Evaluating Effectiveness of Management Actions for the Neuse River Basin – Update Through 2015

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FINAL REPORT

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Author’s Note

Corrections to the report incorporated into this September 23, 2016 revised draft affect some of the reported data values but do not affect the overall patterns presented or the conclusions of the report. After the report was released on June 9, 2016, it was discovered that two of the figures (11 and 12) that present relative improvements in loading of nitrogen fractions and total phosphorus for the six locations evaluated were based on actual estimated loads rather than on flow-normalized or long-term average flows, as described in the report. The corrected report includes updated versions of Figures 11 and 12 along with any text reporting values based on the relative changes.

In terms of changes to the results reported in the corrected version, variation in the estimated progress toward achieving the 30% reduction in total nitrogen mandated by the Neuse Estuary Total Maximum Daily Load (TMDL) across the post-TMDL period decreased for flow-normalized loads compared with estimated actual loading. The difference is associated with removal of the effect of year-to year variation in river flow on loading trends. However, reduced variation did not change the reported spatial pattern in the percentage reduction for the 2004-2015 period.

The overall conclusions of the report remain the same. There has been success at decreasing nitrate (NO_3-N) in all locations except the Trent River at Trenton, but the success has been largely offset by increases in the Organic nitrogen fraction. Increases in both nitrogen and phosphorus were evident for the Trent River at Trenton location.

EXECUTIVE SUMMARY

Management efforts to control nutrient-driven excess algal growth in the Neuse River and Estuary began in the 1980s, with an initial focus on phosphorus (P) controls. Continued water quality problems in the 1990s led to development of a Total Maximum Daily Load (TMDL) for nitrogen (N) (as Total N, TN) in 1999 to reduce algal growth in estuarine waters. Evaluation of the effectiveness of management actions implemented in the Neuse River basin is a challenging endeavor due to natural variations in climate and how these variations affect export of nutrients from watershed sources. For example, large episodic events, such as tropical storms and hurricanes, have a large impact on freshwater discharge and, hence, nutrient loads. Conversely, decreased river flow and TN and Total P (TP) loading would be associated with periods of prolonged regional droughts (months to years). Accurate assessment of progress toward achieving the prescribed N load reduction target for the Neuse River basin must account for these year-to-year variations in flow.

The focus of this paper is to describe and apply a relatively simple approach to account for flow variation over time to provide feedback on progress in achieving nutrient reductions in key watersheds draining to the Neuse Estuary. The approach was initially applied to data compiled for five locations through 2009, which was published in 2012. This paper extends the prior analysis to include data collected by monitoring programs in the basin at the five original locations and for a sixth location for the Neuse River at Fort Barnwell. In the prior work, the evaluation of N and P concentrations in the Neuse River Basin was done by comparing concentrations of nutrient fractions for low, middle, and high flow conditions before and after management actions were implemented. In grouping the nutrient data, long-term flow records for each site were used to separate data into the three flow groups; lowest one-third of flows (0-33%), the middle-third (34-66%), and the highest one-third of flows (67-100%). The same flow groupings were used across time periods to allow reliable comparisons across time for parameters affected by river flow. Nutrient fractions evaluated included ammonia (NH_3-N), nitrate+nitrite (NO_3-N), total Kjeldahl N (TKN), total N (TN), and total P (TP). The same approach is used for this updated analysis.

Evaluation of N and P concentrations at stations along the Neuse River showed differences in response to the overall set of control actions implemented for flow-normalized loads. For TP, five of six stations evaluated showed decreases in concentrations and loads associated with 1988 control actions, with the largest changes for low and middle flow conditions. Changes in N fractions, however, were more variable. In terms of location, decrease in TN (post-TMDL) was largest for the Clayton station (1-27%) in the upper portion of the basin while smaller decreases were found at Kinston (2-21%) in the middle of the basin and Streets Ferry (-2 to 13%) at the head of the Neuse Estuary. The Fort Barnwell location above Streets Ferry showed a -3 to 16% reduction, depending on the 5-year period of comparison. The largest changes in TN

concentrations occurred for low flows, with limited reduction or increases under high flows. In terms of N fractions, the NO_3-N concentration decreased at all four main stem locations, but the observed decreases in NO_3-N were partially, or completely, offset by increases in predicted loading of the TKN fraction. The lack of change in TKN concentration was likely associated with particulate organic N, particularly under middle and high flow conditions. The spatial pattern of lower N removal efficiency moving downstream along the Neuse River indicates less effectiveness of the TMDL in watersheds draining to the middle and lower portions of the basin.

Data available for monitoring locations on Contentnea Creek and the Trent River are consistent with the spatial pattern along the Neuse River. Overall, there was no change in TN for Contentnea Creek despite a small decrease in the NO_3-N fraction for the post-TMDL period. In fact, the reduction in N evident for the assessment of data through 2009 summarized in the prior effort has been reversed, and TN has now increased in recent years. For TP, the average decreased beginning in 1988, but consistently lower values (e.g. <0.2 mg/L) did not occur until after 2000. At the Trent River monitoring location, patterns in N and P concentrations, and projected loading, did not appear to show reductions following the management actions enacted in 1988 (P controls) and beginning in 1999 (N controls). The NO_3-N concentration generally decreased during the early 1990s but then increased again in the 2000s. In fact, several of the N and P fractions in the Trent River have increased in concentration over the past 15 years. Better understanding is needed of the effectiveness of implemented actions in watersheds in the middle and lower portions of the basin, including the potential for time lags between implementation and observed instream reductions.

The TMDL developed for the Neuse River basin to reduce chlorophyll a concentrations in the Neuse Estuary mandates a 30% reduction in TN loading to estuarine waters compared with the 1991-95 baseline period. The approach described in this report complements estimates of actual TN loading to the Neuse Estuary but provides more immediate feedback on progress toward achieving the established reduction goal. Effective management actions ultimately must result in decreased TN loading in the river network. However, grouping of nutrient concentration data by flow conditions coupled with parallel evaluations in different regions of the basin can provide direction for additional investigations targeted by source category. It is also possible that nutrient concentration data for stations without flow gauging can be evaluated in a similar approach by using available regional flow data to group nutrient data by low, middle, and high flows. In the end, achieving the required TN reductions in a cost-efficient manner necessitates feedback on progress by region and source category in addition to the total loading to estuarine waters. Tracking average nutrient concentrations by flow conditions at key monitoring locations provides a relatively simple way to evaluate the progress of the Neuse Estuary TN TMDL in combination with quantification by source and actual instream TN loads and concentrations.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i
TABLE OF CONTENTS iii
LIST OF TABLES iv
LIST OF FIGURES v
LIST OF APPENDICES vi
INTRODUCTION 1
METHODS 4
  Conceptual Approach 4
  Application to Neuse River Basin 5
  Data Sources 6
NUTRIENT TIME SERIES 10
  Neuse River @ Clayton 10
  Neuse River @ Kinston 10
  Neuse River @ Fort Barnwell 11
  Neuse River @ Streets Ferry 12
  Contentnea Creek @ Hookerton 12
  Trent River @ Trenton 13
  Comparison of Fort Barnwell and Streets Ferry 13
PREDICTED NUTRIENT LOADS 23
  Dissolved Inorganic N 23
  Total Kjeldahl N 24
  Total N 24
  Total P 25
TMDL EFFECTIVENESS 31
DISCUSSION AND CONCLUSIONS 34
REFERENCES 38

LIST OF TABLES

Table Number	Title	Page Number
1	Time periods used to group data for analysis	5
2	Flow information for monitoring locations evaluated	7
3	Nutrient data sources used in analysis	8
4a	Mean concentrations for Neuse River basin stations by flow interval and time period – Clayton, Hookerton, and Trenton	14
4b	Mean concentrations for Neuse River basin stations by flow interval and time period – Kinston, Fort Barnwell, and Streets Ferry	15
5	Calculated slope and correlation (r^2) for each location and parameter using annual averages for the years 2000-2015 by flow bin	16
6a	Flow-normalized loads (10^6 lbs/yr) by flow interval and time period – Clayton, Hookerton, and Trenton	26
6b	Flow-normalized loads (10^6 lbs/yr) by flow interval and time period – Kinston, Fort Barnwell, and Streets Ferry	27

LIST OF FIGURES

Figure Number	Title	Page Number
1	General schematic for data analysis	6
2	Annual NH_3-N concentrations by flow bin and location	17
3	Annual NO_3-N concentrations by flow bin and location	18
4	Annual TKN concentrations by flow bin and location	19
5	Annual TN concentrations by flow bin and location	20
6	Annual TP concentrations by flow bin and location	21
7	Annual TN averages at Fort Barnwell and Streets Ferry	22
8	Annual average daily flows by location	28
9	Annual TN loads by location	29
10	Annual TP loads by location	30
11	Nitrogen reduction by location for average flow conditions	32
12	Reduction in TP by location for average flow conditions	33
13	TMDL attainment status for 2011-15 for actual loads	37

LIST OF APPENDICES

Appendix Number	**Title**
A	Tables of sample numbers for nutrient data and average values
B	Nutrient time series plots by station
C	Actual loads by year and location
D	Nutrient concentrations: 5-yr averages

INTRODUCTION

The Neuse River Estuary has experienced a variety of water quality problems over the past half a century attributable to intense agricultural, industrial, residential, and municipal development in the region. Concern over excessive nutrients in the Neuse River became a central issue in the late 1970s following several large freshwater nuisance algal blooms along the lower river (Christian et al., 1986; NCDEM, 1982; Paerl, 1983). Over recent decades, investigations of nutrient use, application, and production have shown large increases in both total N (TN) and P (TP) production (Stanley, 1988; Stow et al., 2001). Important factors noted were human population growth, large confined animal operations, and the intensity of rural land uses. In the 1990s the issue shifted downstream to estuarine waters due to fish kills, recurrent low bottom water dissolved oxygen (DO), and increased nutrient and chlorophyll levels (e.g. NCDWQ, 1996; Paerl et al., 2004). Studies during the 1990s showed that algal blooms in the middle portion of the estuary downstream of the city of New Bern are associated with periods of increased inorganic N loading (e.g. Paerl et al., 1995, 1998), which affects the resident phytoplankton assemblages (Pinckney et al., 1999; Valdes-Weaver et al., 2006).

Management efforts to control nutrient-driven excess algal growth in the Neuse River and Estuary began in the 1980s and initially focused on TP controls (e.g. Paerl et al., 2004). In 1983, the upper portions of the Neuse River basin were declared nutrient-sensitive, and this designation was extended to the entire basin in 1988 (NCDWQ, 1996). The phosphorus detergent ban and TP discharge limits on point sources implemented to address freshwater algal blooms resulted in decreased inorganic and total P concentrations throughout the Neuse River system and decreased algal blooms in the tidal freshwater portion of the Neuse Estuary (Lebo et al., 2002; Paerl et al., 2004; Stow et al., 2001). Despite enactment of TP controls, fish kills and low bottom water DO levels were regularly observed in the 1990s, leading to a re-examination of management actions necessary to protect water quality in the Neuse Estuary (NCDWQ, 1996; Paerl et al., 2004). Scientific consensus and available monitoring data provided the basis for the development of the Neuse River Nutrient Sensitive Waters (NSW) Management Rules, approved in December 1997, requiring a 30% reduction in TN loading to the Neuse Estuary at New Bern (15A NCAC 2B .0232). In order to achieve the required TN load reduction, additional rules enacted specified required TN load reductions from agriculture, new development, and point source discharges, in addition to protection of existing riparian buffers. These control actions were submitted to the U.S. Environmental Protection Agency (USEPA) as part of a Total Maximum Daily Load (TMDL) for TN reductions in the Neuse River basin and were approved in 1999 (NCDENR, 1999, 2001).

The delivery of nutrients to estuarine waters is a product of both landscape and instream processes throughout the watershed (USEPA, 2001). In the context of land-based inputs of nutrients, the mobility of nutrients can be affected by a number of factors including the amount and timing of fertilizer used, the location and extent of land disturbance, the efficiency of stormwater conveyance, and the integrity of riparian vegetation to provide a filtering of sheet flow from land surfaces to streams. For the Neuse River basin, management actions to reduce TN loading to the estuary focus on either maintaining current protections (i.e. riparian buffers) or reducing export from predominant sources. Once nutrients enter surface waters, the downstream transport may be affected by instream processes (e.g. sedimentation, biological uptake, etc.), with less effective trapping generally occurring in larger tributaries and main stem portions of rivers (Alexander et al., 2000, 2008). Assessing the effectiveness of management actions to reduce nutrient exports is confounded by large climatic variation among and within years. Periods of elevated rainfall, whether associated with a general weather pattern or a large storm event, result in high nutrient loads in the Neuse River (e.g. Lebo et al., 2002; Paerl et al., 2006a, b; Stow et al., 2001). An accurate evaluation of management actions must separate the impacts of the practices or limits implemented from expected variation in nutrient transport driven by variation in flow.

Achieving a successful outcome from the nutrient management efforts in the Neuse River basin must result in decreased nutrient concentrations, and ultimately loads, entering estuarine waters. A key challenge is determining trends in the near-term against a background of year-to-year fluctuations in river flow associated with climatic variability. There have been a number of efforts over the years to evaluate trends in nutrient fractions in the Neuse River system. In terms of general conclusions from the efforts, researchers documented a decrease in TP after 1988 (following a P-detergent ban and improved wastewater treatment) and increased nitrate (NO_3-N) and TN in the middle of the basin (e.g. at Kinston) through the mid-1990s (Lebo et al., 2002; NCDENR, 1999; Qian et al., 2000; Stow et al., 2001). An uncertainty with interpreting nutrient trend data over the past two decades is the series of tropical storms and hurricanes that elevated flow in rivers in Eastern North Carolina in several years. Paerl et al. (2006a, b, c, 2007) have shown that enhanced river flow and associated nutrient discharge is an important factor affecting both data interpretations and the ecology of the system.

Evaluation of nutrient trends in the Neuse River basin have utilized a range in complexity in the statistical approach to quantifying change. In two of the previous efforts (Lebo et al., 2002; Stow et al., 2001), the analysis considered river flow impacts on nutrient trends in determining flow-corrected trends. However, the approaches used are data-intensive and involve considerable statistical manipulation. Lebo et al. (2012) used a simple stratification of nutrient data into three flow categories (low, middle, and high) to look at data trends for concentrations by flow category and loading for actual and long-term flow conditions for data collected through 2009. Decreases in nitrate+nitrite (NO_3-N) concentrations occurred throughout the basin and were largest just downstream of the Raleigh metropolitan area. Conversely, concentrations of total Kjeldahl N (TKN) increased at several stations, particularly under high flow conditions. This indicates a relative increase in organic N (Org-N) inputs since the mid-1990s. Overall, patterns in different N fractions indicated both partial success in reducing TN inputs and ongoing challenges for reducing TN loading under high flow conditions.

The focus of this paper is to utilize the simpler approach described in Lebo et al. (2012) to account for flow variation over time based on data available for the Neuse River basin stations through 2015. As indicated above, the prior trend analysis for data available through 2009 indicated partial success in reducing TN loading to the Neuse Estuary. The analysis in this paper extends the evaluation of trends in TN as a whole and the components of TN (NH_3-N, NO_3-N, and TKN) through 2015 to determine the current status of attainment of required TN reductions under the Neuse Estuary TMDL. As in the prior analyses, an assessment of the status of TP reductions relative to the early 1980s is included in the analysis.

METHODS

Conceptual Approach

The incorporation of river flow variation into trend analysis and effectiveness evaluation of management actions is receiving increasing attention. In the context of recent TMDL development, USEPA (2007) has developed an approach to apply load duration curves to account for flow effects on water quality and to provide improved identification of dominant sources to impacted waters. An important confounding factor in understanding the effectiveness of controls implemented is seasonal and year-to-year variation in river flow, which can greatly influence the amount of a pollutant entering a waterbody. The simple concept underlying flow-based analysis approaches is to compare data collected for the same flow conditions. If management actions have been effective, then the concentration of the constituent of interest should decrease compared with the prior value for the same flow condition.

When multiple flow regimes are compared, as with the load duration approach, the evaluation can provide feedback both on whether the system is improving as a whole and on the relative effectiveness of actions targeted for difference sources. The capacity of the analysis to separate contributions from different categories of sources is based on the general concept that point sources impact river nutrient levels more under low flow conditions while nonpoint sources dominate under high flows. In cases where spatial gradients in land use and urban development exist, the approach can be utilized to evaluate the relative effectiveness of management actions targeting specific sources of the pollutant being controlled (i.e. TN or TP).

In grouping the nutrient data, long-term flow records for each site were used to separate data into three groups: lowest one-third of flows (0-33%), the middle-third (34-66%), and the highest one-third of flows (67-100%). The same flow intervals were used across time periods to allow reliable comparisons across time for parameters affected by river flow. Once the average concentrations of nutrient fractions are determined, the potential impact on downstream transport of nutrients associated with changes in concentrations can be estimated by multiplying average flow for each interval by the corresponding nutrient concentrations. These derived loads provide a more direct measure of the effectiveness of management actions than comparisons of actual nutrient loads, since the large year-to-year variations in flow do not dominate the calculated loads.

Ultimately, the success of management actions will be judged by reductions in average nutrient loads in the river, as required under the NSW Rules and the TMDL. However, the methodology described in this updated paper provides feedback, even with year-to-year variation in river flow, on whether progress is being made toward achieving established nutrient reduction goals. The segregation of data by flow regime also provides feedback on whether effectiveness of controls differs for point and nonpoint sources of nutrients.

Application to Neuse River Basin

The evaluation of N and P concentrations in the Neuse River Basin was done by comparing concentrations of nutrient fractions by flow intervals for periods before and after management actions were implemented. Available nutrient data were segregated into five time periods based on when management actions were adopted and ultimately fully implemented. For TP, time periods before and after the 1988 adoption of controls (e.g. NCDWQ, 1996) were used to assess effectiveness. However, the subsequent focus on TN controls was more gradual, involving a several year implementation timeframe. Table 1 lists the periods used in this analysis to evaluate the effectiveness of TN and TP controls in the Neuse River basin. In addition, average concentrations of TN fractions were computed for 1991-1995, as the baseline condition specified in the Neuse River NSW Rules. Determination of the baseline was done both for actual estimated TN loads and for flow-normalized loads at long-term average flows for direct comparison with other trend results presented in this paper.

Table 1. Time periods used to group data for analysis. Average concentrations of TN fractions for 1991-1995 were used to evaluate relative progress toward achieving the 30% reduction in TN loading to the Neuse Estuary specified in the TMDL.

Time Period	**TP Controls**	**TN Controls**	**Comment**
1980-1987	Pre-NSW	Pre-TMDL	
1988-1995	NSW Implemented	Pre-TMDL	
1996-1999	NSW Implemented	Pre-TMDL	Hurricanes; TN Study
2000-2003	NSW Implemented	Early Implementation	Varies by Source
2004-2015	NSW Implemented	TMDL Implemented	Three summary periods
1991-1995	NSW Implemented	Pre-TMDL	TMDL Baseline

Monitoring locations in the Neuse River basin included in this analysis were selected to capture total input to the Neuse River estuary as well as to characterize trends in different nutrient source regions (Figure 1). Three of the six locations evaluated represent drainage from areas that are predominantly urban (Clayton) or rural (Hookerton and Trenton) land uses. The other three sites in the lower Neuse River basin along the main stem of the Neuse River represent locations where nutrient concentrations are expected to reflect an integration of a mixture of land uses throughout upstream drainage areas. The addition of the Fort Barnwell location along the Neuse River main stem is new to this updated assessment of nutrient trends.

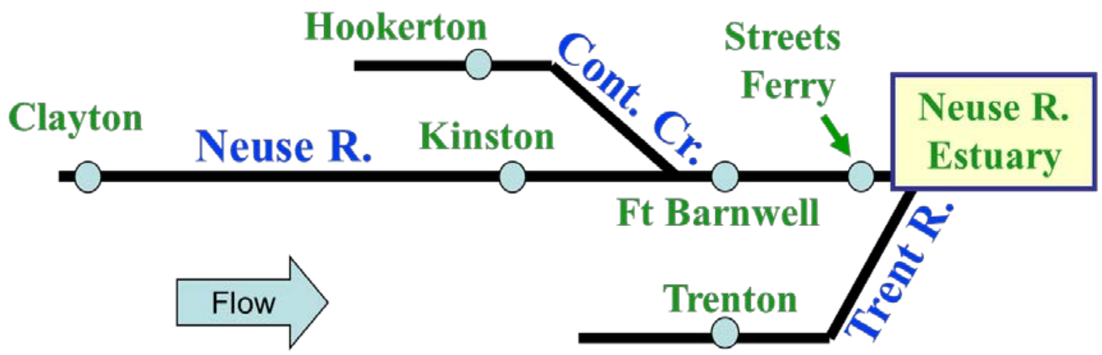


Figure 1. General schematic for data analysis. The Clayton location receives drainage from the Raleigh/Durham area while the Hookerton and Trenton locations are in rural portions of the basin.

Data Sources

Flow data for sites evaluated were obtained from U.S. Geological Survey data records available through the Internet. Table 2 lists the periods for which flow data were used to define the flow distribution for each site. A common period (1970-2015) was used for all locations to minimize the impacts of any decade-scale variation of the flow distribution on the trend analysis. Daily average flows for each gauging location were used in the analysis, with the exception of the Fort Barnwell and Streets Ferry locations on the Neuse River. For Streets Ferry, reported flow data from upstream gauges at Kinston and Hookerton were used to estimate flow intervals for a longer time period than could be done using the gauge installed at Fort Barnwell in 1996. Estimated daily flow at Streets Ferry, except during September-October 1999 following Hurricane Floyd, was computed as:

$$Q_{SFB} = Q_{kinston} + 1.84 \text{ x } Q_{hookerton} \qquad (1)$$

where $Q_{kinston}$ and $Q_{hookerton}$ are 2-day average flows for the current and prior day at Kinston and Hookerton, respectively, to account for downstream time of travel. The average flow at Hookerton was multiplied by 1.84, to account for ungauged drainage area. For the period affected by Hurricane Floyd, estimated flow for the Fort Barnwell location was used to better represent flow at Streets Ferry due to excessive rainfall in the Contentnea Creek watershed that was not representative of overall drainage to Streets Ferry.

The USGS gauge at Fort Barnwell (02091814) was installed during the later portion of 1996. For the Fort Barnwell location, daily flows prior to the gauge installation (from 1970-1996) were estimated using the same method described above for Streets Ferry using the upstream daily flows from Kinston and Hookerton. Daily averages for days missing data after the installation of the gauge at Fort Barnwell were estimated using the same method. For the period for which USGS has finalized data for the Fort Barnwell gauge, flow data report for the location was used in this assessment.

A factor that could affect the flow distribution for the Neuse River at Clayton was the creation of Falls Reservoir in 1982. Falls Reservoir was built in 1982 and could have an effect on the flow distribution of the Neuse River at Clayton due to changes in the overall flow distribution associated with flood control and low-flow augmentation objectives of the project. The impacts from Falls Reservoir are acknowledged but not explicitly taken into account in the analysis.

Table 2. Flow information for monitoring locations evaluated. Long-term average flows are listed for the three flow intervals used to group nutrient concentration data.

Location	USGS ID	Data Record	Flow Averages (cfs)			DWQ ID
			Low	Middle	High	
Neuse River Mainstem Stations						
Clayton	02087500	1970-2015 [4]	248	507	2418	J4170000
Kinston	02089500	1970-2015	642	1729	5894	J6150000
Fort Barnwell	02091814	1996-2015 [2]	890	2615	8788	J7850000
Streets Ferry	See Note 3	1970-2015	900	2628	8957	J7930000
Tributaries						
Contentnea Creek @ Hookerton	02091500	1970-2015	123	459	1734	J7450000
Trent River @ Trenton	02092500	1970-2015	15	86	463	J8690000

Notes: (1) Flow data exist before the date range used for five of the locations. A standard range was used for each location to minimize period-specific differences in flow distributions; (2) Prior to the USGS gauge installation in 1996, flows gauged at Kinston and Hookerton were used to estimate flows; (3) Flows at Kinston and Hookerton were used to estimate long-term flow range except following Hurricane Floyd when Fort Barnwell station 02091814 was used; (4) Building of Falls Reservoir impacted flow distribution beginning in 1983.

Table 3. Nutrient data sources used in analysis.

Data Source	Location	Years	Parameters [2]
ECU	Neuse@StreetsFerry	1980-1984	NH_3, NO_3, TKN, TN, TP
LNBA	Neuse@Clayton	1995-2015	NH_3, NO_3, TKN, TN, TP
	Neuse@Kinston	2000-2015	NH_3, NO_3, TKN, TN, TP
	Neuse@FtBarnwell	1995-2015	NH_3, NO_3, TKN, TN, TP
NCDWR	Neuse@Clayton	1972-2001	NH_3, NO_3, TKN, TN, TP
	Neuse@Kinston	1975-2015	NH_3, NO_3, TKN, TN, TP
	Neuse@StreetsFerry	1979-2015	NH_3, NO_3, TKN, TN, TP
	Neuse@FtBarnwell	1975-2015	NH_3, NO_3, TKN, TN, TP
	Contentnea@Hookerton	1973-2015	NH_3, NO_3, TKN, TN, TP
	Trent@Trenton	1973-2015	NH_3, NO_3, TKN, TN, TP
UNC-IMS	Neuse@StreetsFerry	1981-2015 [1]	NH_3, NO_3, TKN, TN
USGS	Neuse@Clayton	1972-1999	NH_3, NO_3, TKN, TN, TP
	Neuse@Kinston	1975-1996	NH_3, NO_3, TKN, TN, TP
	Contentnea@Hookerton	1979-1995	NH_3, NO_3, TKN, TN, TP
	Trent@Trenton	1978-1981	NH_3, NO_3, TKN, TN, TP
Weyerhaeuser	Neuse@StreetsFerry	1978-2002	NH_3, NO_3, TKN, TN, TP

Notes: (1) TKN and TN beginning in 2000; (2) General parameter set but not necessarily available for all dates. Abbreviations indicate: (ECU) East Carolina University; (LNBA) Lower Neuse Basin Association; (NCDWR) North Carolina Dept. of Environment Quality, Division of Water Resources; (UNC-IMS) University of North Carolina at Chapel Hill, Institute of Marine Sciences ModMon Program; (USGS) U.S. Geological Survey; and (Weyerhaeuser) Weyerhaeuser Company.

Nutrient fractions evaluated included ammonia (NH_3-N), nitrate+nitrite (NO_3-N), total Kjeldahl N (TKN), total N (TN), and total P (TP). For inorganic P fractions, data were insufficient across the time period evaluated to include in the analysis. Table 3 lists nutrient data sources included in the trend analysis and the years from which data were available. In terms of overall data available for each location, Appendix A lists the number of data points for each location by time period and nutrient fraction. Data for NCDWR and USGS were extracted from the STORET and NWIS databases, respectively, and accessed through the Internet, with the exception of NCDWR data from 2014 and 2015, which were provided by staff at NCDWR for this analysis. For data collected by the Lower Neuse Basin Association (LNBA), data were obtained from STORET for data prior to 2014 and from the LNBA website, with permission, for 2014 and 2015. The data from ECU studies on the Neuse River from the early 1980s were obtained from Robert

Christian, Dept. of Biology, East Carolina University during previous data compilation efforts. Data collected by Weyerhaeuser and UNC-IMS (ModMon Program) were available from the prior compilation of data for trend analysis (see Lebo et al. 2012). Recent data from the ModMon program were provided by Ben Peierls at UNC-IMS for 2009-2015.

The majority of the data included in the analysis was collected as grab samples from the photic zone (upper mixed layer) of the water column. For data collected by NCDWR at the Kinston location, data were available from both the long-term ambient monitoring program and an intensive effort beginning in 1995 utilizing an automated sampler. With the exception of 2001 to 2003, the ambient monitoring data from NCDWR were used so that the number of sampling dates across periods would be generally similar. For 2001-2003, the nutrient data collected through automated monitoring were subsampled to generate two survey dates per month comparable to the frequency of data collection throughout the analysis period; the closest sampling date to the 1st and 15th of each month were used. The same subsampling approach was used for the Fort Barnwell location for which data were compiled for this paper. Parameter values listed as less than the detection limit were included at the detection limit (DL) provided the DL was equal to or less than 0.05 mg/L for NH_3-N, NO_3-N, and TP or less than or equal to 0.1 mg/L for TKN and TN. For reported non-detect samples with elevated DL, the reported DL was not used and the data point was omitted from the analysis. Average concentrations by flow interval for each year and for diagnostic multi-year periods were determined both as means and as flow-weighted averages.

NUTRIENT TIME SERIES

The change in nutrient parameter values over time is presented in a series of plots at the end of this section based on annual average concentrations by flow bin and location (Figures 2-6). In the plots, available data for each of the three flow bins are integrated into an average value for each flow bin, provided data were reported for the flow bin for the particular year and location. Breaks in the lines indicate a year in which no data points were available for the particular flow bin. Overall average concentrations for each of seven flow periods by flow bin are provided in Table 4. For the TMDL implementation period, annual nutrient concentrations by flow bin were used to evaluate overall change in concentrations by linear regression as shown in Table 5. Significant differences are highlighted in Table 5 by bold text. Finally, the plots of annual values of TN concentration by flow bin for the Fort Barnwell and Streets Ferry locations are shown in Figure 7 with a reduced concentration range compared with common range used in Figure 5 for all six locations. The data for Fort Barnwell and Streets Ferry are shown on Figure 7 to allow a closer examination of how data compare for the two locations commonly used to evaluate nutrient loading to the Neuse Estuary. Plots of actual data values by parameter and location are provided in Appendix B.

Neuse River @ Clayton

Nutrient concentrations in the Neuse River at Clayton showed consistent responses to management efforts to control nitrogen and phosphorus. Annual average concentrations of NH_3-N, NO_3-N, TKN, TN, and TP are shown on Figures 2-6. Time series of NO_3-N and TN concentration showed decreases from values commonly 2-4 mg/L in the 1990s to 0-1 and 0.5-2.0 mg/L, respectively, after 1998. Grouping of measurements by low, middle, and high flows showed changes in NO_3-N and TN occurred across all flows, with less difference in concentrations between low and high flows after the decrease in 1998 (Table 4a). In contrast, concentrations of NH_3-N and TKN decreased in the late 1970s to early 1980s (see Appendix B), with a more recent increase in TKN after 2000 (Figure 4). For TKN, increased concentrations after 2000 occurred across all flow bins (see Table 4a), with overall increases of 31-46% in TKN (Table 5). The lack of significant decreases in NO_3-N and TN for the 2000-2015 period is attributable to the large decrease in concentrations that occurred in 1997-98. For TP concentrations in the Neuse River at Clayton, values decreased in the late 1980s from concentrations typically 0.5 to 2.0 mg/L (see Appendix B) to values consistently 0.1-0.4 mg/L (see Table 4a). Like NO_3-N and TN, the relative difference between low and high flow values for TP diminished substantially beginning in 1988 (see Figure 6).

Neuse River @ Kinston

Time series of nutrient concentrations for the Neuse River at Kinston showed similarities to the upstream pattern at the Clayton station, although peak concentrations were lower. Nitrate at Kinston progressively increased during the 1990s to values generally ranging from 0.5-1.5 mg/L (see Appendix B) and then decreased in 1998 to 0.3-0.8 mg/L (Figure 3). At the time of the decrease in NO_3-N, there was a corresponding decrease in TN; typical concentrations of TN decreased from 1.5±0.5 mg/L to approximately 1.0±0.5 mg/L. The change in NO_3-N and TN concentrations at the Kinston station occurred concurrent with the upstream change at Clayton, with a relative minimum in concentrations in the 2000-03 period (Table 4b). Like the patterns at Clayton, average values for NO_3-N and TN at Kinston in the 2000s were not elevated for low flows, as they were in the 1990s. In contrast, TKN concentrations at the Kinston station showed only minor changes in the late 1990s. TKN concentrations did start to gradually increase starting early 2000s from 0.3-0.6 to 0.5-0.8 mg/L in 2015. The increases in TKN were 47-58% of the values for 2000, with the observed increases significant ($P<0.05$) for all three flow bins (Table 5). Increases in TN of 30-37% during the 2000-15 period were also significant, with high flow concentrations higher than in 1995-99 but lower concentrations for the low and middle flows. Thus, progress at low and middle flows was evident but not at high flows. The NH_3-N fraction generally comprised a small fraction (<10%) of TN concentrations (Table 4b). The TP concentration showed a decrease in concentration beginning in 1988 after management actions were enacted in the basin (Table 4b; see also Appendix B for plot).

Neuse River @ Fort Barnwell

Similar to other locations on the Neuse River, the Fort Barnwell location showed a rapid decrease in NO_3-N beginning in 1999 (see Appendix B). The NO_3-N concentrations remained relatively constant throughout the 2000s with little variance between flow conditions (Figure 3). However, there is a small increase in concentration for all flow conditions starting in 2012 through present. Overall for the 2000-15 period, the NO_3-N concentration increased by 9-17% depending on flow fraction (Table 5). TN concentrations followed a similar pattern to those at NO_3-N, with concentrations increasing by 18-28% during 2000-15 (Figure 5; Table 5). The change in TN concentrations for the low and middle flow bins were significant at $P<0.05$. TKN concentrations decreased during the 1980s and early 1990s before increasing by 11-49% during 2000-15 (change in middle flows significant at $P<0.05$). The high values for TKN and TN for 2001 for the high flow bin reflect a limited number of high flow samples (n=6) and a reported TKN of 4.1 mg/L for one of the samples, which would diminish the percent change for TKN for the 2000-2015 period (see Table 5). One interesting note is that high and middle flow conditions have seen the highest increase in TKN concentrations, with values consistently higher than for low flow conditions after 2000. TP concentrations saw a decrease in 1988 when the actions to reduce TP were enacted and have been fairly steady since then with concentrations remaining between 0.1 and 0.2 mg/L for all three flow bins (see Table 4b).

Neuse River @ Streets Ferry

Temporal changes in N and P concentrations in the Neuse River at Streets Ferry, as with the Fort Barnwell location, reflect upstream sources illustrated by the Kinston station and data from Contentnea Creek at Hookerton (see below). The time series for NO_3-N at Streets Ferry shows a pattern of increasing concentration during the 1980s to a broad peak in the early 1990s at 1.0 ± 0.5 mg/L followed by a general decrease in concentration to 0.5 ± 0.3 mg/L in the late 1990s (Figure 3). Somewhat different, TN concentrations were steady but variable during the 1980s and early 1990s before decreasing concurrent with the patterns at the Clayton and Kinston stations on the Neuse River (Figure 5). Another difference in patterns observed at Streets Ferry compared with the stations in the middle and upper basin is the lack of historically elevated concentrations, on average, under low flow conditions, which probably reflects the integration of multiple sources of nutrient inputs throughout the basin and instream processes. In contrast, the TKN concentrations in the Neuse River at Streets Ferry showed minimal change over time across all flow regimes (Figure 4), although there is a gradual increase in concentrations starting in 2005 for all flow bins (Table 4b). For the 2000-2015 period, there were significant ($P<0.05$) increases in NH_3-N, TKN, and TN for the high flow bin (Table 5). As with other main stem stations, TP concentrations were highest in the 1980-87 period and then decreased after P controls were enacted. The pattern for TP at Streets Ferry, in contrast to NO_3-N and TN, showed higher concentrations under low flows prior to enactment of controls compared with middle and high flows.

Contentnea Creek @ Hookerton

Variation in N and P concentrations in Contentnea Creek at Hookerton diverged in a number of ways from the patterns described above for the Neuse River stations. Peaks in NO_3-N and TN in Contentnea Creek occurred in the early 1980s and commonly ranged 1-3 mg/L and 1.5-3.5 mg/L, respectively (Figures 3 and 5). Concentrations of NO_3-N and TN then 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. Significant changes for the 2000-15 period were a decrease in NH_3-N for low flows and increases in TKN for low and middle flows (Table 5). For TP, there was a decrease in concentration beginning in 1988, but consistently lower values (e.g. <0.2 mg/L) did not occur until after 2000. Notably, higher values of NH_3-N, TKN, and TP occurred in the late 1990s following high rainfall events associated with hurricanes (e.g. Fran in 1996, Dennis and Floyd in 1999) that impacted Eastern North Carolina, including the Neuse River watershed (c.f. Paerl et al., 2001; 2006a, c; Peierls et al., 2003). An interesting pattern for nutrients in Contentnea Creek is that all nutrient fractions were higher for low flow conditions for 1980-87, but the differences diminished beginning in 1988.

Trent River @ Trenton

Temporal patterns in nutrient concentrations in the Trent River did not appear to reflect management actions enacted in 1988 to reduce TP concentrations and beginning in 1999 for TN concentrations. The NO_3-N concentration generally decreased during the 1990s to a broad minimum in the mid- to late-1990s and then increased again throughout the 2000s (Figure 3). Unlike the locations along the Neuse River main stem, there was little to no difference in concentrations across the three flow bins. The TN and TKN concentrations followed similar patterns reaching a minimum in the late 1990s before steadily rising throughout the 2000s and 2010s (Figures 4 and 5). In fact, NO_3-N, TKN, and TN have increased in concentration by 8-41% over the past 15 years (see Table 5). TP concentrations remained fairly constant except in years associated with hurricanes impacting the region in the late 1990s (see Appendix B). Thus, the key patterns evident in nutrient data for the Trent River at Trenton are short-term increases in TP concentrations following hurricanes and potential overall increases in concentrations of several N fractions over the past decade.

Comparison of Fort Barnwell and Streets Ferry

The addition of the Fort Barnwell location on the Neuse River main stem allows a comparison of N fraction concentrations at Fort Barnwell to the Streets Ferry location. Both stations are in the tidal freshwater portion of the Neuse Estuary, but there would be the potential for particle settling or uptake of NH_3-N or NO_3-N by suspended algae along the 15 mile distance between the two locations, particularly under low to middle flow conditions. Average concentrations of N fractions for the two locations are listed in Table 4b. During the TMDL implementation period of 2000-15, concentrations of NO_3-N and TKN were lower at Streets Ferry than at Fort Barnwell, leading to 5-15% lower TN concentrations. The percent change for the 2000-15 period was also greater (see Table 5), in terms of increase, at Fort Barnwell than at the Streets Ferry location. Thus, the nutrient trends at the Fort Barnwell location would have a high bias relative to the delivery to the Neuse Estuary at the Streets Ferry location.

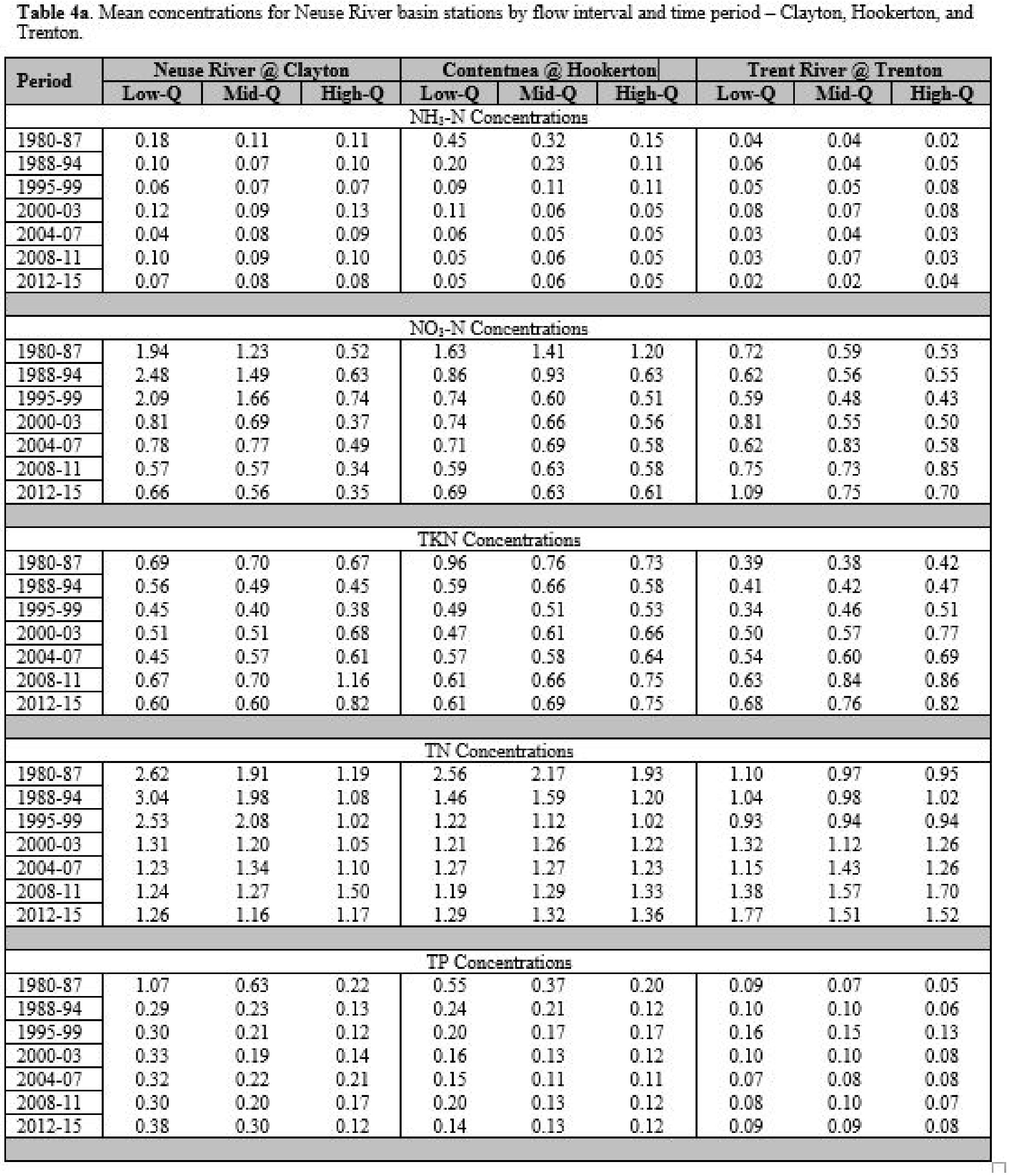
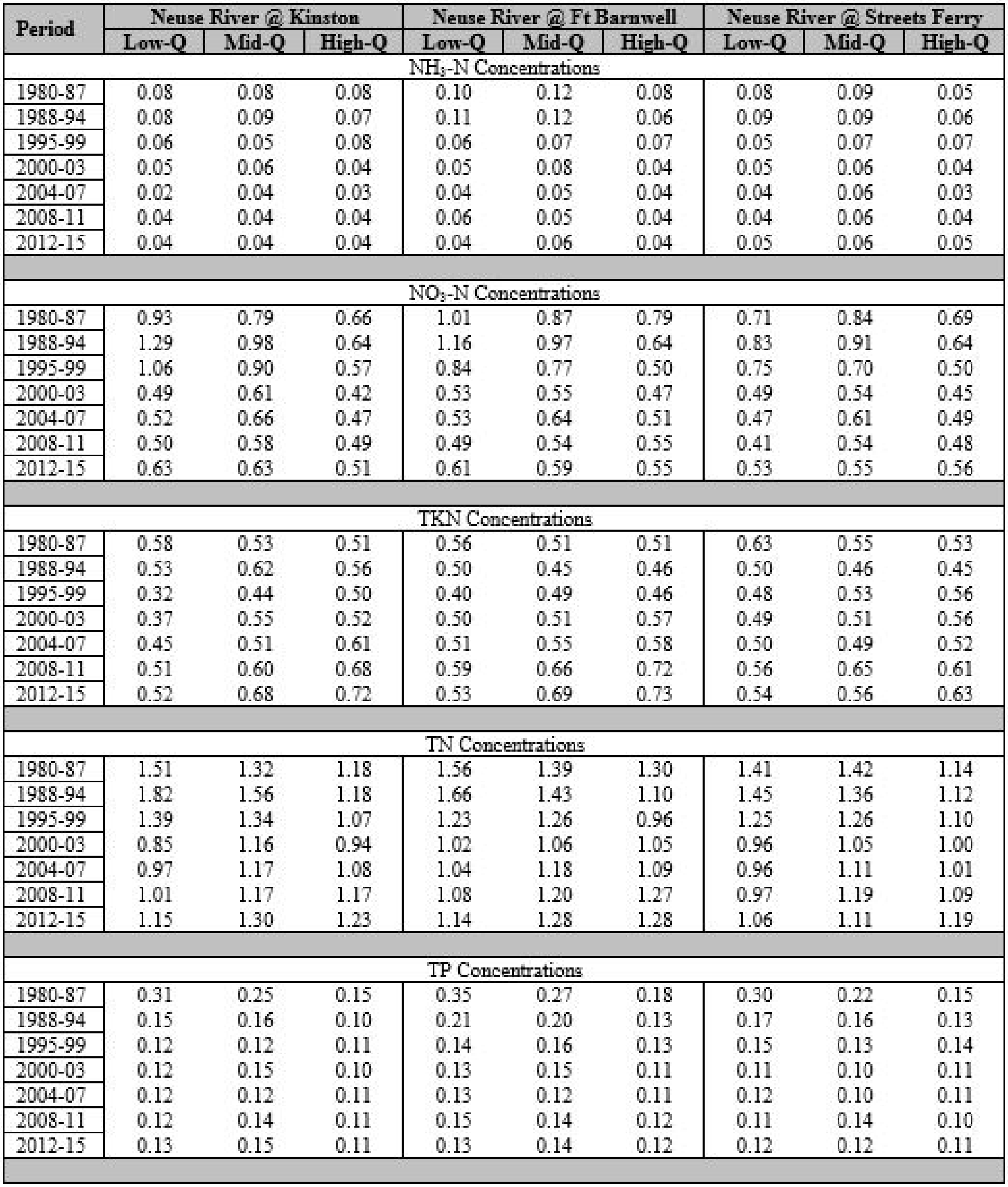


Table 4a. Mean concentrations for Neuse River basin stations by flow interval and time period – Clayton, Hookerton, and Trenton.

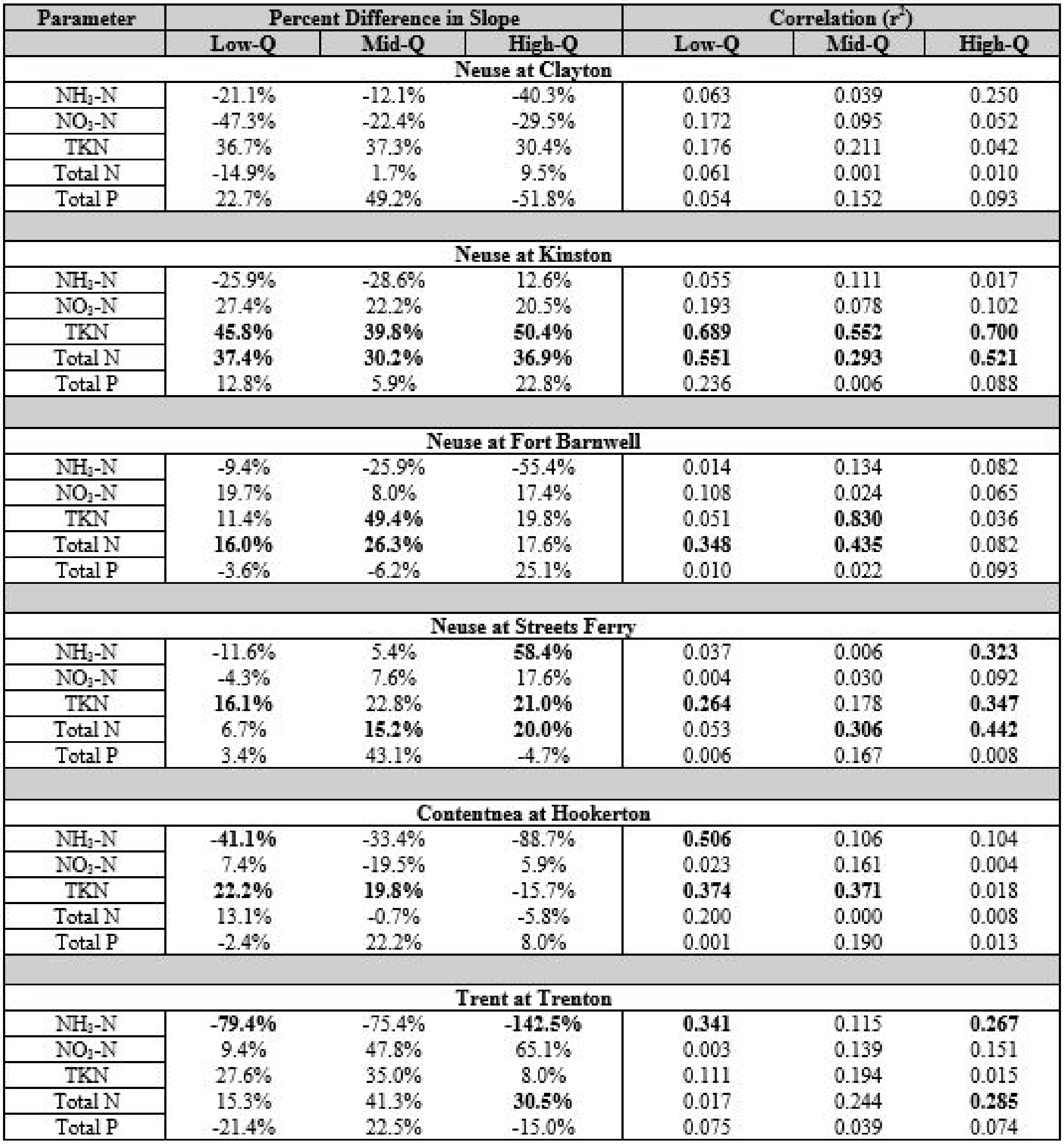
Period	Neuse River @ Clayton			Contentnea @ Hookerton			Trent River @ Trenton		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
				NH_3-N Concentrations					
1980-87	0.18	0.11	0.11	0.45	0.32	0.15	0.04	0.04	0.02
1988-94	0.10	0.07	0.10	0.20	0.23	0.11	0.06	0.04	0.05
1995-99	0.06	0.07	0.07	0.09	0.11	0.11	0.05	0.05	0.08
2000-03	0.12	0.09	0.13	0.11	0.06	0.05	0.08	0.07	0.08
2004-07	0.04	0.08	0.09	0.06	0.05	0.05	0.03	0.04	0.03
2008-11	0.10	0.09	0.10	0.05	0.06	0.05	0.03	0.07	0.03
2012-15	0.07	0.08	0.08	0.05	0.06	0.05	0.02	0.02	0.04
				NO_3-N Concentrations					
1980-87	1.94	1.23	0.52	1.63	1.41	1.20	0.72	0.59	0.53
1988-94	2.48	1.49	0.63	0.86	0.93	0.63	0.62	0.56	0.55
1995-99	2.09	1.66	0.74	0.74	0.60	0.51	0.59	0.48	0.43
2000-03	0.81	0.69	0.37	0.74	0.66	0.56	0.81	0.55	0.50
2004-07	0.78	0.77	0.49	0.71	0.69	0.58	0.62	0.83	0.58
2008-11	0.57	0.57	0.34	0.59	0.63	0.58	0.75	0.73	0.85
2012-15	0.66	0.56	0.35	0.69	0.63	0.61	1.09	0.75	0.70
				TKN Concentrations					
1980-87	0.69	0.70	0.67	0.96	0.76	0.73	0.39	0.38	0.42
1988-94	0.56	0.49	0.45	0.59	0.66	0.58	0.41	0.42	0.47
1995-99	0.45	0.40	0.38	0.49	0.51	0.53	0.34	0.46	0.51
2000-03	0.51	0.51	0.68	0.47	0.61	0.66	0.50	0.57	0.77
2004-07	0.45	0.57	0.61	0.57	0.58	0.64	0.54	0.60	0.69
2008-11	0.67	0.70	1.16	0.61	0.66	0.75	0.63	0.84	0.86
2012-15	0.60	0.60	0.82	0.61	0.69	0.75	0.68	0.76	0.82
				TN Concentrations					
1980-87	2.62	1.91	1.19	2.56	2.17	1.93	1.10	0.97	0.95
1988-94	3.04	1.98	1.08	1.46	1.59	1.20	1.04	0.98	1.02
1995-99	2.53	2.08	1.02	1.22	1.12	1.02	0.93	0.94	0.94
2000-03	1.31	1.20	1.05	1.21	1.26	1.22	1.32	1.12	1.26
2004-07	1.23	1.34	1.10	1.27	1.27	1.23	1.15	1.43	1.26
2008-11	1.24	1.27	1.50	1.19	1.29	1.33	1.38	1.57	1.70
2012-15	1.26	1.16	1.17	1.29	1.32	1.36	1.77	1.51	1.52
				TP Concentrations					
1980-87	1.07	0.63	0.22	0.55	0.37	0.20	0.09	0.07	0.05
1988-94	0.29	0.23	0.13	0.24	0.21	0.12	0.10	0.10	0.06
1995-99	0.30	0.21	0.12	0.20	0.17	0.17	0.16	0.15	0.13
2000-03	0.33	0.19	0.14	0.16	0.13	0.12	0.10	0.10	0.08
2004-07	0.32	0.22	0.21	0.15	0.11	0.11	0.07	0.08	0.08
2008-11	0.30	0.20	0.17	0.20	0.13	0.12	0.08	0.10	0.07
2012-15	0.38	0.30	0.12	0.14	0.13	0.12	0.09	0.09	0.08

Table 4b. Mean concentrations for Neuse River basin stations by flow interval and time period – Kinston, Fort Barnwell, and Streets Ferry.

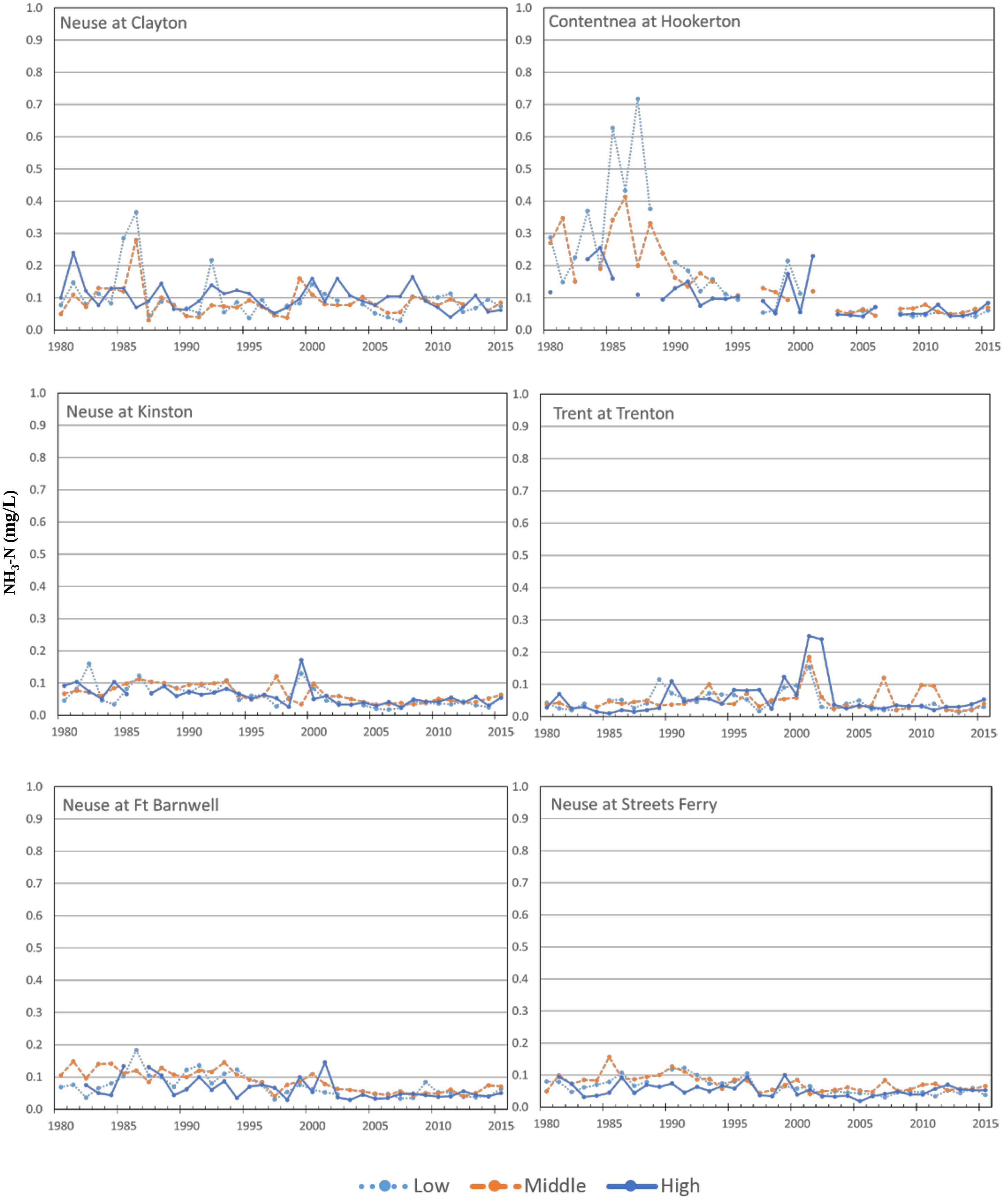


Period	Neuse River @ Kinston			Neuse River @ Ft Barnwell			Neuse River @ Streets Ferry		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
NH_3-N Concentrations									
1980-87	0.08	0.08	0.08	0.10	0.12	0.08	0.08	0.09	0.05
1988-94	0.08	0.09	0.07	0.11	0.12	0.06	0.09	0.09	0.06
1995-99	0.06	0.05	0.08	0.06	0.07	0.07	0.05	0.07	0.07
2000-03	0.05	0.06	0.04	0.05	0.08	0.04	0.05	0.06	0.04
2004-07	0.02	0.04	0.03	0.04	0.05	0.04	0.04	0.06	0.03
2008-11	0.04	0.04	0.04	0.06	0.05	0.04	0.04	0.06	0.04
2012-15	0.04	0.04	0.04	0.04	0.06	0.04	0.05	0.06	0.05
NO_3-N Concentrations									
1980-87	0.93	0.79	0.66	1.01	0.87	0.79	0.71	0.84	0.69
1988-94	1.29	0.98	0.64	1.16	0.97	0.64	0.83	0.91	0.64
1995-99	1.06	0.90	0.57	0.84	0.77	0.50	0.75	0.70	0.50
2000-03	0.49	0.61	0.42	0.53	0.55	0.47	0.49	0.54	0.45
2004-07	0.52	0.66	0.47	0.53	0.64	0.51	0.47	0.61	0.49
2008-11	0.50	0.58	0.49	0.49	0.54	0.55	0.41	0.54	0.48
2012-15	0.63	0.63	0.51	0.61	0.59	0.55	0.53	0.55	0.56
TKN Concentrations									
1980-87	0.58	0.53	0.51	0.56	0.51	0.51	0.63	0.55	0.53
1988-94	0.53	0.62	0.56	0.50	0.45	0.46	0.50	0.46	0.45
1995-99	0.32	0.44	0.50	0.40	0.49	0.46	0.48	0.53	0.56
2000-03	0.37	0.55	0.52	0.50	0.51	0.57	0.49	0.51	0.56
2004-07	0.45	0.51	0.61	0.51	0.55	0.58	0.50	0.49	0.52
2008-11	0.51	0.60	0.68	0.59	0.66	0.72	0.56	0.65	0.61
2012-15	0.52	0.68	0.72	0.53	0.69	0.73	0.54	0.56	0.63
TN Concentrations									
1980-87	1.51	1.32	1.18	1.56	1.39	1.30	1.41	1.42	1.14
1988-94	1.82	1.56	1.18	1.66	1.43	1.10	1.45	1.36	1.12
1995-99	1.39	1.34	1.07	1.23	1.26	0.96	1.25	1.26	1.10
2000-03	0.85	1.16	0.94	1.02	1.06	1.05	0.96	1.05	1.00
2004-07	0.97	1.17	1.08	1.04	1.18	1.09	0.96	1.11	1.01
2008-11	1.01	1.17	1.17	1.08	1.20	1.27	0.97	1.19	1.09
2012-15	1.15	1.30	1.23	1.14	1.28	1.28	1.06	1.11	1.19
TP Concentrations									
1980-87	0.31	0.25	0.15	0.35	0.27	0.18	0.30	0.22	0.15
1988-94	0.15	0.16	0.10	0.21	0.20	0.13	0.17	0.16	0.13
1995-99	0.12	0.12	0.11	0.14	0.16	0.13	0.15	0.13	0.14
2000-03	0.12	0.15	0.10	0.13	0.15	0.11	0.11	0.10	0.11
2004-07	0.12	0.12	0.11	0.13	0.12	0.11	0.12	0.10	0.11
2008-11	0.12	0.14	0.11	0.15	0.14	0.12	0.11	0.14	0.10
2012-15	0.13	0.15	0.11	0.13	0.14	0.12	0.12	0.12	0.11

Table 5. Calculated slope and correlation (r^2) for each location and parameter using annual averages for the years 2000-2015 by flow bin. Bold values indicate significant trends at $p < 0.05$. Percentage differences are based on change from the 2000-03 average concentration reported in Table 4.



Parameter	Percent Difference in Slope			Correlation (r^2)		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
Neuse at Clayton						
NH_3-N	-21.1%	-12.1%	-40.3%	0.063	0.039	0.250
NO_3-N	-47.3%	-22.4%	-29.5%	0.172	0.095	0.052
TKN	36.7%	37.3%	30.4%	0.176	0.211	0.042
Total N	-14.9%	1.7%	9.5%	0.061	0.001	0.010
Total P	22.7%	49.2%	-51.8%	0.054	0.152	0.093
Neuse at Kinston						
NH_3-N	-25.9%	-28.6%	12.6%	0.055	0.111	0.017
NO_3-N	27.4%	22.2%	20.5%	0.193	0.078	0.102
TKN	**45.8%**	**39.8%**	**50.4%**	**0.689**	**0.552**	**0.700**
Total N	**37.4%**	**30.2%**	**36.9%**	**0.551**	**0.293**	**0.521**
Total P	12.8%	5.9%	22.8%	0.236	0.006	0.088
Neuse at Fort Barnwell						
NH_3-N	-9.4%	-25.9%	-55.4%	0.014	0.134	0.082
NO_3-N	19.7%	8.0%	17.4%	0.108	0.024	0.065
TKN	11.4%	**49.4%**	19.8%	0.051	**0.830**	0.036
Total N	**16.0%**	**26.3%**	17.6%	**0.348**	**0.435**	0.082
Total P	-3.6%	-6.2%	25.1%	0.010	0.022	0.093
Neuse at Streets Ferry						
NH_3-N	-11.6%	5.4%	**58.4%**	0.037	0.006	**0.323**
NO_3-N	-4.3%	7.6%	17.6%	0.004	0.030	0.092
TKN	**16.1%**	22.8%	**21.0%**	**0.264**	0.178	**0.347**
Total N	6.7%	**15.2%**	**20.0%**	0.053	**0.306**	**0.442**
Total P	3.4%	43.1%	-4.7%	0.006	0.167	0.008
Contentnea at Hookerton						
NH_3-N	**-41.1%**	-33.4%	-88.7%	**0.506**	0.106	0.104
NO_3-N	7.4%	-19.5%	5.9%	0.023	0.161	0.004
TKN	**22.2%**	**19.8%**	-15.7%	**0.374**	**0.371**	0.018
Total N	13.1%	-0.7%	-5.8%	0.200	0.000	0.008
Total P	-2.4%	22.2%	8.0%	0.001	0.190	0.013
Trent at Trenton						
NH_3-N	**-79.4%**	-75.4%	**-142.5%**	**0.341**	0.115	**0.267**
NO_3-N	9.4%	47.8%	65.1%	0.003	0.139	0.151
TKN	27.6%	35.0%	8.0%	0.111	0.194	0.015
Total N	15.3%	41.3%	**30.5%**	0.017	0.244	**0.285**
Total P	-21.4%	22.5%	-15.0%	0.075	0.039	0.074



CLIENT: City of Raleigh
LOCATION: Raleigh, NC
PROJECT/FILE: 161012

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FIGURE 2
Annual NH$_3$-N concentrations by flow bin and location

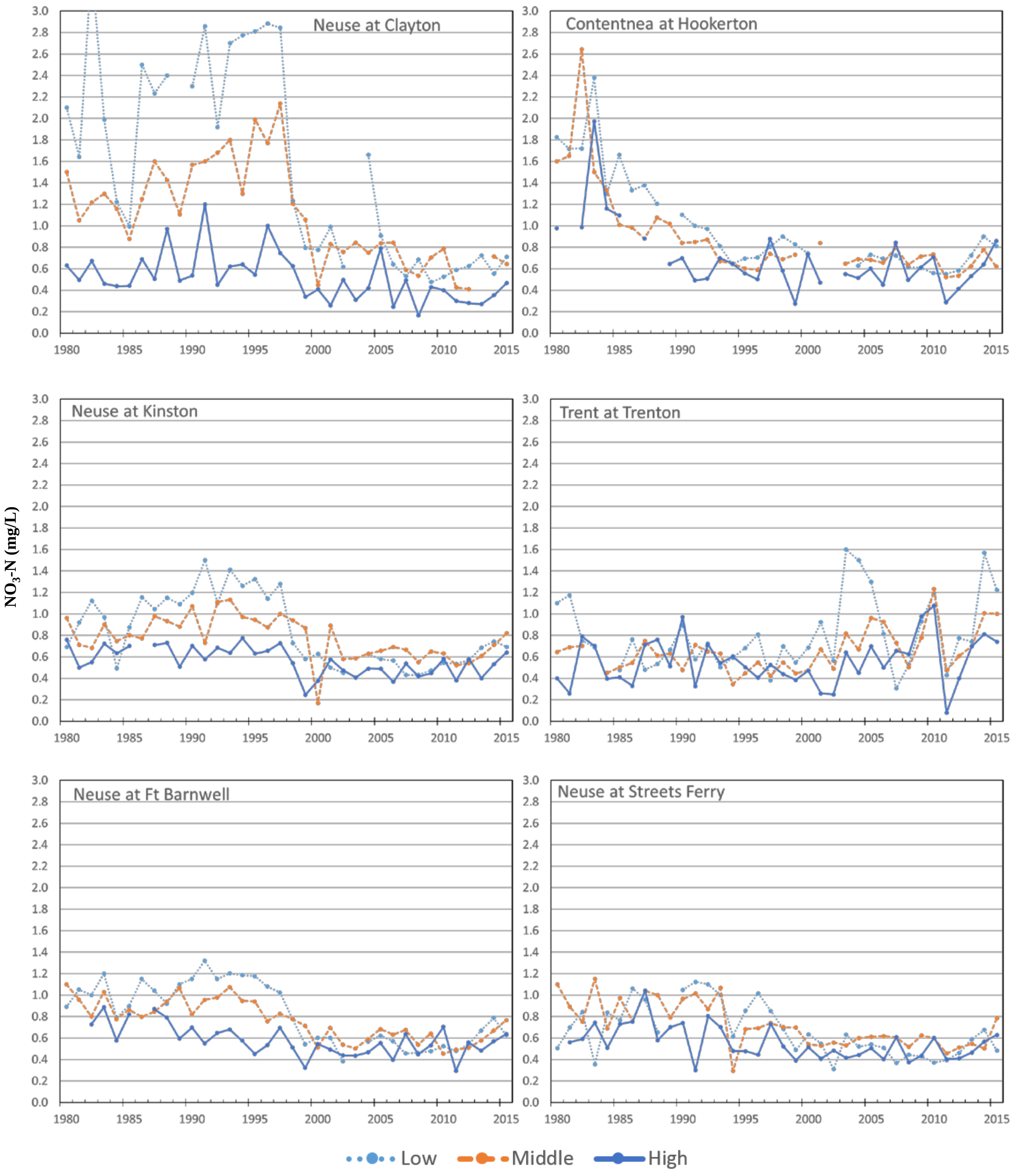

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FIGURE 3
Annual NO$_3$-N concentrations by flow bin and location

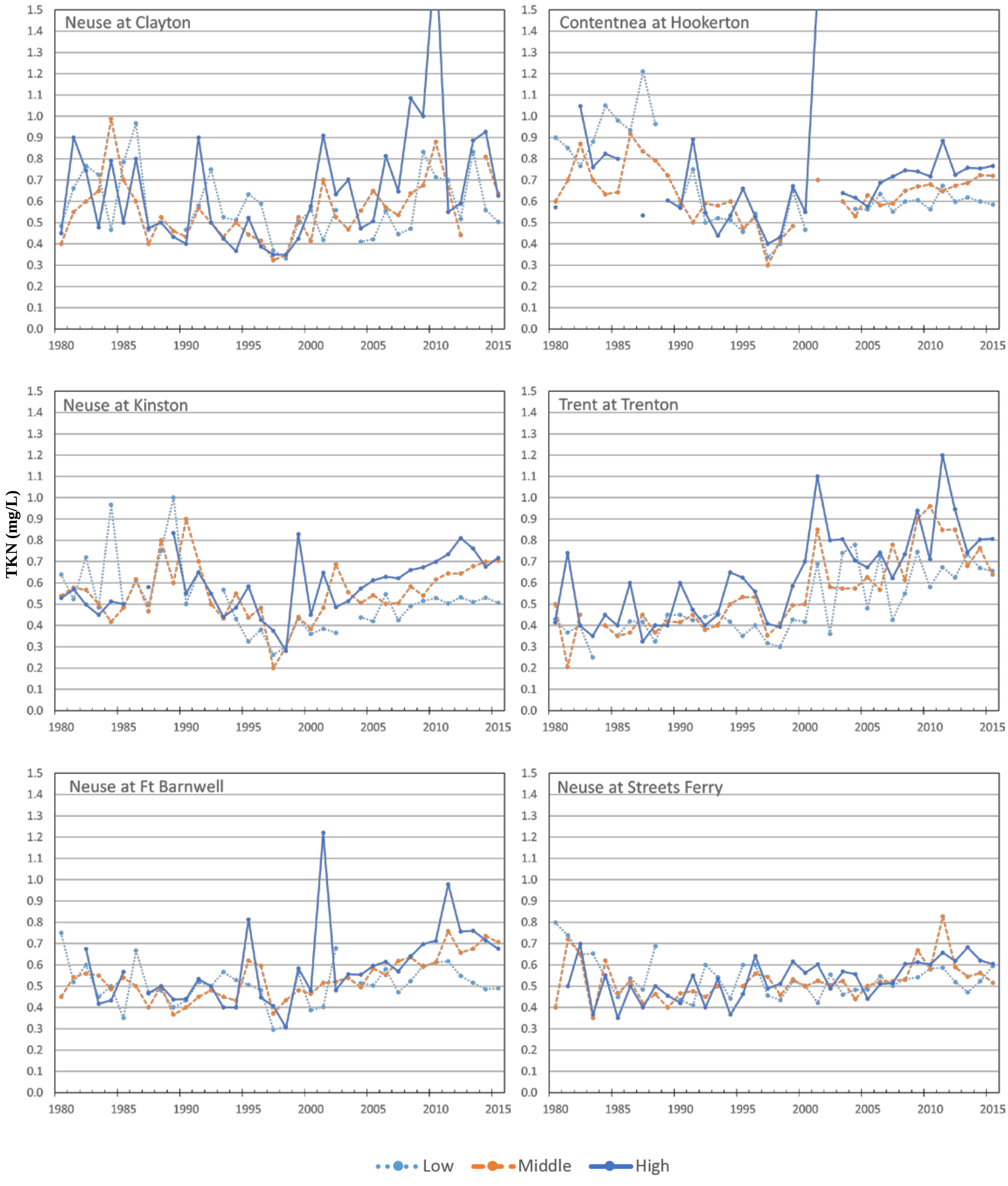

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FIGURE 4
Annual TKN concentrations
by flow bin and location

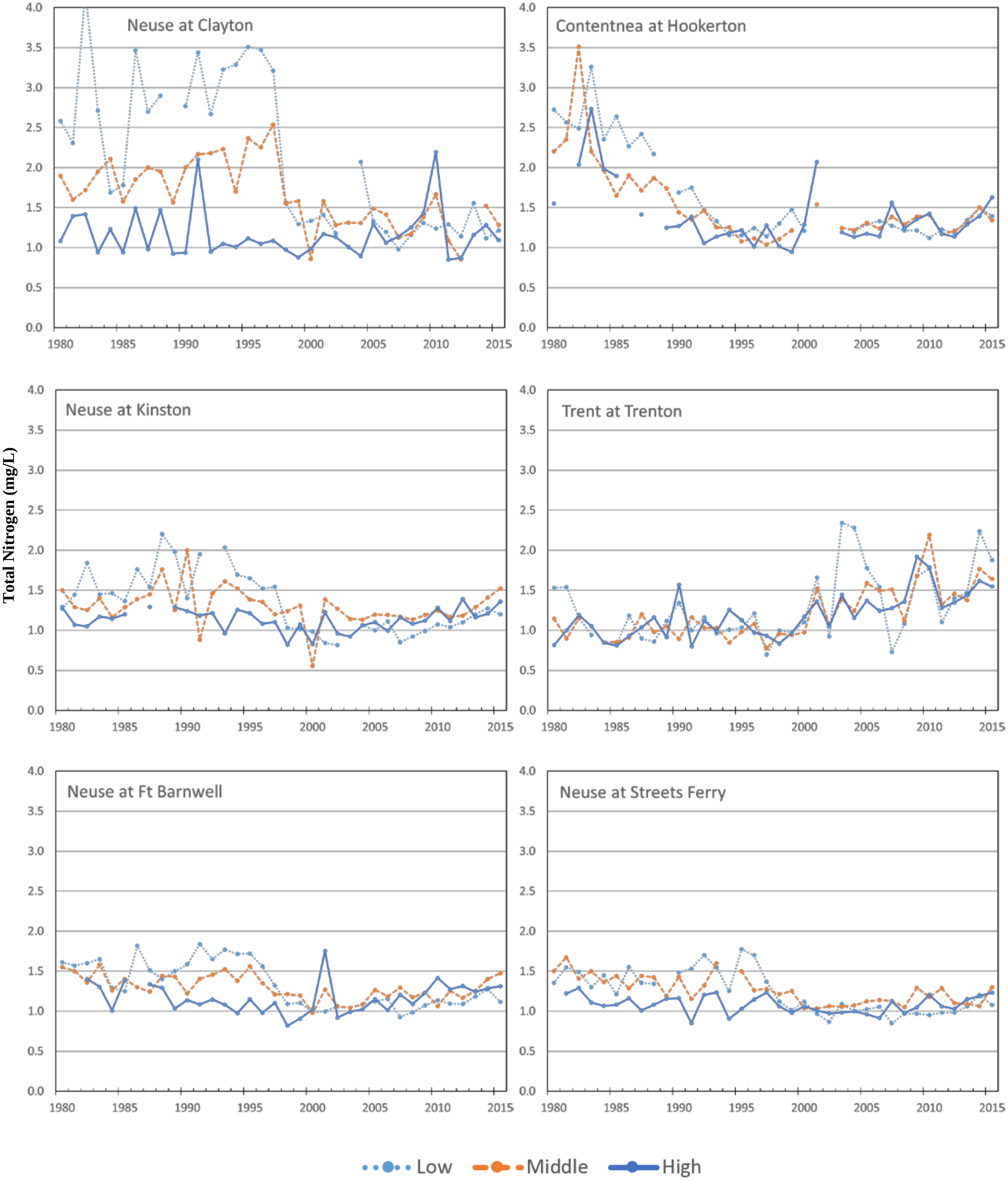

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FIGURE 5
Annual TN concentrations by flow bin and location

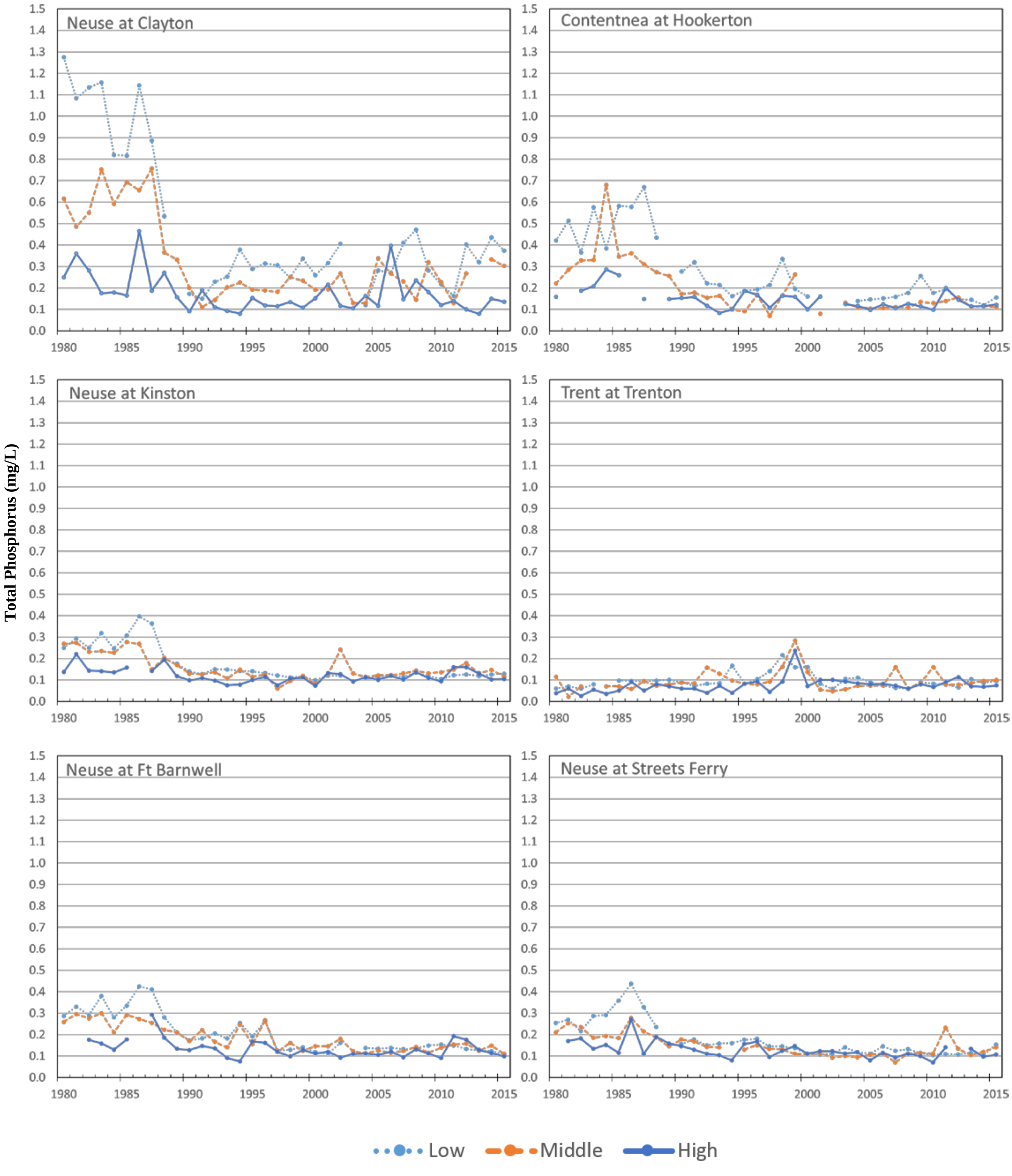

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FIGURE 6
Annual TP concentrations by flow bin and location

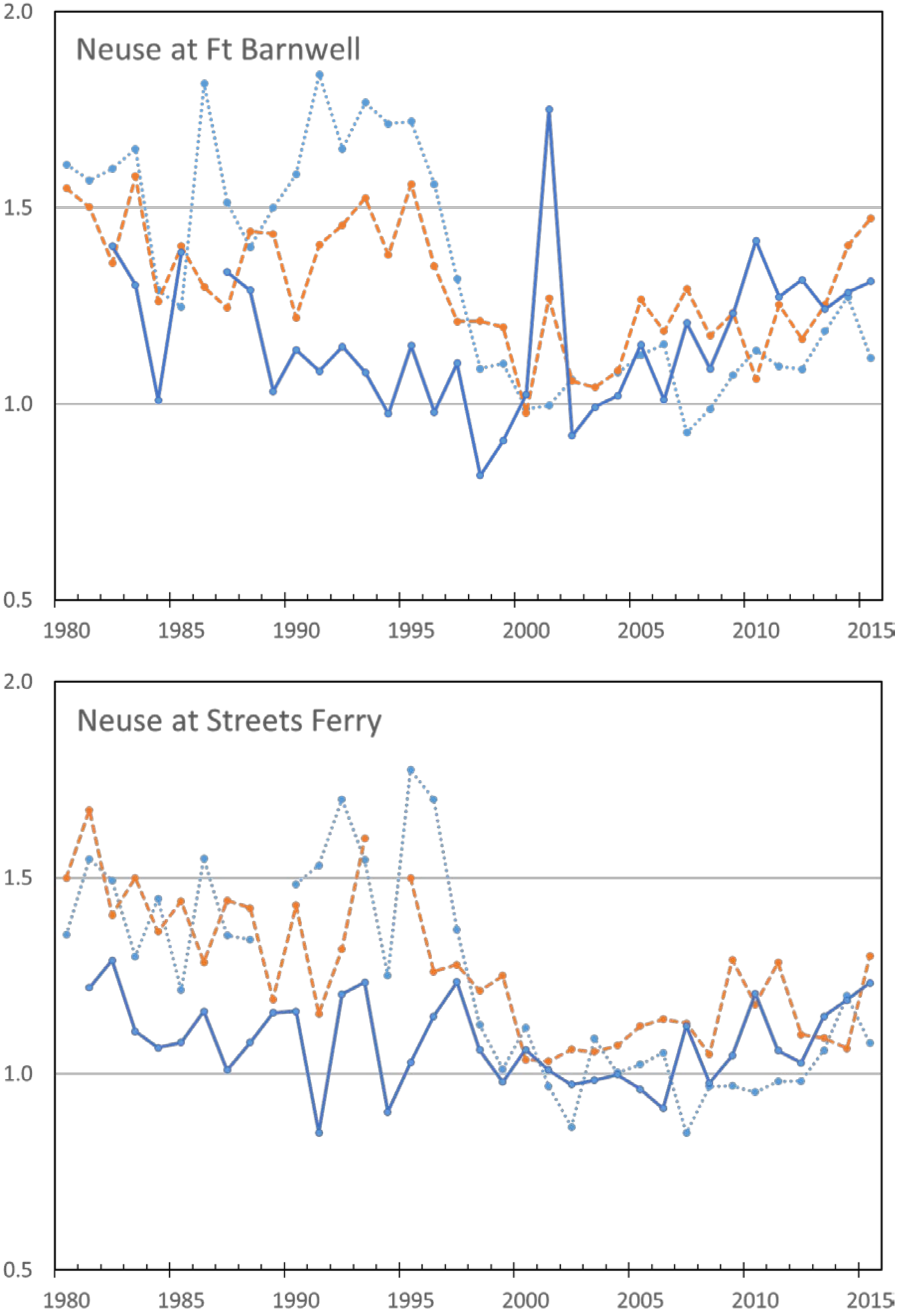

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FIGURE 7
Annual TN averages at
Fort Barnwell and Streets Ferry

PREDICTED NUTRIENT LOADS

Average nutrient concentrations were combined with flow for each location to estimate change in nutrient loading for 1980-2015. First, actual annual flows were used to compute nutrient loads by year and location. Annual flows are shown in Figure 8. In the calculation, nutrient data for a 3-yr period were used to estimate the concentration of each N fraction and TP by flow bin and year. A 3-yr period, including the prior year and next year, was used to provide more data to define the average concentrations by year. Actual loads by year are shown in Figures 9 and 10. In addition, flow-normalized loads were calculated from concentrations listed in Table 4 and average long-term flows listed in Table 2. The flow-normalized loads were computed to evaluate trends associated with nutrient fractions as a means to track progress of management actions on controlling N and P export to the Neuse Estuary and from different regions of the basin. The integration of N and P concentrations by flow bin with the proportion of total flow volume contributed by the flow bin allows patterns in flow-normalized loadings to be evaluated (Table 6).

Dissolved Inorganic N

Average nutrient concentrations by flow interval for each time period were combined with mean flows for each flow interval to derive relative nutrient loads for each time period under long-term average flow conditions. For the dissolved inorganic N (DIN) fractions of N in the Neuse River and the two tributaries evaluated, the predominant form was NO_3-N, as illustrated by concentrations reported in Tables 4a and 4b and relative loads reported in Tables 6a and 6b; the NH_3-N fraction accounted for about 7-13% of calculated DIN load. Figure 9 shows the actual TN load by location and year with stacked bars representing the components of the total. Conversion of NO_3-N concentrations to predicted load under average flow conditions showed a substantial decrease at the Clayton location from 2.1 x 10^6 lbs/yr in 1995-99 to 0.8 to 1.1 x 10^6 lbs/yr beginning in 2000. The increase in NO_3-N load in 2004-07 compared with 2000-03 is due to higher NO_3-N concentration under high flow conditions. Predicted loads continued to drop after the 2004-07 period to 0.82-0.84 x 10^6 lbs/yr in 2008-2015.

At the Kinston location, NO_3-N load was also lower after 2000 than the peak value calculated for the 1988-94 period, with the onset of the decrease occurring in 1995-99. The predicted loads have increased slightly since 2004 from 2.5 x 10^6 lbs/yr in 2000-03 to 3.0 x 10^6 lbs/yr in 2012-15. At the Fort Barnwell location, NO_3-N predicted loads steadily decreased for 1980-87 through 2000-03. This decrease was followed by an increase from 2004-07 through 2012-15. The pattern for the Streets Ferry location was similar to Fort Barnwell, showing decreasing NO_3-N for 1980-87 through 2000-03. As with Fort Barnwell this decrease was followed by an increasing pattern for the 2004-07 through 2012-15 periods. Notably, the recent increase in the NO_3-N load at all four stations along the main stem of the Neuse River was due to increases under middle and high flow conditions. Overall, a large fraction of NO_3-N, and hence DIN, load occurred during middle and high flow conditions. The general exception to this pattern was the Clayton station prior to reduction in N inputs associated with implementing requirements of the TMDL for TN.

The temporal patterns in NO_3-N load at tributary stations differed from Neuse River stations. For Contentnea Creek at the Hookerton station, a large decrease (1.9 x 10^6 lbs/yr to 1.1 x 10^6 lbs/yr) in NO_3-N load occurred between 1980-87 and 1988-94 prior to development of N controls for the Neuse River basin as seen in Table 6a. This peak in NO_3-N load in Contentnea Creek in the early 1980s helps explain the peak in the Neuse River at Streets Ferry and at Fort Barnwell, which was not evident at the Kinston location. Following the large decrease in the late 1980s in Contentnea Creek, the NO_3-N load was relatively constant at 0.82 x 10^6 to 0.94 x 10^6 lbs/yr, with a minimum in 1995-99. The predicted average NO_3-N load in the Trent River at Trenton also showed a minimum in the 1995-99 time period, consistent with Contentnea Creek, followed by increasing NO_3-N load in the 2000s to a maximum load in 2008-11. For the peak load in the Trent River in 2008-11, increased concentrations occurred for all flow conditions. However, NO_3-N transport in the Trent River occurred primarily (76-80%) under high flow conditions.

Total Kjeldahl N

The changes in TKN loads over time at the Neuse River monitoring locations diverged from the patterns observed for NO_3-N loads. For the Clayton location, the predicted TKN load for average flow conditions decreased from 1980-87 through 1995-99 and then increased again during the 2000-07 to 2012-15 periods (Table 6). Similarly, the TKN load at Kinston reached a low for 1995-99 before steadily increasing during the 2000-03 through 2012-15 periods. In contrast, the TKN load at Streets Ferry was variable over time from 3.7 x 10^6 to 5.0 x 10^6 lbs/yr, reaching a peak in 2008-11 at 5.0 x 10^6 lbs/yr. Fort Barnwell saw a steady increase in TKN loads for the 1995-99 through 2012-15 periods from 3.7 x 10^6 to 5.7 x 10^6 lbs/yr after a slight decrease in the 1980s. Overall, the vast majority of TKN load occurs under middle and high flow conditions at all four stations along the Neuse River.

For the tributary stations, different patterns were observed in Contentnea Creek and the Trent River. The pattern in Contentnea Creek showed a decreasing TKN load for 1980-87 to 1995-99 and then an increase in the 2000s, as was observed for the Neuse River at several locations (Table 6). In contrast, the pattern for TKN in the Trent River at Trenton showed a clear trend of increasing load over the three decades, with peak load under average flow conditions in 2008-11.

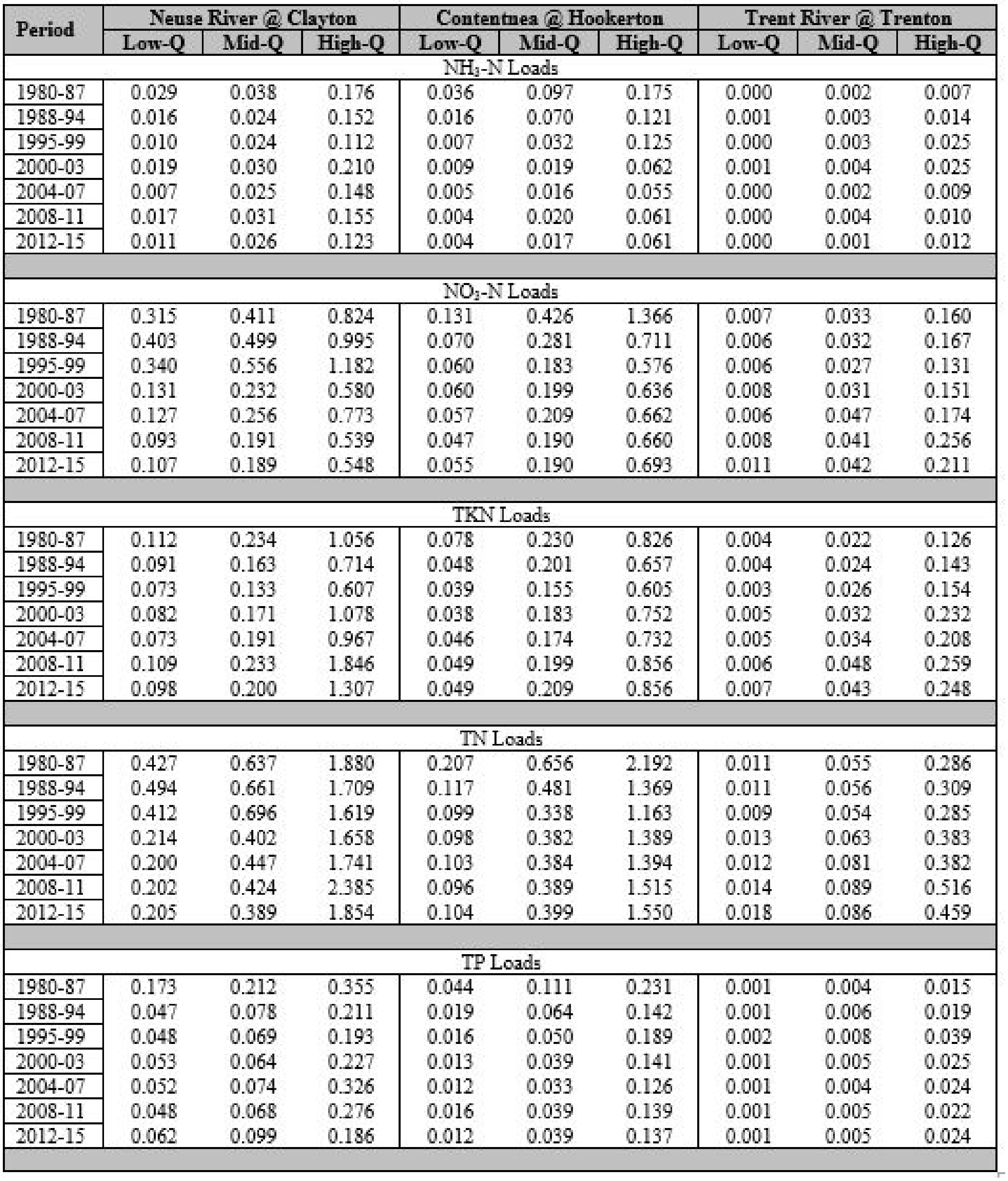
Total N

Changes in TN load along the Neuse River reflected an integration of the decrease in the NO_3-N load in the 2000s and the variable pattern observed for TKN load. For all four locations, the TN load for long-term average flow conditions began to increase in 2004-07 and continued to increase through the 2012-15 period (Table 6). The flow condition with the greatest change along the Neuse was the low flow condition. For the location in Contentnea Creek, the pattern for TN reflects a decrease in both NO_3-N and TKN during 1980-87 to 1996-99 followed by an increase again in the 2000s. The change in TN load for the Trent River, in contrast to the Neuse River and Contentnea Creek, showed variable predicted loads for 1980-87 to 1996-99 followed by a substantial increase beginning in the 2000s, largely associated with high flows.

Total P

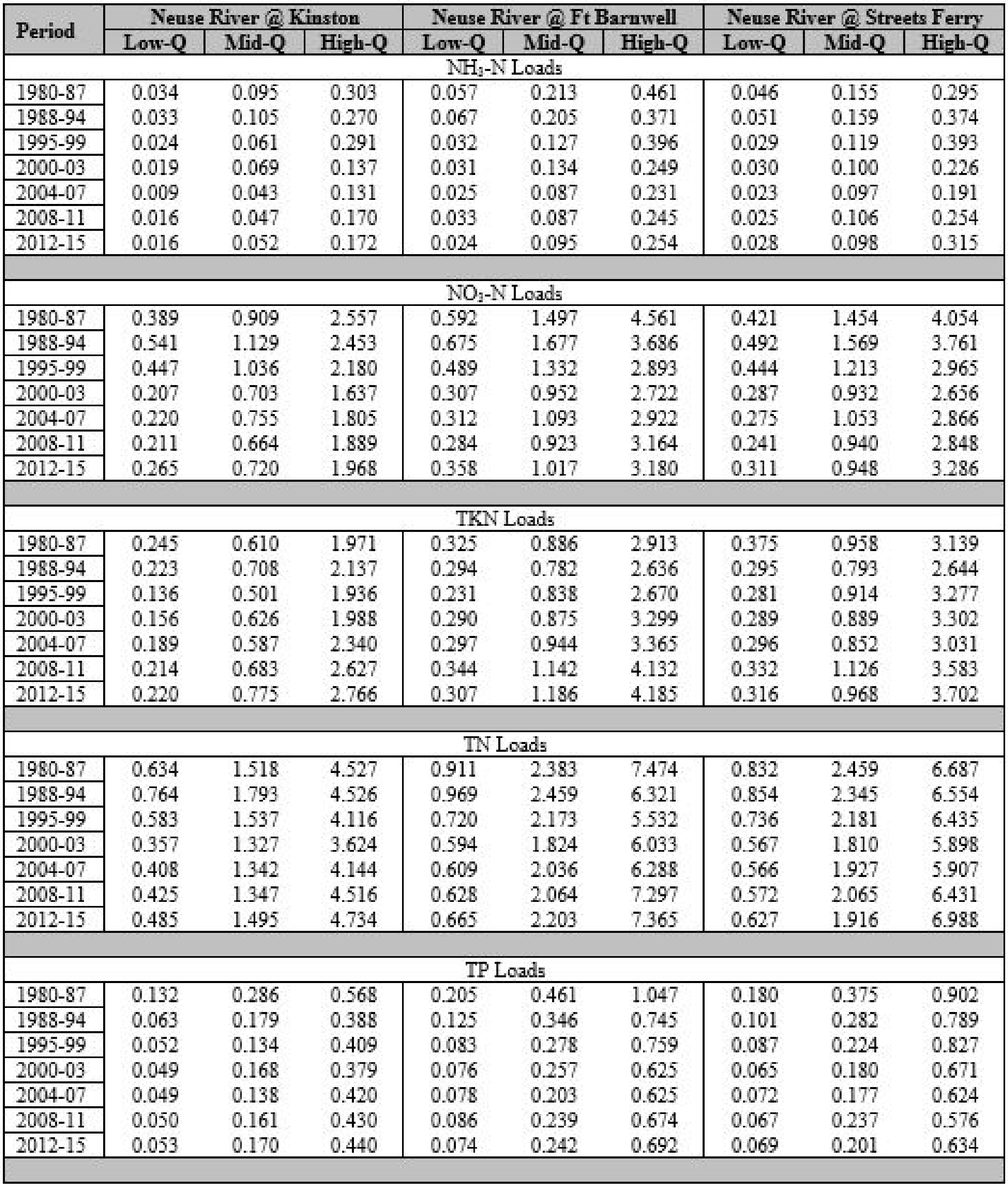
Changes in TP load along the Neuse River reflected the implementation of P controls in the late 1980s, although the timing of reductions varied by location (Figure 10). For the Clayton and Kinston locations, there was a large decrease in TP load after the 1980-87 period compared with a progressive decrease in TP at Fort Barnwell and at Streets Ferry (Table 6). The different patterns at Fort Barnwell and Streets Ferry, relative to Kinston, can be attributed to input from the Contentnea Creek watershed, which showed a continued decrease over time. In fact, export from Contentnea Creek showed a temporary increase in TP load in 1995-99 concurrent with peak hurricane activity. This peak in 1995-99 was also observed for the Trent River and was mainly associated with high flow conditions. Contrary to the main stem and Contentnea Creek stations, data from the Trent River indicate a general increase in TP load over time, with a large peak associated with elevated hurricane activity in 1995-99. One other notable feature was a peak in the TP load at the Clayton station during 2004-07 primarily associated with middle and high flow conditions, which was not present at downstream Neuse River stations.

Table 6a. Flow-normalized loads (10^6 lbs/yr) by flow interval and time period – Clayton, Hookerton, and Trenton.



Period	Neuse River @ Clayton			Contentnea @ Hookerton			Trent River @ Trenton		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
NH_3-N Loads									
1980-87	0.029	0.038	0.176	0.036	0.097	0.175	0.000	0.002	0.007
1988-94	0.016	0.024	0.152	0.016	0.070	0.121	0.001	0.003	0.014
1995-99	0.010	0.024	0.112	0.007	0.032	0.125	0.000	0.003	0.025
2000-03	0.019	0.030	0.210	0.009	0.019	0.062	0.001	0.004	0.025
2004-07	0.007	0.025	0.148	0.005	0.016	0.055	0.000	0.002	0.009
2008-11	0.017	0.031	0.155	0.004	0.020	0.061	0.000	0.004	0.010
2012-15	0.011	0.026	0.123	0.004	0.017	0.061	0.000	0.001	0.012
NO_3-N Loads									
1980-87	0.315	0.411	0.824	0.131	0.426	1.366	0.007	0.033	0.160
1988-94	0.403	0.499	0.995	0.070	0.281	0.711	0.006	0.032	0.167
1995-99	0.340	0.556	1.182	0.060	0.183	0.576	0.006	0.027	0.131
2000-03	0.131	0.232	0.580	0.060	0.199	0.636	0.008	0.031	0.151
2004-07	0.127	0.256	0.773	0.057	0.209	0.662	0.006	0.047	0.174
2008-11	0.093	0.191	0.539	0.047	0.190	0.660	0.008	0.041	0.256
2012-15	0.107	0.189	0.548	0.055	0.190	0.693	0.011	0.042	0.211
TKN Loads									
1980-87	0.112	0.234	1.056	0.078	0.230	0.826	0.004	0.022	0.126
1988-94	0.091	0.163	0.714	0.048	0.201	0.657	0.004	0.024	0.143
1995-99	0.073	0.133	0.607	0.039	0.155	0.605	0.003	0.026	0.154
2000-03	0.082	0.171	1.078	0.038	0.183	0.752	0.005	0.032	0.232
2004-07	0.073	0.191	0.967	0.046	0.174	0.732	0.005	0.034	0.208
2008-11	0.109	0.233	1.846	0.049	0.199	0.856	0.006	0.048	0.259
2012-15	0.098	0.200	1.307	0.049	0.209	0.856	0.007	0.043	0.248
TN Loads									
1980-87	0.427	0.637	1.880	0.207	0.656	2.192	0.011	0.055	0.286
1988-94	0.494	0.661	1.709	0.117	0.481	1.369	0.011	0.056	0.309
1995-99	0.412	0.696	1.619	0.099	0.338	1.163	0.009	0.054	0.285
2000-03	0.214	0.402	1.658	0.098	0.382	1.389	0.013	0.063	0.383
2004-07	0.200	0.447	1.741	0.103	0.384	1.394	0.012	0.081	0.382
2008-11	0.202	0.424	2.385	0.096	0.389	1.515	0.014	0.089	0.516
2012-15	0.205	0.389	1.854	0.104	0.399	1.550	0.018	0.086	0.459
TP Loads									
1980-87	0.173	0.212	0.355	0.044	0.111	0.231	0.001	0.004	0.015
1988-94	0.047	0.078	0.211	0.019	0.064	0.142	0.001	0.006	0.019
1995-99	0.048	0.069	0.193	0.016	0.050	0.189	0.002	0.008	0.039
2000-03	0.053	0.064	0.227	0.013	0.039	0.141	0.001	0.005	0.025
2004-07	0.052	0.074	0.326	0.012	0.033	0.126	0.001	0.004	0.024
2008-11	0.048	0.068	0.276	0.016	0.039	0.139	0.001	0.005	0.022
2012-15	0.062	0.099	0.186	0.012	0.039	0.137	0.001	0.005	0.024

Table 6b. Flow-normalized loads (10^6 lbs/yr) by flow interval and time period – Kinston, Fort Barnwell, and Streets Ferry.



Period	Neuse River @ Kinston			Neuse River @ Ft Barnwell			Neuse River @ Streets Ferry		
	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q	Low-Q	Mid-Q	High-Q
NH_3-N Loads									
1980-87	0.034	0.095	0.303	0.057	0.213	0.461	0.046	0.155	0.295
1988-94	0.033	0.105	0.270	0.067	0.205	0.371	0.051	0.159	0.374
1995-99	0.024	0.061	0.291	0.032	0.127	0.396	0.029	0.119	0.393
2000-03	0.019	0.069	0.137	0.031	0.134	0.249	0.030	0.100	0.226
2004-07	0.009	0.043	0.131	0.025	0.087	0.231	0.023	0.097	0.191
2008-11	0.016	0.047	0.170	0.033	0.087	0.245	0.025	0.106	0.254
2012-15	0.016	0.052	0.172	0.024	0.095	0.254	0.028	0.098	0.315
NO_3-N Loads									
1980-87	0.389	0.909	2.557	0.592	1.497	4.561	0.421	1.454	4.054
1988-94	0.541	1.129	2.453	0.675	1.677	3.686	0.492	1.569	3.761
1995-99	0.447	1.036	2.180	0.489	1.332	2.893	0.444	1.213	2.965
2000-03	0.207	0.703	1.637	0.307	0.952	2.722	0.287	0.932	2.656
2004-07	0.220	0.755	1.805	0.312	1.093	2.922	0.275	1.053	2.866
2008-11	0.211	0.664	1.889	0.284	0.923	3.164	0.241	0.940	2.848
2012-15	0.265	0.720	1.968	0.358	1.017	3.180	0.311	0.948	3.286
TKN Loads									
1980-87	0.245	0.610	1.971	0.325	0.886	2.913	0.375	0.958	3.139
1988-94	0.223	0.708	2.137	0.294	0.782	2.636	0.295	0.793	2.644
1995-99	0.136	0.501	1.936	0.231	0.838	2.670	0.281	0.914	3.277
2000-03	0.156	0.626	1.988	0.290	0.875	3.299	0.289	0.889	3.302
2004-07	0.189	0.587	2.340	0.297	0.944	3.365	0.296	0.852	3.031
2008-11	0.214	0.683	2.627	0.344	1.142	4.132	0.332	1.126	3.583
2012-15	0.220	0.775	2.766	0.307	1.186	4.185	0.316	0.968	3.702
TN Loads									
1980-87	0.634	1.518	4.527	0.911	2.383	7.474	0.832	2.459	6.687
1988-94	0.764	1.793	4.526	0.969	2.459	6.321	0.854	2.345	6.554
1995-99	0.583	1.537	4.116	0.720	2.173	5.532	0.736	2.181	6.435
2000-03	0.357	1.327	3.624	0.594	1.824	6.033	0.567	1.810	5.898
2004-07	0.408	1.342	4.144	0.609	2.036	6.288	0.566	1.927	5.907
2008-11	0.425	1.347	4.516	0.628	2.064	7.297	0.572	2.065	6.431
2012-15	0.485	1.495	4.734	0.665	2.203	7.365	0.627	1.916	6.988
TP Loads									
1980-87	0.132	0.286	0.568	0.205	0.461	1.047	0.180	0.375	0.902
1988-94	0.063	0.179	0.388	0.125	0.346	0.745	0.101	0.282	0.789
1995-99	0.052	0.134	0.409	0.083	0.278	0.759	0.087	0.224	0.827
2000-03	0.049	0.168	0.379	0.076	0.257	0.625	0.065	0.180	0.671
2004-07	0.049	0.138	0.420	0.078	0.203	0.625	0.072	0.177	0.624
2008-11	0.050	0.161	0.430	0.086	0.239	0.674	0.067	0.237	0.576
2012-15	0.053	0.170	0.440	0.074	0.242	0.692	0.069	0.201	0.634

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FIGURE 8
Annual average daily flows by location

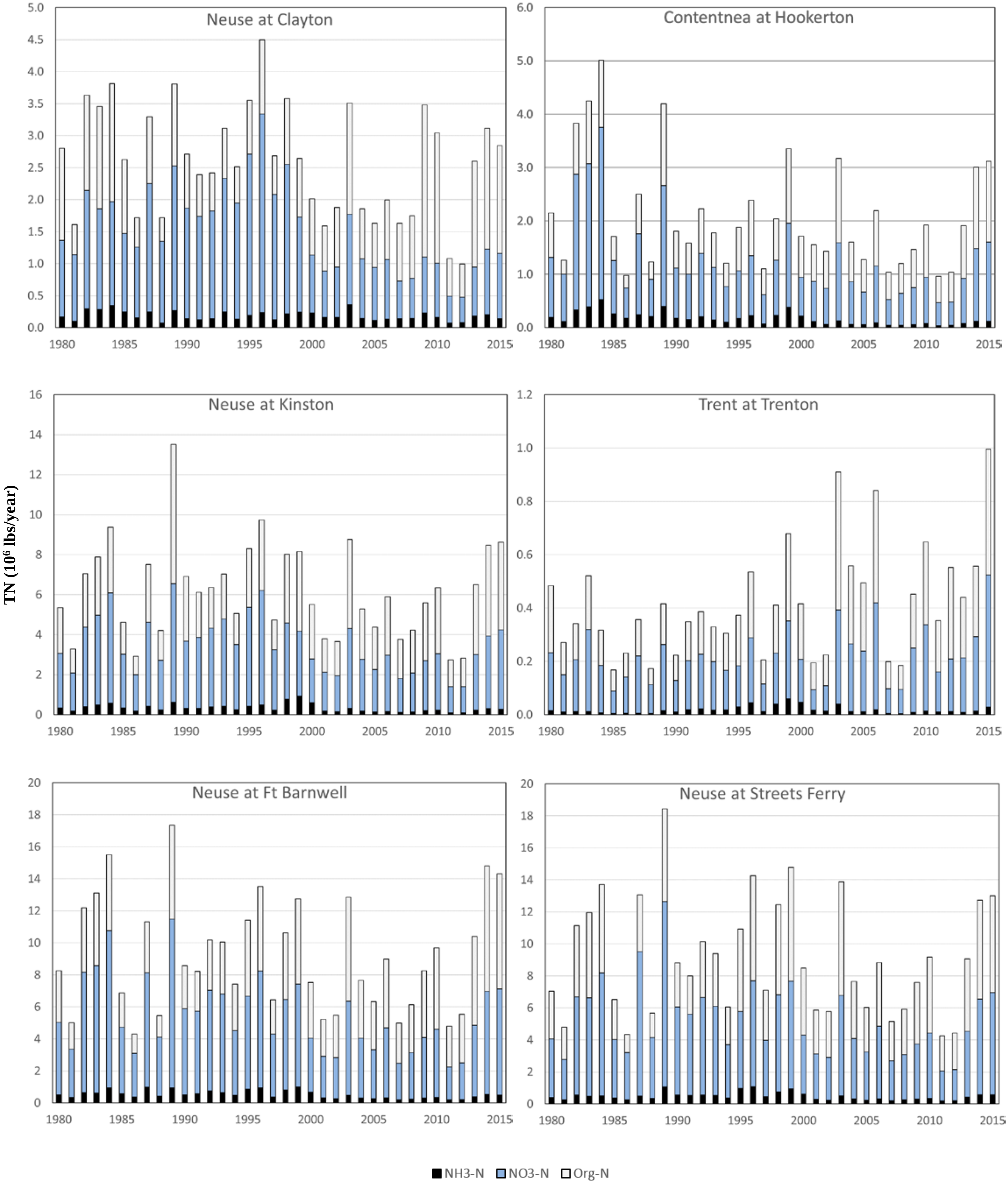

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FIGURE 9
Annual TN loads by location

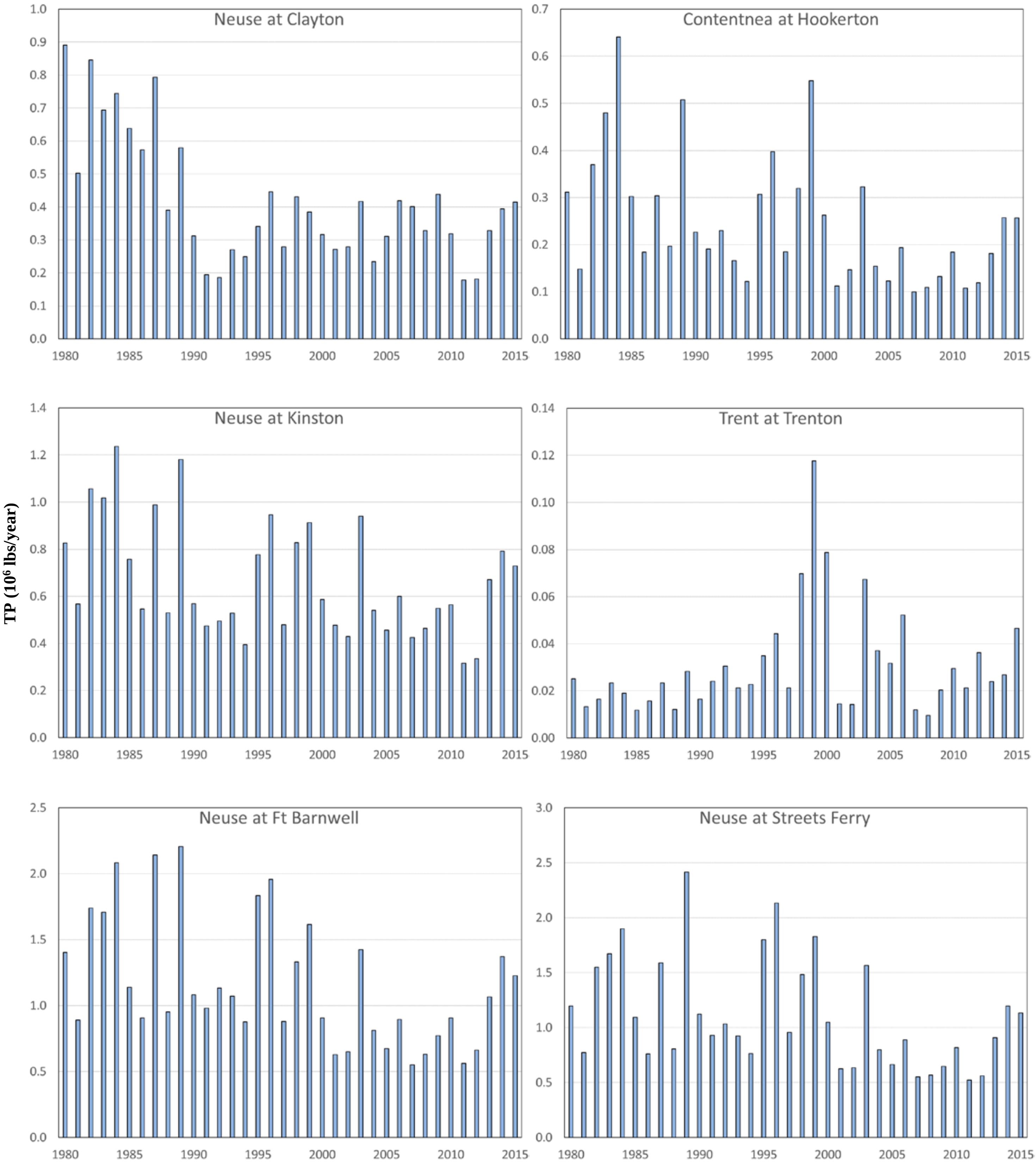

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FIGURE 10
Annual TP loads by location

TMDL EFFECTIVENESS

The TMDL developed for the Neuse River basin to reduce chlorophyll a concentrations in the Neuse Estuary mandates a 30% reduction in TN loading to estuarine waters compared with the 1991-95 baseline period. To evaluate progress toward achieving the required reductions, predicted N loads by fraction and period for long-term average conditions were compared with derived values for 1991-95. In the comparison, N loads for 1991-95 were derived for long-term average flow conditions in an identical fashion to loads reported in the previous section. Thus, the comparisons represent how management actions have reduced N concentrations along the Neuse River and in key tributaries, as a measure of effectiveness of the actions implemented.

A comparison of derived TN loads under long-term average flow conditions by period to the 1991-95 baseline period is presented in Figure 11. In the plots, a value of 0% indicates the predicted load is the same as derived for 1991-95 while negative numbers denote reductions relative to 1991-95. The target level of reduction of 30% is indicated in each plot with a dashed line. For the Clayton and Kinston locations, the target reduction percentage for NO_3-N was achieved beginning with the 1998-2002 data point (plotted in 2002) and was maintained through 2015. However, the reduction in TN was lower than for NO_3-N due to a lack of decrease (or an increase) in TKN for the post-TMDL periods. The same general pattern (reduced NO_3-N but not TKN) was evident for the Streets Ferry location. Overall, the relative effectiveness of the TMDL to reduce TN loads in the Neuse River for periods beginning after 2000 (e.g. 2000-2004 plotted as 2004) was highest at Clayton (1 to 27%, mean of 15%) and decreased moving downstream to the Kinston (2 to 21%, mean of 11%), to Fort Barnwell (-3 to 16%, mean of 6%) and eventually the Streets Ferry (-2 to 13%, mean 6%) locations. Reduction in TP load was typically 40-50% for all main stem stations relative to the 1987 baseline (Figure 12).

Patterns in N reductions for tributary stations show both similarities and differences from the general pattern observed for Neuse River stations. The comparison of N loads by period for stations in Contentnea Creek and the Trent River with 1991-95 derived loads is shown in Figure 11. Similar to the stations along the Neuse River main stem, the TKN fraction was not effectively reduced at tributary stations, with increases for periods ending in 1996-07 and 2014-15 at the Hookerton location and 1996-15 at Trenton. Reductions that were observed at tributary stations were primarily for the NO_3-N fraction. For TP, the reduction at the Hookerton location was similar to Neuse River main stem stations, while TP normalized load was elevated for most 5-yr periods relative to the 1987 baseline (Figure 12).

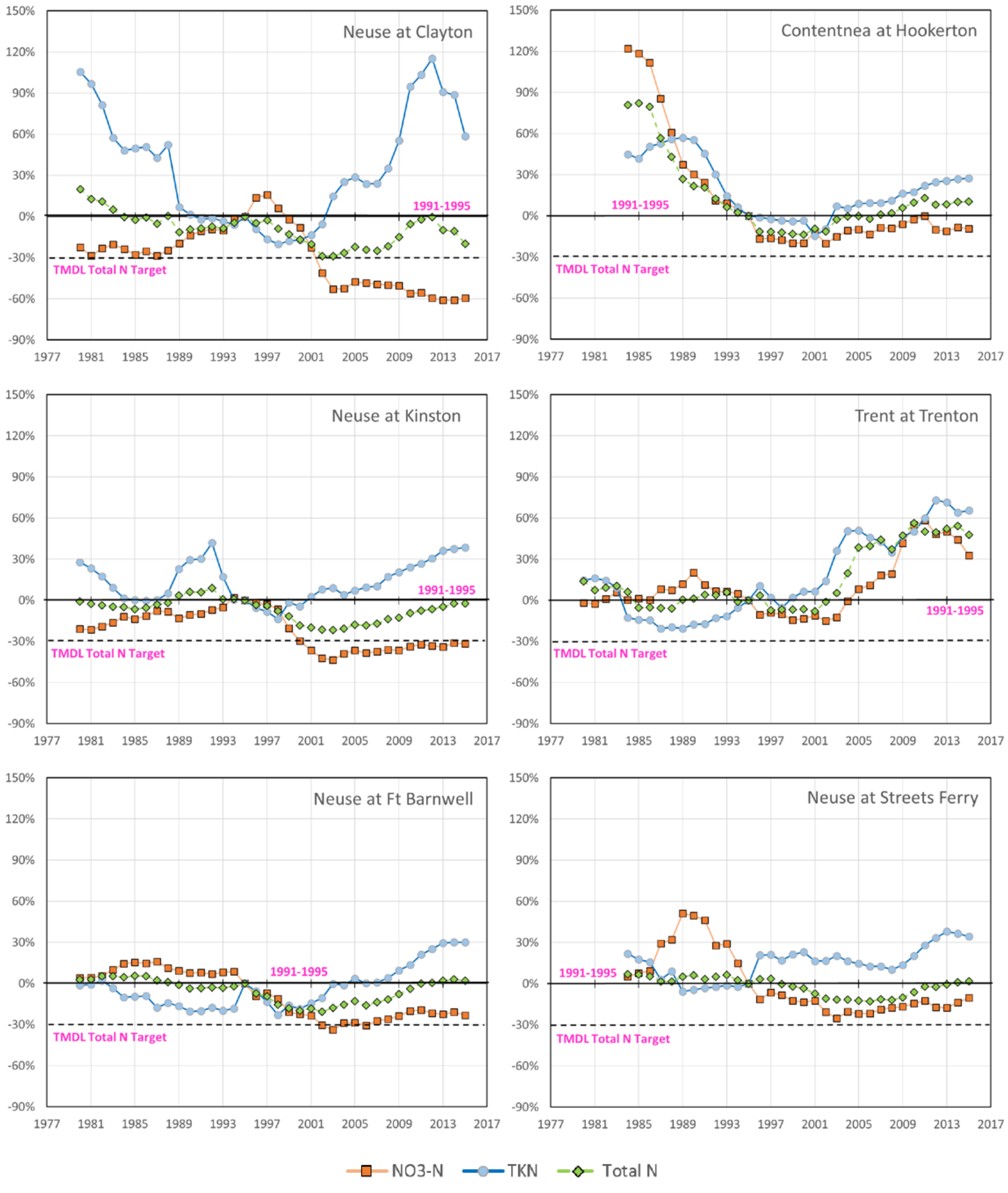

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FIGURE 11
Nitrogen reduction by location for average flow conditions

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FIGURE 12
Reduction in TP by location for average flow conditions

DISCUSSION AND CONCLUSIONS

The evaluation of the effectiveness of management actions is a challenging endeavor due to natural variations in climate and how these variations affect export of nutrients from watershed sources. For the Neuse River basin, episodic events, such as tropical storms and hurricanes, have a large impact on freshwater discharge and, hence, nutrient loads; in years when large, high rainfall hurricanes have passed through the Neuse watershed (e.g. Fran in 1996 and Floyd in 1999), seasonal and annual loads of N and P can be two to three times the “normal” loads (Paerl et al., 2001, 2006a,b; Bales, 2003; Peierls et al., 2003; Christian et al., 2004). Peak flow years can also occur due to unusually wet spring-summer periods associated with extra-tropical events or successive storms. Conversely, decreased river flow and N and P loading would be associated with periods of prolonged regional droughts (months to years). Accurate assessment of progress toward achieving the prescribed N load reduction target for the Neuse River basin must account for these year-to-year variations in flow.

A second factor that complicates the assessment of management action effectiveness is spatial and temporal variation in the coupling of watershed N and P inputs with delivery to the stream network. An indirect effect of climate-driven variation in runoff highlighted in the prior paragraph is the potential flushing of N and P from the watershed during large storms followed by periods of accumulation between major events. Even without this potential climate-driven temporal variation in N cycling, quantifying how management practices on the field scale impact N export to streams is challenging. Thus, the ultimate proof of effectiveness of management actions is decreased instream nutrient levels following implementation of control actions.

Patterns in N and P levels in the Neuse River basin described in this paper augment prior efforts conducted since the 1980s. Because of the complicating factors described above, several approaches have been used to extract trends in N and P over time amidst large interannual variations in river flow. NCDENR (2008) estimated annual N loads in the Neuse River at the Fort Barnwell for 1991-2006, demonstrating large variation among years. In terms of trends in concentrations, Stow et al. (2001) utilized a flow-adjusted approach to evaluate trends in N and P fractions at several locations along the main stem of the Neuse River while Lebo et al. (2002) used a rating curve approach for the Neuse River at Kinston and Streets Ferry and the tributary locations used in this analysis. Both of these efforts concluded P controls in the late 1980s substantially decreased P concentrations along the Neuse River. These prior efforts also showed an apparent decrease in TN and NO_3-N in the Neuse River at Kinston and Fort Barnwell in the mid-1990s prior to implementation of the TMDL. This paper extends prior evaluation of trends in N and P fraction for the Neuse River basin developed by the flow bin approach originally done for data collected through 2009 (Lebo et al., 2012).

The utilization of the flow bin approach by nutrient fraction allows a separation of the N and P concentration patterns into three flow regimes to provide additional feedback on the flow conditions for which decreased concentrations have occurred. In this analysis, temporal patterns for N vary by flow regime, location, and N fraction. Figure 11 shows the decrease in TN, evident in data collected since the Neuse Estuary TN TMDL was approved in 1999, is mainly associated with decreased NO_3-N concentrations. Average concentrations reported in Tables 4a-b illustrate that the pattern occurred at all main stem stations, with the largest change at Clayton. However, TKN (mainly as organic N) did not show a consistent decrease and actually increased at the Clayton location for middle and high flows (see Figure 4).

The status of attainment of the required 30% reduction in TN loading to the Neuse Estuary relative to the 1991-95 period is shown in Figure 13 for data from the 2011-15 period based on estimated actual loads. Clearly, progress has been higher in the Neuse River at Clayton due to a >60% reduction in NO_3-N. For all locations, the estimated TKN load for long-term flow conditions is higher for the last five years than the 1991-95 baseline period defined in the TMDL. This higher loading of TKN to estuarine waters in recent years mainly associated with the organic N component of TKN could affect N availability, and hence algal production, in downstream waters through remineralization of N from settled particles. In terms of the spatial pattern, the overall decrease in TN was highest in the upstream portion of the basin and decreased moving downstream.

The spatial pattern of lower N removal efficiency moving downstream along the Neuse River indicates less effectiveness of the TMDL in watersheds draining to the middle and lower portions of the basin. Data available for Contentnea Creek at Hookerton and the Trent River at Trenton are consistent with the pattern along the Neuse River, showing higher TN concentrations for 2011-15. In terms of progress in reducing tributary N levels, Lebo et al. (2012) pointed out the apparent lack of progress that had occurred through 2009 despite documented efforts to reduce N export from agricultural fields and requirements on new development (NCDENR, 2008). Notable, the maintenance of existing riparian buffers throughout the basin would be a mitigating factor to reduce the relative impact of uncontrolled sources on N export. In the event that the function of existing riparian buffers were reduced, the likely impact would be a further increase in N export from the watershed to the Neuse River estuary. Overall, a better understanding is needed of the effectiveness of implemented actions in watersheds in the middle and lower portions of the basin, and perhaps potential time lags between implementation and instream reductions, in order to fully evaluate the effectiveness of the TN controls enacted to reduce chlorophyll a in the Neuse Estuary.

Finally, the approach described here to develop time trends (Figures 11-12) complements estimates of actual TN and TP loading to the Neuse Estuary (Figures 9-10) but provides more immediate feedback on progress toward achieving the established reduction goal. Effective management actions ultimately must result in decreased TN loading in the river network. For the Neuse Estuary TN TMDL, neither the estimated actual TN loading nor the segregation of nutrient data by flow regime supports substantial progress in the reduction of TN concentrations or loading. The segregation of nutrient concentration data by flow regime coupled with parallel evaluations in different regions of the basin confirmed the tributaries in the middle portion of the Neuse River basin are actually exporting more TN in 2011-15 than during the 1991-95 baseline period. Additional analyses could be done for other monitoring locations in the basin using flow data from available gauges to provide more spatial resolution of temporal patterns in N export from different regions of the basin to provide direction for additional investigations targeted by source category. In the end, achieving the required TN reductions in a cost-efficient manner necessitates feedback on progress by region and source category in addition to the total loading to estuarine waters. Tracking average nutrient concentrations by flow regime at monitored locations provides a relatively simple way to evaluate the progress of the Neuse Estuary TN TMDL in combination with quantification by source and actual instream TN loads.

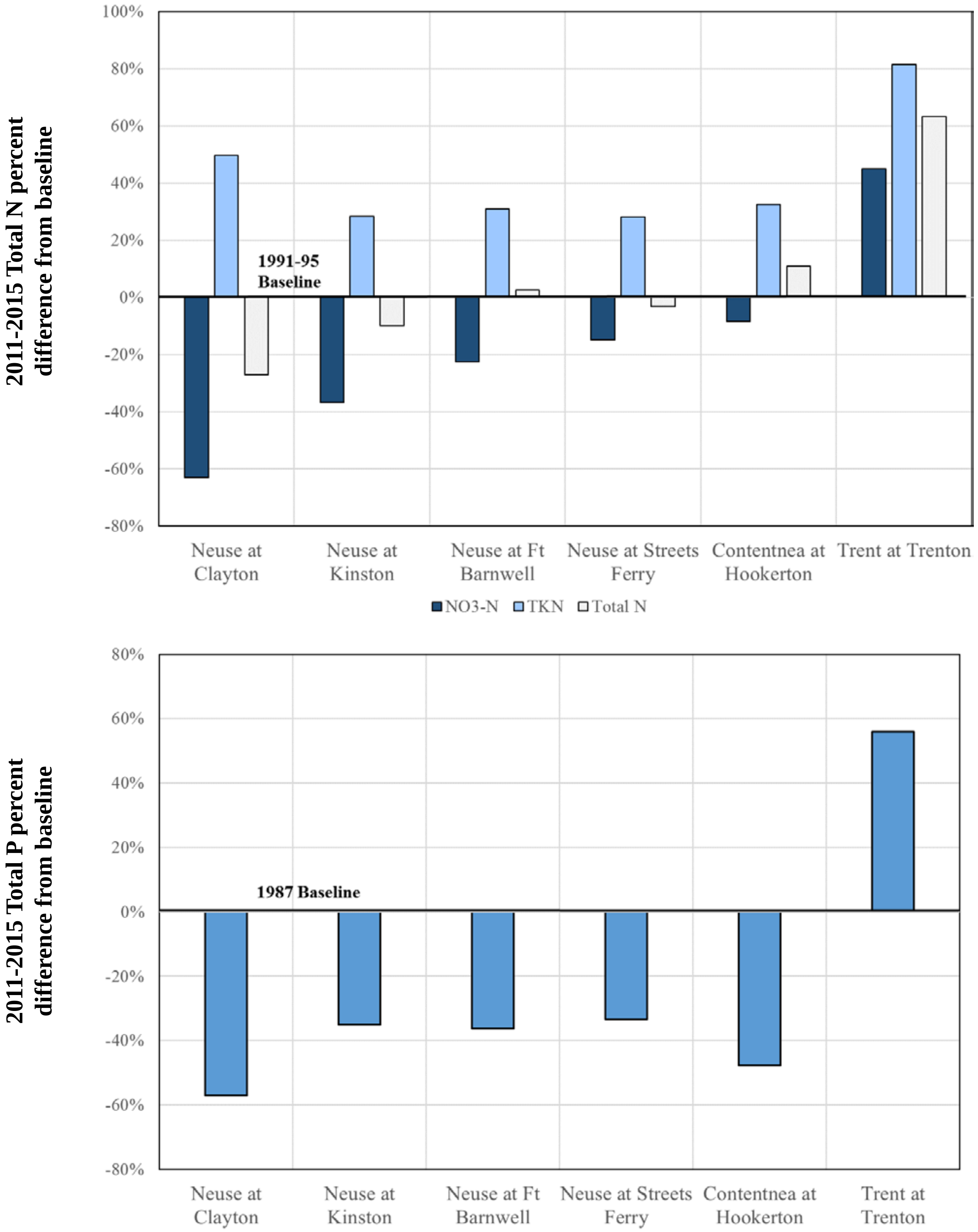

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FIGURE 13
TMDL attainment status for 2011-2015 for actual loads

REFERENCES

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APPENDIX A

TABLES OF SAMPLE NUMBERS FOR NUTRIENT DATA AND AVERAGE VALUES

Neuse River at Clayton - Number of Samples by Flow Interval and Year

Year	Ammonia (Number)			Nitrate (Number)			Total Kjeldahl N (Number)			Total N (Number)			Total P (Number)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	4	1	1	6	2	2	6	2	2	6	2	2	6	2	2
1981	6	1	1	8	2	2	8	2	2	8	2	2	8	2	2
1982	1	4	8	3	3	9	3	4	9	3	3	9	3	4	9
1983	8	4	9	8	4	9	8	4	9	8	4	9	8	4	9
1984	3	6	12	3	8	14	3	9	14	3	9	14	3	9	14
1985	6	3	2	6	3	2	6	3	2	6	3	2	6	3	2
1986	6	2	2	6	2	2	6	2	2	6	2	2	6	2	2
1987	2	3	4	3	3	4	3	3	4	3	3	4	3	3	4
1988	5	4	2	5	4	2	5	4	2	5	4	2	5	4	2
1989	0	5	6	0	5	6	0	5	6	0	5	6	0	5	6
1990	6	3	3	6	3	3	6	3	3	6	3	3	6	3	3
1991	5	3	1	5	3	1	5	3	1	5	3	1	5	3	1
1992	6	5	1	6	5	1	6	5	1	6	5	1	6	5	1
1993	4	3	4	4	3	4	4	3	4	4	3	4	4	3	4
1994	5	2	3	7	1	3	7	2	3	7	1	3	7	2	3
1995	3	4	3	7	9	7	6	9	6	6	9	6	7	9	7
1996	3	20	27	5	23	33	5	22	29	5	22	29	5	23	32
1997	15	20	26	15	20	26	15	19	24	15	19	24	15	20	25
1998	10	17	21	10	17	21	10	17	21	10	17	21	10	17	21
1999	9	12	11	9	12	11	9	12	13	9	12	13	9	12	13
2000	5	8	9	5	8	9	5	8	9	5	8	9	5	8	9
2001	6	6	4	6	7	4	6	5	4	6	5	4	6	7	3
2002	5	4	3	5	4	3	5	4	3	5	4	3	5	4	3
2003	0	5	6	0	5	6	0	5	6	0	5	6	0	5	6
2004	1	9	3	1	9	3	1	9	3	1	9	3	1	9	3
2005	5	4	3	5	4	3	5	4	3	5	4	3	5	4	3
2006	2	7	3	2	7	3	2	7	3	2	7	3	2	7	3
2007	5	4	3	5	4	3	5	4	3	5	4	3	5	4	3
2008	6	4	2	6	4	2	6	4	2	6	4	2	6	4	2
2009	5	4	3	5	4	3	5	4	3	5	4	3	5	4	3
2010	7	3	2	7	3	2	7	3	2	7	3	2	7	3	2
2011	4	7	1	4	7	1	4	7	1	4	7	1	3	4	1
2012	6	5	1	6	5	1	6	5	1	6	5	1	6	5	1
2013	4	0	8	4	0	8	4	0	8	4	0	8	4	0	8
2014	2	3	7	2	3	7	2	3	7	2	3	7	2	3	7
2015	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5

Neuse River at Clayton - Mean Nutrient Concentrations by Flow Interval and Year

Year	Ammonia (mg/L)			Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)			Total P (mg/L)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	0.078	0.050	0.100	2.100	1.500	0.630	0.48	0.40	0.45	2.58	1.90	1.08	1.275	0.615	0.250
1981	0.147	0.110	0.240	1.643	1.050	0.495	0.66	0.55	0.90	2.31	1.60	1.40	1.084	0.485	0.360
1982	0.080	0.073	0.121	3.433	1.217	0.672	0.77	0.60	0.74	4.20	1.72	1.42	1.133	0.550	0.281
1983	0.113	0.130	0.077	1.988	1.300	0.461	0.73	0.65	0.48	2.71	1.95	0.94	1.159	0.753	0.176
1984	0.083	0.128	0.130	1.220	1.159	0.437	0.47	0.99	0.79	1.69	2.11	1.23	0.820	0.592	0.179
1985	0.285	0.120	0.130	0.995	0.877	0.440	0.78	0.70	0.50	1.78	1.58	0.94	0.817	0.693	0.165
1986	0.365	0.280	0.070	2.500	1.250	0.690	0.97	0.60	0.80	3.47	1.85	1.49	1.143	0.655	0.465
1987	0.045	0.030	0.090	2.233	1.600	0.505	0.47	0.40	0.48	2.70	2.00	0.98	0.887	0.757	0.188
1988	0.088	0.100	0.145	2.400	1.425	0.970	0.50	0.53	0.50	2.90	1.95	1.47	0.534	0.365	0.270
1989	N/A	0.078	0.065	N/A	1.106	0.490	N/A	0.46	0.43	N/A	1.57	0.92	N/A	0.332	0.157
1990	0.067	0.043	0.063	2.300	1.567	0.537	0.47	0.43	0.40	2.77	2.00	0.94	0.173	0.200	0.090
1991	0.052	0.040	0.090	2.860	1.600	1.200	0.58	0.57	0.90	3.44	2.17	2.10	0.150	0.110	0.190
1992	0.217	0.076	0.140	1.917	1.680	0.450	0.75	0.50	0.50	2.67	2.18	0.95	0.228	0.144	0.110
1993	0.055	0.073	0.113	2.700	1.800	0.623	0.53	0.43	0.43	3.23	2.23	1.05	0.253	0.203	0.093
1994	0.086	0.070	0.123	2.774	1.300	0.640	0.51	0.50	0.37	3.29	1.70	1.01	0.379	0.225	0.080
1995	0.037	0.093	0.113	2.810	1.990	0.546	0.63	0.44	0.52	3.51	2.37	1.11	0.289	0.192	0.153
1996	0.093	0.073	0.074	2.884	1.770	0.999	0.59	0.41	0.39	3.47	2.25	1.05	0.314	0.188	0.118
1997	0.045	0.047	0.052	2.845	2.139	0.747	0.37	0.32	0.35	3.21	2.54	1.09	0.305	0.182	0.115
1998	0.075	0.038	0.070	1.232	1.205	0.623	0.33	0.35	0.35	1.56	1.55	0.97	0.249	0.251	0.134
1999	0.083	0.160	0.097	0.794	1.057	0.338	0.50	0.53	0.42	1.29	1.58	0.88	0.336	0.233	0.108
2000	0.142	0.110	0.160	0.774	0.447	0.408	0.56	0.41	0.58	1.33	0.86	0.99	0.260	0.191	0.152
2001	0.112	0.080	0.087	0.990	0.830	0.260	0.42	0.70	0.91	1.41	1.58	1.17	0.317	0.193	0.217
2002	0.092	0.077	0.160	0.618	0.758	0.497	0.56	0.53	0.63	1.18	1.28	1.13	0.406	0.267	0.117
2003	N/A	0.078	0.107	N/A	0.844	0.308	N/A	0.47	0.70	N/A	1.31	1.01	N/A	0.130	0.105
2004	0.080	0.102	0.090	1.660	0.751	0.420	0.41	0.56	0.47	2.07	1.31	0.89	0.120	0.129	0.163
2005	0.052	0.077	0.077	0.908	0.838	0.790	0.42	0.65	0.51	1.33	1.49	1.30	0.282	0.337	0.117
2006	0.040	0.053	0.103	0.640	0.843	0.247	0.56	0.57	0.81	1.20	1.41	1.06	0.270	0.267	0.397
2007	0.028	0.055	0.103	0.530	0.590	0.493	0.45	0.54	0.65	0.98	1.13	1.14	0.410	0.230	0.147
2008	0.103	0.103	0.165	0.685	0.535	0.165	0.47	0.64	1.09	1.16	1.17	1.25	0.472	0.145	0.235
2009	0.100	0.095	0.090	0.476	0.705	0.430	0.83	0.68	1.00	1.31	1.38	1.43	0.282	0.320	0.180
2010	0.101	0.077	0.070	0.524	0.787	0.400	0.71	0.88	1.80	1.24	1.67	2.20	0.217	0.227	0.120
2011	0.113	0.096	0.040	0.590	0.424	0.300	0.70	0.66	0.55	1.29	1.09	0.85	0.163	0.130	0.140
2012	0.057	0.080	0.070	0.623	0.410	0.280	0.52	0.44	0.59	1.14	0.85	0.87	0.402	0.268	0.100
2013	0.068	N/A	0.108	0.723	N/A	0.270	0.83	N/A	0.89	1.56	N/A	1.16	0.320	N/A	0.079
2014	0.095	0.060	0.056	0.555	0.713	0.354	0.56	0.81	0.93	1.12	1.52	1.28	0.435	0.333	0.150
2015	0.073	0.085	0.062	0.710	0.645	0.466	0.50	0.64	0.63	1.21	1.28	1.09	0.373	0.303	0.136

Neuse River at Kinston - Number of Samples by Flow Interval and Year															
Year	Ammonia (Number)			Nitrate (Number)			Total Kjeldahl N (Number)			Total N (Number)			Total P (Number)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	10	7	6	10	7	6	11	7	6	11	7	6	11	7	6
1981	12	8	3	12	8	3	12	8	3	12	8	3	12	8	3
1982	5	9	6	5	9	6	5	9	6	5	9	6	5	8	6
1983	6	2	8	6	2	8	6	2	8	6	2	8	6	2	8
1984	3	6	8	3	6	8	3	6	8	3	6	8	3	6	8
1985	7	6	4	7	6	4	7	6	4	7	6	4	7	6	4
1986	11	5	0	12	6	0	12	6	0	12	6	0	12	6	0
1987	9	3	5	9	3	5	9	3	5	9	3	5	9	3	4
1988	6	11	2	6	11	2	2	4	0	2	4	0	6	11	2
1989	2	4	11	2	4	11	1	1	3	1	1	3	2	4	11
1990	7	4	6	7	4	6	2	1	2	2	1	2	7	4	6
1991	6	3	5	6	3	5	2	1	2	2	1	2	6	3	5
1992	1	7	7	1	7	7	0	1	2	0	1	2	1	7	7
1993	9	4	9	9	4	9	6	3	5	6	3	5	9	4	9
1994	13	6	6	13	6	6	13	6	6	13	6	6	13	6	6
1995	4	8	6	4	8	6	4	8	6	4	8	6	4	8	6
1996	5	11	15	5	11	15	5	11	15	5	11	15	5	11	15
1997	8	1	4	8	1	4	8	1	4	8	1	4	8	1	4
1998	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5
1999	3	5	7	3	5	7	3	5	7	3	5	7	3	5	7
2000	4	6	3	5	6	4	5	6	4	5	6	4	5	6	4
2001	11	11	4	13	13	4	10	12	4	10	12	4	11	13	4
2002	18	11	7	18	11	7	18	11	7	18	11	7	18	11	7
2003	0	22	41	0	22	41	0	22	41	0	22	41	0	22	41
2004	10	34	20	10	34	20	10	34	20	10	34	20	10	34	20
2005	20	23	16	20	23	16	20	23	16	20	23	16	20	23	16
2006	16	30	18	16	30	18	16	30	18	16	30	18	16	30	18
2007	32	16	16	31	16	16	32	16	16	31	16	16	32	16	16
2008	24	24	16	24	24	16	24	24	16	24	24	16	24	24	16
2009	25	14	19	25	14	19	25	14	19	25	14	19	25	14	19
2010	25	12	24	25	12	24	25	12	24	25	12	24	25	12	24
2011	38	17	2	38	17	2	38	17	2	38	17	2	36	16	2
2012	34	22	2	34	22	2	34	22	2	34	22	2	34	22	2
2013	12	31	20	12	31	20	12	31	20	12	31	20	12	31	20
2014	9	25	24	9	25	24	9	25	24	9	25	24	9	25	24
2015	7	3	12	7	3	12	7	3	12	7	3	12	7	3	12

Neuse River at Kinston - Mean Nutrient Concentrations by Flow Interval and Year															
Year	Ammonia (mg/L)			Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)			Total P (mg/L)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	0.046	0.067	0.092	0.691	0.963	0.760	0.64	0.54	0.53	1.27	1.50	1.29	0.250	0.269	0.137
1981	0.082	0.076	0.103	0.919	0.713	0.500	0.52	0.58	0.57	1.44	1.29	1.07	0.294	0.274	0.220
1982	0.160	0.071	0.073	1.122	0.683	0.552	0.72	0.57	0.50	1.84	1.25	1.05	0.250	0.231	0.143
1983	0.047	0.060	0.051	0.967	0.900	0.723	0.48	0.50	0.45	1.45	1.40	1.17	0.318	0.235	0.141
1984	0.033	0.085	0.104	0.493	0.747	0.633	0.97	0.42	0.51	1.46	1.16	1.15	0.247	0.227	0.135
1985	0.081	0.098	0.066	0.876	0.802	0.700	0.49	0.48	0.50	1.36	1.29	1.20	0.307	0.277	0.158
1986	0.123	0.112	N/A	1.155	0.772	N/A	0.61	0.62	N/A	1.76	1.39	N/A	0.397	0.268	N/A
1987	0.068	0.103	0.068	1.043	0.980	0.710	0.50	0.47	0.58	1.54	1.45	1.29	0.363	0.150	0.143
1988	0.095	0.100	0.090	1.150	0.932	0.730	0.75	0.80	N/A	2.20	1.76	N/A	0.198	0.203	0.195
1989	0.085	0.083	0.059	1.090	0.883	0.507	1.00	0.60	0.83	1.98	1.25	1.29	0.175	0.170	0.117
1990	0.070	0.095	0.073	1.197	1.070	0.702	0.50	0.90	0.55	1.40	2.00	1.24	0.139	0.130	0.098
1991	0.093	0.097	0.064	1.500	0.730	0.576	0.65	0.70	0.65	1.95	0.88	1.19	0.128	0.127	0.108
1992	0.070	0.099	0.070	1.100	1.111	0.684	N/A	0.50	0.55	N/A	1.46	1.22	0.150	0.136	0.097
1993	0.109	0.105	0.082	1.411	1.133	0.637	0.57	0.43	0.44	2.03	1.61	0.96	0.149	0.108	0.075
1994	0.048	0.060	0.067	1.260	0.972	0.775	0.43	0.55	0.48	1.69	1.52	1.26	0.142	0.148	0.078
1995	0.060	0.049	0.051	1.325	0.945	0.630	0.33	0.44	0.58	1.65	1.38	1.21	0.140	0.115	0.100
1996	0.062	0.060	0.063	1.142	0.875	0.656	0.38	0.48	0.43	1.52	1.36	1.08	0.132	0.125	0.115
1997	0.028	0.120	0.053	1.279	1.000	0.728	0.26	0.20	0.38	1.54	1.20	1.10	0.121	0.060	0.075
1998	0.054	0.050	0.026	0.728	0.940	0.540	0.30	0.30	0.28	1.03	1.24	0.82	0.112	0.095	0.106
1999	0.130	0.034	0.171	0.580	0.868	0.246	0.43	0.44	0.83	1.01	1.31	1.07	0.113	0.120	0.111
2000	0.082	0.098	0.050	0.626	0.170	0.377	0.36	0.38	0.45	0.99	0.55	0.83	0.098	0.082	0.073
2001	0.045	0.059	0.060	0.498	0.890	0.577	0.39	0.48	0.65	0.84	1.39	1.23	0.121	0.125	0.132
2002	0.039	0.059	0.033	0.452	0.581	0.474	0.37	0.69	0.49	0.82	1.27	0.96	0.121	0.241	0.127
2003	N/A	0.050	0.033	N/A	0.587	0.406	N/A	0.56	0.52	N/A	1.14	0.92	N/A	0.130	0.093
2004	0.030	0.041	0.040	0.627	0.628	0.490	0.44	0.51	0.57	1.07	1.13	1.06	0.108	0.114	0.112
2005	0.020	0.033	0.029	0.579	0.656	0.489	0.42	0.54	0.61	1.00	1.20	1.10	0.113	0.121	0.101
2006	0.017	0.035	0.041	0.565	0.690	0.366	0.55	0.50	0.63	1.11	1.19	0.99	0.123	0.122	0.119
2007	0.022	0.037	0.024	0.431	0.667	0.538	0.42	0.51	0.62	0.85	1.17	1.16	0.115	0.131	0.101
2008	0.042	0.033	0.049	0.432	0.552	0.419	0.49	0.58	0.66	0.92	1.14	1.08	0.135	0.143	0.136
2009	0.038	0.040	0.043	0.475	0.651	0.447	0.52	0.54	0.67	0.99	1.19	1.12	0.117	0.131	0.108
2010	0.036	0.051	0.042	0.544	0.630	0.582	0.53	0.62	0.70	1.07	1.25	1.28	0.104	0.136	0.094
2011	0.034	0.046	0.055	0.535	0.522	0.380	0.50	0.64	0.74	1.04	1.17	1.12	0.123	0.149	0.160
2012	0.042	0.039	0.040	0.567	0.540	0.580	0.53	0.64	0.81	1.10	1.18	1.39	0.127	0.179	0.160
2013	0.031	0.042	0.057	0.687	0.607	0.401	0.51	0.68	0.76	1.20	1.28	1.16	0.118	0.132	0.130
2014	0.024	0.052	0.030	0.743	0.710	0.532	0.53	0.70	0.68	1.27	1.41	1.21	0.126	0.147	0.103
2015	0.057	0.063	0.054	0.693	0.820	0.642	0.51	0.70	0.72	1.20	1.52	1.36	0.130	0.117	0.104

Neuse River at Fort Barnwell - Number of Samples by Flow Interval and Year

Year	Ammonia (Number)			Nitrate (Number)			Total Kjeldahl N (Number)			Total N (Number)			Total P (Number)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	6	2	0	5	2	0	6	2	0	5	2	0	6	2	0
1981	5	7	0	5	7	0	5	7	0	5	7	0	5	7	0
1982	3	5	4	3	5	4	3	5	4	3	5	4	3	5	4
1983	2	2	6	2	2	6	2	2	6	2	2	6	2	2	6
1984	2	7	3	2	7	3	2	7	3	2	7	3	2	7	3
1985	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3
1986	6	4	0	6	4	0	6	4	0	6	4	0	6	4	0
1987	7	2	3	7	2	3	7	2	3	7	2	3	7	2	3
1988	5	6	2	5	6	2	5	6	2	5	6	2	5	6	2
1989	1	3	8	1	3	8	1	3	8	1	3	8	1	3	8
1990	6	1	5	6	1	5	6	1	5	6	1	5	6	1	5
1991	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3
1992	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5
1993	6	2	3	6	2	3	6	2	3	6	2	3	6	2	3
1994	7	3	2	7	3	2	7	3	2	7	3	2	7	3	2
1995	4	4	1	7	7	7	6	7	6	6	7	7	7	7	7
1996	3	17	23	4	20	28	4	20	26	4	20	27	4	20	28
1997	24	20	19	24	20	19	24	19	19	24	19	19	24	20	19
1998	26	14	23	26	14	23	25	14	23	25	14	23	26	14	23
1999	21	32	25	21	32	25	21	32	25	21	32	25	21	32	25
2000	23	25	24	23	25	24	23	25	24	23	25	24	23	25	24
2001	30	11	4	34	18	8	30	12	6	30	12	6	32	17	6
2002	30	25	11	30	25	11	30	25	11	30	25	11	29	25	11
2003	0	23	42	0	23	42	0	23	42	0	23	42	0	23	42
2004	11	35	18	11	35	18	11	35	18	11	35	18	11	35	18
2005	20	24	16	20	24	16	20	24	16	20	24	16	20	24	16
2006	20	26	18	20	26	18	20	26	18	20	26	18	20	26	18
2007	36	13	15	36	13	15	36	13	15	36	13	15	36	13	15
2008	29	22	14	29	22	14	29	22	14	29	22	14	29	22	14
2009	30	15	21	30	15	21	30	15	21	30	15	21	30	15	21
2010	34	8	21	34	8	21	34	8	21	34	8	21	34	8	21
2011	34	22	6	34	22	6	34	22	6	34	22	6	32	20	6
2012	28	21	5	28	21	5	28	21	5	28	21	5	28	21	5
2013	13	27	24	13	27	24	13	27	24	13	27	24	13	27	24
2014	7	21	31	7	21	31	7	21	31	7	21	31	7	21	31
2015	6	3	13	6	3	13	6	3	13	6	3	13	6	3	13

Neuse River at Fort Barnwell - Mean Nutrient Concentrations by Flow Interval and Year

Year	Ammonia (mg/L)			Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)			Total P (mg/L)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	0.068	0.105	N/A	0.890	1.100	N/A	0.75	0.45	N/A	1.61	1.55	N/A	0.287	0.260	N/A
1981	0.076	0.149	N/A	1.050	0.959	N/A	0.52	0.54	N/A	1.57	1.50	N/A	0.330	0.296	N/A
1982	0.037	0.096	0.075	1.000	0.800	0.728	0.60	0.56	0.68	1.60	1.36	1.40	0.290	0.276	0.175
1983	0.065	0.140	0.050	1.200	1.030	0.887	0.45	0.55	0.42	1.65	1.58	1.30	0.380	0.300	0.158
1984	0.080	0.141	0.043	0.790	0.776	0.577	0.50	0.49	0.43	1.29	1.26	1.01	0.280	0.210	0.130
1985	0.103	0.110	0.133	0.898	0.862	0.820	0.35	0.54	0.57	1.25	1.40	1.39	0.335	0.292	0.177
1986	0.183	0.120	N/A	1.150	0.798	N/A	0.67	0.50	N/A	1.82	1.30	N/A	0.425	0.273	N/A
1987	0.104	0.085	0.130	1.041	0.845	0.870	0.47	0.40	0.47	1.51	1.25	1.34	0.410	0.255	0.293
1988	0.100	0.128	0.105	0.920	0.940	0.790	0.48	0.50	0.50	1.40	1.44	1.29	0.280	0.222	0.185
1989	0.070	0.107	0.044	1.100	1.067	0.595	0.40	0.37	0.44	1.50	1.43	1.03	0.210	0.210	0.134
1990	0.122	0.100	0.062	1.152	0.820	0.698	0.43	0.40	0.44	1.59	1.22	1.14	0.173	0.170	0.128
1991	0.136	0.120	0.100	1.320	0.955	0.550	0.52	0.45	0.53	1.84	1.41	1.08	0.182	0.220	0.147
1992	0.080	0.116	0.060	1.150	0.976	0.646	0.50	0.48	0.50	1.65	1.46	1.15	0.205	0.166	0.136
1993	0.110	0.145	0.087	1.202	1.075	0.680	0.57	0.45	0.40	1.77	1.53	1.08	0.182	0.140	0.090
1994	0.123	0.107	0.035	1.186	0.947	0.575	0.53	0.43	0.40	1.71	1.38	0.98	0.254	0.247	0.075
1995	0.093	0.093	0.070	1.177	0.940	0.451	0.51	0.62	0.81	1.72	1.56	1.15	0.191	0.154	0.167
1996	0.077	0.084	0.076	1.080	0.756	0.534	0.48	0.60	0.45	1.56	1.35	0.98	0.263	0.267	0.161
1997	0.030	0.041	0.067	1.023	0.827	0.696	0.30	0.37	0.41	1.32	1.21	1.10	0.126	0.120	0.119
1998	0.054	0.076	0.029	0.779	0.777	0.513	0.31	0.43	0.31	1.09	1.21	0.82	0.129	0.161	0.098
1999	0.076	0.086	0.100	0.541	0.715	0.322	0.56	0.48	0.58	1.10	1.20	0.91	0.140	0.124	0.129
2000	0.062	0.109	0.054	0.601	0.512	0.545	0.39	0.46	0.48	0.99	0.98	1.02	0.119	0.146	0.111
2001	0.052	0.078	0.145	0.602	0.695	0.494	0.40	0.52	1.22	1.00	1.27	1.75	0.111	0.145	0.120
2002	0.046	0.063	0.037	0.384	0.537	0.438	0.68	0.52	0.48	1.06	1.06	0.92	0.162	0.180	0.093
2003	N/A	0.060	0.029	N/A	0.504	0.435	N/A	0.54	0.56	N/A	1.04	0.99	N/A	0.122	0.109
2004	0.055	0.055	0.045	0.565	0.589	0.467	0.51	0.50	0.55	1.08	1.08	1.02	0.137	0.113	0.112
2005	0.047	0.048	0.033	0.622	0.683	0.555	0.50	0.58	0.60	1.13	1.27	1.15	0.134	0.126	0.104
2006	0.047	0.043	0.035	0.571	0.632	0.396	0.58	0.55	0.61	1.15	1.19	1.01	0.138	0.115	0.121
2007	0.034	0.056	0.047	0.457	0.675	0.637	0.47	0.62	0.57	0.93	1.29	1.21	0.132	0.124	0.094
2008	0.035	0.041	0.048	0.462	0.538	0.449	0.52	0.64	0.64	0.99	1.17	1.09	0.137	0.142	0.131
2009	0.084	0.050	0.043	0.478	0.641	0.532	0.60	0.59	0.70	1.07	1.23	1.23	0.149	0.115	0.111
2010	0.052	0.049	0.039	0.524	0.454	0.704	0.61	0.61	0.71	1.14	1.06	1.42	0.153	0.139	0.091
2011	0.051	0.061	0.040	0.479	0.494	0.295	0.62	0.76	0.98	1.10	1.25	1.27	0.149	0.154	0.193
2012	0.039	0.040	0.056	0.540	0.508	0.560	0.55	0.66	0.76	1.09	1.17	1.32	0.133	0.158	0.176
2013	0.038	0.050	0.043	0.670	0.576	0.482	0.52	0.68	0.76	1.19	1.25	1.24	0.125	0.125	0.129
2014	0.040	0.074	0.040	0.787	0.669	0.569	0.49	0.74	0.72	1.27	1.40	1.28	0.123	0.148	0.113
2015	0.063	0.070	0.051	0.627	0.767	0.636	0.49	0.71	0.68	1.12	1.47	1.31	0.108	0.110	0.098

Neuse River at Streets Ferry - Number of Samples by Flow Interval and Year

Year	Ammonia (Number)			Nitrate (Number)			Total Kjeldahl N (Number)			Total N (Number)			Total P (Number)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	13	1	0	14	1	0	12	1	0	12	1	0	14	1	0
1981	18	4	2	19	4	2	13	3	1	13	3	1	12	3	1
1982	5	6	9	5	6	9	5	6	9	5	6	9	3	4	6
1983	14	2	6	24	2	6	9	2	6	9	2	6	19	2	6
1984	5	10	14	4	10	14	3	8	13	3	8	13	5	10	13
1985	8	3	2	8	3	2	8	3	2	8	3	2	8	3	2
1986	20	7	2	20	7	2	9	4	1	9	4	1	9	4	1
1987	16	6	9	16	6	9	6	5	2	6	5	2	6	5	2
1988	4	10	1	4	10	1	4	8	1	4	8	1	4	8	1
1989	0	2	9	0	2	9	0	2	9	0	2	9	0	2	9
1990	6	3	5	6	3	5	6	3	5	6	3	5	6	3	5
1991	5	3	2	5	2	2	5	3	2	5	3	2	5	3	2
1992	1	8	3	1	8	3	1	8	3	1	8	3	1	8	3
1993	10	3	3	10	3	3	9	2	3	9	2	3	9	2	3
1994	19	2	8	18	2	6	7	0	3	7	0	3	7	0	3
1995	9	7	18	10	8	19	2	1	8	2	1	8	2	1	8
1996	3	24	27	3	24	29	1	8	15	1	8	15	1	8	15
1997	20	12	19	21	12	19	10	7	9	10	7	9	10	7	9
1998	20	11	20	20	11	20	11	5	10	11	5	10	11	5	10
1999	11	20	21	10	18	21	6	10	10	6	10	10	6	10	10
2000	15	16	18	15	16	18	11	11	12	11	11	12	8	7	10
2001	21	16	10	21	18	10	21	15	10	21	15	10	10	7	4
2002	21	15	8	21	15	8	21	15	8	21	15	8	10	7	4
2003	1	12	25	1	12	25	1	12	25	1	12	25	1	3	10
2004	7	18	13	7	18	13	7	15	13	7	15	13	4	5	4
2005	15	14	8	15	14	8	15	13	6	15	13	6	4	7	1
2006	8	17	8	9	19	10	9	19	10	9	19	10	2	7	4
2007	12	4	7	19	5	11	20	5	11	20	5	11	8	1	4
2008	15	12	5	14	12	5	15	12	5	14	12	5	5	7	1
2009	15	10	7	15	10	7	15	10	7	15	10	7	5	6	1
2010	15	7	9	15	7	9	15	7	9	15	7	9	7	2	2
2011	20	10	2	20	10	2	20	10	2	20	10	2	7	4	1
2012	12	13	1	12	13	1	12	13	1	12	13	1	5	3	0
2013	6	16	10	6	16	10	6	16	10	6	16	10	2	7	3
2014	6	9	17	6	9	17	6	9	17	6	9	17	3	3	6
2015	11	4	14	11	4	14	11	4	14	11	4	14	3	1	5

Neuse River at Streets Ferry - Mean Nutrient Concentrations by Flow Interval and Year

Year	Ammonia (mg/L)			Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)			Total P (mg/L)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	0.080	0.050	N/A	0.506	1.100	N/A	0.80	0.40	N/A	1.35	1.50	N/A	0.254	0.210	N/A
1981	0.079	0.099	0.095	0.698	0.890	0.561	0.74	0.72	0.50	1.55	1.67	1.22	0.270	0.253	0.170
1982	0.047	0.072	0.073	0.844	0.752	0.591	0.65	0.65	0.70	1.49	1.41	1.29	0.217	0.235	0.182
1983	0.061	0.085	0.032	0.355	1.150	0.742	0.65	0.35	0.37	1.30	1.50	1.11	0.286	0.185	0.133
1984	0.070	0.083	0.036	0.838	0.688	0.509	0.54	0.62	0.55	1.45	1.36	1.07	0.292	0.194	0.152
1985	0.079	0.157	0.045	0.764	0.973	0.730	0.45	0.47	0.35	1.21	1.44	1.08	0.359	0.183	0.115
1986	0.108	0.091	0.093	1.061	0.757	0.754	0.54	0.52	0.50	1.55	1.29	1.16	0.437	0.277	0.270
1987	0.067	0.087	0.044	0.958	1.040	1.041	0.48	0.42	0.40	1.35	1.44	1.01	0.328	0.214	0.110
1988	0.079	0.095	0.070	0.654	0.999	0.580	0.69	0.46	0.50	1.34	1.42	1.08	0.235	0.186	0.190
1989	N/A	0.100	0.063	N/A	0.790	0.700	N/A	0.40	0.46	N/A	1.19	1.16	N/A	0.145	0.159
1990	0.119	0.127	0.074	1.049	0.963	0.740	0.44	0.47	0.42	1.48	1.43	1.16	0.156	0.177	0.146
1991	0.122	0.111	0.045	1.122	1.015	0.300	0.41	0.48	0.55	1.53	1.15	0.85	0.178	0.168	0.130
1992	0.100	0.086	0.063	1.100	0.869	0.803	0.60	0.45	0.40	1.70	1.32	1.20	0.150	0.143	0.110
1993	0.073	0.089	0.050	0.999	1.066	0.700	0.54	0.50	0.53	1.55	1.60	1.23	0.159	0.140	0.103
1994	0.074	0.057	0.067	0.616	0.292	0.479	0.44	N/A	0.37	1.25	N/A	0.90	0.160	N/A	0.080
1995	0.079	0.086	0.058	0.855	0.683	0.477	0.60	0.50	0.46	1.78	1.50	1.03	0.175	0.130	0.156
1996	0.105	0.083	0.094	1.016	0.693	0.444	0.60	0.56	0.64	1.70	1.26	1.15	0.180	0.151	0.167
1997	0.037	0.044	0.037	0.853	0.738	0.731	0.46	0.54	0.49	1.37	1.28	1.23	0.145	0.133	0.095
1998	0.035	0.054	0.034	0.684	0.701	0.523	0.43	0.46	0.51	1.13	1.21	1.06	0.145	0.132	0.124
1999	0.066	0.069	0.100	0.489	0.698	0.391	0.52	0.53	0.62	1.01	1.25	0.98	0.137	0.110	0.147
2000	0.058	0.085	0.039	0.635	0.542	0.514	0.50	0.50	0.56	1.12	1.04	1.06	0.111	0.109	0.111
2001	0.066	0.042	0.055	0.548	0.527	0.407	0.42	0.53	0.60	0.97	1.03	1.01	0.106	0.113	0.122
2002	0.032	0.049	0.035	0.310	0.558	0.484	0.56	0.50	0.49	0.86	1.06	0.97	0.111	0.092	0.123
2003	0.050	0.054	0.033	0.630	0.532	0.415	0.46	0.52	0.57	1.09	1.06	0.98	0.140	0.100	0.111
2004	0.045	0.061	0.036	0.521	0.600	0.442	0.48	0.44	0.56	1.00	1.07	1.00	0.118	0.094	0.118
2005	0.043	0.052	0.019	0.540	0.610	0.504	0.48	0.50	0.44	1.02	1.12	0.96	0.110	0.106	0.080
2006	0.041	0.048	0.034	0.508	0.619	0.401	0.55	0.52	0.51	1.05	1.14	0.91	0.145	0.110	0.115
2007	0.030	0.084	0.041	0.366	0.605	0.608	0.50	0.52	0.51	0.85	1.13	1.12	0.124	0.070	0.093
2008	0.046	0.051	0.049	0.443	0.518	0.373	0.53	0.53	0.60	0.97	1.05	0.98	0.132	0.111	0.110
2009	0.049	0.055	0.040	0.428	0.623	0.435	0.54	0.67	0.61	0.97	1.29	1.05	0.114	0.113	0.100
2010	0.046	0.070	0.040	0.372	0.599	0.603	0.58	0.58	0.60	0.95	1.18	1.20	0.104	0.110	0.070
2011	0.034	0.073	0.058	0.394	0.456	0.402	0.59	0.83	0.66	0.98	1.28	1.06	0.109	0.233	0.140
2012	0.052	0.052	0.070	0.461	0.511	0.410	0.52	0.59	0.62	0.98	1.10	1.03	0.106	0.133	N/A
2013	0.044	0.057	0.055	0.589	0.546	0.465	0.47	0.55	0.68	1.06	1.09	1.15	0.115	0.104	0.133
2014	0.059	0.057	0.053	0.676	0.503	0.567	0.52	0.56	0.62	1.20	1.07	1.19	0.103	0.120	0.097
2015	0.038	0.066	0.053	0.484	0.784	0.628	0.59	0.52	0.60	1.08	1.30	1.23	0.153	0.140	0.106

Contentnea Creek at Hookerton - Number of Samples by Flow Interval and Year															
Year	Ammonia (Number)			Nitrate (Number)			Total Kjeldahl N (Number)			Total N (Number)			Total P (Number)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	8	1	4	8	1	4	8	1	4	8	1	4	8	1	4
1981	5	4	0	6	4	0	6	4	0	6	4	0	6	4	0
1982	2	2	0	3	4	3	3	4	3	3	4	3	2	4	3
1983	2	0	3	5	1	5	5	1	5	5	1	5	5	1	5
1984	1	1	2	2	3	5	2	3	5	2	3	5	2	3	5
1985	7	5	1	10	6	2	10	6	2	10	6	2	9	5	2
1986	12	6	0	12	6	0	12	6	0	12	6	0	12	6	0
1987	10	2	6	9	2	6	9	2	6	10	2	6	9	2	6
1988	5	12	0	5	12	0	5	12	0	5	12	0	5	12	0
1989	0	7	9	0	7	9	0	7	9	0	7	9	0	7	9
1990	6	4	7	6	4	7	6	4	7	6	4	7	6	4	7
1991	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5
1992	2	5	7	2	5	7	2	5	7	2	5	7	2	5	7
1993	6	1	4	11	3	9	11	3	9	11	3	9	11	3	9
1994	7	0	3	14	2	6	14	2	6	14	2	6	14	2	6
1995	6	4	3	7	8	5	7	8	5	7	8	5	7	8	5
1996	0	0	0	22	102	123	22	102	127	22	102	123	22	102	127
1997	8	1	4	8	1	4	8	1	4	8	1	4	8	1	4
1998	2	5	6	2	5	6	2	5	6	2	5	6	2	5	6
1999	2	6	7	2	6	7	2	6	7	2	6	7	2	6	7
2000	3	0	2	3	0	2	3	0	2	3	0	2	3	0	2
2001	0	1	1	0	1	1	0	1	1	0	1	1	0	1	1
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	16	32	0	16	32	0	16	32	0	16	32	0	16	32
2004	11	24	17	11	24	17	11	24	17	11	24	17	11	24	17
2005	16	16	15	16	16	15	16	16	15	16	16	15	16	16	15
2006	9	20	6	10	27	15	10	27	15	10	27	15	10	27	15
2007	0	0	0	30	11	11	30	11	11	30	11	11	30	11	11
2008	27	16	9	27	16	9	27	16	9	27	16	9	27	16	9
2009	24	13	15	24	13	15	24	13	15	24	13	15	24	13	15
2010	24	11	16	24	11	16	24	11	16	24	11	16	24	11	16
2011	21	23	6	21	23	6	21	23	6	21	23	6	21	23	6
2012	19	21	8	19	21	8	19	21	8	19	21	8	19	21	8
2013	17	22	13	17	22	13	17	22	13	17	22	13	17	22	13
2014	5	13	29	5	13	29	5	13	29	5	13	29	5	13	29
2015	2	1	7	2	1	7	2	1	7	2	1	7	2	1	7

Contentnea Creek at Hookerton - Mean Nutrient Concentrations by Flow Interval and Year

Year	Ammonia (mg/L)			Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)			Total P (mg/L)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	0.288	0.270	0.118	1.825	1.600	0.978	0.90	0.60	0.57	2.73	2.20	1.55	0.421	0.220	0.158
1981	0.148	0.348	N/A	1.717	1.650	N/A	0.85	0.70	N/A	2.57	2.35	N/A	0.513	0.285	N/A
1982	0.225	0.150	N/A	1.720	2.643	0.987	0.77	0.87	1.05	2.49	3.51	2.03	0.365	0.328	0.187
1983	0.370	N/A	0.220	2.380	1.500	1.974	0.88	0.70	0.76	3.26	2.20	2.73	0.576	0.330	0.208
1984	0.200	0.190	0.255	1.300	1.333	1.160	1.05	0.63	0.82	2.35	1.97	1.98	0.385	0.680	0.286
1985	0.627	0.342	0.160	1.660	1.008	1.095	0.98	0.64	0.80	2.64	1.65	1.90	0.582	0.346	0.260
1986	0.433	0.413	N/A	1.331	0.985	N/A	0.93	0.92	N/A	2.26	1.90	N/A	0.578	0.362	N/A
1987	0.717	0.200	0.110	1.378	0.880	0.882	1.21	0.84	0.53	2.42	1.72	1.42	0.670	0.310	0.148
1988	0.376	0.332	N/A	1.204	1.077	N/A	0.96	0.79	N/A	2.17	1.87	N/A	0.434	0.273	N/A
1989	N/A	0.239	0.094	N/A	1.019	0.644	N/A	0.72	0.60	N/A	1.74	1.25	N/A	0.256	0.148
1990	0.210	0.163	0.130	1.103	0.840	0.699	0.58	0.60	0.57	1.69	1.44	1.27	0.277	0.173	0.153
1991	0.185	0.135	0.150	1.000	0.848	0.492	0.75	0.50	0.89	1.75	1.35	1.38	0.320	0.178	0.158
1992	0.120	0.176	0.076	0.970	0.872	0.509	0.50	0.59	0.55	1.47	1.46	1.05	0.220	0.154	0.117
1993	0.158	0.150	0.098	0.811	0.670	0.699	0.52	0.58	0.44	1.33	1.25	1.14	0.215	0.163	0.083
1994	0.111	N/A	0.097	0.642	0.650	0.648	0.51	0.60	0.53	1.15	1.25	1.18	0.161	0.100	0.100
1995	0.095	0.108	0.103	0.696	0.603	0.558	0.46	0.48	0.66	1.15	1.08	1.22	0.187	0.090	0.186
1996	N/A	N/A	N/A	0.704	0.591	0.502	0.54	0.52	0.53	1.25	1.12	1.01	0.193	0.167	0.168
1997	0.054	0.130	0.090	0.805	0.740	0.878	0.34	0.30	0.40	1.14	1.04	1.28	0.214	0.070	0.108
1998	0.060	0.118	0.052	0.900	0.688	0.582	0.40	0.42	0.43	1.30	1.11	1.02	0.335	0.164	0.163
1999	0.215	0.093	0.174	0.825	0.732	0.274	0.65	0.48	0.67	1.48	1.22	0.95	0.195	0.262	0.159
2000	0.113	N/A	0.055	0.743	N/A	0.735	0.47	N/A	0.55	1.21	N/A	1.29	0.160	N/A	0.100
2001	N/A	0.120	0.230	N/A	0.840	0.470	N/A	0.70	1.60	N/A	1.54	2.07	N/A	0.080	0.160
2002	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	N/A	0.059	0.049	N/A	0.646	0.551	N/A	0.60	0.64	N/A	1.25	1.19	N/A	0.131	0.124
2004	0.055	0.050	0.046	0.629	0.689	0.514	0.56	0.53	0.62	1.19	1.22	1.13	0.139	0.110	0.116
2005	0.058	0.064	0.043	0.732	0.683	0.601	0.56	0.63	0.57	1.29	1.31	1.18	0.146	0.104	0.097
2006	0.071	0.045	0.072	0.694	0.655	0.451	0.64	0.58	0.69	1.33	1.24	1.14	0.151	0.107	0.124
2007	N/A	N/A	N/A	0.722	0.796	0.842	0.55	0.59	0.72	1.27	1.39	1.56	0.158	0.112	0.105
2008	0.052	0.066	0.048	0.614	0.639	0.494	0.60	0.65	0.75	1.21	1.29	1.24	0.177	0.108	0.127
2009	0.042	0.067	0.050	0.608	0.715	0.612	0.61	0.67	0.74	1.22	1.38	1.35	0.257	0.135	0.114
2010	0.047	0.078	0.050	0.559	0.733	0.708	0.56	0.68	0.72	1.12	1.41	1.43	0.177	0.129	0.098
2011	0.055	0.056	0.078	0.551	0.521	0.287	0.67	0.65	0.89	1.22	1.17	1.17	0.194	0.139	0.200
2012	0.044	0.050	0.044	0.584	0.535	0.411	0.60	0.67	0.73	1.18	1.21	1.14	0.148	0.155	0.145
2013	0.046	0.054	0.044	0.725	0.625	0.531	0.62	0.69	0.76	1.34	1.31	1.29	0.145	0.111	0.115
2014	0.042	0.065	0.054	0.902	0.778	0.639	0.60	0.72	0.75	1.50	1.50	1.39	0.120	0.115	0.116
2015	0.060	0.070	0.084	0.810	0.620	0.860	0.59	0.72	0.77	1.40	1.34	1.63	0.155	0.110	0.121

Trent River at Trenton - Number of Samples by Flow Interval and Year

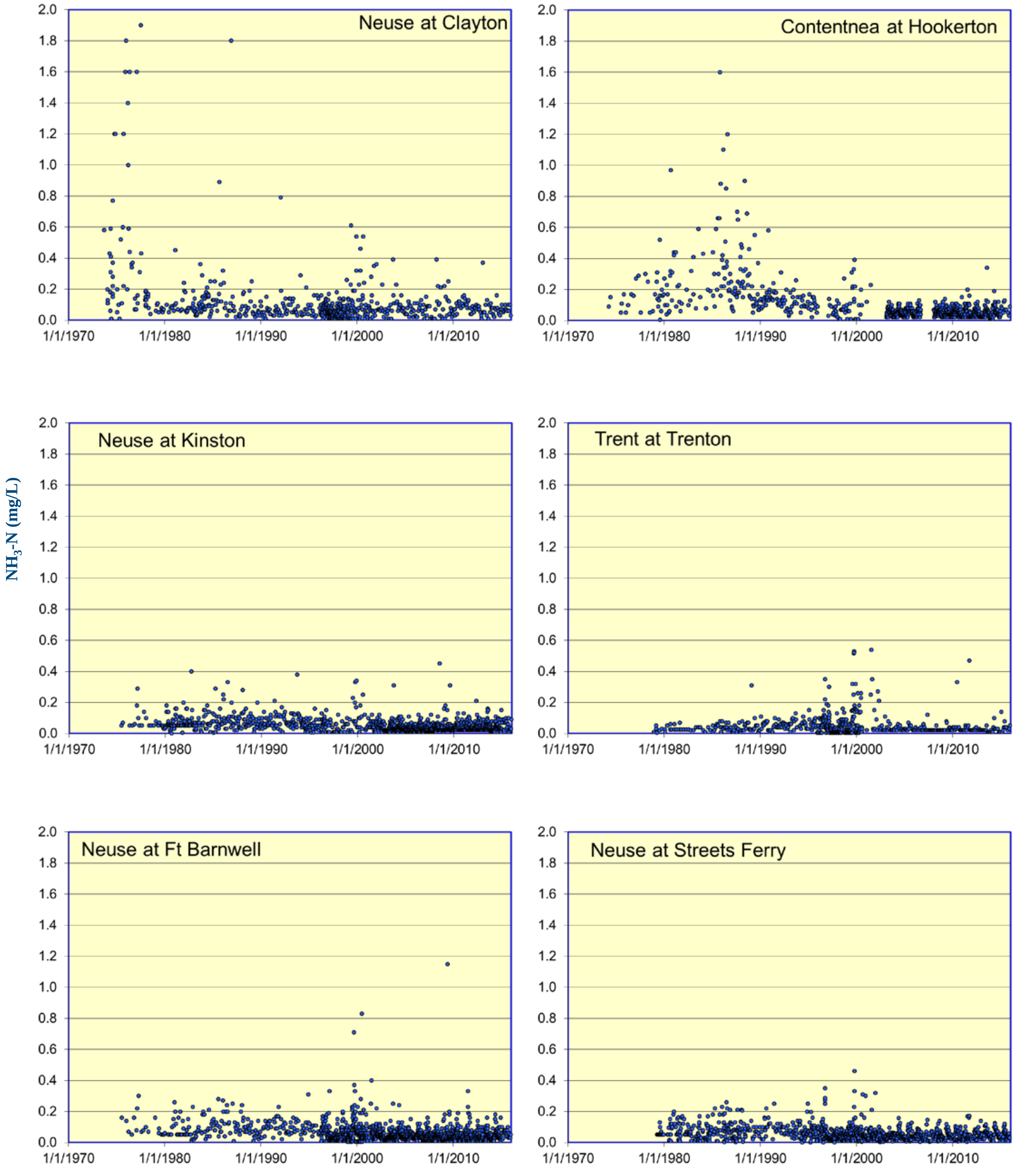
Year	Ammonia (Number)			Nitrate (Number)			Total Kjeldahl N (Number)			Total N (Number)			Total P (Number)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3
1981	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1
1982	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
1983	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
1984	0	2	2	0	2	2	0	2	2	0	2	2	0	2	2
1985	4	4	2	4	4	2	4	4	2	4	4	2	4	4	2
1986	5	6	1	5	6	1	5	6	1	5	6	1	5	6	1
1987	6	2	4	6	2	4	6	2	4	6	2	4	6	2	4
1988	8	3	1	8	3	1	8	3	1	8	3	1	8	3	1
1989	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3
1990	4	7	1	4	7	1	4	7	1	4	7	1	4	7	1
1991	4	2	4	4	2	4	4	2	4	4	2	4	4	2	4
1992	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2
1993	5	1	4	6	1	4	5	1	4	5	1	4	6	1	4
1994	6	3	2	6	3	2	6	3	2	6	3	2	6	3	2
1995	6	6	4	6	6	4	6	6	4	6	6	4	6	6	4
1996	6	18	18	6	18	18	6	18	17	6	18	17	6	18	18
1997	18	17	13	18	17	13	18	17	13	18	17	13	18	17	13
1998	23	10	16	23	10	16	23	10	16	23	10	16	23	10	16
1999	11	18	23	11	18	23	11	18	23	11	18	23	11	18	23
2000	6	10	10	6	10	10	6	10	10	6	10	10	6	10	10
2001	5	2	1	6	2	1	5	2	1	5	2	1	5	2	1
2002	6	4	2	6	4	2	6	4	2	6	4	2	6	4	2
2003	2	3	7	2	3	7	2	3	7	2	3	7	2	3	7
2004	1	7	4	1	7	4	1	7	4	1	7	4	1	7	4
2005	1	6	4	1	6	4	1	6	4	1	6	4	1	6	4
2006	3	5	4	3	5	4	3	5	4	3	5	4	3	5	4
2007	7	1	4	7	1	4	7	1	4	7	1	4	7	1	4
2008	8	3	2	8	3	2	8	3	2	8	3	2	8	3	2
2009	6	3	4	6	3	4	6	3	4	6	3	4	6	3	4
2010	5	4	3	5	4	3	5	4	3	5	4	3	5	4	3
2011	5	6	1	5	6	1	5	6	1	5	6	1	5	6	1
2012	2	7	3	2	7	3	2	7	3	2	7	3	2	7	3
2013	3	6	3	3	6	3	3	6	3	3	6	3	3	6	3
2014	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
2015	2	1	7	2	1	7	2	1	7	2	1	7	2	1	7

Trent River at Trenton - Mean Nutrient Concentrations by Flow Interval and Year

Year	Ammonia (mg/L)			Nitrate (mg/L)			Total Kjeldahl N (mg/L)			Total N (mg/L)			Total P (mg/L)		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
1980	0.043	0.038	0.028	1.100	0.645	0.400	0.43	0.50	0.41	1.53	1.15	0.81	0.060	0.115	0.038
1981	0.025	0.043	0.070	1.173	0.690	0.260	0.37	0.21	0.74	1.54	0.90	1.00	0.070	0.023	0.060
1982	0.020	0.025	0.025	0.750	0.700	0.790	0.40	0.45	0.40	1.15	1.15	1.19	0.060	0.070	0.025
1983	0.040	N/A	0.030	0.690	N/A	0.700	0.25	N/A	0.35	0.94	N/A	1.05	0.080	N/A	0.055
1984	N/A	0.030	0.015	N/A	0.450	0.395	N/A	0.40	0.45	N/A	0.85	0.85	N/A	0.070	0.035
1985	0.050	0.048	0.010	0.478	0.503	0.410	0.35	0.35	0.40	0.83	0.85	0.81	0.098	0.070	0.050
1986	0.052	0.040	0.020	0.762	0.543	0.330	0.42	0.37	0.60	1.18	0.91	0.93	0.096	0.058	0.090
1987	0.027	0.045	0.015	0.480	0.750	0.713	0.42	0.45	0.33	0.90	1.20	1.04	0.093	0.095	0.050
1988	0.041	0.050	0.020	0.534	0.610	0.760	0.33	0.37	0.40	0.86	0.98	1.16	0.098	0.073	0.080
1989	0.115	0.034	0.027	0.665	0.630	0.513	0.45	0.42	0.40	1.12	1.05	0.91	0.100	0.080	0.070
1990	0.073	0.037	0.110	0.893	0.477	0.970	0.45	0.41	0.60	1.34	0.89	1.57	0.090	0.087	0.060
1991	0.055	0.040	0.048	0.575	0.710	0.325	0.43	0.45	0.48	1.00	1.16	0.80	0.073	0.085	0.060
1992	0.046	0.056	0.055	0.724	0.650	0.715	0.44	0.38	0.40	1.16	1.03	1.12	0.082	0.158	0.040
1993	0.072	0.100	0.055	0.503	0.630	0.540	0.46	0.40	0.45	0.96	1.03	0.99	0.085	0.130	0.073
1994	0.068	0.040	0.040	0.593	0.347	0.605	0.42	0.50	0.65	1.01	0.85	1.26	0.167	0.097	0.040
1995	0.067	0.039	0.083	0.683	0.448	0.503	0.35	0.53	0.63	1.03	0.98	1.13	0.083	0.083	0.083
1996	0.053	0.072	0.081	0.808	0.548	0.405	0.40	0.53	0.56	1.21	1.08	0.97	0.103	0.079	0.093
1997	0.016	0.031	0.083	0.381	0.424	0.525	0.32	0.35	0.41	0.70	0.78	0.93	0.141	0.093	0.045
1998	0.045	0.051	0.024	0.698	0.549	0.440	0.30	0.41	0.39	1.00	0.96	0.83	0.216	0.162	0.092
1999	0.090	0.055	0.124	0.548	0.446	0.385	0.43	0.49	0.58	0.98	0.94	0.97	0.159	0.283	0.237
2000	0.097	0.059	0.067	0.687	0.474	0.471	0.42	0.50	0.70	1.10	0.97	1.17	0.160	0.137	0.071
2001	0.154	0.185	0.250	0.922	0.670	0.260	0.69	0.85	1.10	1.66	1.52	1.36	0.082	0.055	0.100
2002	0.030	0.060	0.240	0.563	0.490	0.250	0.36	0.58	0.80	0.92	1.07	1.05	0.058	0.048	0.100
2003	0.025	0.023	0.037	1.600	0.817	0.640	0.74	0.57	0.80	2.34	1.39	1.44	0.105	0.057	0.093
2004	0.040	0.034	0.025	1.500	0.669	0.450	0.78	0.57	0.71	2.28	1.24	1.16	0.110	0.073	0.085
2005	0.050	0.030	0.035	1.300	0.962	0.698	0.48	0.63	0.67	1.78	1.59	1.37	0.090	0.073	0.080
2006	0.023	0.034	0.028	0.813	0.926	0.500	0.73	0.57	0.74	1.54	1.49	1.24	0.073	0.074	0.083
2007	0.020	0.120	0.025	0.306	0.730	0.655	0.43	0.78	0.62	0.73	1.51	1.28	0.063	0.160	0.073
2008	0.020	0.020	0.035	0.530	0.503	0.625	0.55	0.61	0.74	1.08	1.12	1.36	0.059	0.060	0.060
2009	0.032	0.027	0.033	0.930	0.780	0.978	0.75	0.90	0.94	1.68	1.68	1.92	0.090	0.087	0.080
2010	0.032	0.098	0.033	1.194	1.233	1.077	0.58	0.96	0.71	1.77	2.19	1.79	0.082	0.160	0.067
2011	0.040	0.095	0.020	0.428	0.473	0.080	0.67	0.85	1.20	1.10	1.32	1.28	0.080	0.078	0.090
2012	0.020	0.021	0.030	0.775	0.609	0.400	0.63	0.85	0.95	1.40	1.46	1.35	0.065	0.077	0.113
2013	0.013	0.017	0.030	0.740	0.697	0.697	0.73	0.68	0.74	1.47	1.38	1.44	0.103	0.087	0.070
2014	0.023	0.020	0.038	1.567	1.005	0.812	0.67	0.76	0.80	2.24	1.77	1.62	0.087	0.095	0.068
2015	0.030	0.040	0.053	1.220	1.000	0.740	0.66	0.64	0.81	1.88	1.64	1.55	0.095	0.100	0.074

APPENDIX B

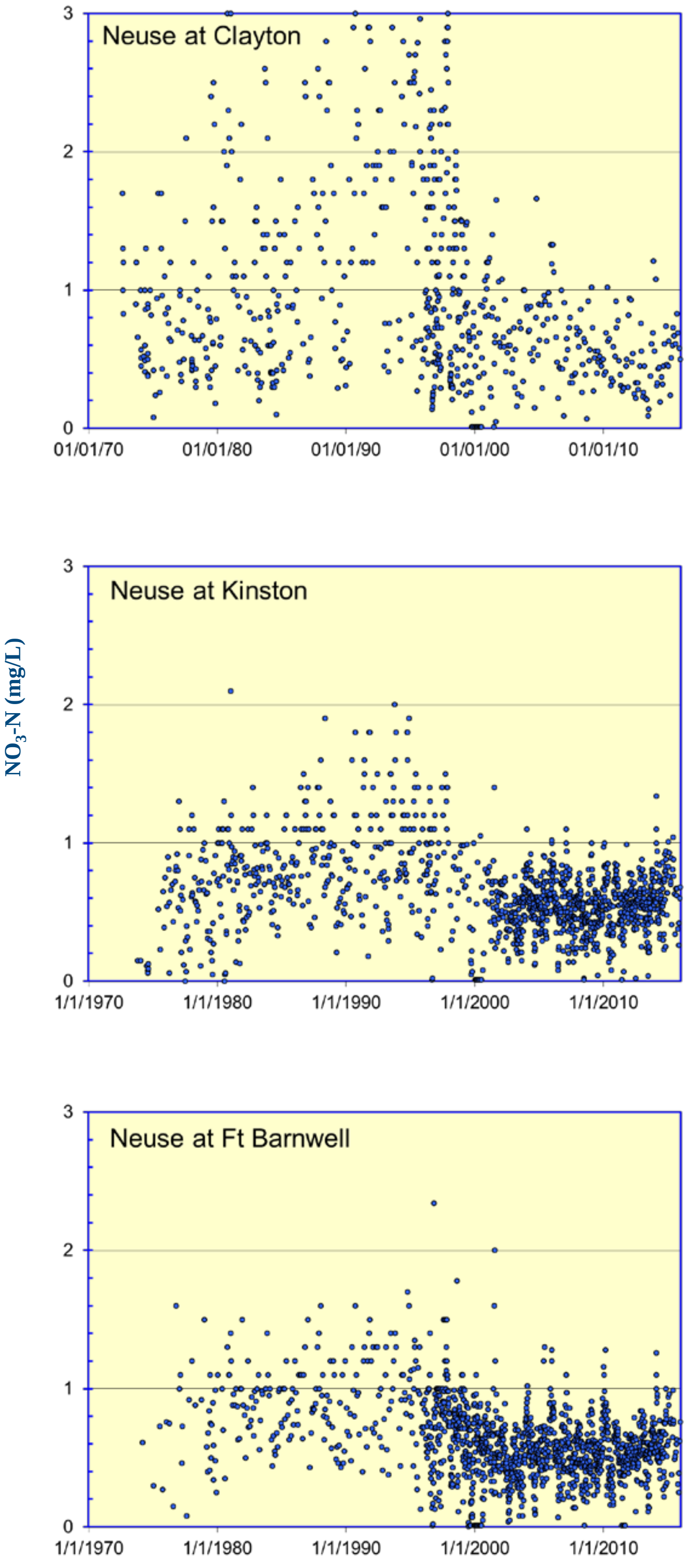
NUTRIENT TIME SERIES PLOTS BY STATION

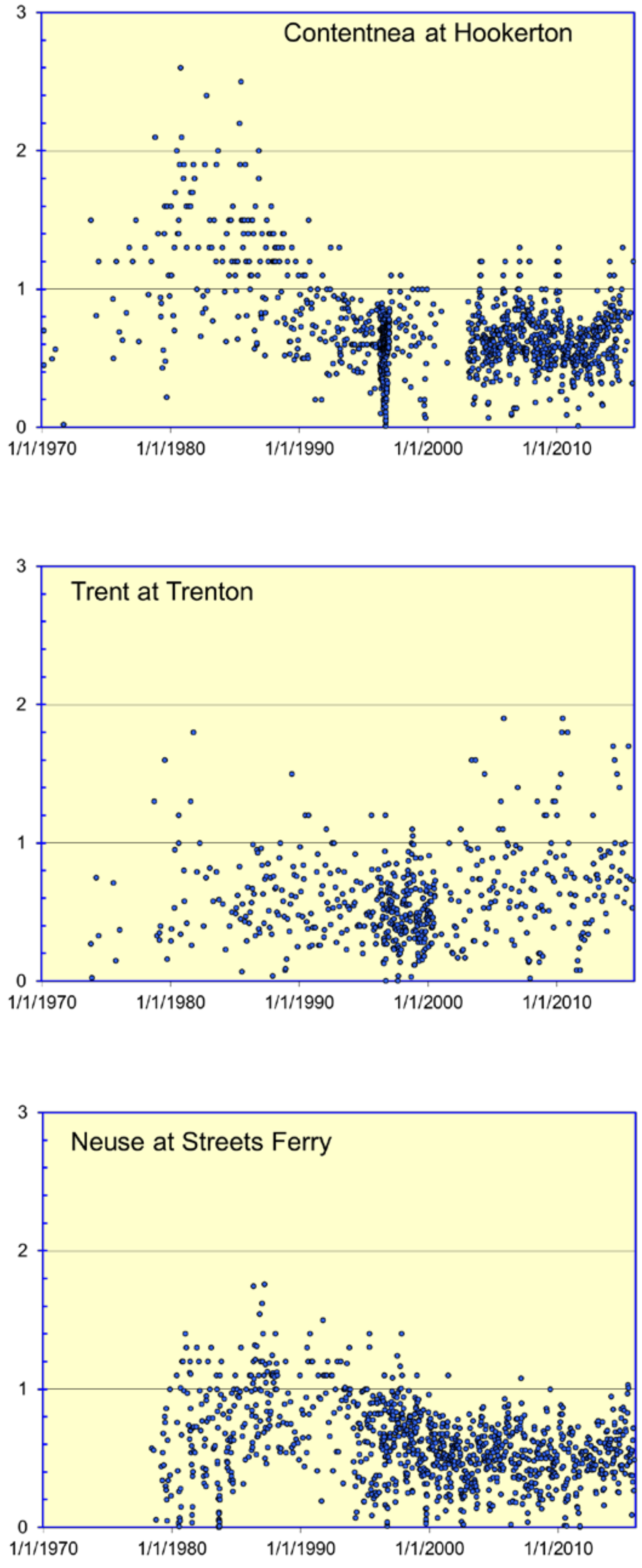


CLIENT: City of Raleigh
LOCATION: Raleigh, NC
PROJECT/FILE: 161012

optimizing resources | water, air, earth

FIGURE B-1
Time series by location: NH_3-N





CLIENT: City of Raleigh
LOCATION: Raleigh, NC
PROJECT/FILE: 161012

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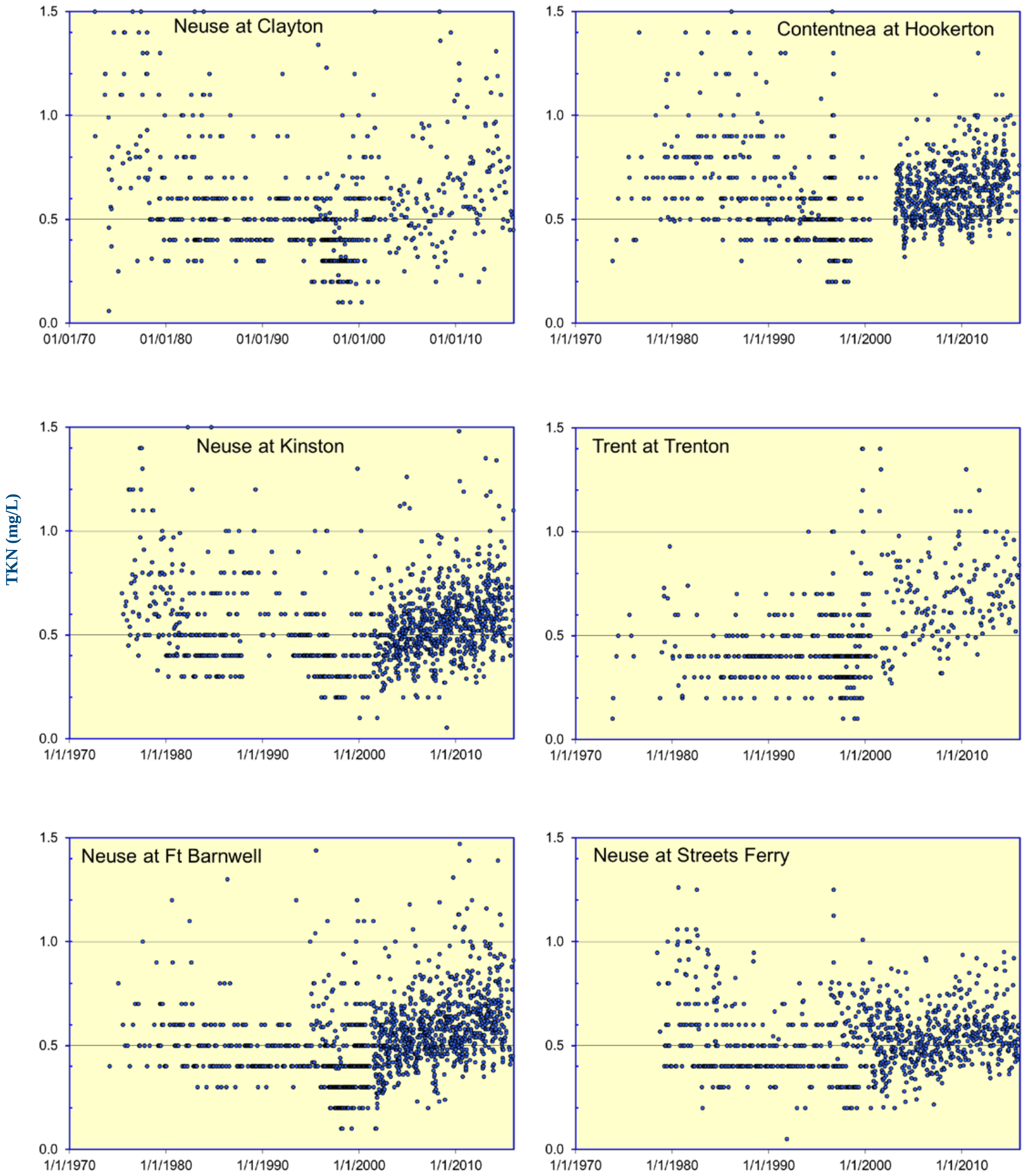
FIGURE B-2
Time series by location: NO$_3$-N



CLIENT: City of Raleigh
LOCATION: Raleigh, NC
PROJECT/FILE: 161012

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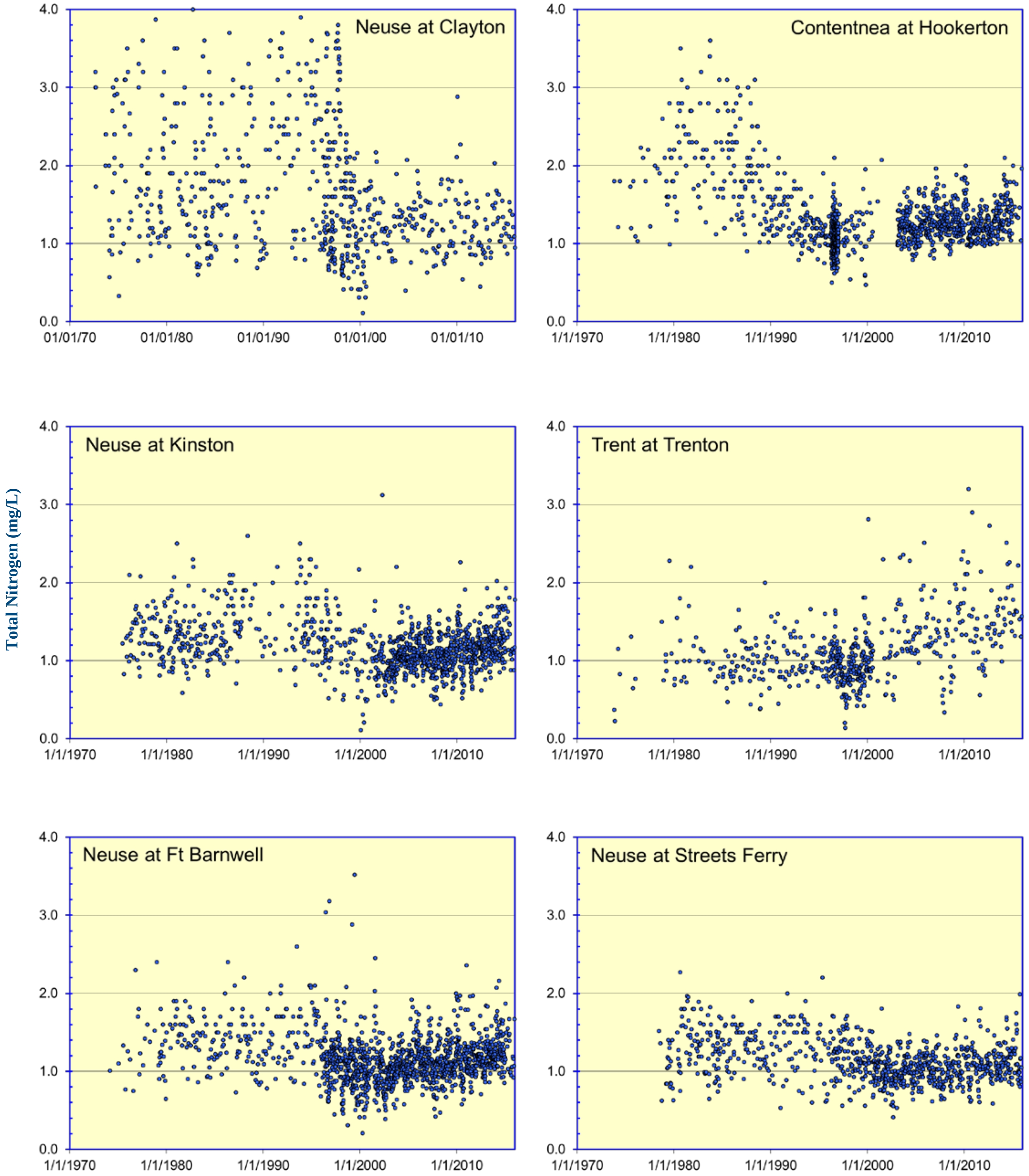
FIGURE B-3
Time series by location: TKN



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LOCATION: Raleigh, NC
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FIGURE B-4
Time series by location: TN

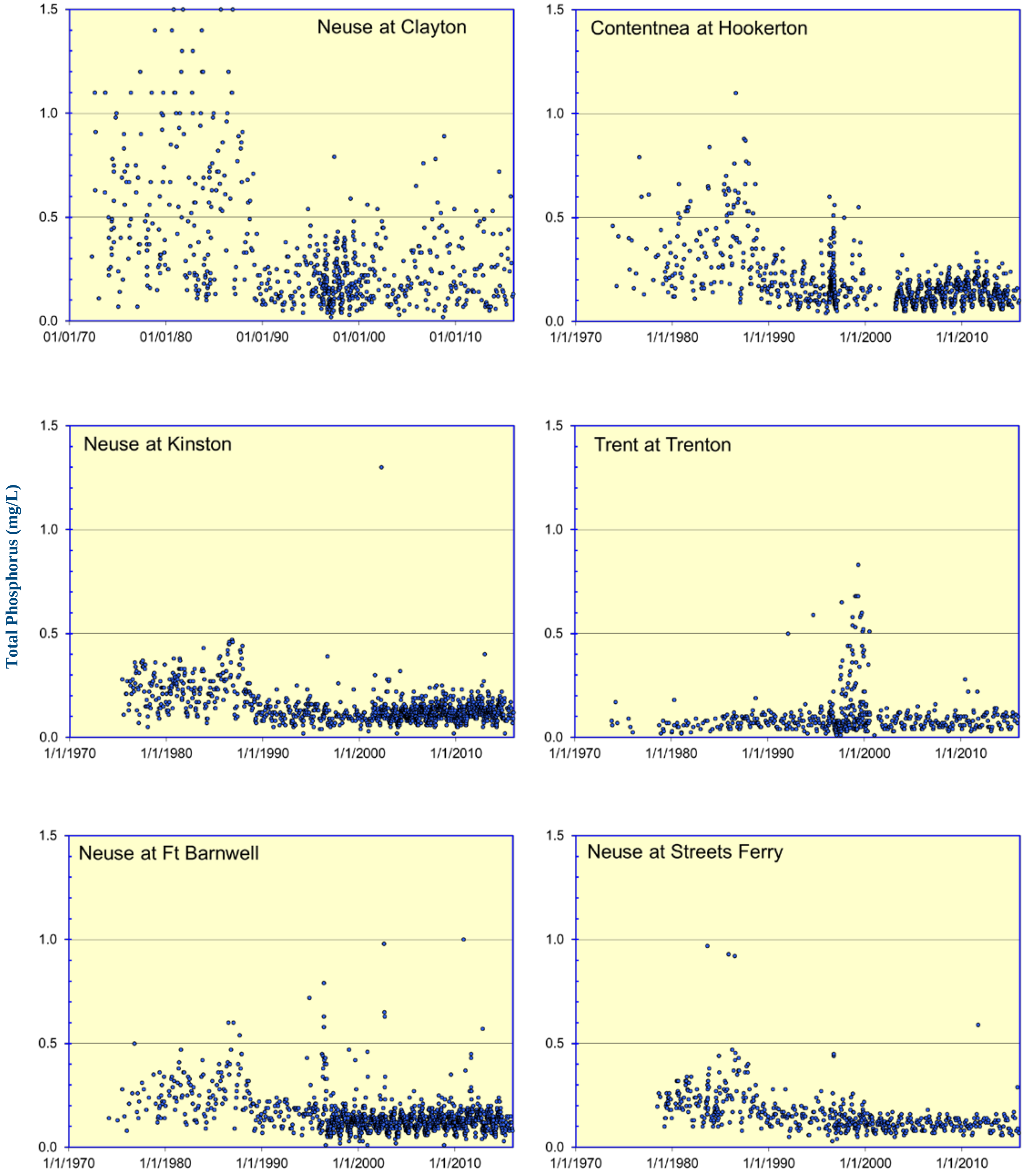

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FIGURE B-5
Time series by location: TP

APPENDIX C

ACTUAL LOADS BY YEAR AND LOCATION

Neuse River at Clayton calculated loads						
Year	NH3-N	NO3-N	Org-N	TKN	Total N	Total P
	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr
1980	0.168	1.196	1.439	1.608	2.804	0.891
1981	0.103	1.035	0.472	0.575	1.600	0.502
1982	0.297	1.849	1.485	1.781	3.621	0.846
1983	0.286	1.572	1.600	1.886	3.454	0.694
1984	0.350	1.617	1.845	2.195	3.807	0.744
1985	0.249	1.223	1.157	1.406	2.622	0.638
1986	0.159	1.099	0.460	0.618	1.717	0.574
1987	0.247	2.005	1.043	1.290	3.295	0.794
1988	0.073	1.274	0.373	0.446	1.720	0.390
1989	0.270	2.256	1.283	1.553	3.809	0.580
1990	0.139	1.729	0.844	0.983	2.713	0.312
1991	0.125	1.616	0.650	0.775	2.391	0.194
1992	0.138	1.687	0.593	0.731	2.418	0.186
1993	0.248	2.083	0.784	1.032	3.112	0.270
1994	0.138	1.809	0.568	0.706	2.529	0.249
1995	0.196	2.515	0.842	1.037	3.161	0.341
1996	0.237	3.103	1.160	1.396	4.065	0.446
1997	0.124	1.958	0.605	0.729	2.531	0.279
1998	0.217	2.337	1.023	1.240	3.577	0.431
1999	0.245	1.482	0.916	1.161	2.673	0.385
2000	0.230	0.908	0.877	1.107	2.082	0.316
2001	0.162	0.719	0.707	0.869	1.584	0.272
2002	0.159	0.788	0.929	1.089	1.880	0.279
2003	0.358	1.416	1.734	2.092	3.508	0.417
2004	0.145	0.934	0.777	0.922	1.856	0.235
2005	0.115	0.826	0.692	0.807	1.632	0.312
2006	0.135	0.930	0.931	1.067	1.996	0.419
2007	0.140	0.587	0.906	1.046	1.633	0.401
2008	0.146	0.623	0.979	1.126	1.749	0.328
2009	0.233	0.871	2.379	2.612	3.483	0.438
2010	0.161	0.848	2.036	2.197	3.045	0.318
2011	0.070	0.421	0.590	0.660	1.082	0.178
2012	0.081	0.395	0.523	0.604	0.999	0.181
2013	0.183	0.768	1.651	1.834	2.602	0.328
2014	0.206	1.020	1.887	2.094	3.113	0.394
2015	0.142	1.022	1.682	1.825	2.847	0.415

Neuse River at Kinston calculated loads						
Year	NH3-N	NO3-N	Org-N	TKN	Total N	Total P
	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr
1980	0.343	2.711	2.292	2.636	5.333	0.827
1981	0.197	1.885	1.208	1.404	3.274	0.567
1982	0.414	3.959	2.670	3.084	7.043	1.057
1983	0.504	4.480	2.905	3.408	7.889	1.018
1984	0.582	5.518	3.284	3.866	9.384	1.237
1985	0.336	2.698	1.593	1.929	4.627	0.758
1986	0.192	1.810	0.924	1.117	2.926	0.547
1987	0.423	4.195	2.894	3.318	7.457	0.989
1988	0.241	2.478	1.485	1.726	4.231	0.529
1989	0.636	5.926	6.963	7.599	12.961	1.182
1990	0.327	3.354	3.240	3.567	6.402	0.569
1991	0.324	3.549	2.251	2.576	5.560	0.475
1992	0.400	3.921	2.036	2.436	6.037	0.496
1993	0.420	4.374	2.237	2.657	6.933	0.529
1994	0.257	3.247	1.560	1.816	5.033	0.396
1995	0.421	4.960	2.922	3.342	8.302	0.777
1996	0.504	5.707	3.523	4.028	9.735	0.946
1997	0.229	3.023	1.482	1.711	4.734	0.480
1998	0.777	3.801	3.447	4.224	8.025	0.828
1999	0.918	3.258	3.990	4.908	8.167	0.914
2000	0.591	2.192	2.724	3.316	5.500	0.587
2001	0.195	1.923	1.687	1.883	3.794	0.477
2002	0.150	1.796	1.718	1.868	3.654	0.429
2003	0.317	4.002	4.445	4.762	8.764	0.941
2004	0.182	2.584	2.518	2.700	5.283	0.540
2005	0.142	2.123	2.111	2.252	4.376	0.457
2006	0.174	2.804	2.923	3.097	5.900	0.601
2007	0.127	1.683	1.948	2.074	3.756	0.425
2008	0.141	1.948	2.141	2.282	4.230	0.464
2009	0.201	2.495	2.897	3.098	5.593	0.549
2010	0.220	2.834	3.299	3.519	6.353	0.565
2011	0.097	1.298	1.335	1.433	2.731	0.316
2012	0.103	1.304	1.419	1.522	2.826	0.336
2013	0.227	2.780	3.488	3.716	6.495	0.671
2014	0.306	3.635	4.530	4.836	8.471	0.792
2015	0.266	3.979	4.376	4.642	8.621	0.729

Neuse River at Fort Barnwell calculated loads						
Year	NH3-N	NO3-N	Org-N	TKN	Total N	Total P
	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr
1980	0.519	4.518	3.229	3.748	8.252	1.403
1981	0.335	3.020	1.660	1.995	5.002	0.891
1982	0.649	7.521	4.026	4.675	12.195	1.740
1983	0.620	7.958	4.538	5.158	13.115	1.708
1984	0.934	9.823	4.739	5.674	15.497	2.083
1985	0.574	4.155	2.132	2.706	6.861	1.139
1986	0.368	2.731	1.192	1.560	4.291	0.906
1987	0.979	7.158	3.176	4.156	11.314	2.143
1988	0.422	3.693	1.347	1.769	5.462	0.951
1989	0.941	10.553	5.849	6.790	17.343	2.204
1990	0.520	5.358	2.697	3.217	8.575	1.083
1991	0.568	5.161	2.491	3.059	8.221	0.980
1992	0.753	6.286	3.149	3.902	10.188	1.134
1993	0.635	6.166	3.241	3.876	10.043	1.072
1994	0.471	4.050	2.891	3.362	7.282	0.876
1995	0.847	5.835	4.737	5.585	11.281	1.835
1996	0.950	7.275	5.288	6.238	13.408	1.958
1997	0.356	3.953	2.131	2.486	6.443	0.880
1998	0.819	5.642	4.178	4.997	10.642	1.332
1999	0.997	6.420	5.339	6.336	12.755	1.615
2000	0.659	3.388	3.480	4.138	7.538	0.906
2001	0.320	2.595	2.297	2.617	5.218	0.629
2002	0.255	2.562	2.649	2.904	5.464	0.651
2003	0.480	5.880	6.494	6.974	12.855	1.425
2004	0.309	3.738	3.600	3.909	7.647	0.814
2005	0.250	3.073	3.004	3.254	6.327	0.673
2006	0.320	4.374	4.293	4.613	8.988	0.895
2007	0.190	2.294	2.502	2.692	4.986	0.549
2008	0.244	2.893	3.007	3.251	6.145	0.631
2009	0.296	3.799	4.156	4.452	8.250	0.774
2010	0.333	4.255	5.110	5.443	9.698	0.908
2011	0.185	2.069	2.527	2.713	4.782	0.561
2012	0.220	2.290	3.023	3.244	5.533	0.662
2013	0.377	4.485	5.536	5.913	10.398	1.067
2014	0.531	6.446	7.823	8.354	14.800	1.371
2015	0.493	6.631	7.188	7.681	14.311	1.226

Neuse River at Streets Ferry calculated loads

Year	NH3-N	NO3-N	Org-N	TKN	Total N	Total P
	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr
1980	0.414	3.644	2.985	3.399	7.136	1.195
1981	0.264	2.514	2.017	2.280	4.882	0.773
1982	0.553	6.138	4.461	5.015	11.335	1.551
1983	0.481	6.157	5.321	5.802	12.138	1.671
1984	0.520	7.662	5.526	6.046	13.957	1.899
1985	0.359	3.665	2.505	2.864	6.541	1.096
1986	0.258	2.944	1.131	1.389	4.018	0.759
1987	0.502	9.022	3.537	4.039	9.854	1.590
1988	0.340	3.818	1.514	1.854	5.412	0.805
1989	1.068	11.579	5.784	6.852	18.375	2.417
1990	0.562	5.491	2.754	3.316	8.618	1.124
1991	0.532	5.065	2.393	2.925	7.834	0.930
1992	0.553	6.109	3.477	4.030	9.947	1.032
1993	0.528	5.568	3.303	3.831	10.007	0.924
1994	0.368	3.336	2.340	2.708	6.897	0.765
1995	0.965	4.800	5.168	6.133	11.589	1.799
1996	1.091	6.607	6.566	7.658	14.811	2.133
1997	0.440	3.534	3.120	3.560	7.270	0.955
1998	0.740	6.093	5.610	6.350	12.618	1.481
1999	0.949	6.721	7.100	8.049	14.889	1.828
2000	0.617	3.687	4.195	4.812	8.468	1.049
2001	0.277	2.845	2.748	3.025	5.779	0.627
2002	0.243	2.663	2.868	3.111	5.760	0.635
2003	0.515	6.262	7.107	7.622	13.907	1.566
2004	0.317	3.759	3.580	3.897	7.704	0.798
2005	0.239	3.016	2.782	3.022	6.066	0.664
2006	0.326	4.520	3.977	4.304	8.843	0.888
2007	0.214	2.485	2.449	2.664	5.141	0.551
2008	0.257	2.823	2.837	3.094	5.910	0.567
2009	0.305	3.436	3.851	4.156	7.590	0.647
2010	0.346	4.091	4.744	5.090	9.181	0.818
2011	0.200	1.843	2.203	2.403	4.246	0.524
2012	0.217	1.917	2.286	2.503	4.420	0.561
2013	0.438	4.090	4.534	4.972	9.062	0.907
2014	0.586	5.968	6.166	6.753	12.721	1.197
2015	0.582	6.367	6.054	6.637	13.004	1.131

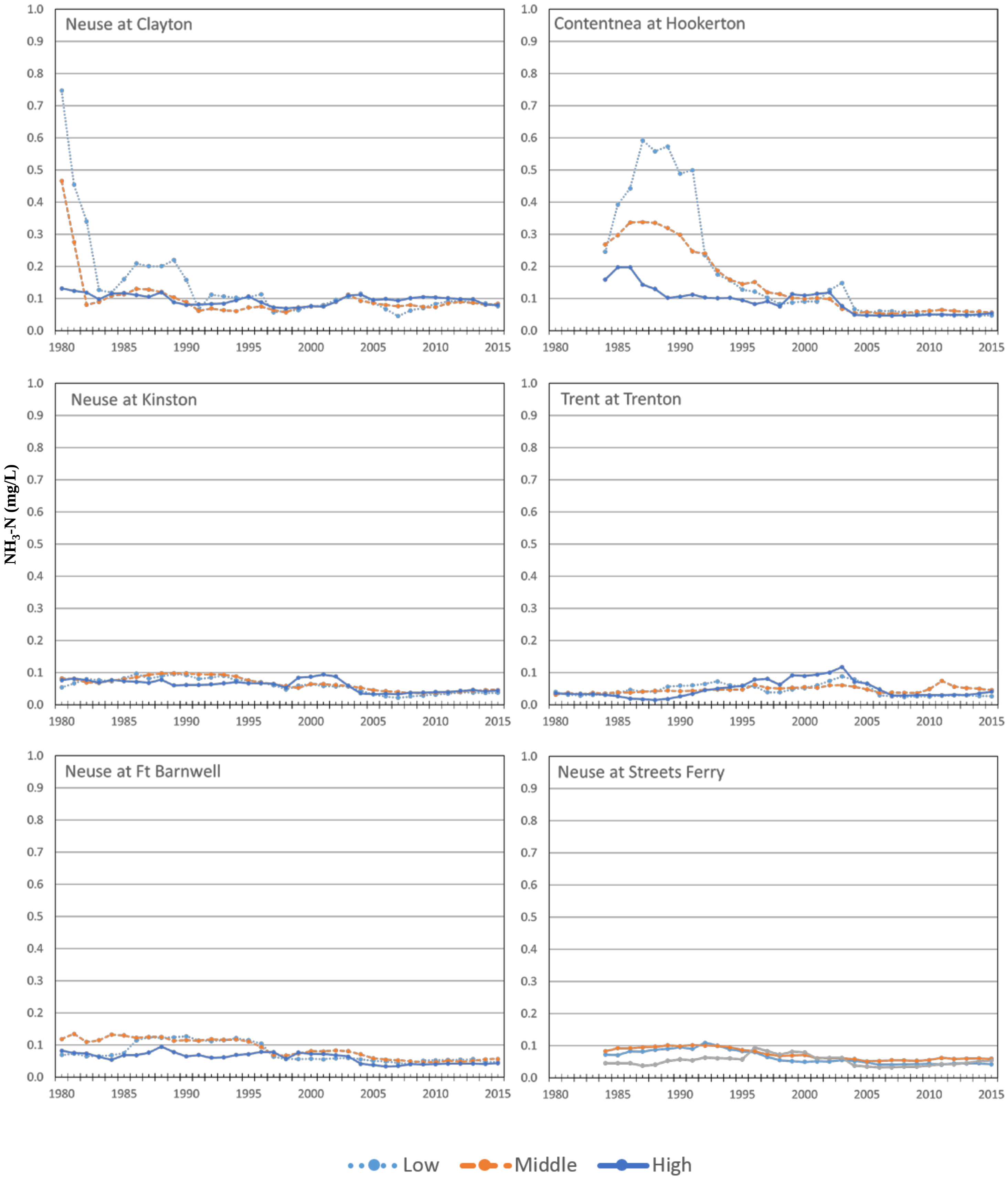
Contentnea Creek at Hookerton calculated loads						
Year	NH3-N	NO3-N	Org-N	TKN	Total N	Total P
	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr
1980	0.191	1.126	0.833	1.024	2.150	0.311
1981	0.116	0.884	0.265	0.381	1.265	0.148
1982	0.336	2.542	0.954	1.290	3.832	0.370
1983	0.389	2.684	1.174	1.563	4.247	0.480
1984	0.524	3.229	1.257	1.781	5.011	0.641
1985	0.255	1.003	0.448	0.702	1.705	0.303
1986	0.181	0.565	0.238	0.419	0.980	0.184
1987	0.242	1.515	0.746	0.988	2.499	0.304
1988	0.213	0.691	0.332	0.544	1.227	0.197
1989	0.395	2.269	1.534	1.929	4.199	0.507
1990	0.178	0.938	0.693	0.870	1.809	0.226
1991	0.157	0.844	0.584	0.741	1.585	0.191
1992	0.203	1.186	0.840	1.043	2.229	0.230
1993	0.143	0.989	0.646	0.789	1.778	0.166
1994	0.101	0.669	0.433	0.535	1.203	0.122
1995	0.175	0.889	0.815	0.990	1.845	0.307
1996	0.223	1.124	1.041	1.264	2.340	0.397
1997	0.073	0.542	0.489	0.563	1.085	0.185
1998	0.228	1.038	0.771	1.000	2.038	0.320
1999	0.383	1.575	1.397	1.781	3.355	0.548
2000	0.219	0.723	0.770	0.989	1.712	0.263
2001	0.116	0.749	0.687	0.803	1.552	0.112
2002	0.065	0.673	0.693	0.758	1.431	0.147
2003	0.127	1.463	1.578	1.706	3.168	0.323
2004	0.067	0.791	0.745	0.812	1.603	0.154
2005	0.055	0.610	0.610	0.665	1.275	0.123
2006	0.091	1.063	1.041	1.132	2.195	0.194
2007	0.047	0.482	0.509	0.556	1.037	0.100
2008	0.048	0.591	0.561	0.609	1.200	0.109
2009	0.058	0.693	0.713	0.771	1.465	0.132
2010	0.075	0.865	0.982	1.058	1.922	0.184
2011	0.041	0.429	0.490	0.532	0.960	0.108
2012	0.045	0.439	0.558	0.603	1.042	0.119
2013	0.074	0.848	0.992	1.066	1.914	0.181
2014	0.120	1.363	1.527	1.647	3.010	0.257
2015	0.125	1.479	1.515	1.639	3.118	0.257

Trent River at Trenton calculated loads

Year	NH3-N	NO3-N	Org-N	TKN	Total N	Total P
	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr	10^6 lbs/yr
1980	0.016	0.217	0.251	0.267	0.484	0.025
1981	0.010	0.141	0.120	0.130	0.271	0.013
1982	0.013	0.193	0.135	0.148	0.341	0.016
1983	0.013	0.307	0.201	0.214	0.521	0.023
1984	0.008	0.177	0.132	0.140	0.317	0.019
1985	0.005	0.084	0.079	0.083	0.168	0.012
1986	0.006	0.135	0.090	0.097	0.231	0.016
1987	0.007	0.213	0.136	0.143	0.357	0.023
1988	0.005	0.108	0.060	0.065	0.173	0.012
1989	0.016	0.247	0.153	0.169	0.416	0.028
1990	0.011	0.118	0.094	0.105	0.223	0.016
1991	0.020	0.183	0.146	0.166	0.349	0.024
1992	0.022	0.206	0.158	0.180	0.386	0.031
1993	0.017	0.183	0.131	0.147	0.330	0.021
1994	0.017	0.149	0.138	0.156	0.305	0.023
1995	0.030	0.153	0.191	0.221	0.375	0.035
1996	0.045	0.244	0.246	0.291	0.537	0.044
1997	0.013	0.103	0.090	0.103	0.206	0.021
1998	0.040	0.192	0.179	0.219	0.411	0.070
1999	0.060	0.291	0.327	0.387	0.678	0.118
2000	0.047	0.161	0.207	0.255	0.415	0.079
2001	0.016	0.077	0.101	0.118	0.195	0.015
2002	0.014	0.095	0.116	0.130	0.225	0.014
2003	0.040	0.353	0.516	0.556	0.909	0.067
2004	0.013	0.253	0.292	0.305	0.558	0.037
2005	0.012	0.227	0.255	0.267	0.494	0.032
2006	0.020	0.400	0.421	0.441	0.841	0.052
2007	0.005	0.093	0.101	0.106	0.199	0.012
2008	0.004	0.091	0.089	0.093	0.184	0.010
2009	0.009	0.241	0.202	0.211	0.452	0.020
2010	0.014	0.324	0.310	0.324	0.648	0.029
2011	0.010	0.151	0.192	0.202	0.353	0.021
2012	0.013	0.196	0.343	0.356	0.552	0.036
2013	0.009	0.203	0.228	0.237	0.440	0.024
2014	0.014	0.278	0.264	0.278	0.557	0.027
2015	0.029	0.494	0.472	0.501	0.995	0.047

APPENDIX D

NUTRIENT CONCENTRATIONS: 5-YR AVERAGES



CLIENT: City of Raleigh
LOCATION: Raleigh, NC
PROJECT/FILE: 161012

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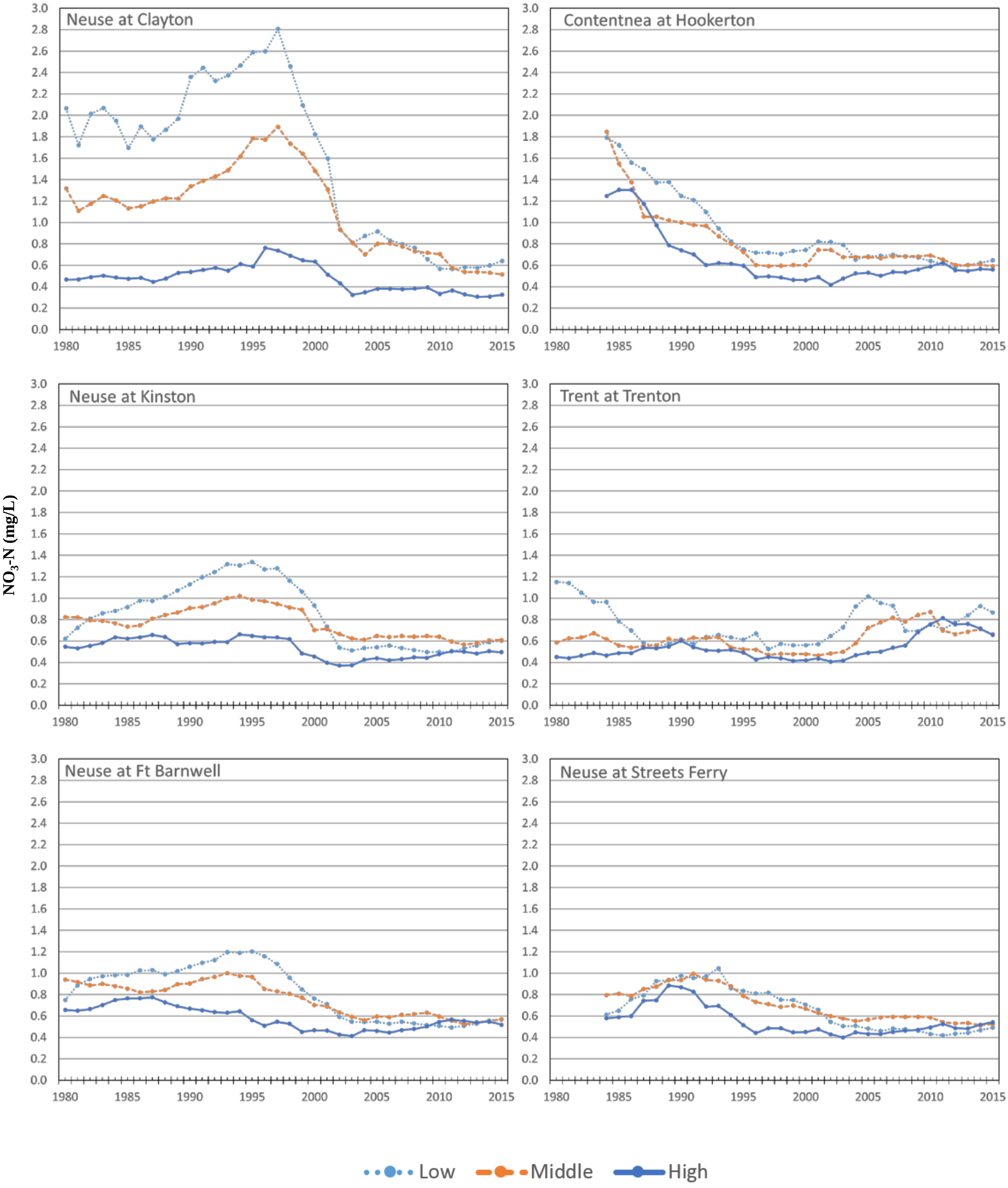
FIGURE D-1
Five-year mean concentrations by flow bin and location: NH$_3$-N



CLIENT: City of Raleigh
LOCATION: Raleigh, NC
PROJECT/FILE: 161012

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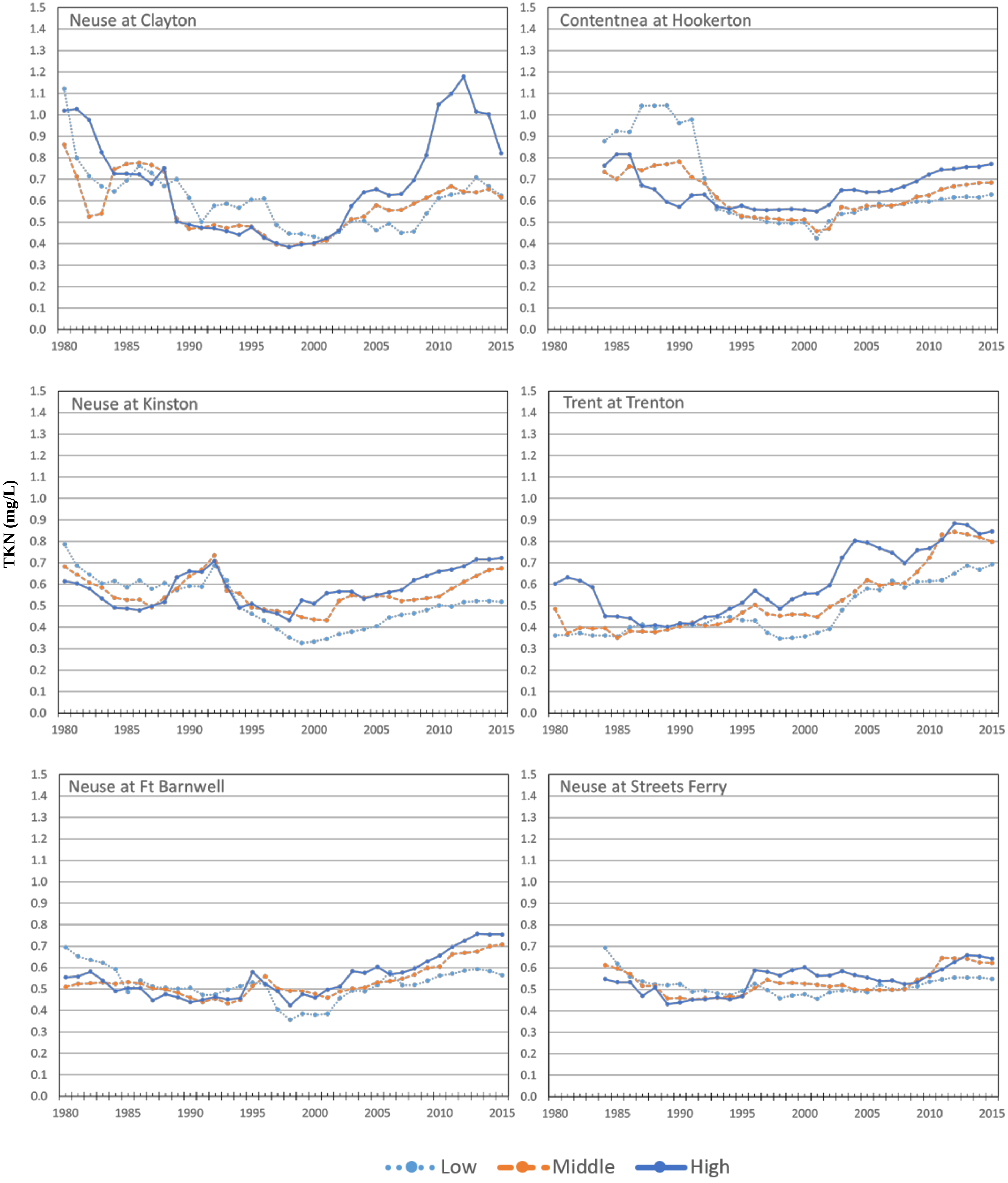
FIGURE D-2
Five-year mean concentrations by flow bin and location: NO_3-N



CLIENT: City of Raleigh
LOCATION: Raleigh, NC
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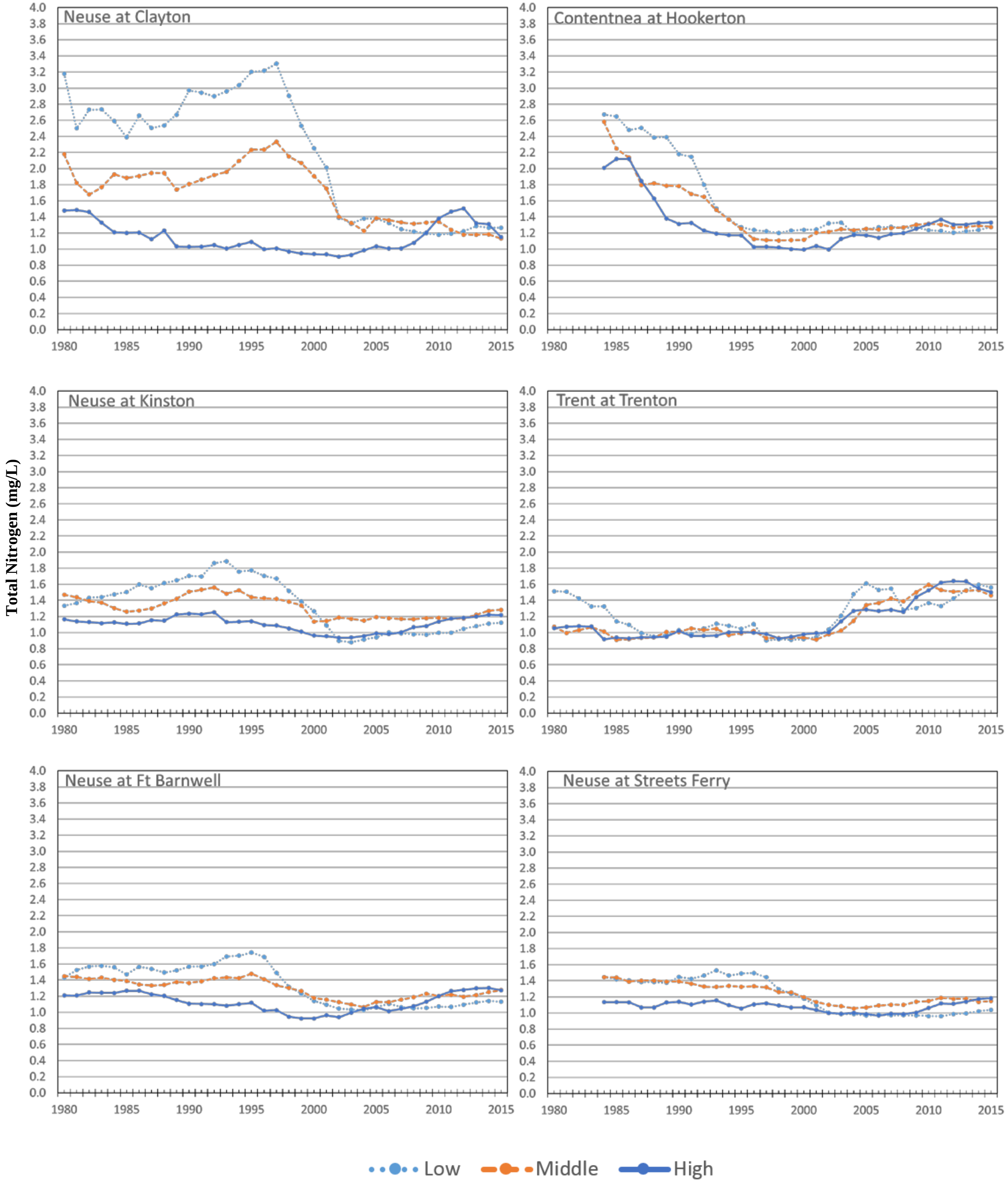
FIGURE D-3
Five-year mean concentrations by flow bin and location: TKN



CLIENT: City of Raleigh
LOCATION: Raleigh, NC
PROJECT/FILE: 161012

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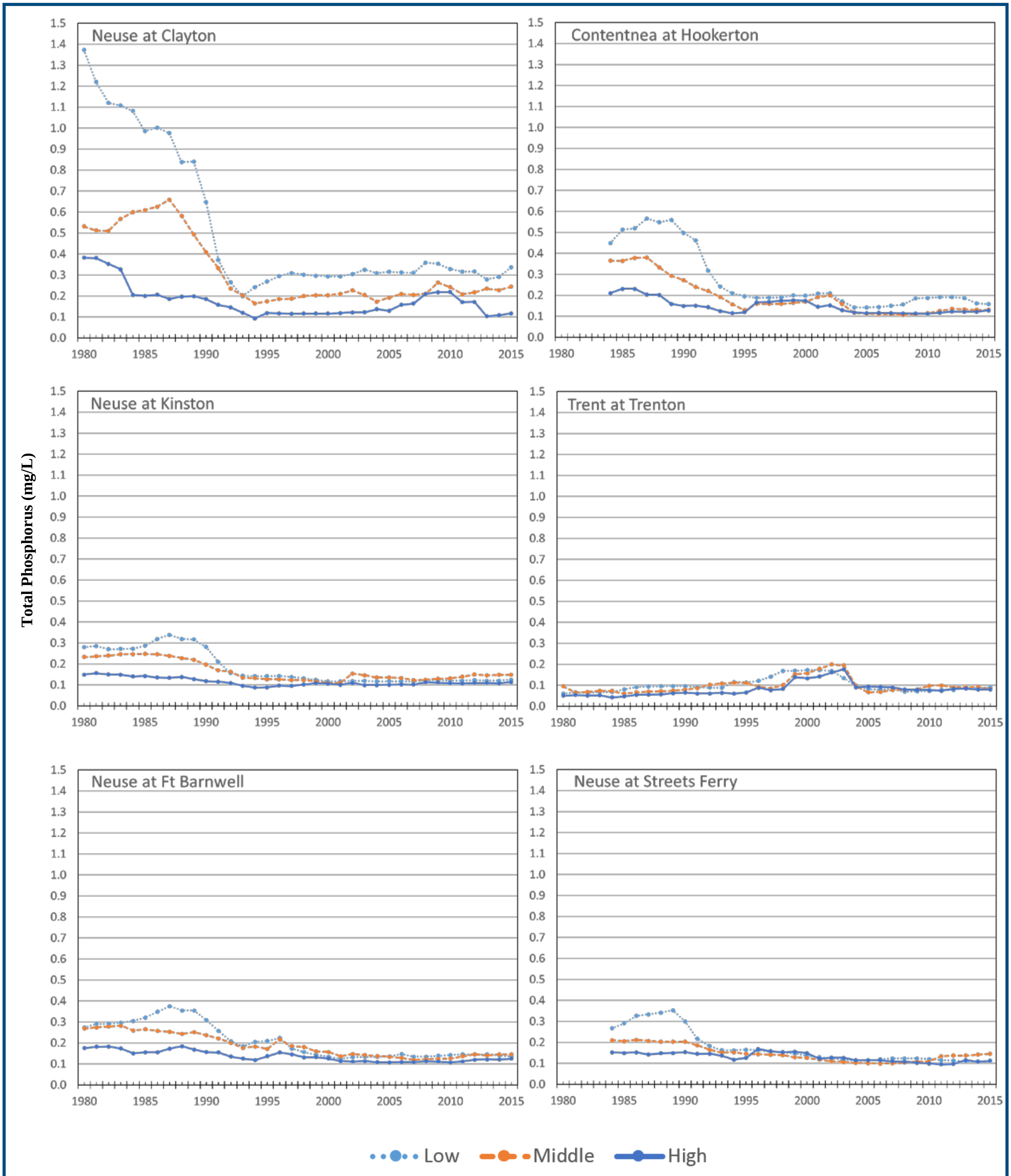
FIGURE D-4
Five-year mean concentrations by flow bin and location: TN



CLIENT: City of Raleigh
LOCATION: Raleigh, NC
PROJECT/FILE: 161012

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FIGURE D-5
Five-year mean concentrations by flow bin and location: TP