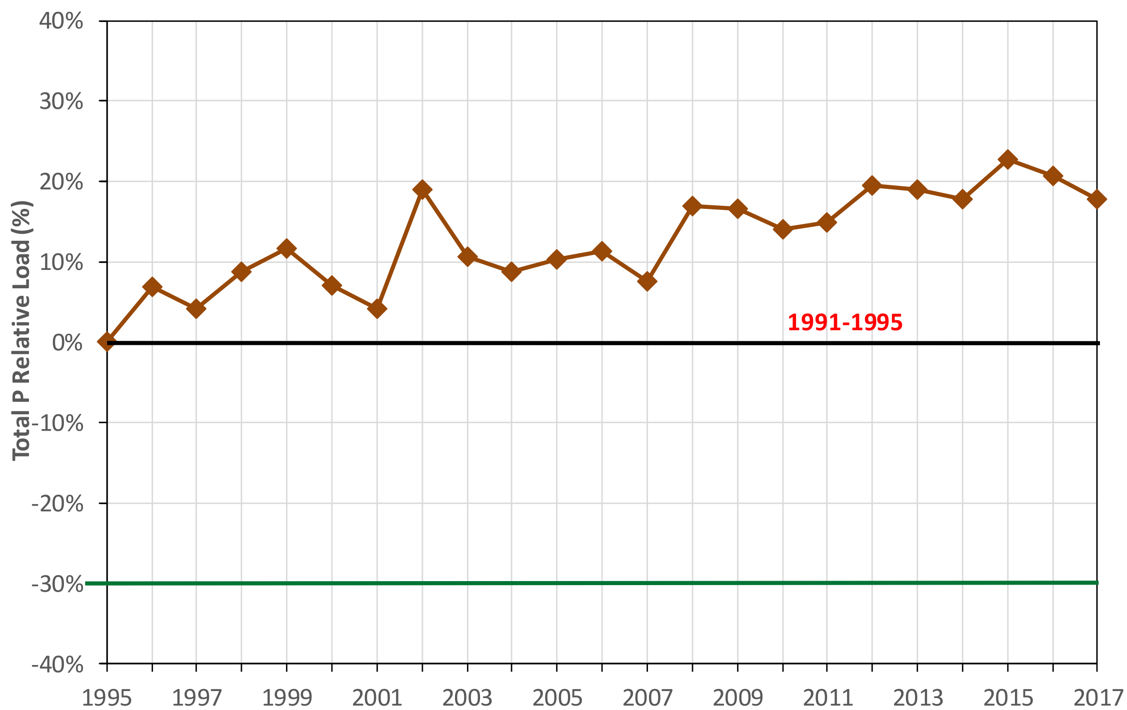

Figure 11. TP reduction for average flow condition compared to the 1991-1995 baseline for Neuse River at Neuse River at Kinston

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Changes in Concentration

Table 12 shows average concentrations of N fraction by flow interval at the Neuse River at Kinston. Peak concentration of NOx was observed in the early 1980s, but concentrations of NOx, TKN, and TN decreased through the mid-1990s. Subsequently, concentrations started to increase in the late 1990s and early 2000s and continued to increase gradually from 2006-present. The average concentrations of NOx decreased more for the low and middle flow intervals than the high flow intervals. The average concentration of the TKN fraction increased more for the middle and high flow intervals. For example, reductions in NOx for the 2001–2017 period from corresponding values for 1991–2000 were 49%, 25%, and 7%, respectively, for the low, middle, and high flow intervals. Conversely, the changes in TKN concentrations for 2001-2017 from the corresponding values for 1991-2000 were 24%, 38%, and 28%, respectively, for the low, middle, and high flow intervals.

TN concentrations decreased for low flow and middle flow intervals by 29%, and 2%, respectively, and increased by 11% for high flow intervals during the same period. The increase in TKN for middle and high flow intervals and in TN concentrations for high flow intervals could indicate that high flow events deliver more TKN from sediments and other NPS landscape processes. Total Phosphorus concentrations for the 2013-2017 period decreased by 5% for low flow intervals, and increased by 20, and 13% for middle and high flow intervals, respectively, from corresponding values for the 1991-2000 period.

Table 12. Average nutrient concentrations at Neuse River at Kinston by 5-year period and flow interval

Period	Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
1980-1984	0.887	0.772	0.637	0.63	0.54	0.49	1.49	1.31	1.12
1981-1985	0.929	0.740	0.626	0.58	0.54	0.48	1.51	1.28	1.11
1986-1990	1.122	0.906	0.574	0.58	0.66	0.65	1.70	1.54	1.23
1991-1995	1.333	0.997	0.603	0.46	0.47	0.53	1.78	1.42	1.12
1996-2000	0.942	0.707	0.458	0.33	0.43	0.51	1.27	1.14	0.97
2001-2005	0.538	0.648	0.445	0.40	0.55	0.55	0.94	1.19	1.00
2006-2010	0.482	0.629	0.490	0.49	0.55	0.66	0.97	1.18	1.15
2011-2015	0.597	0.611	0.502	0.52	0.66	0.72	1.12	1.28	1.22
2012-2016	0.627	0.631	0.521	0.53	0.67	0.71	1.15	1.30	1.23
2013-2017	0.682	0.654	0.523	0.51	0.67	0.71	1.19	1.33	1.23
	Ammonia (mg/L)			Total P (mg/L)					
1980-1984	0.073	0.074	0.078	0.278	0.244	0.141			
1981-1985	0.083	0.079	0.075	0.291	0.248	0.144			
1986-1990	0.091	0.099	0.060	0.285	0.183	0.122			
1991-1995	0.073	0.081	0.063	0.143	0.119	0.090			
1996-2000	0.055	0.073	0.085	0.115	0.111	0.105			
2001-2005	0.032	0.045	0.035	0.118	0.135	0.102			
2006-2010	0.031	0.038	0.040	0.118	0.132	0.108			
2011-2015	0.037	0.046	0.044	0.124	0.147	0.116			
2012-2016	0.041	0.046	0.046	0.126	0.145	0.113			
2013-2017	0.040	0.048	0.047	0.126	0.136	0.112			

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Flow Normalized Loading Analysis Results – Contentnea Creek

Figure 12 shows annual TN loading for Contentnea Creek at Hookerton. The results show that annual TN loading at Hookerton ranged from 0.9 to 4.0 x 10^6 lbs/year for the 1990–2017 timeframe, with a median value of 1.8 x 10^6 lbs/year. Average contributions of ammonia, NOx, and Org-N to the TN load for the 1990–2017 period were 6.3, 49.3 and 44.4%, respectively. The Org-N fraction and the NOx fraction to TN loading ranged from 33 to 69 and 23 to 57%, respectively. The average Org-N and NOx contribution were 44% and 50% of TN for the 1990 –2017 period. Figure 13 shows annual TN loading at Contentnea Creek at Hookerton by flow interval. The average TN contributions from the low, middle, and high flow intervals were 5, 20 and 75%, respectively. The annual TP loading ranged from 0.10 to 0.6 x 10^6 lbs/year, with a median value of 0.20 x 10^6 lbs/year. The average TP contributions from low, middle, and high flows were 8, 19 and 71%, respectively (Figure 14).

These results show that high flow events contribute substantially large amount of nutrients in this watershed, possibly from sediments and other nonpoint source processes. These include, increases in sediment release from agricultural runoff, forest converted to farmland, erosion from upstream development, washout of upstream legacy millponds and mid- and lower watershed swamps and wetlands by increasingly “flashy” storm events which could be a significant source of nitrogen (Lebo et al. 2011).

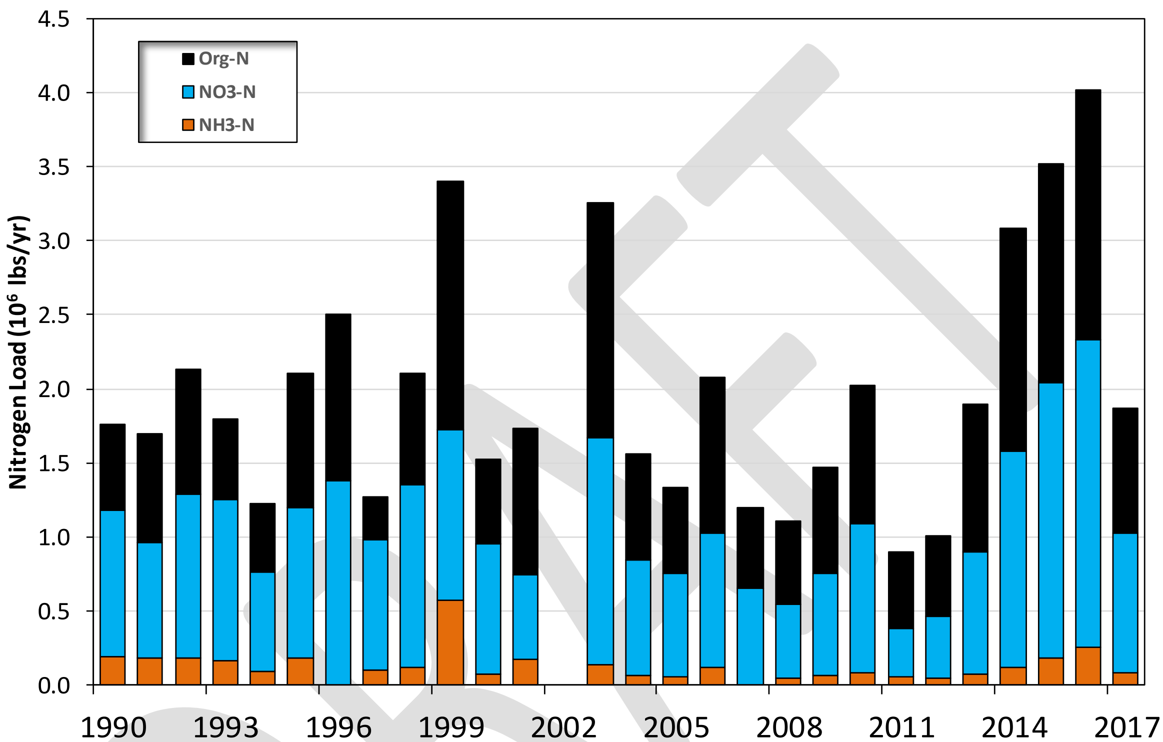

Figure 12 – Annual total N load by constituents for Contentnea Creek at Hookerton

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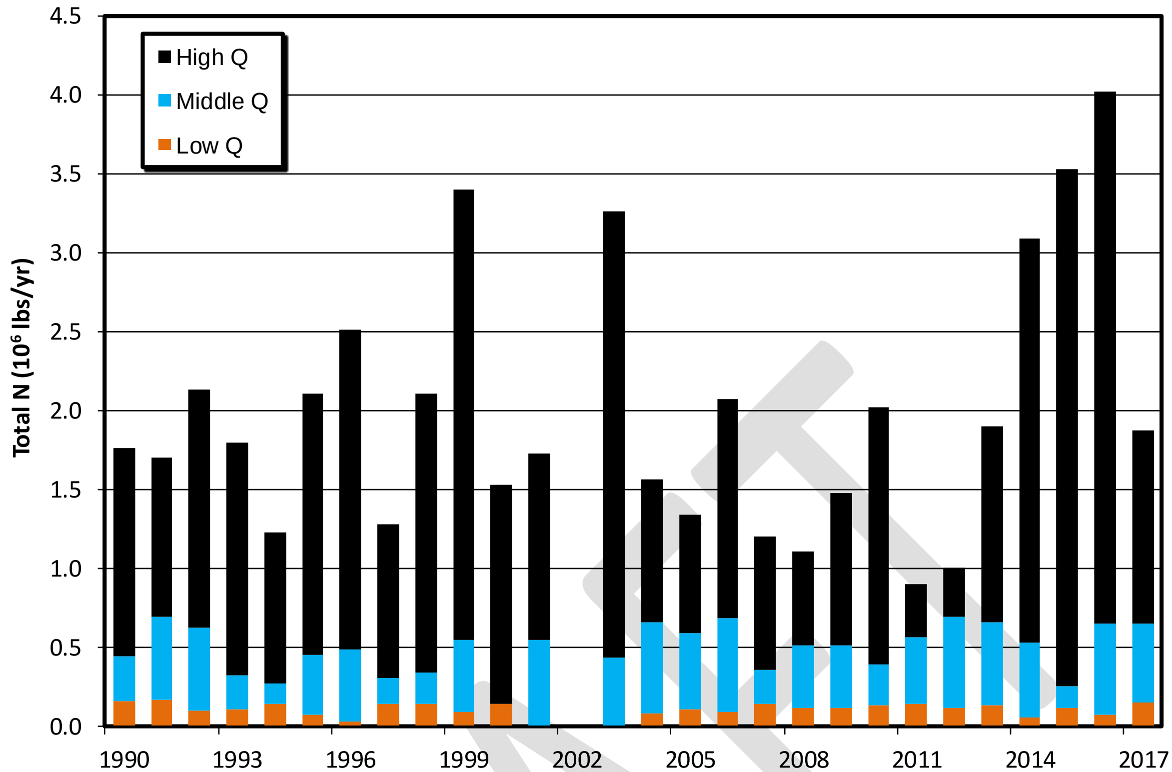

Figure 13. Annual total N load by flow bin for Contentnea Creek at Hookerton

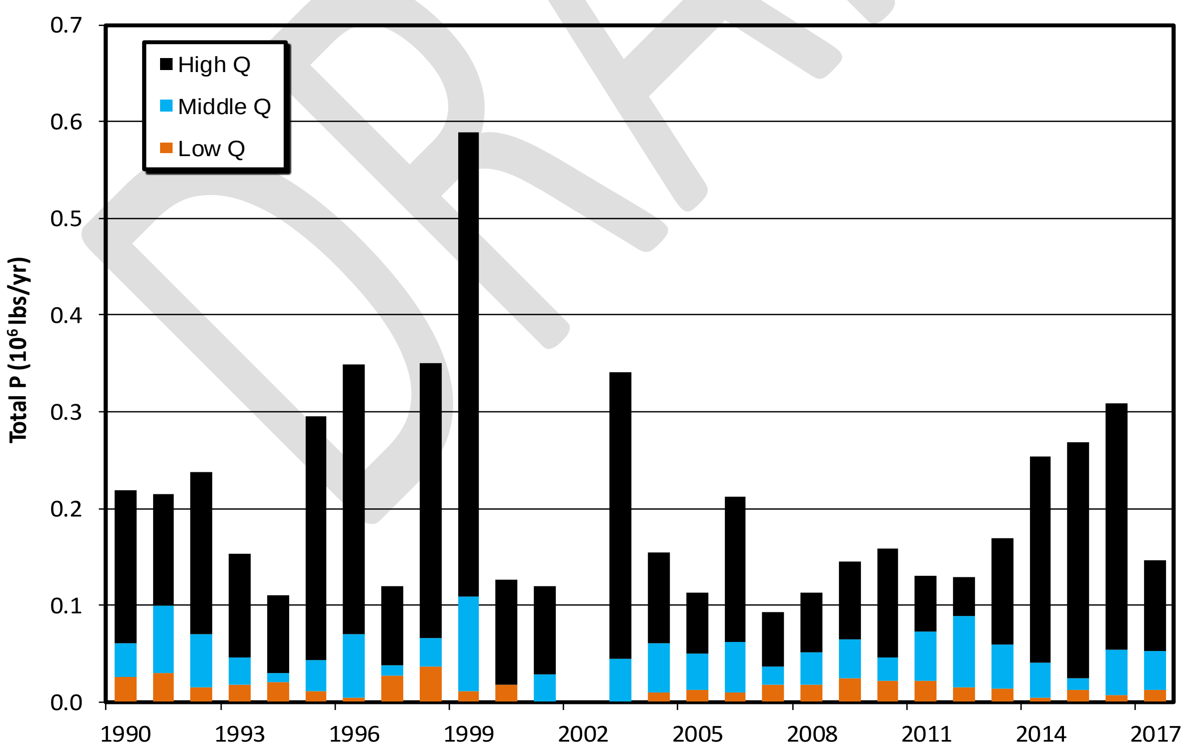

Figure 14. Annual total P load by flow bin for Contentnea Creek at Hookerton

At the Contentnea Creek location, flow normalized NOx predicted loads based on the long-term flow average steadily decreased for 1991-1995 period through 1998-2002. This increase was followed by a slight increase through 2013-2017. The flow normalized loads decreased from 0.97 x 10^6 lbs/yr in 1991-1995 to 0.78 x 10^6 lbs/yr in 1998-2002 and steadily increased to 1.0 x 10^6 lbs/yr in 2013-2017. A steady decrease in TKN loads was observed for the 1991-1995 through 1998-2002 periods from 0.77 x 10^6 to 1.14 x 10^6 lbs/yr through the 2013 -2017 periods. Overall, Org-N and NOx constitute around 46% and 48% of the TN load, respectively and a large fraction of the NOx and TKN load occurred during middle and high flow conditions. Predicted FN loads for long-term average hydrology for the selected stations are provided in Appendix B.

Changes in TN load exhibited the combination of patterns of the NOx load and the TKN load. The TN load for long-term average flow conditions steadily decreased until the 1998-2002 period and steadily increased afterwards. The flow normalized TN loads decreased from 1.84 x 10^6 lbs/yr in 1991-1995 to 1.62 x 10^6 lbs/yr in the 1998-2002 period and steadily increased afterwards to 2.14 x 10^6 lbs/yr through the 2013-2017 period. Flow normalized TP loads at the Contentnea Creek station steadily increased from 0.19 x 10^6 lbs/yr from the 1991-1995 period to 0.25 x 10^6 lbs/yr for the 1998-2002 period and then steadily declined to 0.18 x 10^6 lbs/yr through the 2013-2017 period. A large proportion of the P load occurred during the high flow conditions.

The results of the FN loading analysis indicate reduction in NOx loading, but an increase in TKN loading for the majority of the five-year periods (Figure 15). Flow-normalized NOx loading decreased beginning in the 1992–1996 period and reached a minimum value of -20 % in the 1998–2002 time-period relative to the 1991-1995 baseline loading and increased steadily afterwards. The average reduction achieved was approximately 8% for all periods beginning with 1992–1996 (Figure 15). The flow-normalized TKN loading for Contentnea Creek at Hookerton decreased from the baseline period and reached a minimum value of -11% in the 1996-2000 period and increased gradually afterwards reaching a maximum of 32%.

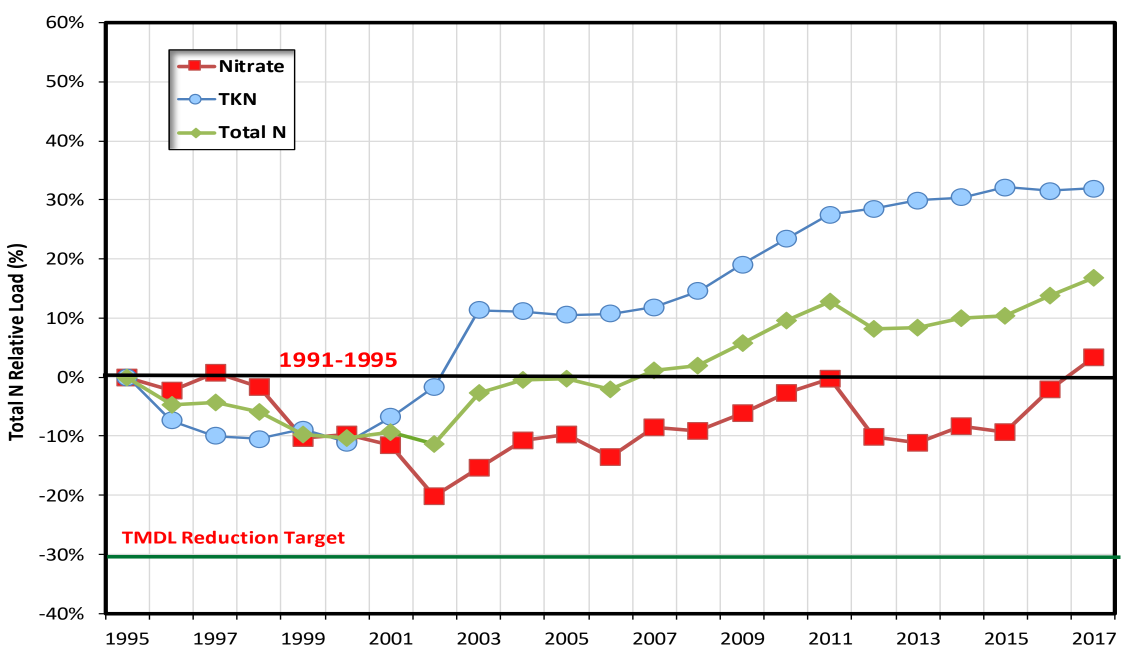

Figure 15. Nitrogen reduction for average flow condition compared to the 1991-1995 baseline for Contentnea Creek at Hookerton

Flow-normalized TKN loading has been consistently higher than the 1991–1995 baseline period throughout the past 15 years starting from the 1998-2002 period and increased by an average 22% during this period. Since ammonia loading declined by about 50% over the same time-period, the increase in TKN loading was primarily due to an increase in the Org-N fraction during mid and high flow events. The recent increase in NOx and TKN flow normalized loadings is mainly due to increases for the high flow intervals.

Flow-normalized TN loading exhibited the combination of the patterns for NOx and TKN and has been consistently lower than the corresponding 1991-1995 baseline loading until the 1998-2002 period. The flow-normalized TN loading decreased to a minimum value of -11% in the 1998-2002 period and increased gradually afterwards. The average reduction in flow-normalized TN loading for the periods ending in 1998-2002 was approximately 9%. Total Nitrogen loading was consistently higher than the 1991-1995 baseline period and increased by an average of 6% during this period. The reduction in TP relative to the 1991-1995 period ranges from -8 to 31% (Figure 16). Similar results are reported for the Contentnea Creek at Hookerton station for the period ending in 2015 (AquAeTer, 2016).

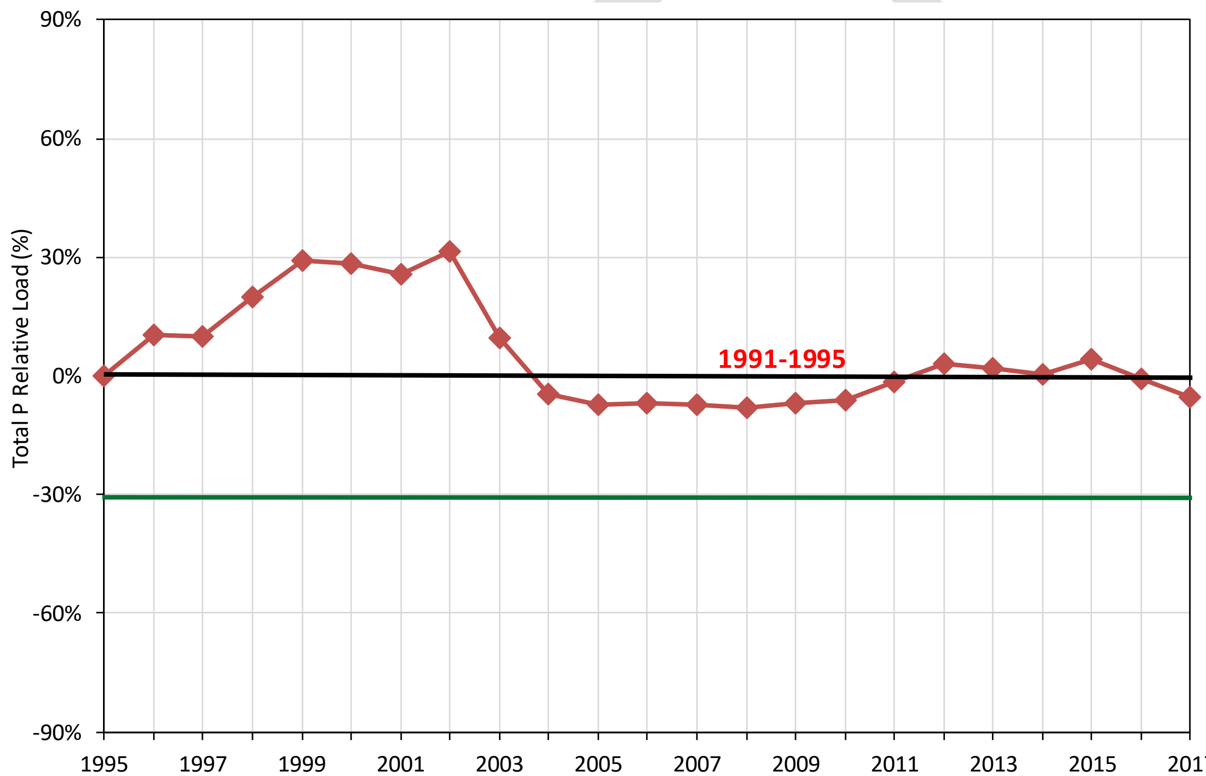

Figure 16. TP Reduction for average flow condition compared to the 1991-1995 baseline for Contentnea Creek at Hookerton

<u>Changes in Concentration</u>

Table 13 shows average concentrations of nitrogen fractions and phosphorus by flow interval at Contentnea Creek at Hookerton. Peak concentration of NOx was observed in the early 1980s, but concentrations of NOx and TN decreased through the mid-1990s before concentrations started to increase in the late 2000s. TKN concentrations showed a rapid decrease in concentrations in the early 1990s and remained fairly steady until early 2000s where it started a gradual increase from 2000-

present. The average concentrations of the NOx fraction decreased more for the low and middle flow intervals and increased for high flow intervals. The average concentrations of the TKN fraction increased more for the middle and high flow intervals. For example, reductions in NOx for the 2001–2017 period from corresponding values for 1991–2000 were 11 and 7%, respectively, for the low, and middle flow intervals and the increase for high flow interval was 5%. The changes in TKN concentrations for the 2001-2017 values from the corresponding values for 1991-2000 were 26%, 28%, and 35%, respectively, for the low, middle, and high flow interval. TN concentrations increased for low flow, middle flow, and high flow intervals by 3, 7, and 20%, respectively during the same period. The increase in TKN and TN concentrations for middle and high flow intervals could indicate that high flow events deliver more TKN from sediments and other NPS landscape processes. Phosphorus concentrations decreased more during low flow and middle flow conditions than high flows. Total Phosphorus concentrations for 2013-2017 period decreased by 23, 22, and 12% for low, middle, and high flow intervals, respectively, from the corresponding value for 1991-2000 period.

Table 13. Average nutrient concentrations at Contentnea Creek at Hookerton by 5-year period and flow interval

Period	Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
1980-1984	1.798	1.840	1.247	0.883	0.738	0.763	2.681	2.578	2.010
1981-1985	1.723	1.548	1.304	0.925	0.700	0.817	2.648	2.248	2.120
1986-1990	1.246	1.000	0.741	0.963	0.782	0.572	2.180	1.782	1.313
1991-1995	0.748	0.723	0.596	0.525	0.528	0.577	1.273	1.252	1.172
1996-2000	0.807	0.690	0.519	0.434	0.493	0.509	1.242	1.183	1.028
2001-2005	0.686	0.676	0.531	0.567	0.576	0.640	1.252	1.252	1.171
2006-2010	0.639	0.690	0.590	0.597	0.624	0.722	1.236	1.313	1.312
2011-2015	0.646	0.592	0.560	0.633	0.681	0.771	1.278	1.273	1.331
2012-2016	0.700	0.634	0.606	0.611	0.691	0.765	1.310	1.325	1.370
2013-2017	0.781	0.680	0.633	0.619	0.695	0.766	1.400	1.375	1.400

	Ammonia (mg/L)			Total P (mg/L)		
1980-1984	0.253	0.259	0.159	0.458	0.362	0.210
1981-1985	0.392	0.297	0.197	0.513	0.364	0.231
1986-1990	0.489	0.298	0.105	0.497	0.272	0.149
1991-1995	0.128	0.146	0.095	0.195	0.129	0.119
1996-2000	0.091	0.099	0.110	0.207	0.183	0.151
2001-2005	0.058	0.057	0.048	0.144	0.112	0.115
2006-2010	0.051	0.061	0.050	0.190	0.117	0.112
2011-2015	0.048	0.056	0.055	0.158	0.130	0.128
2012-2016	0.046	0.058	0.057	0.143	0.127	0.122
2013-2017	0.045	0.061	0.059	0.135	0.112	0.119

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Flow-Normalized Loading Analysis Results – Trent River

Figure 17 shows annual TN loading for Trent River at Trenton. The results show that annual TN loading at Trenton ranged from 0.2 to 1.1 x 10^6 lbs/year for the 1990–2017 timeframe, with a median value of 0.4 x 10^6 lbs/year. Average contributions of ammonia, NOx, and Org-N to the TN load for 1990–2017 period were 4.2, 47.2 and 48.6%, respectively. The Org-N fraction and the NOx fraction to TN loading ranged from 16 to 64 and 31 to 80%, respectively. The average Org-N and NOx contribution were 49% and 46% of TN for 1990 –2017 period. Figure 18 shows annual TN loading at Trent River at Trenton by flow interval. The average TN contributions from low, middle, and high flow interval were 3, 16 and 81%, respectively. The annual TP loading ranged from 0.08 to 2.0 x 10^5 lbs/year, with a median value of 0.3 x 10^5 lbs/year. The average TP contributions from low, middle, and high flows were 3, 17 and 80%, respectively (Figure 19).

These results show that high flow events contribute substantially large amount of nutrients in this watershed, possibly from sediments and other nonpoint source processes.

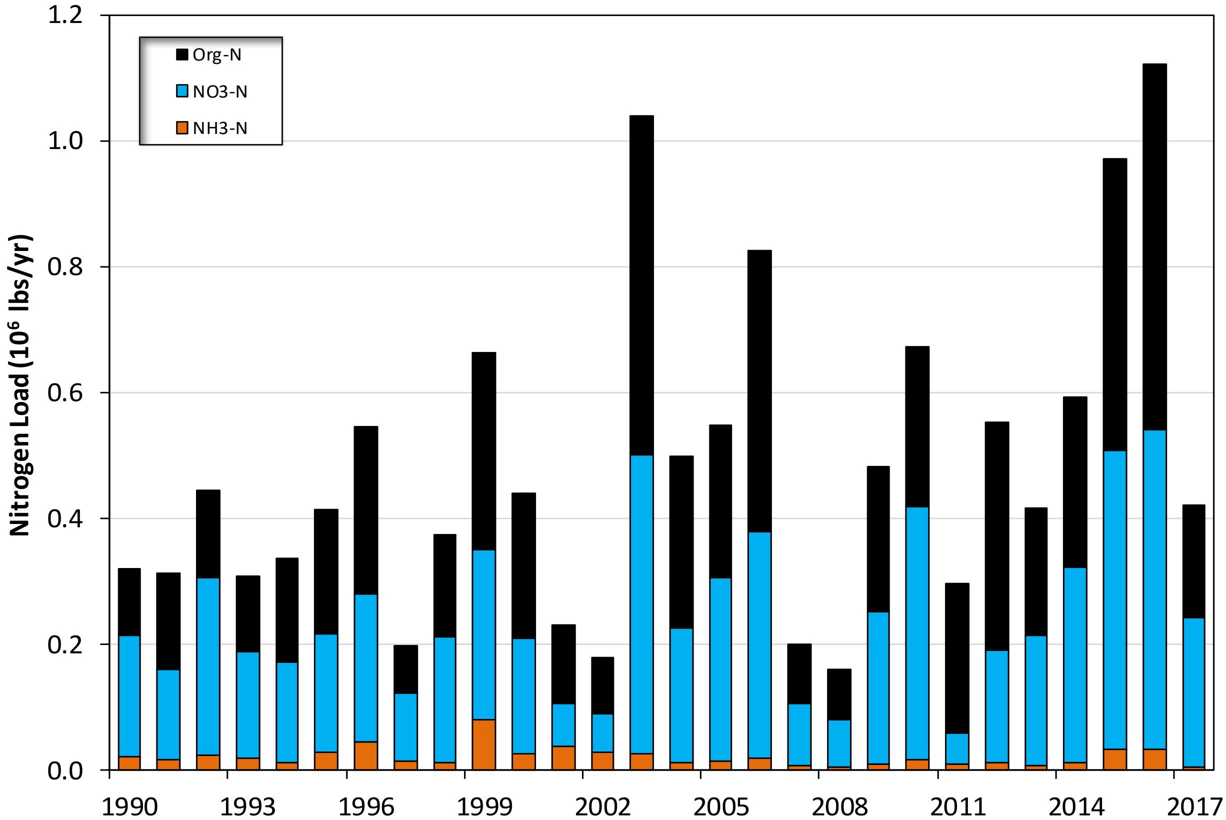

Figure 17 – Annual total N load by constituent for Trent River at Trenton

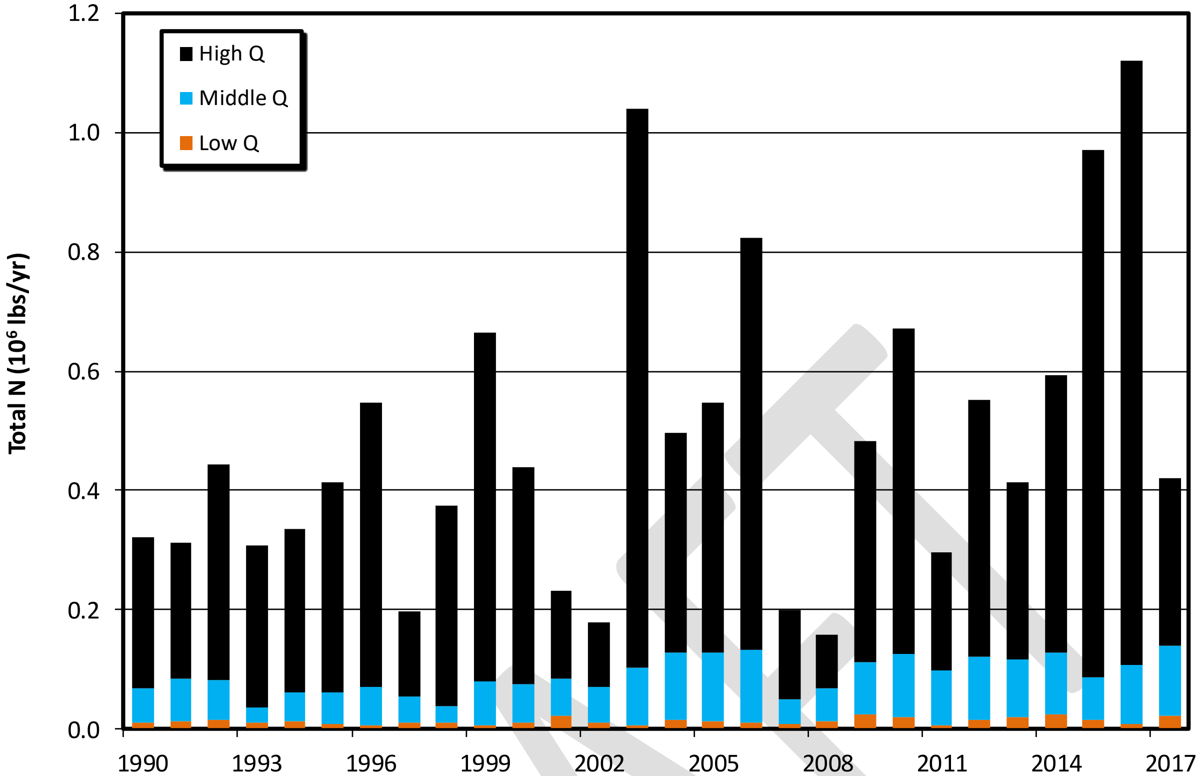

Figure 18. Annual total N load by flow bin for Trent River at Trenton

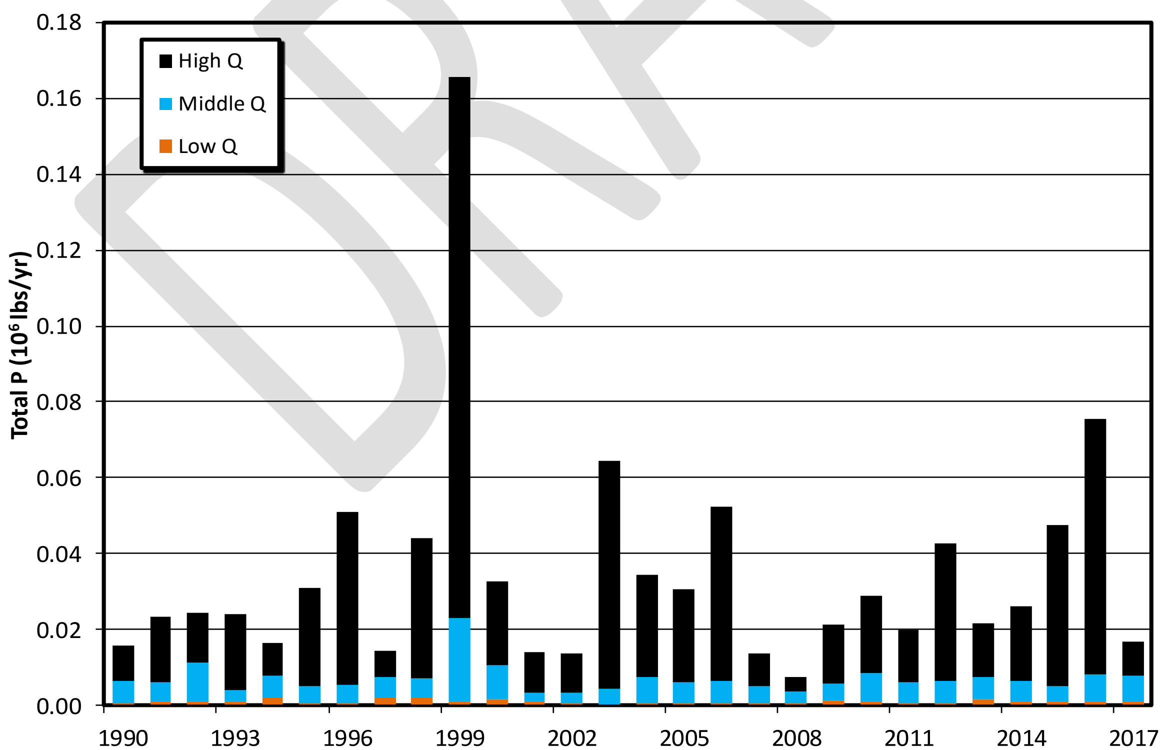

Figure 19. Annual total P load by flow bin for Trent River at Trenton

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At the Trent River location, flow normalized NO3-N predicted loads based on the long-term flow average steadily decreased from the 1991-1995 period through 1998-2002. This decrease was followed by a slight increase through 2013-2017. The flow normalized loads decreased from 0.21 x 10^6 lbs/yr in 1991-1995 to 0.17 x 10^6 lbs/yr in 1998-2002 and steadily increased to 0.29 x 10^6 lbs/yr in 2013-2017. A slight decrease in TKN loads was observed at the Trent River location for the 1991-1995 through 1994-1998 periods from 0.0.38 x 10^6 to 0.35 x 10^6 lbs/yr and then it steadily increased to 0.6 x 10^6 lbs/yr through the 2013 -2017 periods. Overall, Org-N and NOx constitute around 49% and 46% of the TN load, respectively. A large fraction of the NOx and TKN load and increases occurred during middle and high flow conditions. Predicted FN loads for long-term average hydrology for the selected stations are provided in Appendix B.

Changes in TN load followed the combination of patterns of changes in NOx load and TKN load. The TN load for long-term average flow conditions steadily decreased until the 1994-1998 period and steadily increased afterwards. The flow normalized TN loads decreased from 0.38 x 10^6 lbs/yr in 1991-1995 to 0.35 x 10^6 lbs/yr in 1994-1998 period and steadily increased afterwards to 0.6 x 10^6 lbs/yr through the 2013-2017 period. Flow normalized TP loads at the Trent River station steadily increased from 0.02 x 10^6 lbs/yr from the 1991-1995 period to 0.07 x 10^6 lbs/yr for the 1999-2003 period and then stayed around 0.03 x 10^6 lbs/yr from the 2000-2004 period through the 2013-2017 period. A large proportion of the P load also occurred during high flow conditions.

The results of the FN loading analysis indicate increases in NOx, TKN, and TN loading (Figure 20). Flow-normalized NOx loading slightly decreased beginning in the 1992–1996 period and reached a minimum value of -15 % in the 1995–1999 time-period relative to the 1991-1995 baseline loading and increased steadily afterwards reaching a maximum of 59% in the 2007-2011 time-period. The average reduction achieved was approximately 12% for periods beginning with 1992–1996 and ending with 1999-2003. The average NOx increase for periods beginning 2000-2004 and ending with 2013-2017 was approximately 37% (Figure 20). Flow-normalized TKN loading for Trent River at Trenton decreased from the baseline period and reached a minimum value of -5% in the 1993-1997 period, increased steadily afterwards and reached a maximum of 73% in the 2008-2012 period. Flow-normalized TKN loading has been consistently higher than the 1991–1995 baseline period throughout the past 22 years starting from the 1995-1999 period. Flow-Normalized TKN loading has increased by an average 44% during this period. Ammonia loading increased by about 40% between the 1992-1996 and 2001-2005 periods, but the loading declined by about 37% over the period beginning in 2002-2006 and ending in 2013-2017. TKN in the Trent River at Trenton showed a clear trend of increasing load over the study period. The increase in TKN loading was primarily due to an increase in the Org-N fraction during mid and high flow events.

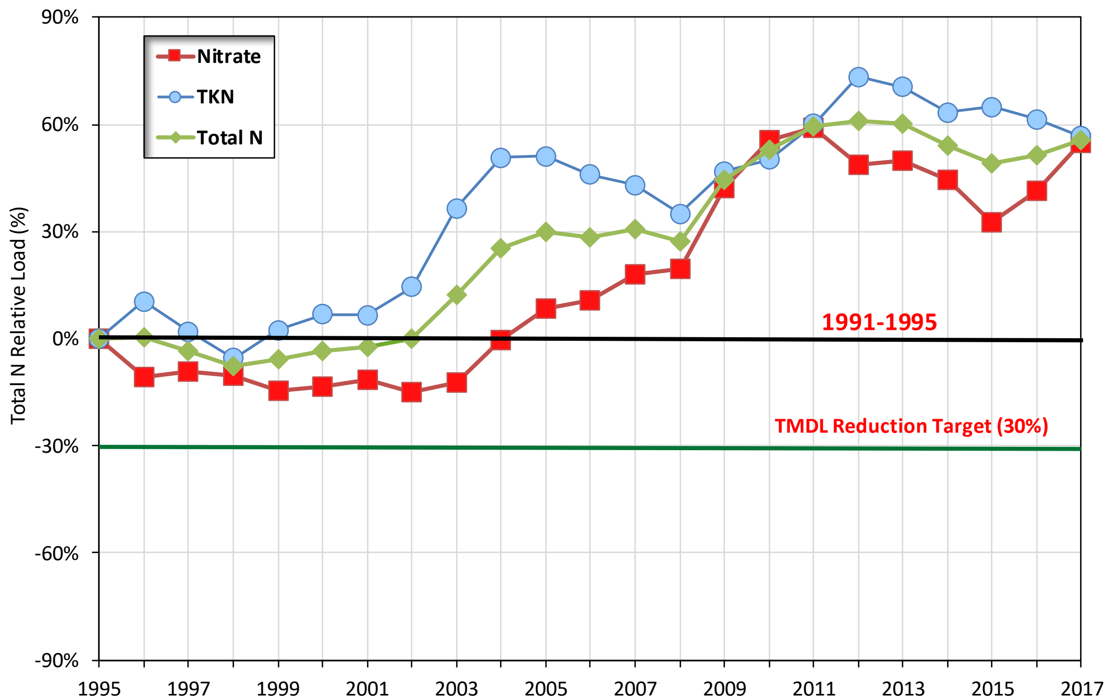

Figure 20. Nitrogen reduction for average flow conditions compared to the 1991-1995 baseline for Trent River at Trenton

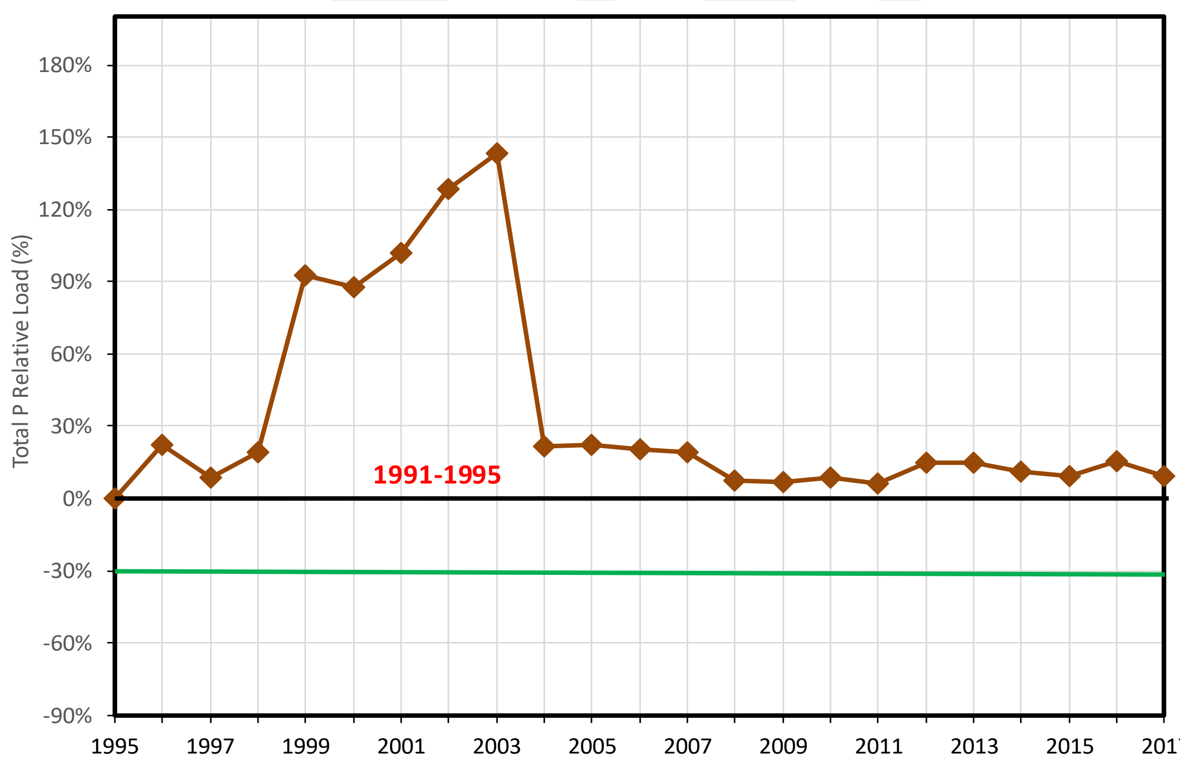

Figure 21. TP reduction for average flow conditions compared to the 1991-1995 baseline for Trent River at Trenton

Flow-normalized TN loading exhibited the combination of patterns for NOx and TKN and has been consistently higher than the corresponding 1991-1995 baseline loading after the 1998-2002 period. The flow-normalized TN loading decreased to a minimum value of -8% in the 1994-1998 period and increased gradually afterwards. The average reduction in flow-normalized TN loading for the periods ending in 1998-2002 was approximately 2%. Total Nitrogen loading was consistently higher than the 1991-1995 baseline period after the 1998-2000 period and increased to an average of 43% during this period. Flow Normalized TP loading was consistently higher than the 1991-1995 period baseline loading and the increase ranges from 6 to 143% relative to the 1991-1995 loading with peak loading observed during 1999-2003 period possibly resulting from the impact of hurricanes in the late 1990s (Figure 21). Similar results are reported for the Trent River station at Trenton for the period ending in 2015 (AquAeTer, 2016).

Changes in Concentration

Table 14 shows average concentrations of N fractions and P by flow interval at Trent River at Trenton. The NOx concentration generally decreased during the 1990s to a minimum in the 1996-2000 period and increased afterwards. There was very small difference in NOx concentrations across the three flow intervals. The TN and TKN concentrations showed similar patterns reaching a minimum during 1996-2000 period and gradually increasing afterwards.

There was little or no difference in the average concentrations among the three flow intervals. The average concentrations of the NOx fraction increased by 52, 49, and 48% for low, middle, and high flow intervals, respectively, from 1991-2000 to 2001-2017. Similarly, the increases in TKN concentrations for the 2001-2017 period from the corresponding values for 1991-2000 were 64%, 59%, and 50%, respectively, for the low, middle, and high flow interval. TN concentrations increased for low flow, middle flow, and high flow intervals by 57, 54, and 49%, respectively during the same period. Overall, there have been increases in concentrations of several N fractions over the past 18 years.

Total Phosphorus concentrations for 2013-2017 period decreased by 39, 35, and 17% for low, middle, and high flow intervals, respectively, from corresponding value for 1991-2000 period. TP concentrations were relatively higher in the 1996-2000 period possibly resulting from the impacts of hurricanes in the region in the late 1990s. Overall, TP concentrations decreased more for low flow and middle flow interval than high flows.

Table 14. Average nutrient concentrations at Trent River at Trenton by 5-year period and flow interval

Period	Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
1980-1984	0.878	0.617	0.464	0.35	0.40	0.45	1.23	1.01	0.92
1981-1985	0.729	0.558	0.487	0.35	0.35	0.45	1.07	0.91	0.94
1986-1990	0.615	0.605	0.600	0.41	0.40	0.42	1.03	1.01	1.02
1991-1995	0.612	0.522	0.492	0.43	0.47	0.51	1.05	0.99	1.01
1996-2000	0.562	0.482	0.418	0.36	0.46	0.56	0.92	0.94	0.98
2001-2005	1.018	0.723	0.491	0.58	0.62	0.79	1.61	1.34	1.29
2006-2010	0.718	0.903	0.757	0.61	0.73	0.77	1.33	1.63	1.53
2011-2015	0.811	0.666	0.658	0.68	0.82	0.84	1.49	1.49	1.50
2012-2016	0.904	0.727	0.696	0.66	0.78	0.83	1.57	1.50	1.52
2013-2017	1.002	0.737	0.772	0.69	0.73	0.80	1.70	1.47	1.58
	Ammonia (mg/L)			Total P (mg/L)					
1980-1984	0.030	0.035	0.031	0.067	0.073	0.042			
1981-1985	0.034	0.039	0.027	0.078	0.060	0.047			
1986-1990	0.059	0.043	0.026	0.096	0.079	0.065			
1991-1995	0.059	0.048	0.059	0.114	0.111	0.065			
1996-2000	0.052	0.055	0.090	0.172	0.157	0.133			
2001-2005	0.066	0.048	0.066	0.083	0.067	0.094			
2006-2010	0.025	0.050	0.030	0.071	0.100	0.076			
2011-2015	0.025	0.049	0.040	0.088	0.084	0.079			
2012-2016	0.019	0.024	0.043	0.091	0.092	0.083			
2013-2017	0.019	0.026	0.043	0.100	0.091	0.077			

Flow-Normalized Loading Analysis Results - Goldsboro

Figure 22 shows annual TN loading for the Neuse River at Goldsboro. The results show that annual TN loading at Goldsboro ranged from 0.7 to 8.4 x 10^6 lbs/year for the 1990–2017 timeframe, with a median value of 4.7 x 10^6 lbs/year. Average contributions of ammonia, NOx, and Org-N to the TN load for the 1990–2017 period were 6, 47 and 47%, respectively. The Org-N fraction and the NOx fraction to TN loading ranged from 28 to 67 and 27 to 67%, respectively. Figure 23 shows annual TN loading at the Neuse River at Goldsboro by flow interval. The average TN contributions from low, middle, and high flow intervals were 9, 22 and 69%, respectively. The annual TP loading ranged from 0.11 to 1.0 x 10^6 lbs/year, with a median value of 0.50 x 10^6 lbs/year. The average TP contributions from low, middle, and high flows were 9, 23 and 68%, respectively (Figure 24).

These results show that high flow events contribute substantially large amount of nutrients in this watershed, suggesting that high flow events deliver more nutrients possibly from sediments and other nonpoint source processes.

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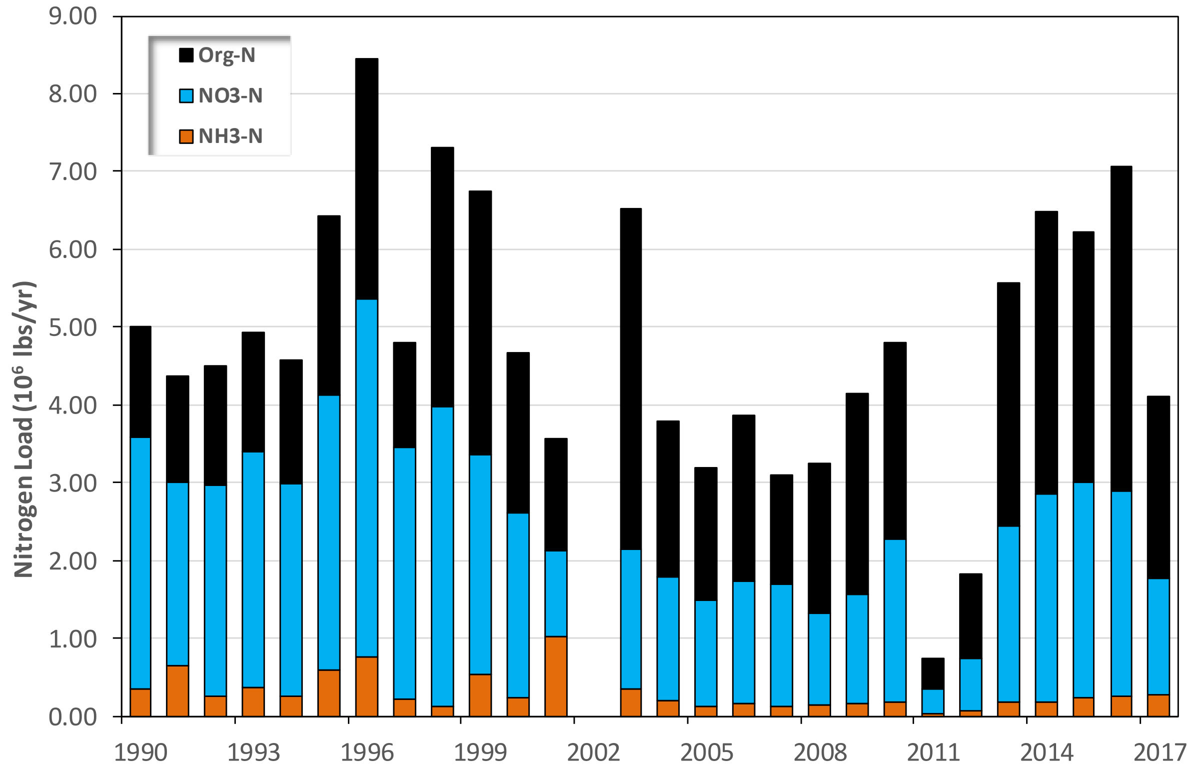

Figure 22 – Annual total N load by constituents for Neuse River at Goldsboro

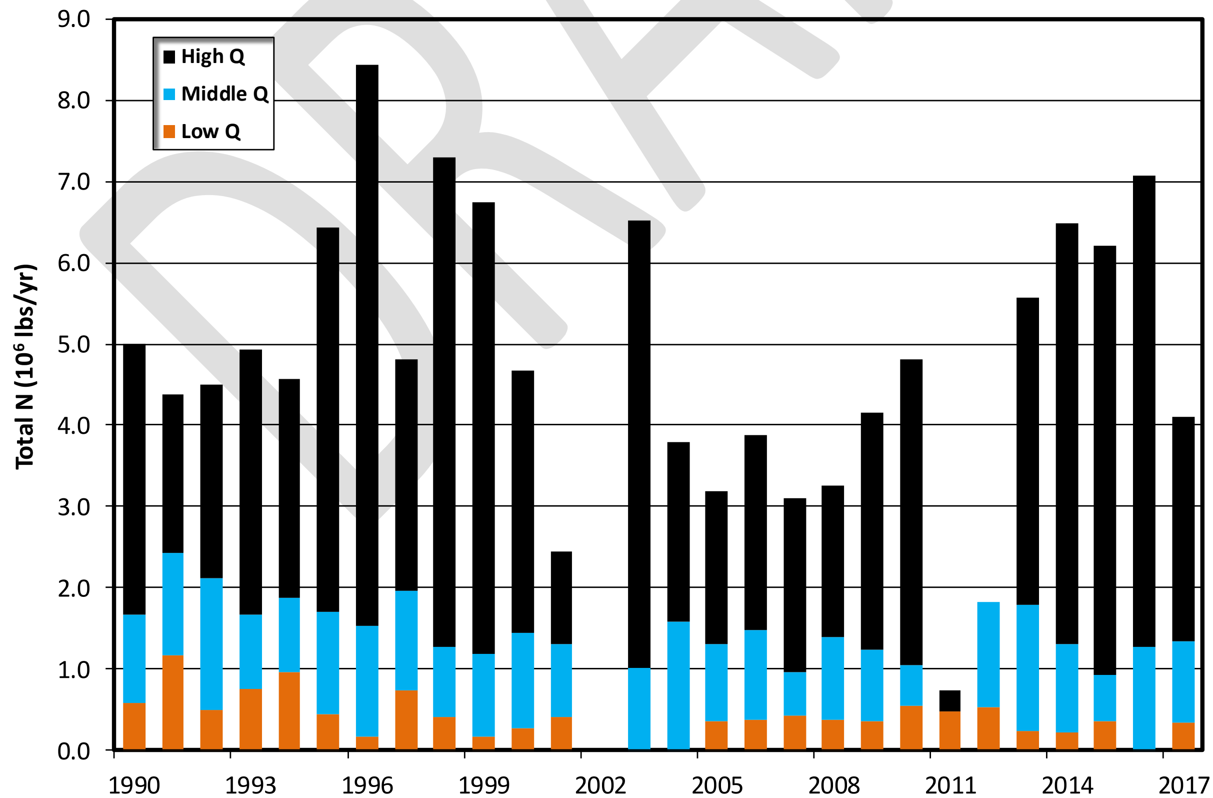

Figure 23. Annual total N load by flow bin for Neuse River at Goldsboro

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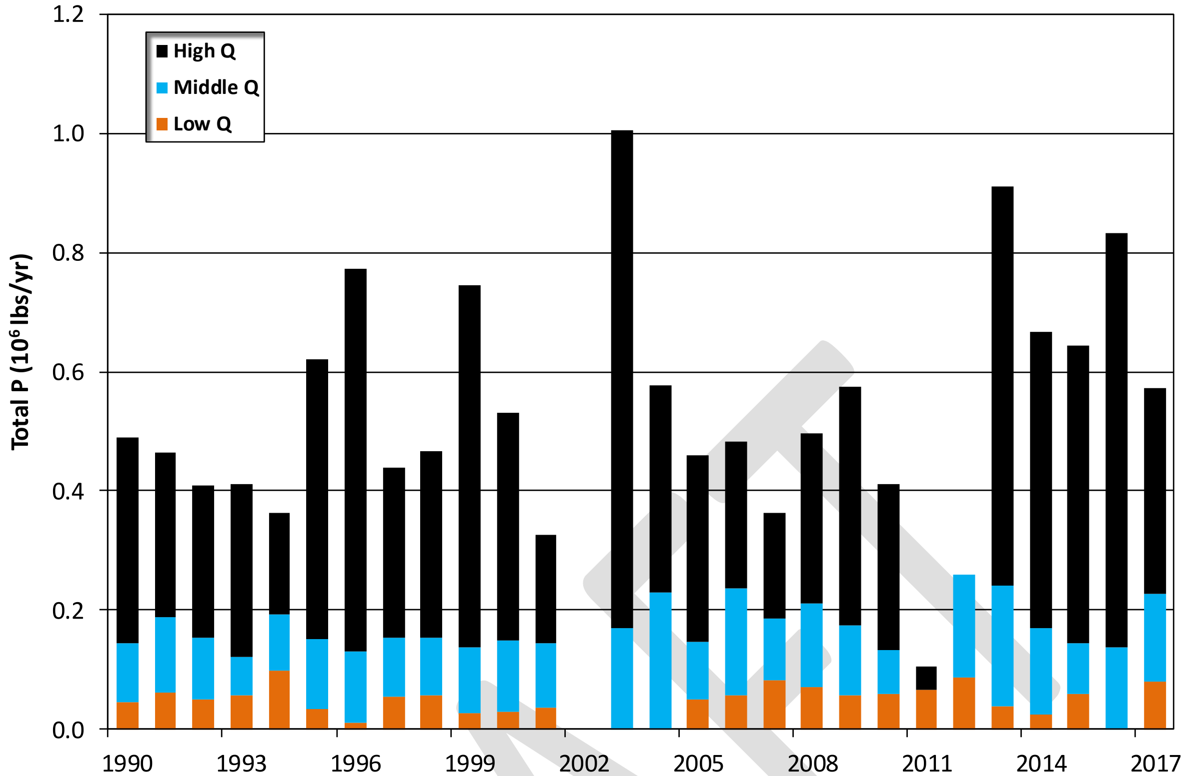

Figure 24. Annual total P load by flow bin for Neuse River at Goldsboro

At the Goldsboro location, flow normalized NOx predicted loads based on the long-term flow average steadily decreased for the 1991-1995 period through 2002-2006. This decrease was followed by a slight increase from 2003-2007 through 2013-2017. The flow normalized loads decreased from 2.9 x 10^6 lbs/yr in 1991-1995 to 1.6 x 10^6 lbs/yr in 2002-2006 and increased from 1.7 x 10^6 lbs/yr in 2003-2007 to 2.0 x 10^6 lbs/yr in 2013-2017. A steady increase in TKN loads was observed at Goldsboro for the 1991-1995 through 2009-2013 periods from 2.1 x 10^6 to 3.2 x 10^6 lbs/yr and slightly decreased to 2.9 x 10^6 lbs/yr for the 2013-2017 period. Overall, a large fraction of the NOx and TKN loads occurred during middle and high flow conditions. Predicted FN loads for long-term average hydrology for the selected stations are provided in Appendix B.

Changes in TN load exhibited the combination of patterns of the decrease in the NOx load in the 2000s and the increasing pattern observed for TKN load. The TN load for long-term average flow conditions steadily decreased until the 1999-2003 period and steadily increased through the 2013 -2017 period. The flow normalized loads decreased from 5.0 x 10^6 lbs/yr in 1991-1995 to 4.0 x 10^6 lbs/yr in 1999-2013 and slightly increased back to 5.0 x 10^6 lbs/yr in 2013-2017. Flow normalized TP loads at the Goldsboro station generally stayed around 0.5 x 10^6 lbs/yr from the 1991-1995 period to the 1999-2003 period and then steadily increased to 0.7 x 10^6 lbs/yr through 2009-2013 period before slightly decreasing to 0.6 x 10^6 lbs/yr through the 2013-2017 period.

The results of the FN loading analysis indicate a reduction in NOx loading, but an increase in TKN loading (Figure 25). Flow-normalized NOx loading decreased beginning in the 1994–1998 period and reached a minimum value of -45 % in the 1999–2003 time-period relative to the 1991-1995 baseline loading. It remained below the required 30% reduction level until the 2009-2013 period and increased slightly afterwards, but remained below the 1991-1995 baseline values. The average reduction achieved was approximately 35% for all periods beginning with 1994–1998 (Figure 25). The flow-normalized TKN loading for Neuse River at Goldsboro remained consistently above the values for the baseline period for all periods. The increase in TKN remained around 4% until the 1997-2001 period and increased gradually towards a maximum of 50% in the 2009-2013 period, and declined slightly afterwards. Flow-normalized TKN loading has been consistently higher than the 1991–1995 baseline period for all periods and increased by an average of 27%. Since ammonia loading declined by about 29% over the same time-period, the increase in TKN loading was primarily due to an increase in the Org-N fraction during mid and high flow events. The recent increase in NOx and TKN flow normalized loadings is mainly due to increases for the high flow intervals.

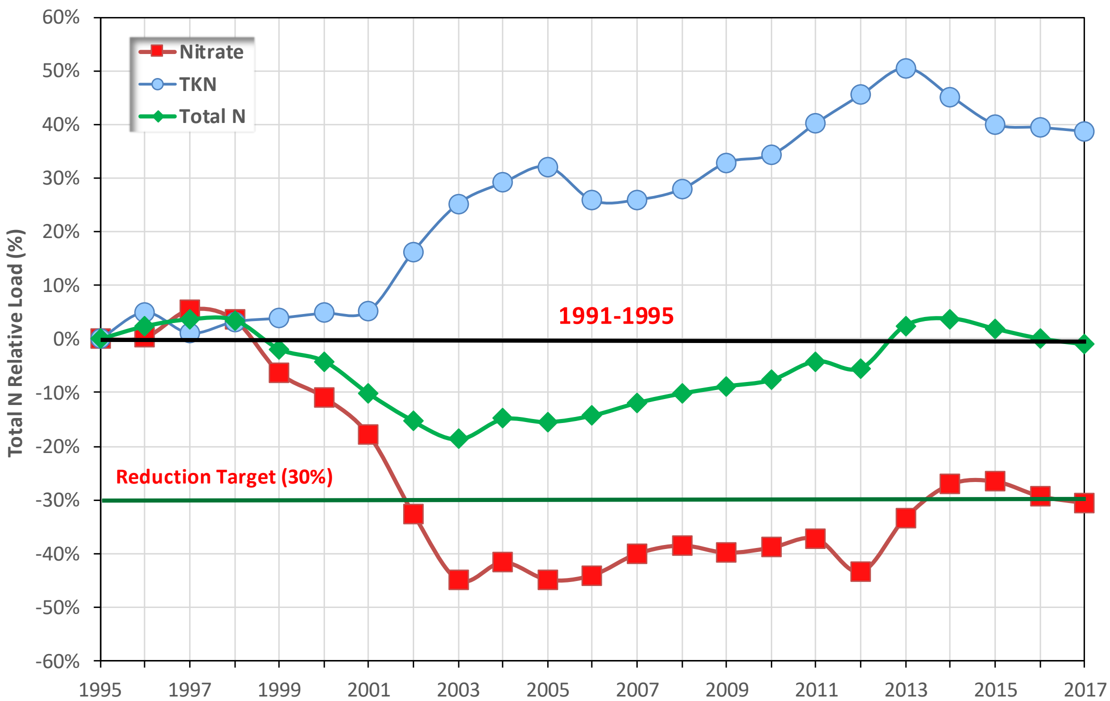

Figure 25. Nitrogen reduction for average flow conditions compared to the 1991-1995 baseline for Neuse River at SR 1915 near Goldsboro

Flow-normalized TN loading exhibited the combination of the patterns for NOx and TKN and has been consistently lower than the corresponding 1991-1995 baseline loading until the 2009-2013 period. The flow-normalized TN loading decreased to a minimum value of -19% in the 1999-2003 period and increased gradually afterwards. The average reduction in flow-normalized TN loading for the periods ending in 2008-2012 was approximately 10%. TP loading was consistently higher than the 1991-1995 loading from the 1998-2002 period to 2013-2017. TP loading stayed at the 1991-1995 level until the 1999-2003 period and increased afterwards. The increase in TP loading relative to the 1991-1995 period ranges from 8 to 56% from 1999-2003 to 2013-2017 (Figure 26).

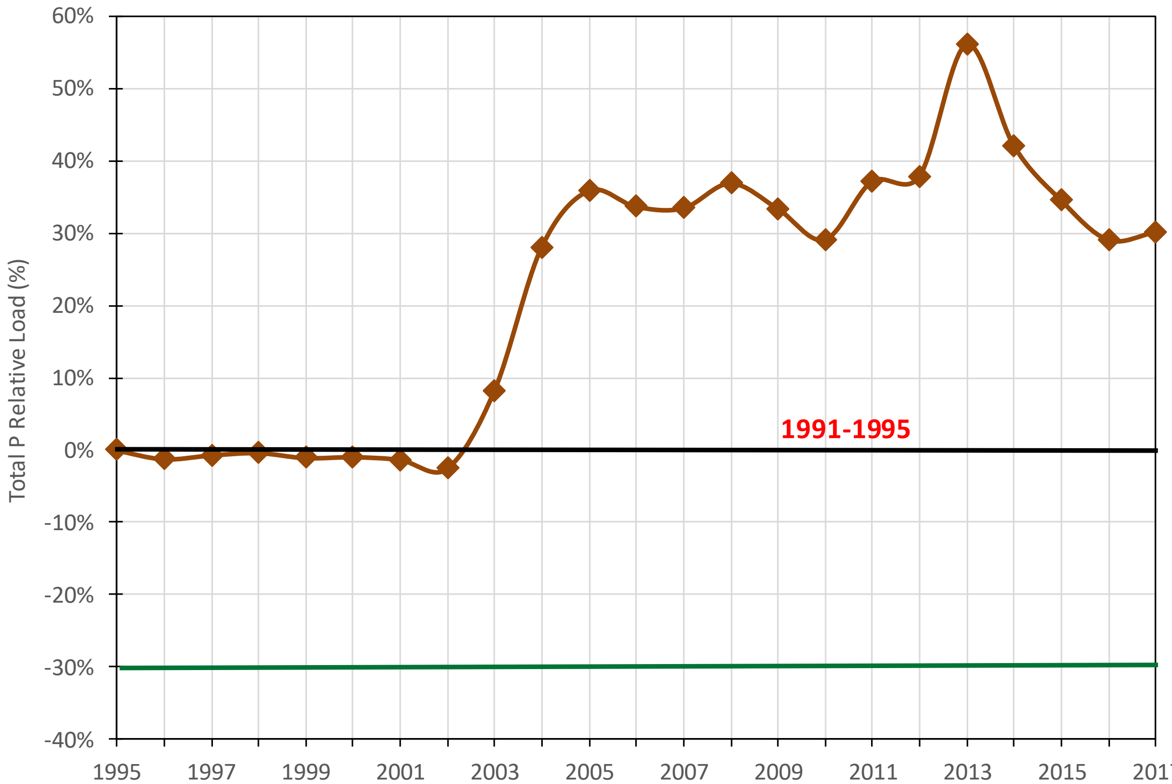

Figure 26. TP reduction for average flow conditions compared to the 1991-1995 baseline for Neuse River at SR 1915 near Goldsboro

Changes in Concentration

Table 15 shows average concentrations of N fractions and P by flow interval at the Neuse River at Goldsboro. Peak concentration of NOx was observed in the 1990s especially for the low flow intervals, but concentrations of NOx and stayed between 0.51 and 0.54 mg/L from 2001-present. The average concentrations of the NOx fraction decreased more for the low and middle flow intervals than the high flow intervals. The average concentrations of the TKN fraction increased more for the middle and high flow intervals. For example, reductions in NOx for the 2001–2017 period from corresponding values for 1991–2000 were 54, 44, and 22%, respectively, for the low, middle, and high flow intervals. Conversely, the changes in TKN concentrations for the 2001-2017 from the corresponding values for 1991-2000 were -3%, 32%, and 41%, respectively, for the low, middle, and high flow interval. TN concentrations decreased for low flow and middle flow intervals by 37 and 19%, respectively, and increased by 8% for high flow intervals during the same period. The increase in TKN for middle and high flow intervals and in TN concentrations for high flow intervals could indicate that high flow events deliver more TKN from sediments and other NPS landscape processes. Total phosphorus concentrations for 2001-2017 period increased by 11%, 26%, 35% for low flow, middle flow, and high flow intervals, respectively, from the corresponding values for 1991-2000 period.

Table15 . Average nutrient concentrations for Neuse River at Goldsboro by 5-year period and flow interval

Period	Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
1982-1986	1.026	0.676	0.585	0.43	0.49	0.48	1.46	1.17	1.07
1986-1990	1.159	0.799	0.487	0.45	0.45	0.44	1.61	1.25	0.93
1990-1994	1.235	0.863	0.516	0.62	0.47	0.42	1.86	1.33	0.94
1991-1995	1.262	0.883	0.479	0.63	0.48	0.43	1.89	1.36	0.91
1996-2000	0.899	0.827	0.438	0.36	0.38	0.51	1.26	1.20	0.95
2001-2005	0.528	0.487	0.288	0.48	0.47	0.64	1.01	0.94	0.88
2006-2010	0.515	0.449	0.340	0.54	0.55	0.63	1.06	1.00	0.97
2011-2015	0.529	0.487	0.430	0.51	0.65	0.65	1.04	1.13	1.08
2012-2016	0.543	0.495	0.404	0.54	0.63	0.65	1.09	1.13	1.05
2013-2017	0.509	0.478	0.402	0.53	0.60	0.65	1.04	1.08	1.05
	Ammonia (mg/L)			Total P (mg/L)					
1982-1986	0.093	0.083	0.070	0.432	0.236	0.155			
1986-1990	0.118	0.094	0.051	0.377	0.188	0.133			
1990-1994	0.254	0.111	0.057	0.148	0.114	0.095			
1991-1995	0.247	0.116	0.061	0.151	0.116	0.091			
1996-2000	0.070	0.070	0.071	0.138	0.117	0.091			
2001-2005	0.070	0.045	0.100	0.126	0.136	0.135			
2006-2010	0.042	0.044	0.038	0.177	0.160	0.117			
2011-2015	0.044	0.046	0.033	0.158	0.150	0.129			
2012-2016	0.048	0.045	0.033	0.169	0.144	0.122			
2013-2017	0.043	0.042	0.036	0.179	0.141	0.123			

Flow-Normalized Loading Analysis Results – Crabtree Creek

Figure 27 shows annual TN loading for Crabtree Creek at SR 1649 near Raleigh. Water quality data for Crabtree Creek is only available from 1998 to 2017 and data is missing for 2002. The results show that annual TN loading for Crabtree Creek near Raleigh ranged from 0.03 to 0.2 x 10^6 lbs/year for the 1998–2017 timeframe, with a median value of 0.2 x 10^6 lbs/year (Figure 27). Average contributions of ammonia, NOx, and Org-N to the TN load for the 1998–2017 period were 8, 28 and 65%, respectively. The Org-N fraction and the NOx fraction to TN loading ranged from 44 to 77 and 17 to 51%, respectively. Figure 28 shows annual TN loading at Crabtree Creek at SR 1649 near Raleigh by flow interval. The average TN contributions from low, middle, and high flow interval were 6, 14 and 80%, respectively. The annual TP loading ranged from 0.01 to 0.06 x 10^6 lbs/year, with a median value of 0.030 x 10^6 lbs/year. The average TP contributions from low, middle, and high flows were 11, 15 and 74%, respectively (Figure 29). These results show that high flow events contribute substantially large amount of nutrients in this watershed, suggesting that high flow events deliver more nutrients possibly from urban runoff, sediments and other nonpoint source products and processes.

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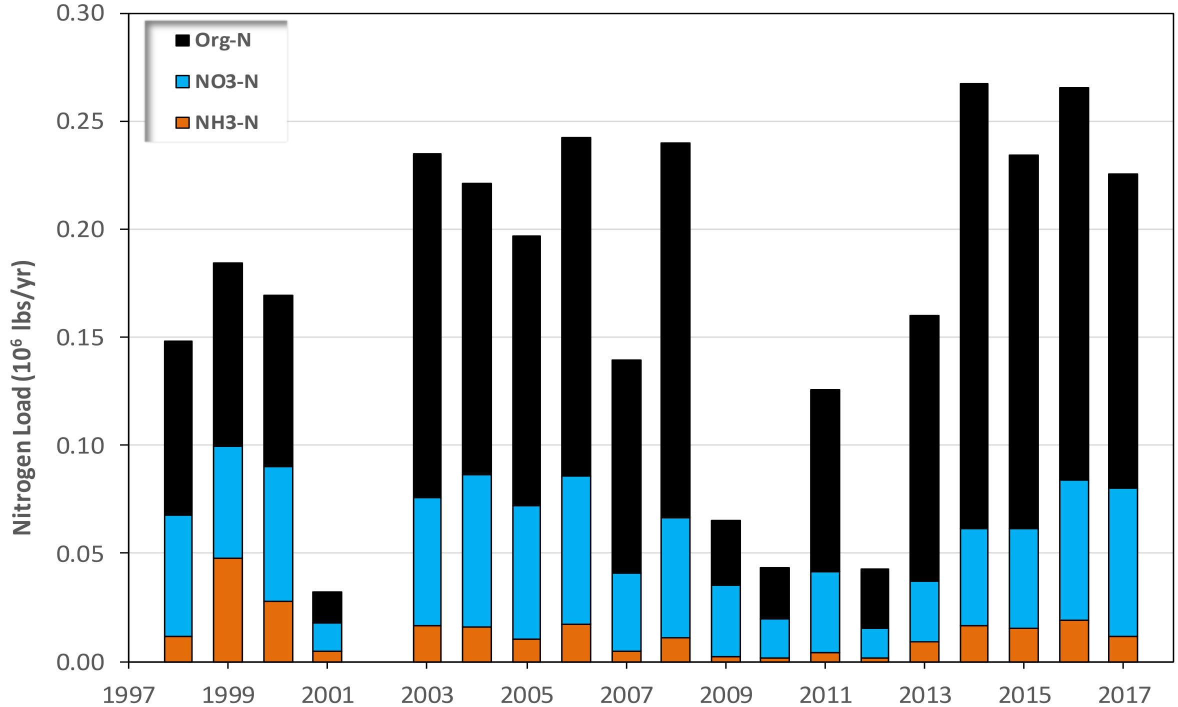

Figure 27 – Annual total N load by constituents for Crabtree Creek at SR 1649 near Raleigh

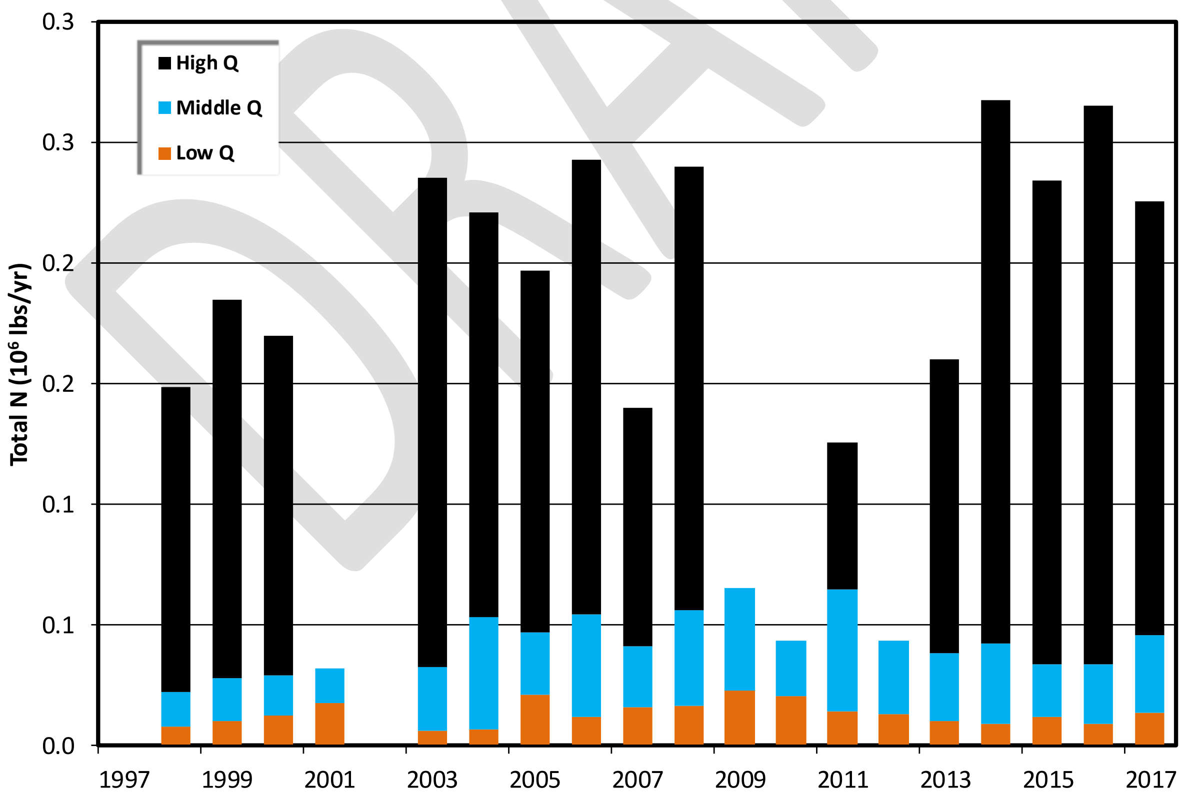

Figure 28. Annual total N load by flow bin for Crabtree Creek at SR 1649 near Raleigh

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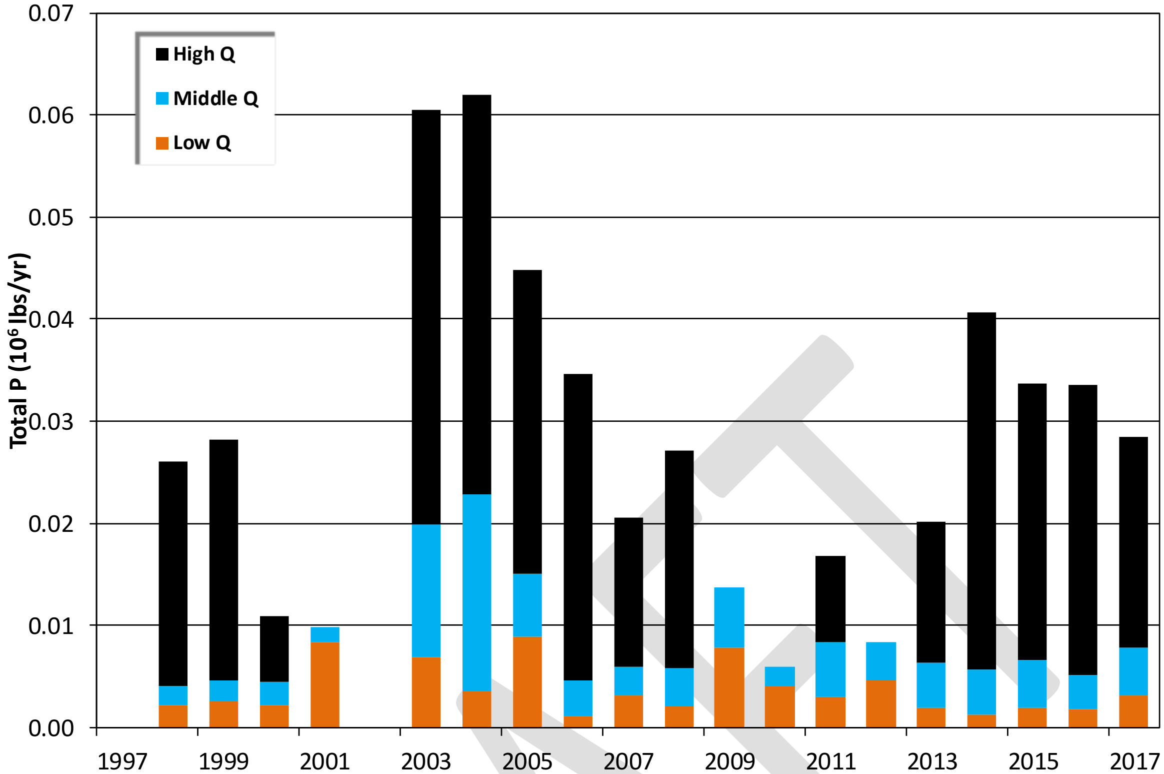

Figure 29. Annual total P load by flow Bin for Crabtree Creek at SR 1649 near Raleigh

At the Crabtree Creek location, flow normalized NOx predicted loads based on the long-term flow average steadily increased for the 1998-2002 period through 2001-2005. This increase was followed by a slight decrease through 2001-2017. The flow normalized loads increased from 0.05 x 106 lbs/yr in 1998-2002 to 0.06 x 106 lbs/yr in 2001-2005 and slightly decreased to 0.04 x 106 lbs/yr in 2013-2017. A steady increase in TKN loads was observed at Crabtree Creek for the 1998-2002 through 2008-2012 periods from 0.1 x 106 to 0.2 x 106 lbs/yr and slightly decreased to 0.1 x 106 lbs/yr for the 2009 -2017 period. Overall, TKN and NOx constitute around 68% and 25% of the TN load, respectively and a large fraction of the NOx and TKN load occurred during middle and high flow conditions. Predicted FN loads for long-term average hydrology for the selected stations are provided in Appendix B.

Changes in TN load exhibited the combination of patterns from the NOx load and the TKN load. The TN load for long-term average flow conditions steadily increased until the 2001-2005 period and stayed between 0.19 and 0.22 through the 2013 -2017 period. The flow normalized TN loads increased from 0.15 x 10^6 lbs/yr in 1998-2002 to 0.22 x 10^6 lbs/yr in 2005-2009 and then stayed between 0.18 to 0.2 x 10^6 lbs/yr from the 2006-2010 period through the 2008-2012 period. Flow normalized TP loads at the Crabtree Creek station steadily increased from 0.02 x 10^6 lbs/yr from the 1998-2002 period to 0.05 x 10^6 lbs/yr for the 2001-2005 period. It then steadily decreased to 0.03 x 10^6 lbs/yr through 2008-2012 period and remained at the same level through the 2013-2017 period. A large proportion of the P load occurred during high flow conditions.

The results of the FN loading analysis indicate a reduction in FN NOx loading, but an increase in TKN loading (Figure 30). Flow-normalized NOx loading was more than the 1998-2002 period until the 2005-2009 period and continued to decrease to a minimum value of -37 % in the 2010–2014 time-period relative to the 1998-2002 baseline loading. It increased slightly afterwards. The average reduction

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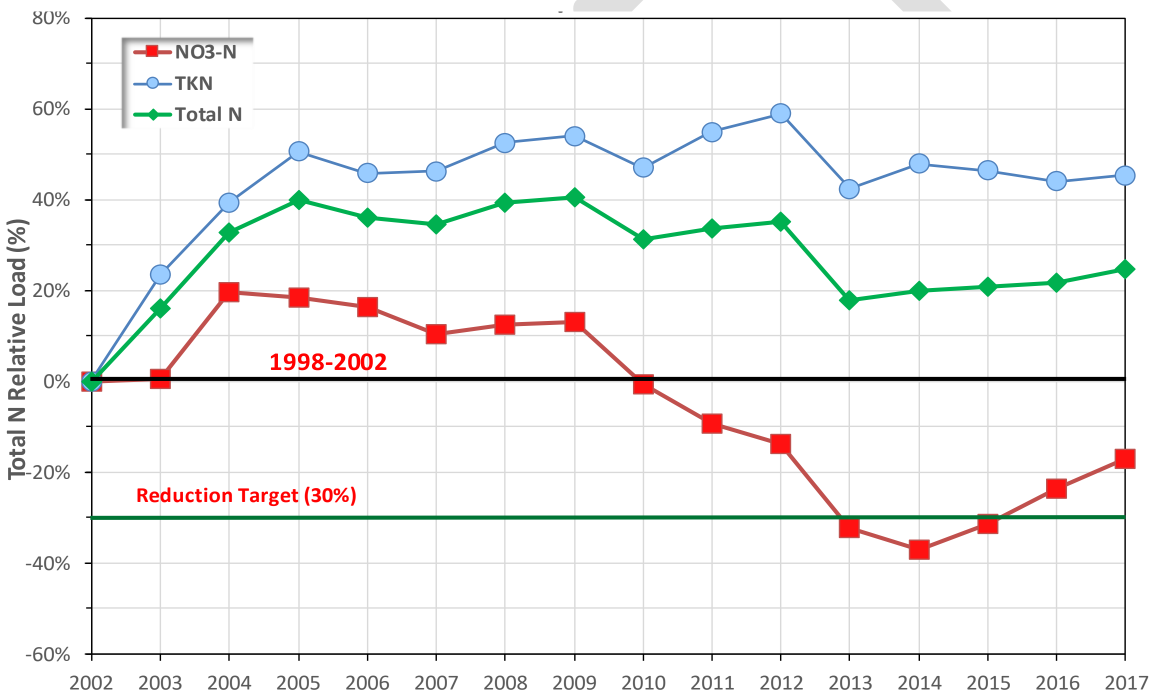
achieved was approximately 21% for periods beginning with the 2006-2010 period (Figure 30). Flow-normalized TKN loading remained consistently above the values for the baseline period for the entire data record. TKN increased gradually to a maximum of 59% in the 2009-2013 period and declined slightly afterwards. Flow-normalized TKN loading has been consistently higher than the 1998–2002 baseline period and increased by an average 46% from the baseline to the 2013-2017 period. Since ammonia loading declined by about 52% over the same time-period, the increase in TKN loading was primarily due to an increase in the Org-N fraction during mid and high flow events. The recent increase in NOx and TKN flow normalized loadings is mainly due to increases for the high flow intervals.

Flow-normalized TN loading exhibited the combination of the patterns for NOx and TKN and has been consistently higher than the corresponding 1998-2002 baseline loading until the 2009-2013 period. The flow-normalized TN loading increased to a maximum value of 41% in the 2005-2009 period and decreased slightly afterwards. The average increase in flow-normalized TN loading for all periods was approximately 30%. TP loading was consistently higher than the 1998-2002 for all periods and increased to a maximum of 160% before declining to a minimum of 18% in the 2009-2013 period (Figure 31).
Figure 30. Nitrogen reduction for average flow conditions compared to 1991-1995 baseline for Crabtree



Creek at SR 1649 near Raleigh

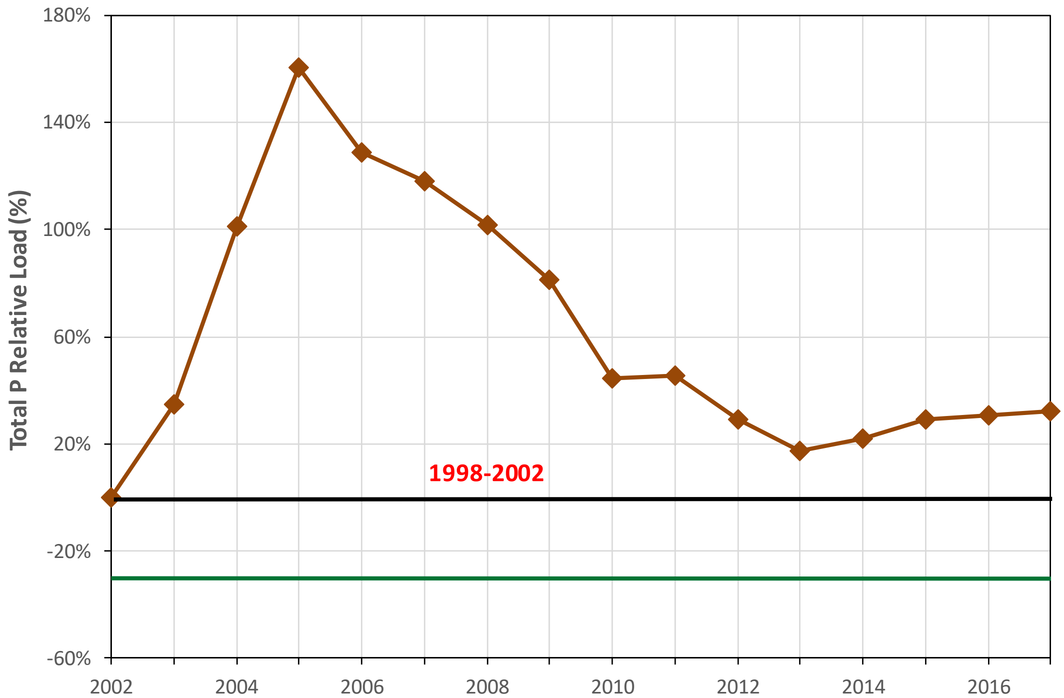


Figure 31. TP reduction for average flow conditions compared to 1991-1995 baseline for Crabtree Creek at SR 1649 near Raleigh

Changes in Concentration

Table 16 shows average concentrations of N fractions and P by flow interval at Crabtree Creek at SR 1649 near Raleigh. Peak concentration of NOx was observed in the 2000s especially for the low flow intervals. Concentrations of NOx stayed between 0.26 and 0.56 mg/l and 0.10 to 0.3 for middle and high flow intervals, respectively. The average concentrations of the NOx fraction increased for low flow fraction and decreased for the middle flow and high flow intervals. For example, the increase in NOx for the 2009-2017 period from corresponding values for 1998–2008 were 1% for the low flow interval and the reduction was 26, and 44%, respectively, for middle, and high flow intervals. The NOx proportion ranged from 39 to 55%, 27 to 46%, and 11 to 30% for the low, middle, and high flow intervals, respectively. In contrast, the Org-N fraction ranged from 45 to 61%, 54 to 73%, and 70 to 89% for the low, middle, and high flow intervals, respectively. The average concentrations of the TKN fraction increased more for the middle flow intervals than the low and high flow intervals.

The average concentration of TKN increased for all flow intervals between the 1998-2002 to 2008-2017 periods, with the highest increase in the middle flow bin. The increases in TKN concentrations for the 2009-2017 period from the corresponding values for 1998–2008 were 6%, 21%, and 4%, respectively, for the low, middle, and high flow intervals. TN concentrations increased for low flow and middle flow intervals by 4, and 1%, respectively, and decreased by 8% for high flow intervals during the same period. The increase in TKN for middle flow intervals could indicate that middle flow events deliver more TKN from sediments and other NPS landscape processes. The high proportion of Org-N from the Crabtree Creek watershed and tributary inputs is consistent with the conclusion of Osburn et al. (2016) that natural and urban runoff sources account for a vast majority of dissolved Org-N (DON) in the upper portion of the Neuse River basin. Total Phosphorus concentrations decreased more for low flow and middle flow intervals than high flows. Total Phosphorus concentrations for the 2009-2017 period decreased by 48%, 42%, 30% for low flow, middle flow, and high flow intervals, respectively, from the corresponding value for the 1998–2008 period.

Table 16. Average nutrient concentrations at Crabtree Creek at SR 1649 near Raleigh by 5-year period and flow interval

Period	Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
1998-2002	0.432	0.331	0.238	0.50	0.39	0.56	0.93	0.72	0.80
1999-2003	0.472	0.330	0.237	0.57	0.44	0.70	1.04	0.77	0.94
2000-2004	0.455	0.406	0.286	0.64	0.55	0.78	1.10	0.95	1.07
2001-2005	0.579	0.467	0.265	0.81	0.62	0.84	1.39	1.08	1.10
2002-2006	0.635	0.518	0.244	0.73	0.66	0.80	1.37	1.18	1.05
2003-2007	0.605	0.504	0.229	0.75	0.66	0.80	1.35	1.17	1.03
2004-2008	0.726	0.542	0.222	0.77	0.68	0.84	1.49	1.22	1.06
2005-2009	0.953	0.561	0.206	0.79	0.71	0.84	1.74	1.27	1.05
2006-2010	0.950	0.534	0.167	0.77	0.71	0.80	1.72	1.25	0.96
2007-2011	0.916	0.521	0.143	0.78	0.72	0.85	1.70	1.24	0.99
2008-2012	0.912	0.512	0.131	0.77	0.72	0.87	1.68	1.24	1.01
2009-2013	0.739	0.455	0.092	0.74	0.69	0.77	1.48	1.15	0.86
2010-2014	0.568	0.336	0.108	0.69	0.67	0.82	1.26	1.01	0.92
2011-2015	0.531	0.311	0.134	0.70	0.69	0.80	1.23	1.00	0.94
2012-2016	0.501	0.262	0.169	0.71	0.69	0.79	1.21	0.95	0.95
2013-2017	0.476	0.283	0.188	0.75	0.70	0.79	1.23	0.98	0.98

	Ammonia (mg/L)			Total P (mg/L)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
1998-2002	0.103	0.068	0.155	0.265	0.084	0.100
1999-2003	0.123	0.070	0.168	0.404	0.128	0.129
2000-2004	0.114	0.058	0.118	0.502	0.319	0.176
2001-2005	0.119	0.048	0.073	0.747	0.381	0.227
2002-2006	0.041	0.061	0.071	0.656	0.301	0.206
2003-2007	0.045	0.059	0.065	0.580	0.284	0.199
2004-2008	0.048	0.065	0.062	0.424	0.252	0.193
2005-2009	0.046	0.064	0.056	0.445	0.161	0.181
2006-2010	0.050	0.062	0.050	0.325	0.130	0.146
2007-2011	0.047	0.053	0.039	0.349	0.144	0.144
2008-2012	0.042	0.055	0.043	0.371	0.145	0.121
2009-2013	0.037	0.048	0.049	0.357	0.149	0.105
2010-2014	0.035	0.050	0.055	0.249	0.128	0.122
2011-2015	0.035	0.056	0.059	0.246	0.154	0.126
2012-2016	0.034	0.052	0.063	0.235	0.147	0.131
2013-2017	0.040	0.049	0.063	0.243	0.151	0.131

III. Nutrient Loading

Load Estimator (LOADEST)

Nutrients loads were also estimated using the USGS LOADEST program. These load estimates are intended to provide a range of annual loading estimates based on flow and concentration records from the selected stations. LOADEST is a USGS program written in FORTRAN that uses a regression model for the estimation of constituent loads (Runkel, et al., 2004) using a time series of streamflow and constituent concentration. The USGS LOADEST estimates monthly loading include upper (UCL) and lower (LCL) 95% confidence limits using the Adjusted Maximum Likelihood Estimation (AMLE) method. The annual loading is calculated from the monthly loads estimated by LOADEST and reported in pounds per year. The following figures show the annual estimated loading confidence intervals and flow for each station.

It should be noted that these are only estimates and all the methods used for load estimation have associated errors in their estimates; therefore, caution should be exercised when interpreting the results. All the results should be interpreted in light of the limitations of the approaches and the existing data.

Data Preparation

Non-detect or zero concentration values were changed to ½ the detection limit for NOx, TKN, and phosphorus. Missing USGS flow value(s) were replaced with the average of the flow value from the day before and day after the missing value(s).

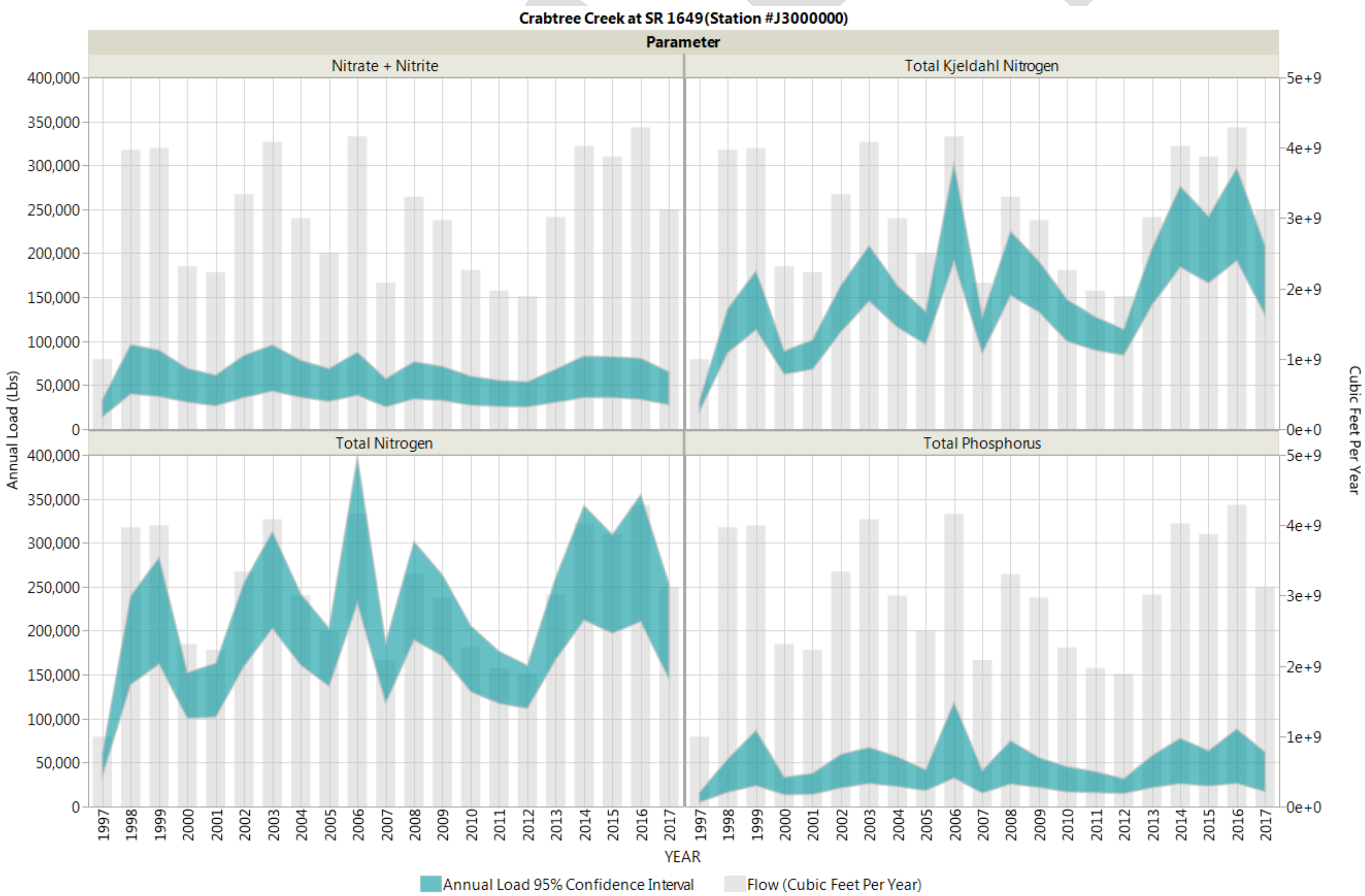


Figure 32. Estimated annual nutrient loading using LOADEST for Crabtree Creek at SR 1649 near Raleigh

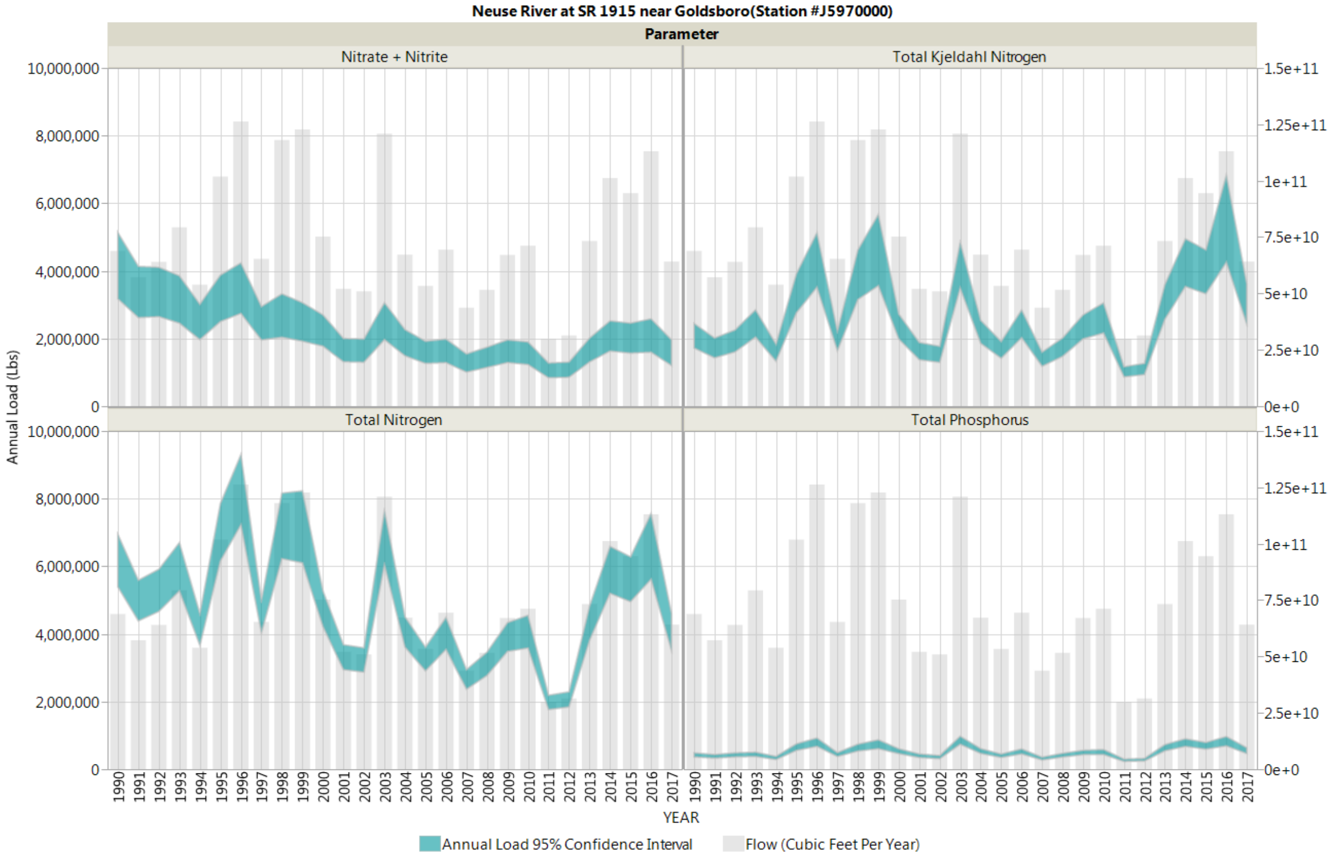


Figure 33. Estimated annual nutrient loading using LOADEST for the Neuse River at SR 1915 near Goldsboro

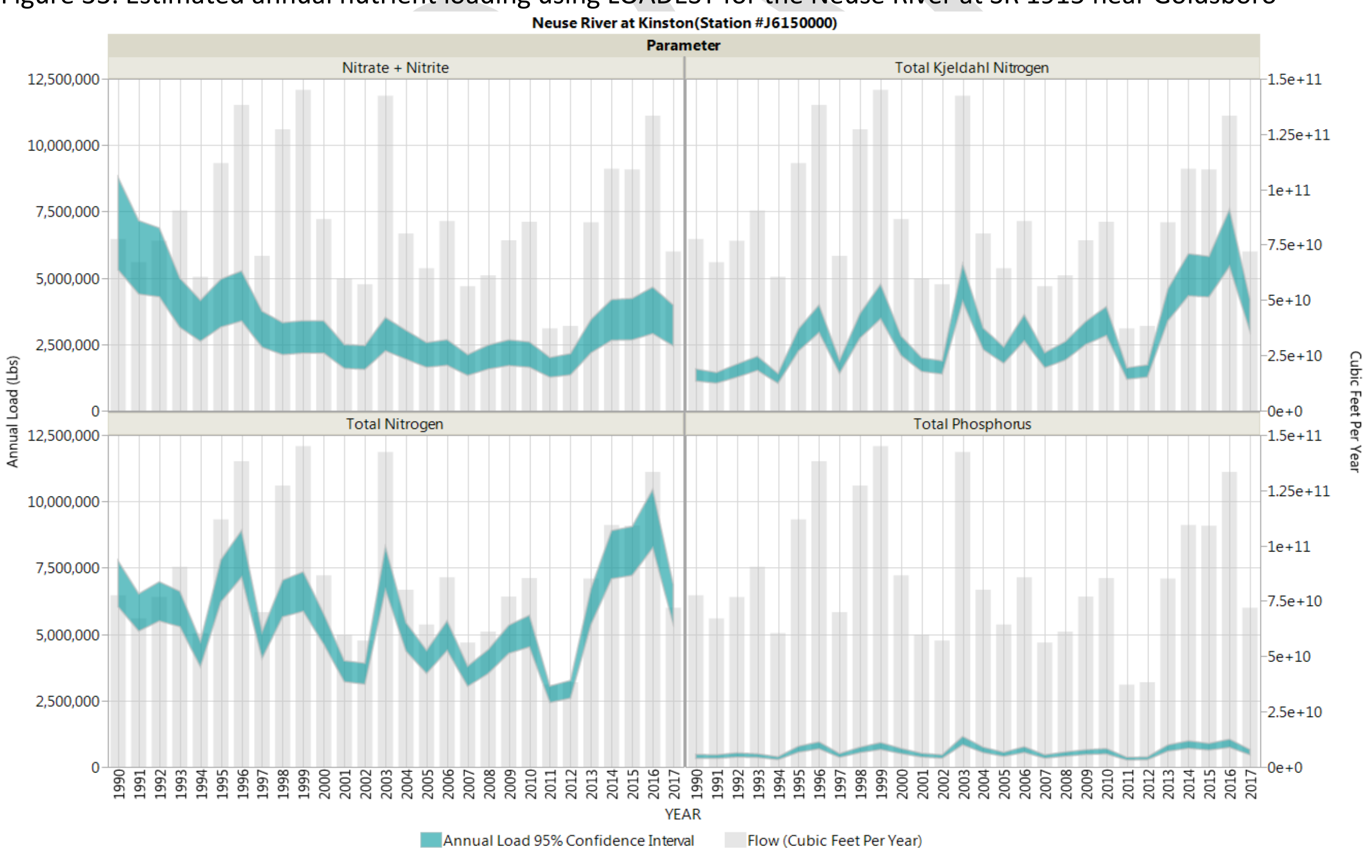


Figure 34. Estimated annual nutrient loading using LOADEST for Neuse River at Kinston

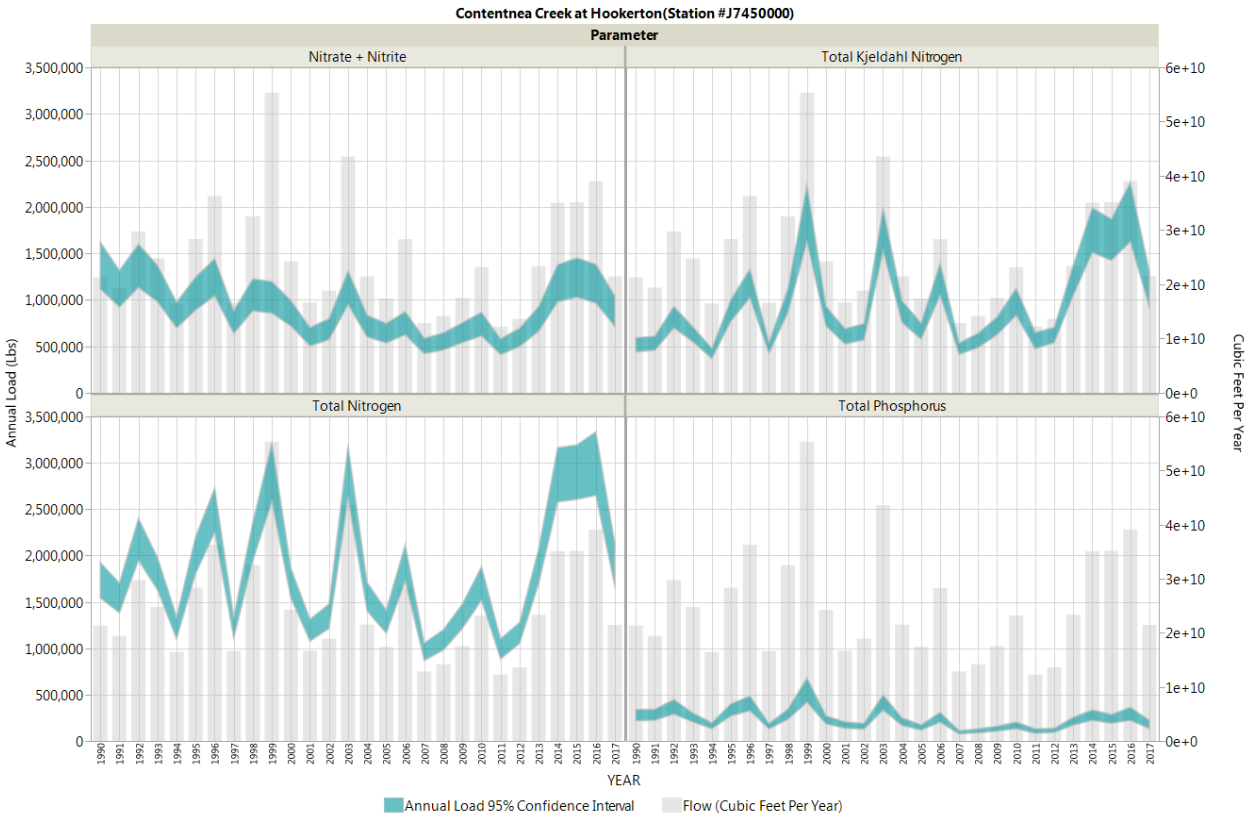


Figure 35. Estimated annual nutrient loading using LOADEST for Contentnea Creek at Hookerton

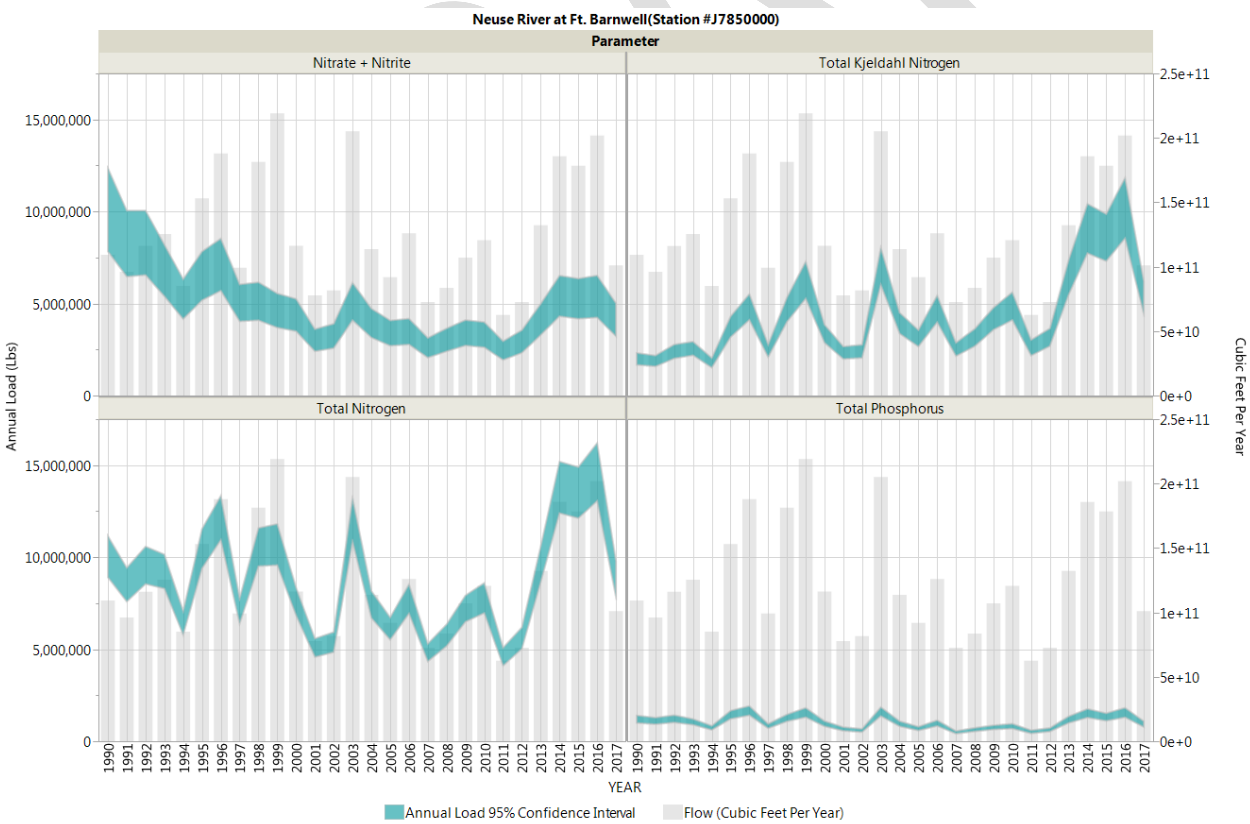


Figure 36. Estimated annual nutrient loading using LOADEST for the Neuse River at Fort Barnwell

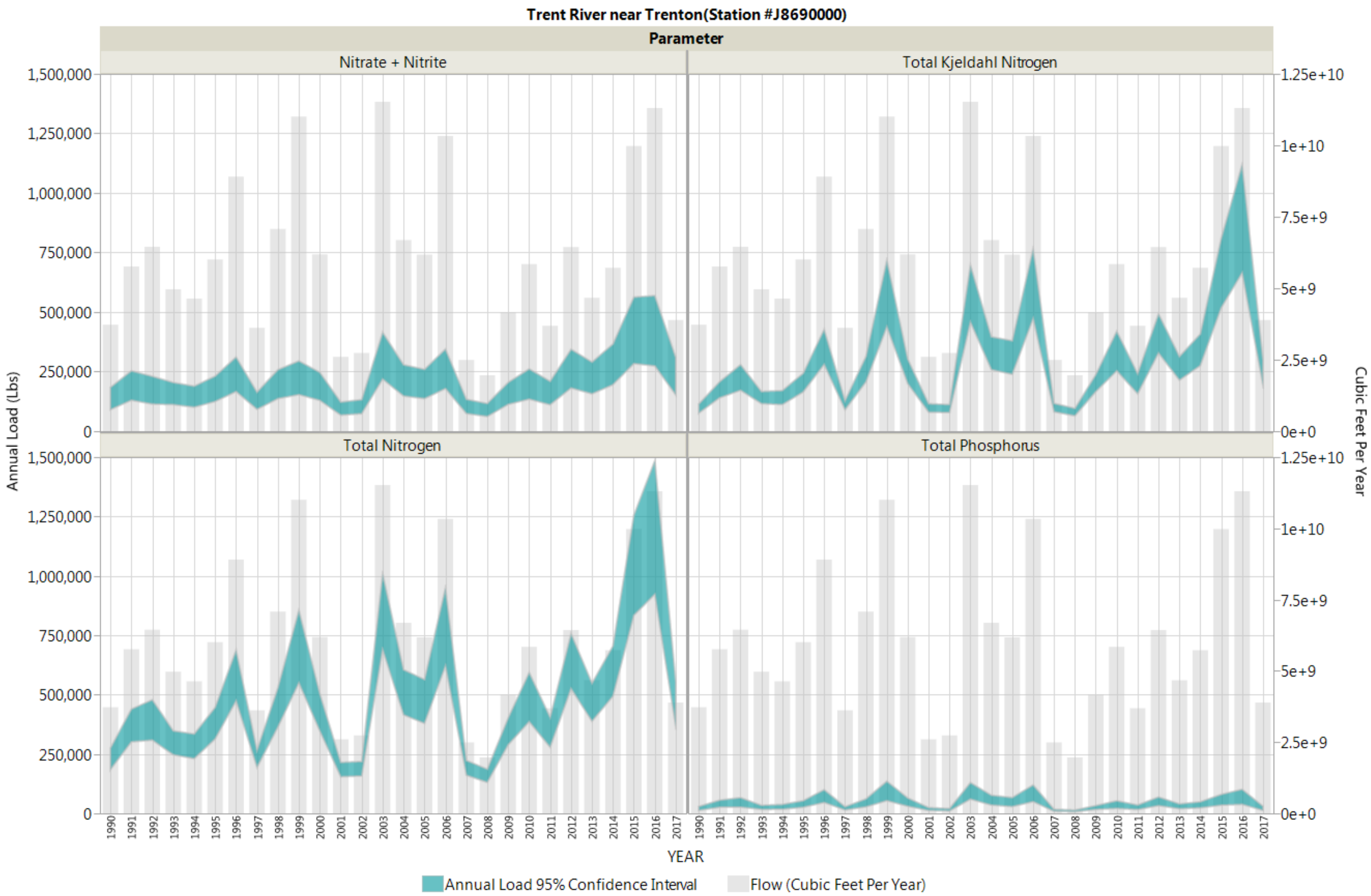


Figure 37. Estimated annual nutrient loading using LOADEST for the Neuse River at SR 1915 near Goldsboro

The loading estimates using the LOADEST method for the six selected stations (Figures 32 – Figure 37) generally show similar patterns presented in the previous sections. Overall, NOx loading decreased until mid-2010s and slightly increased afterwards at all stations except at the Trent River station near Trenton where it showed a steady increase over the entire study period. Total Kjeldahl nitrogen, on the other hand, generally increased at all stations over the study period. Total Nitrogen loading followed the combinations of patterns of NOx and TKN. No discernible change was observed in phosphorus loading based on the LOADEST estimates. In general, all nutrient constituents show increases in recent years.

Conclusion

Trend analyses of ammonia, NOx, TN, TKN, and TP concentrations were performed to evaluate trends in nutrient concentrations and changes in loads based on 1991-2017 data from selected NC ambient monitoring stations in the Neuse River Basin. The WQHYDRO software was used to conduct the Seasonal Kendall test. It was used to test a null hypothesis that no trends in nutrient concentrations exist at the 95% confidence level. An excel based tool was used to carry out the flow normalized loading analysis.

The results of the analyses based on the 1991-2017 data indicate that ammonia, NOx, and TP concentrations showed a significant decreasing trend for the Neuse River stations at Kinston, Goldsboro, and Fort Barnwell, but a significant upward trend was observed at the Trent River station near Trenton. TKN concentration, in contrast, showed a highly significant increasing trend for all the six selected stations for the same time-period. Significant downward trends were observed for TN at Goldsboro, but significant positive trends were observed for Trent River and Contentnea Creek over the same time-period. While TP showed a significant downward trend for the Neuse River at Fort Barnwell and Contentnea Creek at Hookerton, the results show increasing trends for the Neuse River at Goldsboro and Trent River at Trenton.

Trend results based on the 1991-2001 data show that declining trends in NOx were observed at all locations. Data was not available for Crabtree Creek during this period. While TKN decreased significantly at the Goldsboro station, no trends were detected at the other stations for the same time-period. Total nitrogen significantly decreased at Kinston, Goldsboro, Fort Barnwell, and Hookerton while TP significantly decreased only at Fort Barnwell and Kinston for the 1991—2001 period. The trend results based on the 2002-2017 data show statistically increasing trends for TKN and TN for most stations. The Seasonal Kendall test used in this analysis, like any statistical analysis, provides useful information to identify direction of trends and estimate the median rate of change over time. Further investigations should focus on identification of the causes of trends, contributing sources, and nutrient loading processes and mechanisms.

Flow-normalized loading analysis provides useful insights on changes in annual nutrient loading including changes associated with different flow regimes and nutrient constituents and can be used in the evaluation of progress towards nutrient reduction goals and provide additional insight on the relative effectiveness of nutrient management. The results show that there was a reduction in FN loading of NOx, ammonia, and TP and an increase in FN TKN loading. The trend in TKN loading was primarily due to an increase in Org-N and is associated with middle and high flow events. In addition, the USGS LOADEST program was used to estimate annual nutrient loading for the selected sites and similar results were obtained.

Overall, the current analysis indicates that significant reductions in NOx loads were achieved in the early 1990s, but the loadings have shown increases in the 2000s. In contrast the TKN loads have continued to increase steadily over the years. 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 (Alameddine et al., 2011, AquAeTer, 2016, Lebo et al., 2011, and Osburn, et al., 2016,). Therefore, future studies should focus on identification of Org-N sources and effective management options.

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APPENDIX A
Annual Flow Statistics

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Annual streamflow statistics

Figure A1 shows annual streamflow statistics (maximum, median and minimum flow) for the selected sites. Additional flow statistics (10th, 33rd, 66th, and 90th percentile flows) are also shown in Figure A2. The results show that annual streamflow portions (minimum, median, and maximum flow) at all of the mainstem Neuse River stations and the tributary stations of Contentnea Creek and Trent River were relatively stable. Moderate increases in all portions of annual streamflow were observed at the Crabtree Creek station near Raleigh.

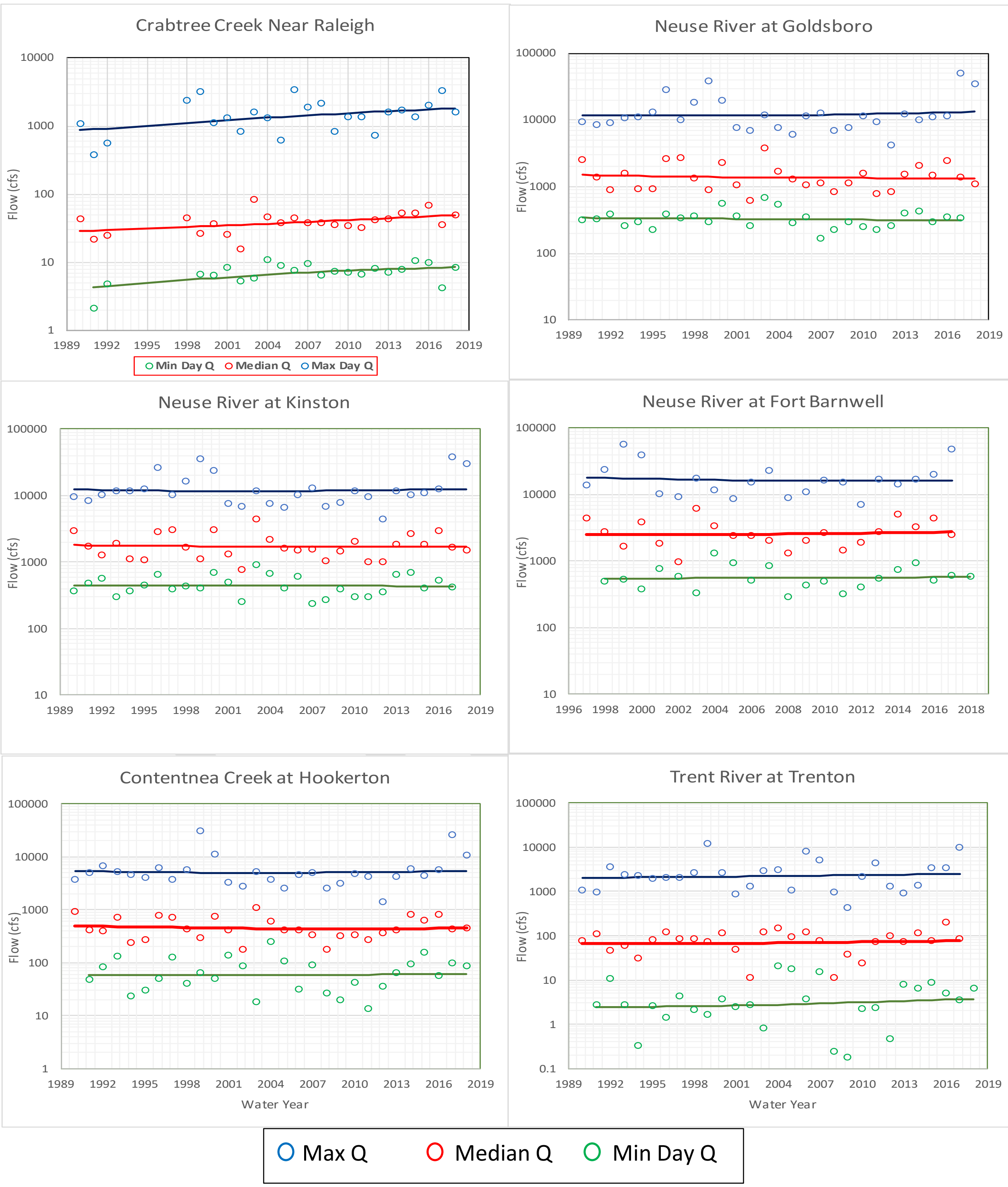

Figure A1. Annual flow statistics at selected sites

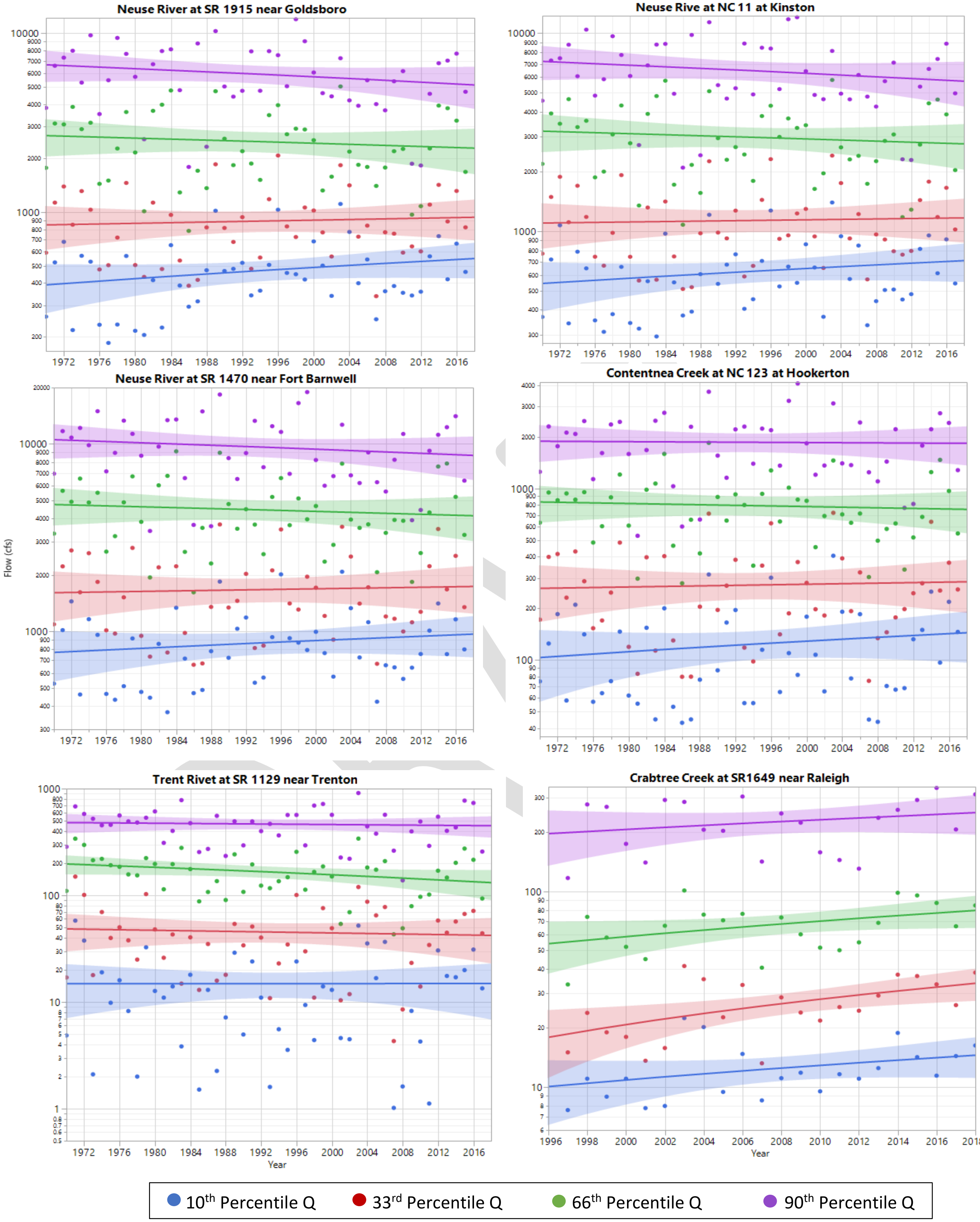

Figure A2. Annual flow statistics at selected sites

Appendix B
Nutrient loads for long-term average hydrology

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Year	Predicted nutrient loads for long-term average hydrology by parameter and year (10^6 lbs/yr) – Neuse River at Fort Barnwell														
	Ammonia			Nitrate			Total Kjeldahl N			Total N			Total P		
	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q
1990	0.071	0.202	0.340	0.689	1.528	4.084	0.249	0.765	2.527	0.938	2.293	6.611	0.106	0.272	0.718
1991	0.079	0.205	0.579	0.776	1.630	3.190	0.307	0.774	3.098	1.083	2.404	6.288	0.107	0.383	0.851
1992	0.041	0.194	0.353	0.589	1.762	3.827	0.295	0.830	2.922	0.884	2.591	6.749	0.112	0.296	0.789
1993	0.066	0.277	0.542	0.711	1.471	4.485	0.334	0.865	2.315	1.046	2.336	6.800	0.107	0.329	0.525
1994	0.077	0.181	0.205	0.682	1.633	3.356	0.320	0.745	2.324	1.002	2.379	5.679	0.160	0.415	0.434
1995	0.054	0.156	0.407	0.694	1.606	2.636	0.300	1.057	4.628	1.014	2.663	6.775	0.113	0.261	0.991
1996	0.045	0.141	0.492	0.632	1.313	2.753	0.283	1.021	2.798	0.915	2.334	5.510	0.155	0.447	0.971
1997	0.018	0.065	0.415	0.615	1.425	4.023	0.170	0.645	2.321	0.785	2.092	6.344	0.077	0.199	0.671
1998	0.033	0.137	0.163	0.456	1.395	2.938	0.182	0.738	1.792	0.637	2.133	4.730	0.076	0.281	0.571
1999	0.046	0.150	0.657	0.305	1.244	1.620	0.349	0.811	3.454	0.654	2.054	5.074	0.084	0.216	0.755
2000	0.028	0.195	0.302	0.371	0.872	3.126	0.211	0.821	2.750	0.582	1.693	5.876	0.066	0.254	0.633
2001	0.030	0.123	0.795	0.363	1.153	2.825	0.224	0.907	7.572	0.582	2.141	10.592	0.065	0.242	0.687
2002	0.029	0.109	0.223	0.236	0.942	2.526	0.387	0.896	2.883	0.623	1.838	5.409	0.101	0.293	0.601
2003		0.110	0.165		0.865	2.550		0.933	3.259		1.798	5.809		0.212	0.634
2004	0.030	0.097	0.261	0.326	1.023	2.629	0.299	0.861	3.256	0.625	1.884	5.885	0.080	0.196	0.651
2005	0.027	0.090	0.181	0.358	1.203	3.195	0.301	0.997	3.479	0.659	2.200	6.674	0.080	0.220	0.599
2006	0.026	0.080	0.195	0.338	1.071	2.287	0.335	0.991	3.548	0.673	2.062	5.835	0.082	0.207	0.686
2007	0.021	0.086	0.264	0.267	1.191	3.665	0.286	1.039	3.299	0.553	2.229	6.964	0.079	0.204	0.540
2008	0.021	0.072	0.284	0.278	0.917	2.570	0.306	1.106	3.690	0.584	2.023	6.259	0.080	0.245	0.762
2009	0.053	0.080	0.254	0.282	1.118	3.151	0.356	1.015	4.040	0.639	2.133	7.190	0.090	0.193	0.642
2010	0.031	0.092	0.220	0.314	0.844	3.954	0.370	1.046	4.097	0.684	1.890	8.051	0.092	0.233	0.542
2011	0.031	0.108	0.227	0.287	0.845	1.467	0.360	1.334	6.270	0.647	2.180	7.737	0.087	0.277	1.279
2012	0.022	0.073	0.326	0.322	0.878	3.277	0.332	1.119	4.385	0.654	1.997	7.663	0.080	0.266	1.019
2013	0.022	0.087	0.265	0.395	1.004	2.644	0.305	1.167	4.542	0.700	2.171	7.186	0.073	0.216	0.760
2014	0.024	0.122	0.229	0.475	1.104	3.360	0.287	1.242	4.139	0.762	2.346	7.499	0.074	0.261	0.641
2015	0.038	0.120	0.301	0.375	1.314	3.724	0.294	1.165	3.970	0.669	2.479	7.693	0.064	0.210	0.571
2016	0.048	0.111	0.248	0.357	1.157	3.615	0.327	1.134	3.695	0.684	2.291	7.310	0.082	0.217	0.611
2017	0.027	0.059	0.425	0.331	1.009	3.246	0.323	0.977	4.103	0.654	1.986	7.349	0.096	0.216	0.770

DRAFT

Year	Predicted nutrient loads for long-term average hydrology by parameter and year (10^6 lbs/yr) – Contentnea Creek at Hookerton														
	Ammonia			Nitrate			Total Kjeldahl N			Total N			Total P		
	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q
1990	0.017	0.048	0.148	0.091	0.253	0.812	0.047	0.182	0.650	0.138	0.434	1.462	0.022	0.053	0.172
1991	0.015	0.041	0.172	0.083	0.254	0.541	0.064	0.152	1.062	0.146	0.406	1.602	0.027	0.054	0.186
1992	0.010	0.055	0.082	0.081	0.263	0.602	0.041	0.176	0.636	0.122	0.439	1.238	0.018	0.043	0.139
1993	0.014	0.045	0.100	0.068	0.201	0.770	0.043	0.175	0.503	0.111	0.376	1.273	0.017	0.050	0.093
1994	0.009		0.101	0.053	0.196	0.738	0.043	0.182	0.629	0.096	0.377	1.367	0.013	0.030	0.116
1995	0.008	0.033	0.118	0.057	0.181	0.687	0.039	0.144	0.764	0.095	0.325	1.451	0.016	0.026	0.208
1996				0.062	0.202	0.634	0.041	0.157	0.594	0.103	0.359	1.228	0.017	0.053	0.183
1997	0.004	0.039	0.103	0.068	0.224	1.034	0.028	0.091	0.456	0.096	0.315	1.490	0.017	0.021	0.120
1998	0.005	0.035	0.057	0.074	0.209	0.656	0.033	0.128	0.449	0.107	0.337	1.105	0.027	0.050	0.173
1999	0.018	0.026	0.194	0.072	0.231	0.290	0.055	0.142	0.713	0.126	0.373	1.003	0.015	0.073	0.186
2000	0.009		0.053	0.062		0.827	0.039		0.600	0.101		1.426	0.013		0.106
2001		0.036	0.264		0.254	0.540		0.212	1.840		0.466	2.380		0.024	0.184
2002															
2003		0.018	0.053		0.192	0.609		0.182	0.739		0.374	1.348		0.039	0.138
2004	0.005	0.015	0.053	0.052	0.211	0.564	0.047	0.158	0.720	0.099	0.369	1.285	0.012	0.032	0.134
2005	0.005	0.019	0.048	0.060	0.204	0.672	0.047	0.188	0.665	0.107	0.393	1.337	0.012	0.031	0.111
2006	0.006	0.013	0.083	0.058	0.198	0.452	0.053	0.175	0.802	0.110	0.373	1.254	0.012	0.032	0.142
2007				0.059	0.243	0.969	0.047	0.177	0.826	0.105	0.421	1.795	0.013	0.035	0.122
2008	0.004	0.020	0.055	0.053	0.189	0.562	0.050	0.199	0.865	0.103	0.388	1.428	0.014	0.034	0.145
2009	0.004	0.020	0.054	0.050	0.214	0.692	0.052	0.200	0.846	0.102	0.414	1.538	0.024	0.041	0.127
2010	0.004	0.023	0.054	0.047	0.217	0.791	0.048	0.205	0.830	0.095	0.422	1.621	0.014	0.041	0.113
2011	0.004	0.017	0.080	0.046	0.154	0.290	0.057	0.198	1.029	0.103	0.353	1.319	0.016	0.042	0.233
2012	0.004	0.015	0.050	0.048	0.162	0.473	0.050	0.205	0.836	0.098	0.367	1.309	0.012	0.047	0.166
2013	0.004	0.017	0.055	0.060	0.188	0.551	0.052	0.207	0.904	0.111	0.395	1.455	0.012	0.033	0.140
2014	0.003	0.020	0.059	0.075	0.232	0.716	0.049	0.219	0.864	0.124	0.452	1.580	0.010	0.035	0.133
2015	0.005	0.021	0.093	0.067	0.188	0.949	0.048	0.218	0.882	0.114	0.405	1.831	0.013	0.033	0.141
2016	0.004	0.022	0.119	0.073	0.241	0.948	0.052	0.210	0.951	0.125	0.451	1.899	0.012	0.037	0.147
2017	0.003	0.017	0.079	0.064	0.195	0.816	0.053	0.198	0.833	0.116	0.393	1.648	0.010	0.031	0.129

DRAFT

Year	Predicted nutrient loads for long-term average hydrology by parameter and year (10^6 lbs/yr) – Neuse River at Kinston														
	Ammonia			Nitrate			Total Kjeldahl N			Total N			Total P		
	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q
1990	0.031	0.113	0.237	0.512	1.129	2.676	0.216	0.867	1.992	0.607	1.904	4.702	0.060	0.150	0.359
1991	0.040	0.148	0.227	0.649	1.162	2.046	0.283	0.000	2.613	0.849	0.000	4.385	0.057	0.191	0.387
1992	0.035	0.125	0.246	0.500	1.183	2.851	0.000	0.662	1.992	0.000	1.510	5.141	0.070	0.138	0.411
1993	0.049	0.131	0.297	0.629	1.236	2.186	0.239	0.535	1.758	0.896	1.557	3.861	0.064	0.111	0.298
1994	0.018	0.086	0.261	0.533	1.178	2.972	0.192	0.611	1.976	0.725	1.790	4.948	0.062	0.176	0.262
1995	0.027	0.057	0.191	0.574	1.165	2.244	0.141	0.490	2.462	0.715	1.655	4.706	0.061	0.118	0.460
1996	0.027	0.070	0.257	0.497	1.025	2.331	0.166	0.583	1.796	0.662	1.609	4.127	0.057	0.148	0.474
1997	0.012	0.142	0.208	0.557	1.186	2.856	0.115	0.237	1.507	0.672	1.423	4.363	0.053	0.071	0.296
1998	0.024	0.059	0.085	0.316	1.112	1.978	0.130	0.356	1.056	0.446	1.468	3.034	0.049	0.113	0.396
1999	0.035	0.090	0.645	0.219	1.059	0.952	0.168	0.496	3.138	0.387	1.554	4.090	0.042	0.153	0.446
2000	0.038	0.115	0.202	0.269	0.177	1.375	0.157	0.460	1.777	0.426	0.637	3.152	0.043	0.098	0.280
2001	0.020	0.070	0.225	0.208	1.023	2.178	0.173	0.574	2.567	0.370	1.622	4.745	0.054	0.148	0.494
2002	0.017	0.073	0.132	0.204	0.686	1.962	0.158	0.858	1.899	0.361	1.545	3.861	0.054	0.314	0.467
2003		0.063	0.126		0.688	1.579		0.678	2.070		1.366	3.648		0.153	0.364
2004	0.013	0.046	0.165	0.273	0.736	1.947	0.192	0.598	2.304	0.464	1.334	4.252	0.047	0.132	0.460
2005	0.009	0.037	0.123	0.253	0.786	1.925	0.184	0.633	2.463	0.437	1.419	4.387	0.050	0.140	0.416
2006	0.007	0.040	0.167	0.241	0.823	1.474	0.239	0.599	2.511	0.480	1.421	3.985	0.055	0.139	0.475
2007	0.010	0.045	0.098	0.191	0.745	2.274	0.189	0.634	2.338	0.377	1.379	4.612	0.051	0.166	0.386
2008	0.018	0.038	0.198	0.191	0.646	1.698	0.206	0.674	2.700	0.398	1.320	4.398	0.058	0.170	0.549
2009	0.018	0.046	0.164	0.200	0.759	1.786	0.219	0.654	2.661	0.419	1.412	4.447	0.050	0.160	0.423
2010	0.015	0.066	0.161	0.237	0.742	2.374	0.231	0.726	2.780	0.468	1.468	5.154	0.045	0.160	0.366
2011	0.015	0.057	0.152	0.232	0.647	1.782	0.217	0.737	2.909	0.449	1.384	4.691	0.053	0.176	0.579
2012	0.019	0.048	0.160	0.246	0.645	2.305	0.235	0.755	3.233	0.481	1.400	5.538	0.056	0.205	0.640
2013	0.012	0.051	0.229	0.296	0.730	1.534	0.221	0.799	3.078	0.517	1.529	4.612	0.052	0.151	0.533
2014	0.011	0.062	0.119	0.330	0.818	2.143	0.230	0.837	2.681	0.560	1.655	4.824	0.053	0.177	0.398
2015	0.026	0.079	0.214	0.305	0.979	2.536	0.222	0.834	2.847	0.528	1.812	5.383	0.056	0.137	0.415
2016	0.033	0.060	0.234	0.214	0.871	2.752	0.211	0.647	2.441	0.425	1.518	5.193	0.055	0.133	0.404
2017	0.019	0.054	0.358	0.276	0.661	2.538	0.215	0.711	2.540	0.491	1.371	5.078	0.062	0.177	0.445

DRAFT

Year	Predicted nutrient loads for long-term average hydrology by parameter and year (10^6 lbs/yr) – Trent River near Trenton														
	Ammonia			Nitrate			Total Kjeldahl N			Total N			Total P		
	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q
1990	0.0008	0.0023	0.0338	0.0089	0.0278	0.2977	0.0049	0.0237	0.1841	0.0138	0.0516	0.4818	0.0010	0.0050	0.0184
1991	0.0006	0.0023	0.0149	0.0059	0.0400	0.0988	0.0045	0.0256	0.1471	0.0104	0.0656	0.2459	0.0008	0.0048	0.0187
1992	0.0005	0.0032	0.0169	0.0074	0.0376	0.2178	0.0049	0.0211	0.1215	0.0123	0.0588	0.3393	0.0009	0.0093	0.0123
1993	0.0006	0.0057	0.0173	0.0060	0.0357	0.1678	0.0049	0.0227	0.1396	0.0111	0.0583	0.3073	0.0011	0.0074	0.0225
1994	0.0007	0.0022	0.0123	0.0060	0.0181	0.1856	0.0046	0.0302	0.1993	0.0106	0.0483	0.3850	0.0021	0.0052	0.0123
1995	0.0007	0.0023	0.0258	0.0077	0.0248	0.1534	0.0037	0.0297	0.1924	0.0113	0.0545	0.3458	0.0009	0.0048	0.0250
1996	0.0005	0.0041	0.0265	0.0086	0.0303	0.1080	0.0044	0.0300	0.1822	0.0130	0.0604	0.2916	0.0011	0.0044	0.0306
1997	0.0002	0.0020	0.0249	0.0040	0.0253	0.1620	0.0035	0.0197	0.1290	0.0075	0.0450	0.2910	0.0016	0.0053	0.0136
1998	0.0005	0.0026	0.0070	0.0071	0.0305	0.1346	0.0033	0.0230	0.1195	0.0103	0.0535	0.2540	0.0022	0.0098	0.0285
1999	0.0010	0.0032	0.0475	0.0053	0.0250	0.1127	0.0044	0.0278	0.1972	0.0097	0.0527	0.3100	0.0020	0.0163	0.0797
2000	0.0012	0.0034	0.0217	0.0073	0.0262	0.1499	0.0044	0.0277	0.2406	0.0118	0.0539	0.3906	0.0015	0.0082	0.0231
2001	0.0019	0.0104	0.0767	0.0112	0.0379	0.0798	0.0080	0.0480	0.3376	0.0200	0.0859	0.4174	0.0009	0.0031	0.0307
2002	0.0003	0.0035	0.0746	0.0057	0.0294	0.0794	0.0039	0.0344	0.2426	0.0096	0.0638	0.3219	0.0007	0.0027	0.0294
2003	0.0003	0.0013	0.0096	0.0169	0.0472	0.1652	0.0078	0.0333	0.2522	0.0246	0.0806	0.4173	0.0011	0.0034	0.0307
2004	0.0004	0.0020	0.0076	0.0158	0.0371	0.1396	0.0082	0.0331	0.2135	0.0240	0.0703	0.3531	0.0012	0.0043	0.0255
2005	0.0005	0.0017	0.0104	0.0137	0.0524	0.2084	0.0051	0.0358	0.2056	0.0187	0.0882	0.4140	0.0009	0.0043	0.0244
2006	0.0002	0.0020	0.0086	0.0086	0.0538	0.1438	0.0076	0.0320	0.2307	0.0162	0.0858	0.3745	0.0008	0.0041	0.0264
2007	0.0002	0.0068	0.0079	0.0046	0.0414	0.1962	0.0049	0.0442	0.1928	0.0095	0.0855	0.3890	0.0007	0.0091	0.0223
2008	0.0002	0.0011	0.0102	0.0049	0.0377	0.1974	0.0061	0.0347	0.2214	0.0110	0.0724	0.4188	0.0006	0.0037	0.0181
2009	0.0004	0.0014	0.0094	0.0095	0.0473	0.3018	0.0078	0.0499	0.2914	0.0173	0.0972	0.5932	0.0009	0.0048	0.0243
2010	0.0003	0.0045	0.0105	0.0126	0.0609	0.3384	0.0062	0.0511	0.2183	0.0188	0.1120	0.5567	0.0008	0.0085	0.0214
2011	0.0005	0.0060	0.0061	0.0054	0.0269	0.0246	0.0078	0.0497	0.3683	0.0132	0.0766	0.3928	0.0011	0.0046	0.0276
2012	0.0002	0.0012	0.0094	0.0076	0.0333	0.1220	0.0064	0.0512	0.2905	0.0140	0.0845	0.4125	0.0006	0.0046	0.0348
2013	0.0001	0.0010	0.0084	0.0068	0.0419	0.2165	0.0075	0.0389	0.2195	0.0143	0.0808	0.4360	0.0011	0.0047	0.0202
2014	0.0002	0.0011	0.0135	0.0166	0.0559	0.2521	0.0072	0.0432	0.2498	0.0238	0.0991	0.5019	0.0009	0.0052	0.0215
2015	0.0003	0.0023	0.0158	0.0118	0.0566	0.2238	0.0072	0.0363	0.2481	0.0190	0.0929	0.4719	0.0010	0.0057	0.0231
2016	0.0002	0.0017	0.0152	0.0079	0.0374	0.2185	0.0066	0.0416	0.2671	0.0145	0.0791	0.4856	0.0015	0.0061	0.0320
2017	0.0002	0.0016	0.0061	0.0122	0.0367	0.3463	0.0076	0.0419	0.2382	0.0199	0.0786	0.5845	0.0009	0.0046	0.0185

DRAFT

Year	Predicted nutrient loads for long-term average hydrology by parameter and year (10^6 lbs/yr) – Crabtree Creek near Raleigh														
	Ammonia			Nitrate			Total Kjeldahl N			Total N			Total P		
	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q	Low Q	Middle Q	High Q
1998	0.0003	0.0012	0.0074	0.0037	0.0071	0.0347	0.0034	0.0094	0.0572	0.0071	0.0165	0.0919	0.0021	0.0022	0.0164
1999	0.0007	0.0025	0.0340	0.0035	0.0109	0.0277	0.0045	0.0114	0.0942	0.0080	0.0223	0.1219	0.0020	0.0023	0.0178
2000	0.0005	0.0022	0.0447	0.0050	0.0094	0.0624	0.0038	0.0118	0.1456	0.0089	0.0212	0.2080	0.0016	0.0027	0.0087
2001	0.0034	0.0003		0.0047	0.0090		0.0096	0.0084		0.0143	0.0174		0.0056	0.0017	
2002															
2003	0.0002	0.0007	0.0105	0.0059	0.0043	0.0338	0.0061	0.0177	0.1103	0.0120	0.0219	0.1441	0.0137	0.0108	0.0270
2004	0.0005	0.0017	0.0141	0.0033	0.0159	0.0488	0.0071	0.0186	0.1274	0.0104	0.0345	0.1763	0.0056	0.0146	0.0394
2005	0.0003	0.0014	0.0107	0.0094	0.0145	0.0434	0.0082	0.0175	0.1449	0.0176	0.0321	0.1883	0.0083	0.0072	0.0384
2006	0.0004	0.0022	0.0099	0.0068	0.0164	0.0289	0.0064	0.0191	0.1094	0.0132	0.0356	0.1383	0.0012	0.0030	0.0220
2007	0.0006	0.0011	0.0054	0.0046	0.0103	0.0271	0.0080	0.0201	0.1278	0.0126	0.0303	0.1549	0.0022	0.0033	0.0260
2008	0.0005	0.0023	0.0077	0.0102	0.0151	0.0251	0.0077	0.0211	0.1462	0.0180	0.0362	0.1713	0.0024	0.0034	0.0196
2009	0.0004	0.0015		0.0134	0.0182		0.0082	0.0220		0.0216	0.0402		0.0069	0.0056	
2010	0.0005	0.0008		0.0092	0.0067		0.0072	0.0159		0.0164	0.0226		0.0026	0.0018	
2011	0.0003	0.0011	0.0047	0.0055	0.0208	0.0094	0.0072	0.0188	0.1162	0.0127	0.0396	0.1256	0.0028	0.0042	0.0173
2012	0.0003	0.0014		0.0038	0.0079		0.0068	0.0201		0.0106	0.0281		0.0036	0.0035	
2013	0.0004	0.0015	0.0084	0.0050	0.0074	0.0155	0.0068	0.0167	0.1225	0.0118	0.0241	0.1380	0.0021	0.0039	0.0164
2014	0.0003	0.0018	0.0106	0.0050	0.0103	0.0230	0.0060	0.0214	0.1426	0.0110	0.0317	0.1656	0.0015	0.0043	0.0249
2015	0.0005	0.0016	0.0101	0.0069	0.0053	0.0271	0.0079	0.0193	0.1223	0.0148	0.0246	0.1494	0.0024	0.0052	0.0209
2016	0.0002	0.0010	0.0107	0.0040	0.0059	0.0348	0.0075	0.0192	0.1182	0.0115	0.0251	0.1530	0.0023	0.0034	0.0211
2017	0.0005	0.0009	0.0104	0.0039	0.0105	0.0520	0.0080	0.0210	0.1286	0.0120	0.0315	0.1806	0.0029	0.0045	0.0213

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