Appendix V

Data –

Trends Analysis for the Neuse River Basin

Neuse River Basin Trend Analysis Review Summary

- DWQ – Trend Analysis of N&P in the Neuse River basin (Rajbhandari, 2007).
- DWQ- Trend & Annual Load Analysis of the Neuse River Basin (Behm, 2006).
- Comprehensive Trend Analysis of nutrients and related variables in a large eutrophic estuary: A decadal study of anthropogenic and climatic influences (Burkholder et al., 2006).
- Assessing the Effects of Nutrient Management in an Estuary Experiencing Climatic Change: The Neuse River, NC (Paerl et al., 2006).
- Long-Term Changes in Watershed Nutrient Inputs and Riverine Exports in the Neuse River, North Carolina (Stow et al., 2000).
- Solving Problems Resulting from Solutions: Evolution of a Dual Nutrient Management Strategy for the Eutrophying Neuse River Estuary, North Carolina (Paerl et al., 2004).
- Seasonal and Long-Term Nutrient Trend Decomposition along a Spatial Gradient in the Neuse River Watershed (Qain et al., 2000).
- Assessing TMDL Effectiveness Using Flow Adjusted Concentrations: A case study of the Neuse River (Stow and Borsuk, 2003).

Neuse River Estuarine Box Plots

- Neuse River – Upper TMDL Segment – Union Point (JA76/J8570000).
- Neuse River – Upper TMDL Segment - Fairfield Harbor (JA81/J8900800).
- Middle TMDL Segment – Channel Marker 11 (Riverdale) – JA85/J8910000.
- Neuse River – Lower TMDL Segment – Minnesott Beach (JA90/J9530000).
- Neuse River – Lower TMDL Segment – Oriental (JA95/J9810000).

Draft Neuse River Basin Trend Analysis Review Summary

Over the past ten years several nutrient concentration and load studies have been performed by various researchers and NCDNER Division of Water Quality staff to measure nutrient trends in the Neuse Estuary. Each study performed used some type of water quality model and / or statistical analysis to evaluate historical water quality and flow data collected from various water quality monitoring stations located throughout the Neuse River Basin. These trend assessment approaches vary from parametric, nonparametric, or a mixture and in some cases include water quality and flow data that is seasonally adjusted. The data are typically statistically evaluated and reported as being "significant" if they meet or exceed a 95% confidence interval. In addition to the variations in analysis methods, the studies also vary by the different sample locations used, time period evaluated, and the fact that some only address water quality conditions in the Neuse River and its major tributaries while others examine trends in areas both above and within the Neuse River Estuary.

Several studies performed are focused more on evaluating how meteorological and flow related factors could influence nutrient concentrations and loads in the Neuse River and Estuary. While each of these studies examines nutrient issues in the Neuse Basin in some fashion, only four of the nine studies reviewed were found to address the effectiveness of the Neuse River Basin nutrient management strategy. These four studies help answer the question of whether the TMDL is being met; that is, whether the required 30% reduction in nitrogen loading to the Neuse Estuary is being achieved. The methods and results of each of these studies are briefly summarized below.

Neuse River Basin Trend Analysis Review Summary (DWQ Studies)

DWQ – Trend Analysis of N&P in the Neuse River basin (Rajbhandari, 2007)

This DWQ study is a monotonic trend evaluation of seasonally adjusted nutrient concentration data at two stations for the time period between 1996-2006. Two DWQ ambient monitoring locations, Contentnea Creek and New Bern, were used. **Neither station showed a statistically significant trend for TN.** Contentnea Creek is a major tributary to the Neuse River above the estuary and the New Bern Station is located at the top of the estuary and is tidally influenced. The Water Quality / Hydrology Graphics Analysis System (WQHYDRO) model was used in this study to compute the Seasonal Kendall test to determine nutrient concentration trends. Analysis used averaged monthly concentrations for TKN, NO_3, NO_2, NH_3, TN, and TP.

The Contentnea Creek site exhibited statistically significant (at 95% C.I.) upward trend of TKN (+ 45%) and downward trends of NH_3 (- 67%) and TP (-36%). The only significant concentration trend observed at the New Bern station was an upward trend for TKN (+71%). No other significant trends were found at either station for seasonally adjusted concentration. Significant trends in nutrient loading were not observed at either ambient monitoring location. There was no significant trend of flow at either station suggesting that variation in nutrient concentrations due to flow was insignificant.

DWQ- Trend & Annual Load Analysis of the Neuse River Basin (Behm, 2006)

This DWQ study is a monotonic trend evaluation of seasonally adjusted nutrient concentrations five DWQ ambient monitoring stations in 6 tributaries to the Neuse River (Eno River, Crabtree Creek, Trent River, Middle Creek, and both Little Rivers. This report presents the results of trends and annual load analysis of the Neuse River Basin for the 1990-2005 time period. Analysis included trends for the following parameters: TN, TP, Temp, and TSS. Annual load analysis was done for TN, TP, and TSS. In this study the monitoring stations and trends represent both urban and rural land uses in small watershed as mainstream monitoring stations were avoided. A total of six water bodies were selected for this study: The Eno River, Little River, Crabtree Creek, Trent River, and Middle Creek. NC DWQ ambient monitoring data and USGS flow data were used. All monitoring locations are located within the watershed North of the Estuary. The WQStat Plus

model was used to evaluate trends in Water Temperature, TN, TP, and TSS concentrations. This model is a multi-faceted computer program, which is capable of completing, flow adjusted concentrations and the non-parametric seasonal Kendall Test. The USACE flux program was used to estimate annual loads of TN, TP, and TSS.

The results of the nutrient trend analysis performed varied by water body. Nutrient Trend analysis for five of the sample locations could not be completed past 2000 due to limited TP and TN data collected. Only the Trent River station had enough TP and TN data for nutrient concentration and loading analysis after 2000and showed a significant increase in TP concentration (24%) and an increase in TN and TP loading of 5.36% and 13.72% respectively when comparing the 2005 load to the 1991-1994 baseline average load.

Neuse River Basin Trend Analysis Review Summary (Non-DWQ Studies)

Comprehensive Trend Analysis of nutrients and related variables in a large eutrophic estuary: A decadal study of anthropogenic and climatic influences (Burkholder et al., 2006)

This study was conducted by the Center for Applied Aquatic Ecology at NCSU. It examines estuarine water quality data collected by the author from May 1993 to June 2003. SAS software was used to perform statistical evaluation of seasonal linear trends in concentration and load data using a parametric autoregressive, integrated, moving average modeling technique that assumes normality in distribution. The study area spans from roughly 13 Km downstream from New Bern to the lower boundary of the estuary at Cherry Point. The study examined six sampling sites in the mesohaline Neuse estuary that were sampled by the research team using an integrated water column sampler. These stations were sampled weekly throughout 1993-1998. From 1999 to 2003 they were sampled bi-weekly from April through October, and monthly from November through March. The authors of this study also began routine sampling at Mills branch in 1999 at the Mills Branch and used additional nutrient data collected at the DWQ ambient monitoring station at Streets Ferry located 10 Km upstream to construct a 10 year data set for the calculation of loading trends at Mills Branch In addition, event-driven sampling efforts were also undertaken to track phytoplankton blooms.

The flow model data used in this study was collected from a boat mounted acoustic doppler current profiler that obtained discharge measurements from cross-estuary transects taken at Mills Branch. This point was selected as the "loading gate" to the estuary because it is the location where the upstream contributions to the estuary is most comprehensive with limited estuarine influence. The modeled daily flow at Mills Branch was coupled with nutrient concentration data to estimate TP, and TN Loading. The water quality data was analyzed with Statistical Analysis System software and the time series models for the nutrient data were created with PROC ARIMA. The data set contained over 135,000 observations from over 350 sampling events. Trend analysis was performed on concentration for each of the following parameters: SS, TP, SRP, TN, Nitrate/Nitrite, TKN, NH_4. Loading trends were performed for TP and TN.

For the full data period, TN and TP concentrations in the estuary decreased by 21% and 23% respectively and NH_4 concentrations increased by 503%. TKN, NO_3 and Chl *a* did not exhibit significant trends with the exception of a 61% increase in Chl *a* concentration at the Kennel Beach monitoring station. The nutrient loading results at Mills Branch show the average annual loading over the 10 year study period of TN and TP to be 21.16 million lbs/yr and 2.14 million /lbs/yr respectively. However, there was no significant trend detected in TP loading. There was a significant decrease in TN loading (-28%) from 1992-2003 both with and without (1996 and 1999) hurricane data included, but no trend when data for the drought years of 2000-2002 was excluded. The authors believed these decreasing trends in TN and TP concentrations and loading can primarily be explained by climatic events rather than management actions, and separately that nutrient reductions from improved management practices in the Neuse watershed over the ten year data period have been offset by increases in human and swine population and related factors.

Assessing the Effects of Nutrient Management in an Estuary Experiencing Climatic Change: The Neuse River, NC (Paerl et al., 2006)

In this study, UNC Institute of Marine Sciences researchers examined the long-term nutrient and hydrologic record for the upper portion of the Neuse River estuary for a study period that spans from 1979 to 2003. Researchers analyzed historical trends and patterns of nutrient concentrations, nutrient loading, and phytoplankton biomass levels. The record was divided into three intervals, and loads and concentrations were compared among them using a statistical approach including the use of the statistical software program SPSS version 1.5. The overall objective of the study was to evaluate the effects of nutrient management efforts and the climatic change of increased Atlantic hurricane activity on these concentrations and loads. The study focused on nutrient and Chl *a* measurements from multiple sources including the DWQ ambient monitoring station and the author's ModMon sampling station at Streets Ferry Bridge riverine monitoring location because this location provided the most complete record of nutrient input into the estuary because it is the most upstream long-term continuous sampling location. Also included in this study was an analysis of Chl *a* concentrations measured at multiple mid-estuarine sites between Johnston Point and Cherry point sampled under the ModMon program to illustrate the response of phytoplankton biomass further downstream.

Daily nutrient loading was calculated by multiplying mean daily stream flow (collected at Ft. Barnwell) and nutrient concentrations. These were summed to annual load estimates. Nutrient and Chl *a* concentration data were averaged by three periods corresponding to specific management and climatic events affecting the estuary during the 25 year study period: (1979-1986) the period before implementation of P reductions, the period immediately after P reductions (1987-1995), and the period coinciding with increased tropical storms and implementation of N reduction practices (1996-2003). Statistical analysis used the software package Spss for Windows. The Ft. Barnwell location showed substantial year-to-year variability in mean annual river discharge and loading rates and the mean annual loading rates were significantly different between the majority of consecutive years from 1979-2003. The authors observed that there was no significant difference in TN or TKN loading between period 1 (1979-1986) and period 3 (1996-2003), but there was a significant decrease in TP loading with each successive period.

Nutrient concentrations were calculated for each of the three time periods and compared. Results showed significant increases of TN (39%), Nitrate (97%), and TP (100%) and a decrease in Chl *a* (-60%) but no significant change in TKN concentration at the Streets Ferry Bridge during the first time period of 1979-1986. Results from the second time period, 1987-1995, indicated that while TN and TKN showed no significant change and there was a significant decrease in TP and Chl *a* (-77%) there was also a significant increase in Nitrate (58%). The third and final time period showed significant decreases in TN, TP, Nitrate and TKN concentrations at Streets Ferry Bridge between 1996 and 2003. However, during the same time period there was a significant increase in Chl *a* concentration (82%) detected at mid-estuary. The author suggested that while sustained N & P reductions in the upstream freshwater segment of the estuary appear to have reduced the occurrence of algae blooms in that area the same can not be said for the lower mesohaline segments of the estuary in which N inputs appear sufficiently high enough to support periodic blooms.

Long-Term Changes in Watershed Nutrient Inputs and Riverine Exports in the Neuse River, North Carolina (Stow et al., 2000)

This study by a Duke University Nicholas School of the Environment and ECU Institute for Coastal and Marine Resources Marine Science researchers compares watershed nutrient inputs to estimated nutrient loads in the Neuse Basin calculated using flow to concentration relationships from three DWQ ambient monitoring stations (Falls Lake Dam, Clayton, and Kinston) for the period from 1979 to 1998. This comparison provides valuable insight regarding possible processes of loss or storage in the watershed and helps to evaluate how long it could take to detect successful attainment of the 30% nitrogen load reduction goal. Flow adjusted concentrations of TKN, Nitrate, Nitrite, TP, and TN and daily flow data were used in concentration regressions models to calculate the nutrient loads at Clayton and Kinston for the study period. Annual

nitrogen and phosphorous inputs to the watershed were estimated in previous reports and updated through 1998.

The annual flows showed considerable variation at each station between 1979-1998. Total Phosphorous loads declined at all three stations corresponding to the 1983 construction of Falls Lake Dam and the 1988 phosphate detergent ban. Total Nitrogen loading patterns over time differed among the three stations. The Falls lake station exhibited nitrogen decreases, Clayton an increase, and Kinston displaying no clear pattern. The authors found that in-stream loads do not generally reflect the increases in watershed inputs and the lack of an increase in riverine exports of nitrogen at Kinston over the last 20 years of this study period is particularly surprising, considering the discernible increase in upstream nitrate load. Estimates indicate that less than 10% of the nitrogen and phosphorous input to the watershed is exported to the river and given annual variability in riverine export, statistically detecting a nitrogen load reduction of 30% will take at least 4 years if the reduction occurs as a single step decrease and a more gradual reduction would take considerably longer to detect.

Solving Problems Resulting from Solutions: Evolution of a Dual Nutrient Management Strategy for the Eutrophying Neuse River Estuary, North Carolina (Paerl et al., 2004)

In this study, UNC Institute of Marine Science researchers evaluated the affect that an evolving nutrient management strategy addressing P and N inputs independently of each other had on the Chl *a* concentrations in the freshwater segments and estuary of the Neuse River Basin. The data used in this historical analysis spans a 30 year time period (1970-2003) and were obtained from several State and University water quality monitoring programs conducted in the Neuse Basin. The data set included concentrations of TP, TN, and Chl *a* from four monitoring locations in the upstream freshwater riverine region between Streets Ferry and New Bern six monitoring stations located between Broad Creek and the bend in the Neuse River to represent the midesturaine region of the estuary. Freshwater discharge to the Estuary was obtained from the USGS gauging station at Kinston. The nutrient loads to the estuary over the study period were calculated by multiplying the average daily freshwater discharge at Kinston by the nutrient concentrations measured at Streets Ferry.

The author's found that while a decrease in P inputs related to the phosphate detergent ban and P discharge limits occurred in the upper freshwater region of the Neuse in the late 1980's, N inputs to the estuary remained unchanged or increased over the study period. This resulted in an increase in the N concentrations relative to P in the midestuarine region. Similarly, while Chl *a* concentrations decreased upstream as a result of less phytoplankton blooms in response to the P reductions, the estuary exhibited increased Chl *a* concentrations as a result of increased N limited phytoplankton blooms. The author's concluded that the earlier P input controls had the unintentional affect of reducing the N-filtering capacity of the upstream region and thus exacerbated the eutrophication potential of the downstream estuary region suggesting that parallel N and P reductions may be needed to address this problem.

Seasonal and Long-Term Nutrient Trend Decomposition along a Spatial Gradient in the Neuse River Watershed (Qain et al., 2000)

This study was conducted through a collaborative partnership between the Environmental Sciences and Resources Department at Portland State University and Duke University's Nicholas School of The Environment. A Nonparametric seasonal trend analysis using Loess (STL) was used to examine the spatial and temporal trends in nutrient concentrations over the study period of 1979-1998 at 12 DWQ ambient monitoring locations extending from just below falls dam and continuing down into the estuary. This method was chosen because it provides a graphical method for describing nonlinear trends with seasonal interaction.

The results of this study are presented as interstation comparisons of long term trend components as well as seasonal trends of three representative stations: Clayton (Station #2), New Bern (Station #7), and the mouth of Palace Sound (Station #12). The nutrient concentrations at Station #1 first station just below falls dam were relatively low compared to other riverine sample stations over the study period. Concentrations rise

sharply by Station #2 which is located downstream of Raleigh and a major WWTP. By the time flow reaches the estuary at station #7 in New Bern the nutrient concentrations levels have declined and continue to do so out into the estuary and reach very low levels at the final station #12) located by the mouth of the Pamlico Sound. Results of the study indicate that the seasonal cycle is weak compared to the longer term trends of TN concentrations, and that while there may have been minor increases in nitrogen concentrations at upstream locations during the study period, these increases are not reflected in the lower river and estuary. Similarly, while TP concentrations were found to be slightly higher during the summer months, phosphorous concentrations dropped considerably for all months in response to the building of falls dam in 1983 and the phosphate detergent ban that went into effect in the lat 1980's.

Assessing TMDL Effectiveness Using Flow Adjusted Concentrations: A case study of the Neuse River (Stow and Borsuk, 2003)

This study by two Duke University Nicholas School of the Environment researchers proposes the use of flow-adjusted pollutant concentrations to evaluate the effectiveness of management actions taken to meet approved TMDLs. The authors contend that annual flow-adjusted riverine nutrient concentrations show a more pronounced relationship with estuarine nutrient concentrations than annual nutrient loads To demonstrate the calculation and interpretation of flow-adjusted concentrations the authors analyzed long-term nutrient data from three DWQ ambient monitoring stations in the Neuse River (Hookerton, Kinston, Ft. Barnwell) and five DWQ stations that fully span the longitudinal salinity gradient of the estuary over a study period spanning 1996-2000. Nutrient loads were calculated for the three riverine stations using available concentration and daily flow data to develop concentration: flow regression models fro TKN, Nitrate, TN, and TP. Flow adjusted concentrations were also calculated for each riverine location. These loads and flow adjusted concentrations at Ft. Barnwell were compared to the median annual estuarine concentrations of five stations in the estuary to evaluate which measure of river input most best relates to conditions in the estuary.

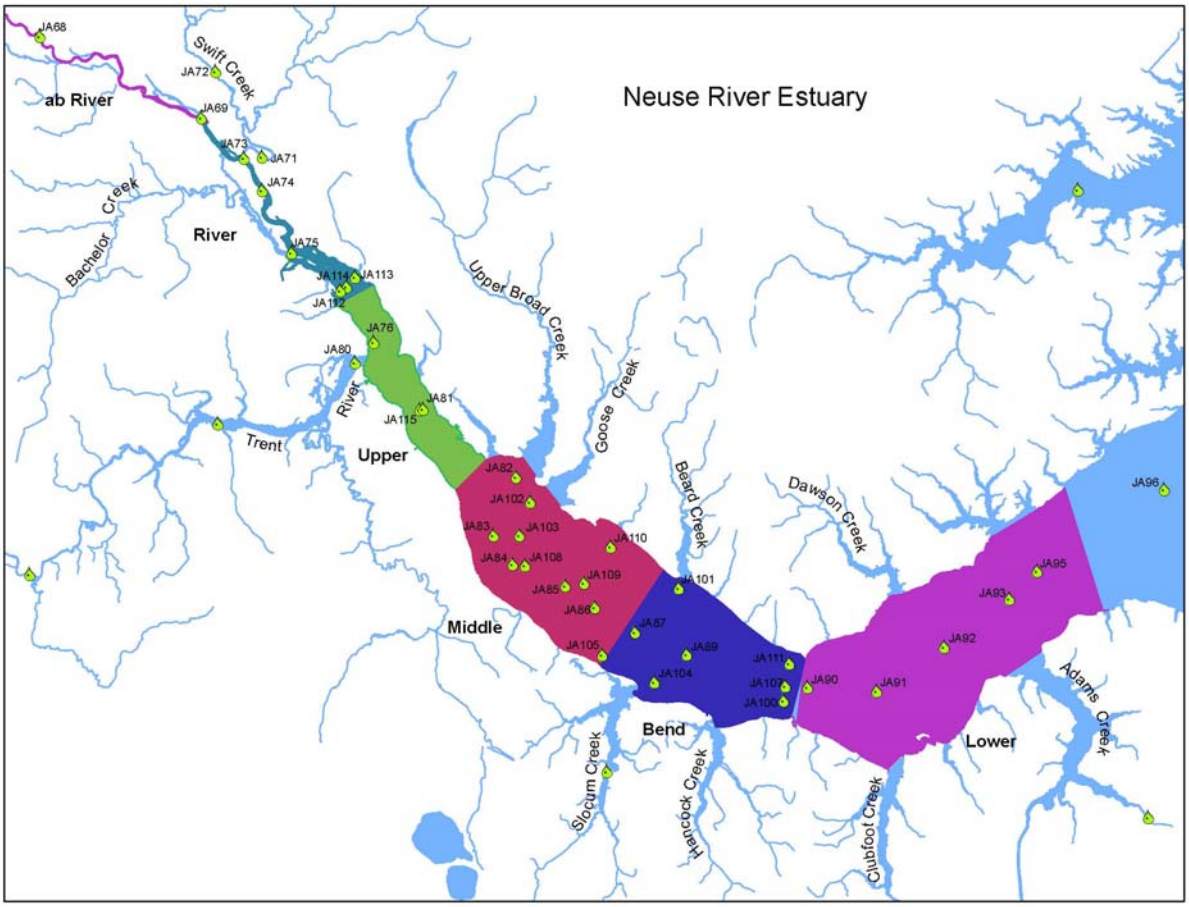
The results indicate that flow adjusted phosphorous concentrations have dropped at all three river stations over the study period. Flow adjusted nitrogen concentrations declined at Hookerton from 1985-1994 and stabilized from 1994 –2000. At Kinston TN concentrations were stable from 1979-1995 and then declined in 1995-2000. Ft. Barnwell TN concentrations were similar to Kinston, with recent declines in TN and nitrate and slow decline in TKN over most of the 22-year period. The concentration to flow ratio calculations indicate that all nutrients except TKN exhibit an inverse flow relationship at all three river sites. Total phosphorous loads show considerable year-to-year variability and Nitrogen loads are also highly variable and exhibit no obvious long-term trends. A comparison of TP and TN slope estimates at each river site indicates that TP decreases more rapidly with flow than does TN. The authors also concluded that there was not statistically discernible relationship between annual phosphorous load and estuarine P concentration and only a slight relationship between the calculated TN load and estuarine TN concentration. However, while the relationship between riverine TN flow adjusted concentration and estuarine concentration was found to be weak, the authors detected a statistically significant relationship between flow-adjusted P concentration at Ft. Barnwell and estuarine concentration.

Box Plots for the Several DWQ Ambient Monitoring Station.

Box plots where produced for chlorophyll *a*, TN, TP, DO and pH. It is important to note that the analytical methodologies have changed for several of the parameters over this time period.

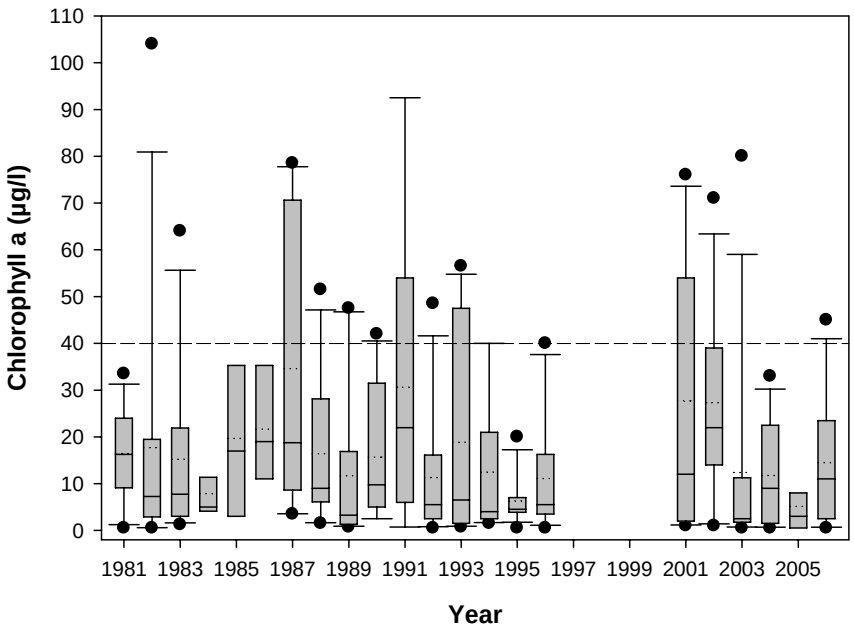
Neuse River Estuarine Box Plots

- Neuse River – Upper TMDL Segment – Union Point (JA76/J8570000).
- Neuse River – Upper TMDL Segment - Fairfield Harbor (JA81/J8900800).
- Middle TMDL Segment – Channel Marker 11 (Riverdale) – JA85/J8910000.
- Neuse River – Lower TMDL Segment – Minnesott Beach (JA90/J9530000).
- Neuse River – Lower TMDL Segment – Oriental (JA95/J9810000).

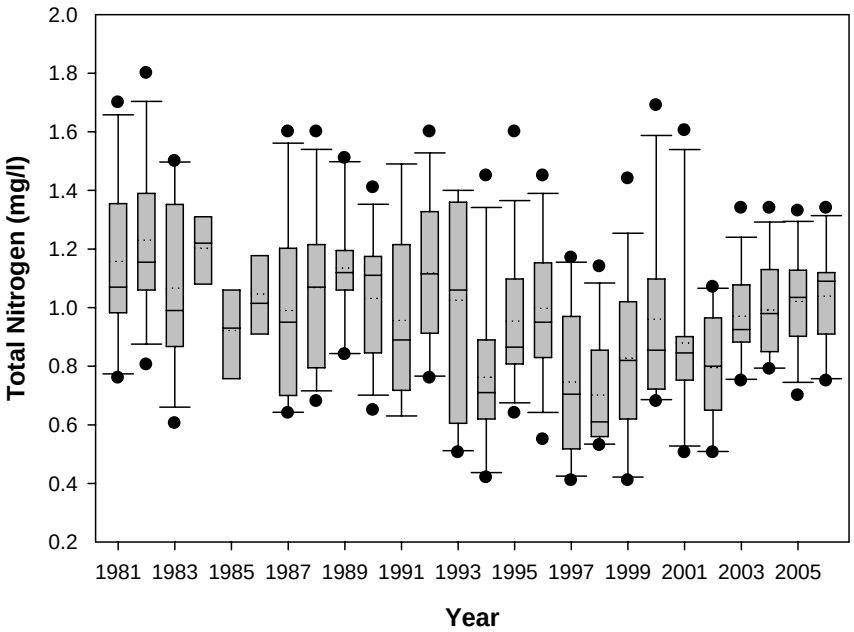


Neuse River – Upper TMDL Segment – Union Point (JA76/J8570000)

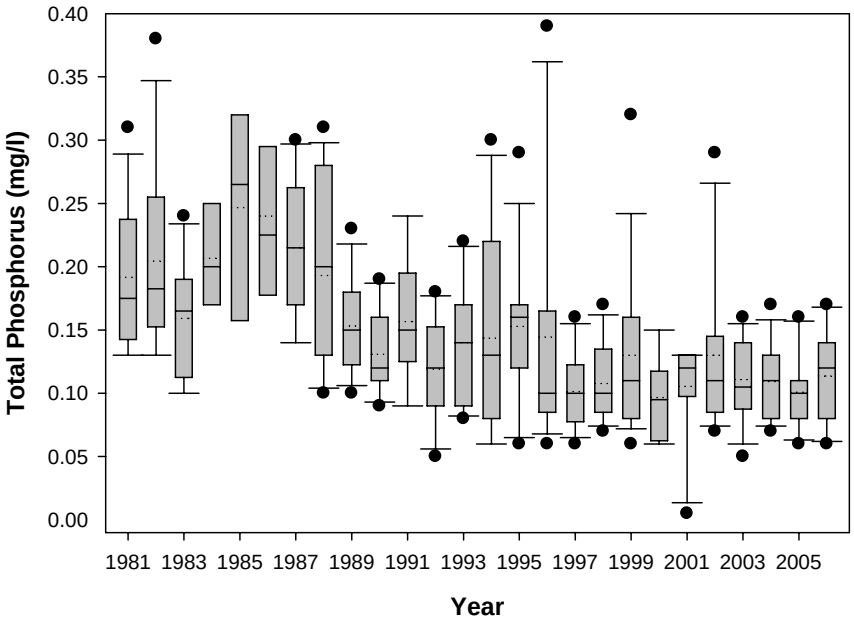
Neuse River Estuary
Upper TMDL Segment
Union Point
JA76/J8570000
Chlorophyll a



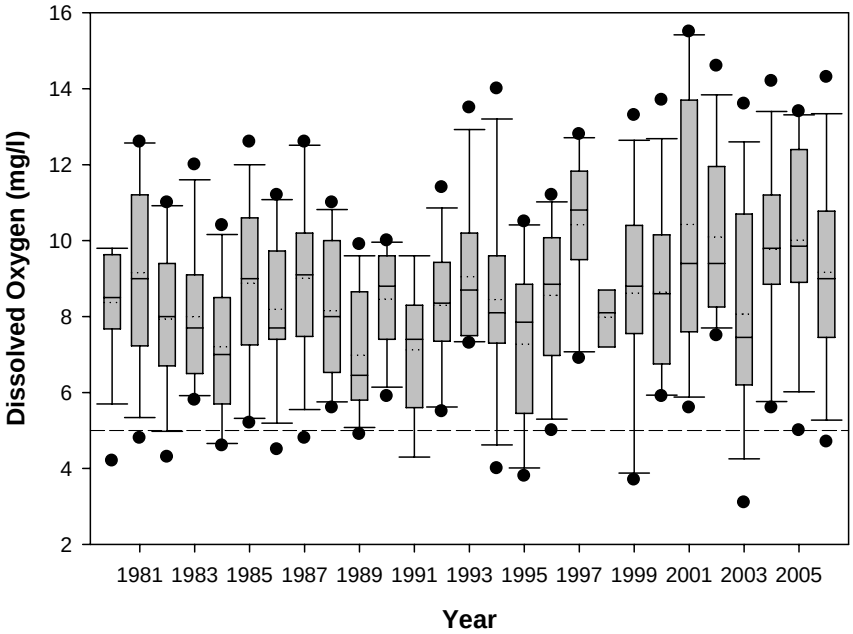
Neuse River Estuary
Upper TMDL segment
Union Point
JA76/J8570000
Total Nitrogen



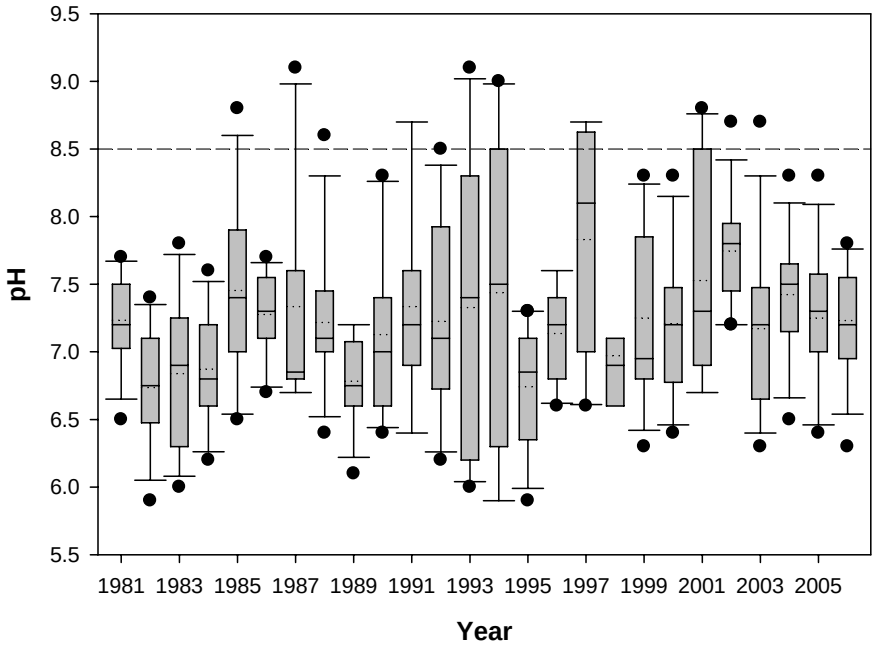
Neuse River Estuary
Upper TMDL Segment
Union Point
JA76/J8570000
Total Phosphorus



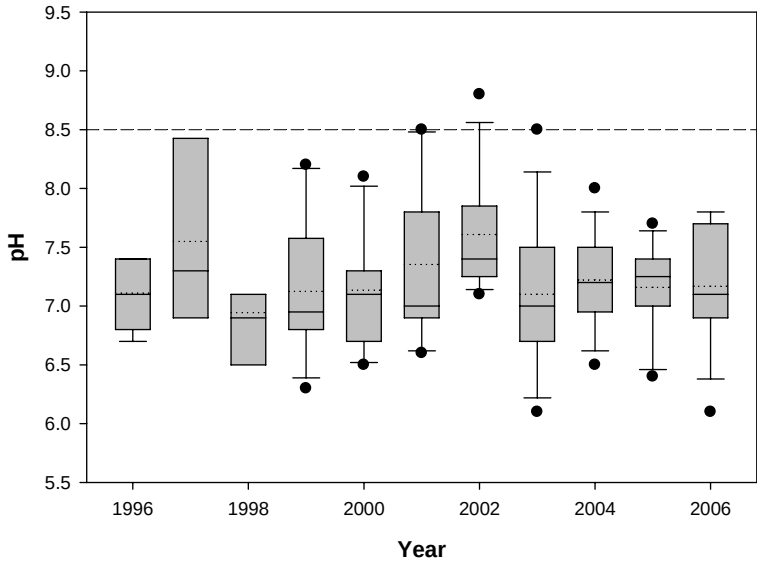
Neuse River Estuary
Upper TMDL Segment
Union Point
JA76/J8570000
Dissolved Oxygen at 0.1 meters



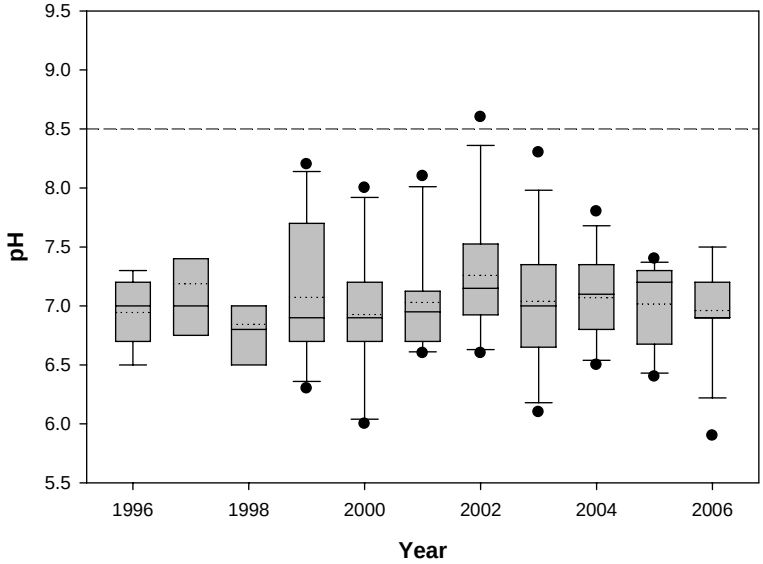
Neuse River Estuary
Upper TMDL Segment
Union Point
JA76/J8570000
pH at 0.1 meter



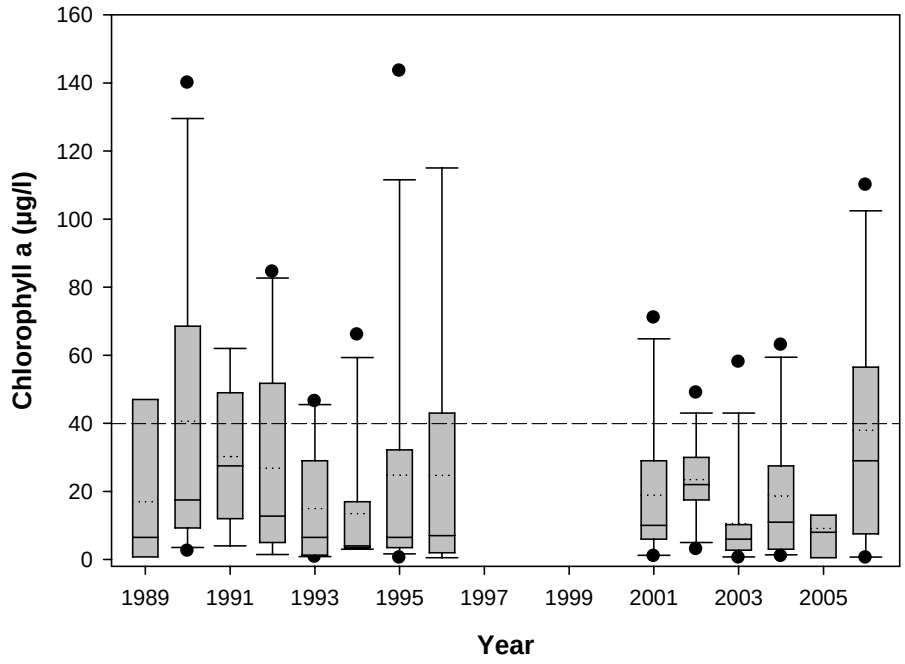
Neuse River Estuary
Upper TMDL Segment
Union Point
JA76/J8570000
pH at 1.0 meters



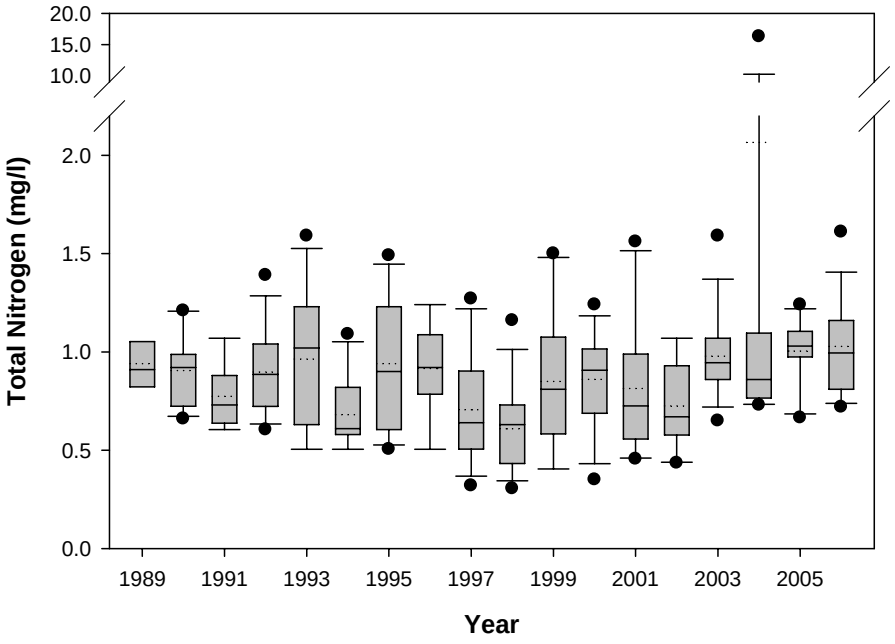
Neuse River Estuary
Upper TMDL Segment
Union Point
JA76/J8570000
pH at 2.0 meters



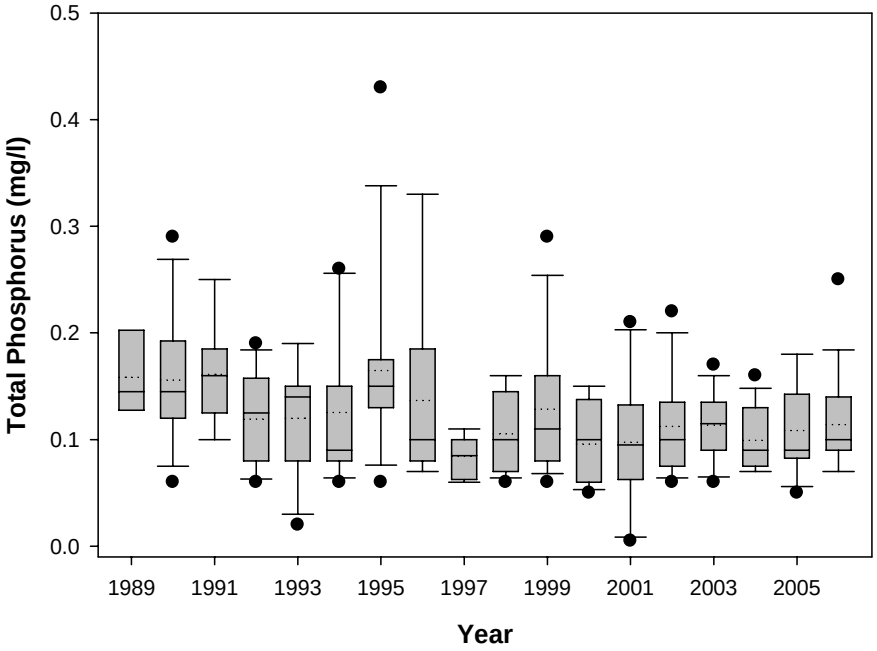
Neuse River Estuary
Upper TMDL Segment
Fairfield Harbor
JA81/J8900800
Chlorophyll a



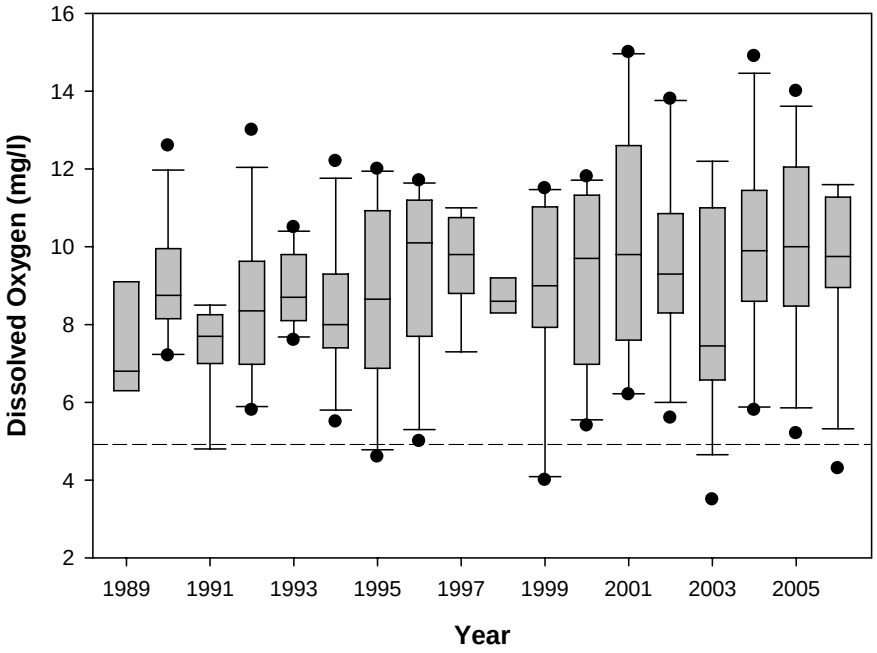
Neuse River Estuary
Upper TMDL segment
Fairfield Harbor
JA81/J8900800
Total Nitrogen



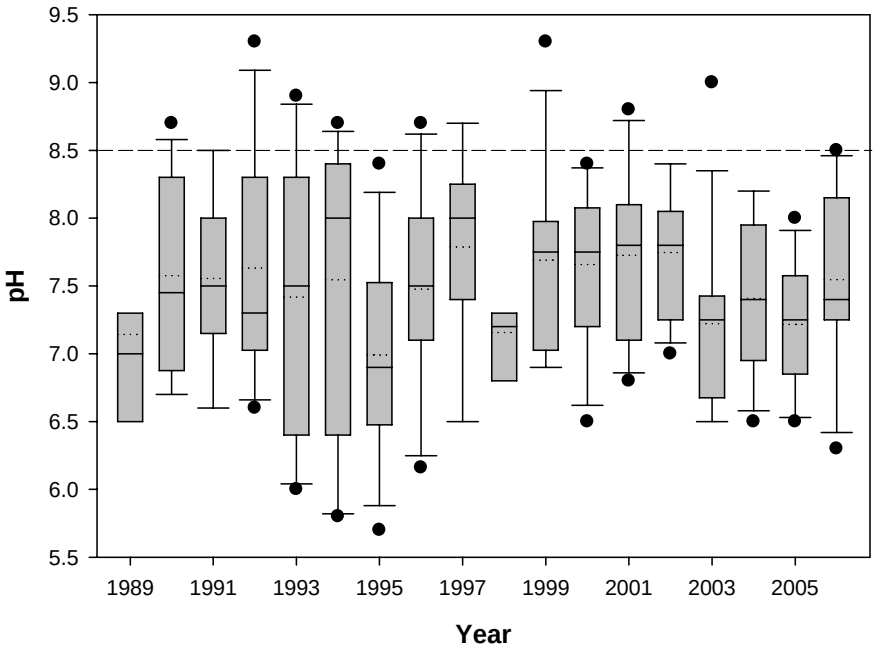
Neuse River Estuary
Upper TMDL Segment
Fairfield Harbor
JA81/J8910000
Total Phosphorus



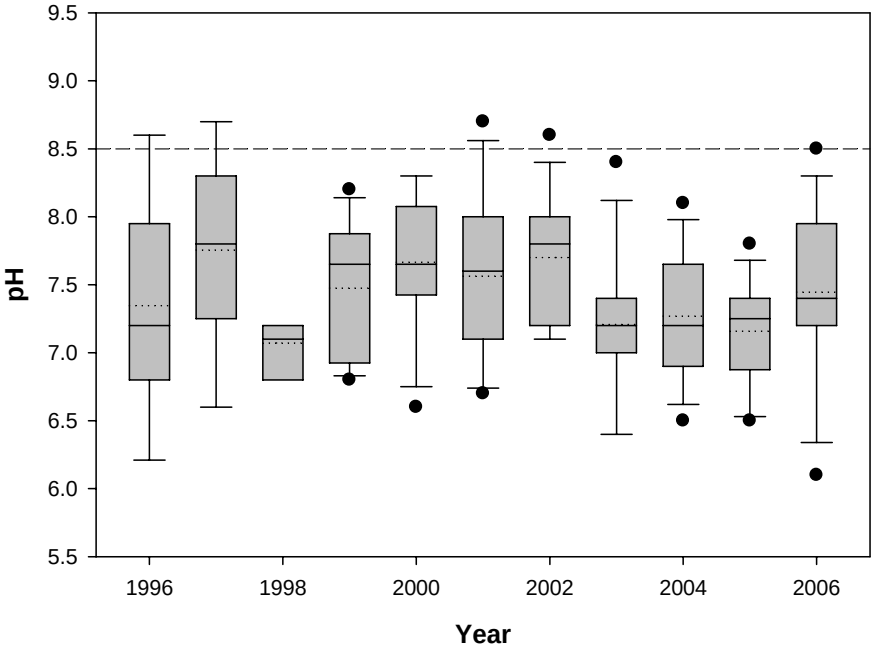
Neuse River Estuary
Upper TMDL Segment
Fairfield Harbor
JA81/J8900800
Dissolved Oxygen at 0.1 meters

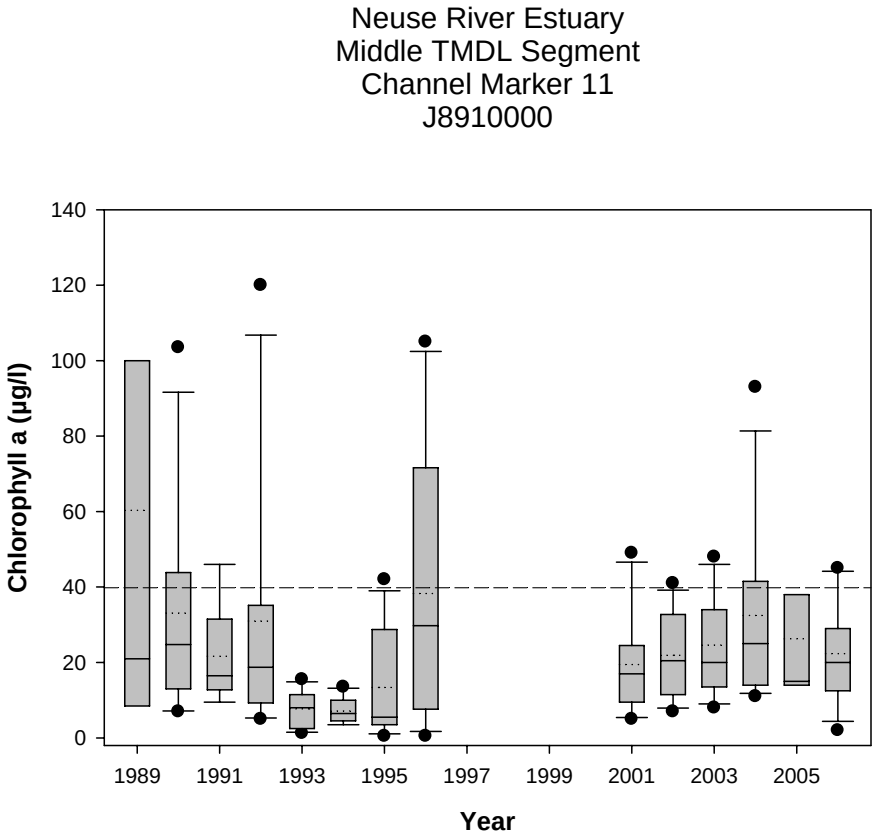


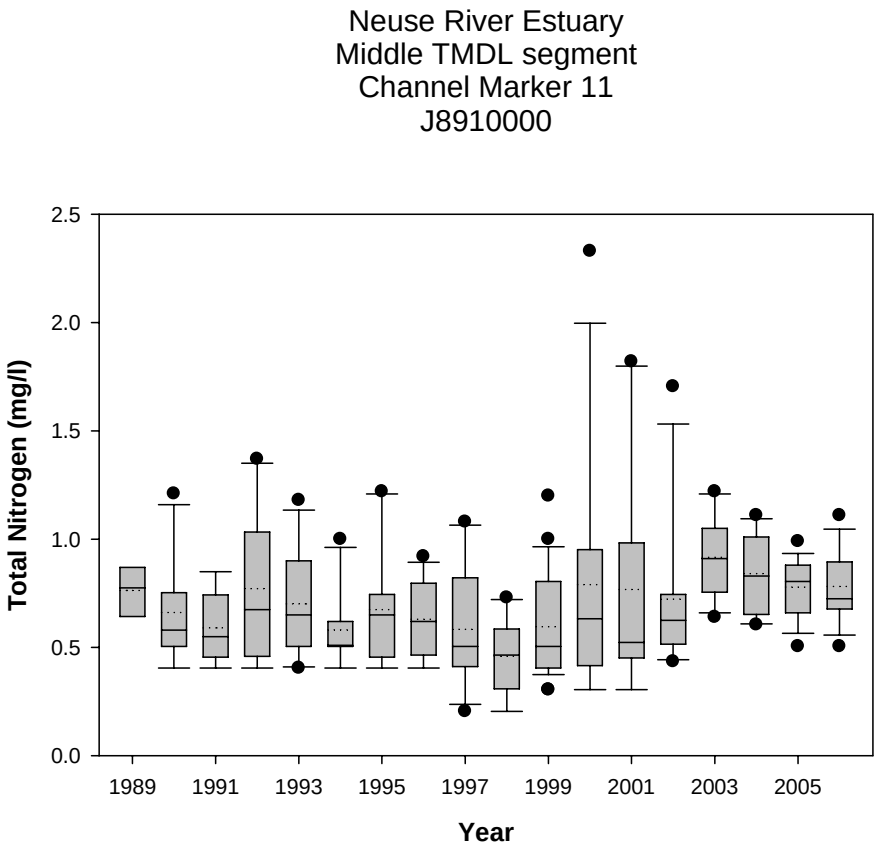
Neuse River Estuary
Upper TMDL Segment
Fairfield Harbor
JA81/J8900800
pH at 0.1 meter



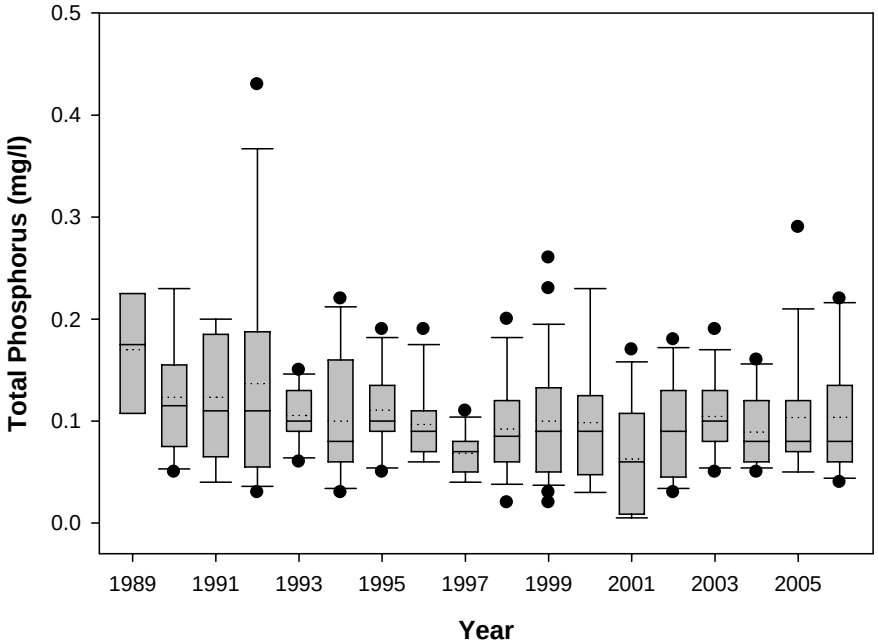
Neuse River Estuary
Upper TMDL Segment
Fairfield Harbor
JA81/J89008000
pH at 1.0 meters



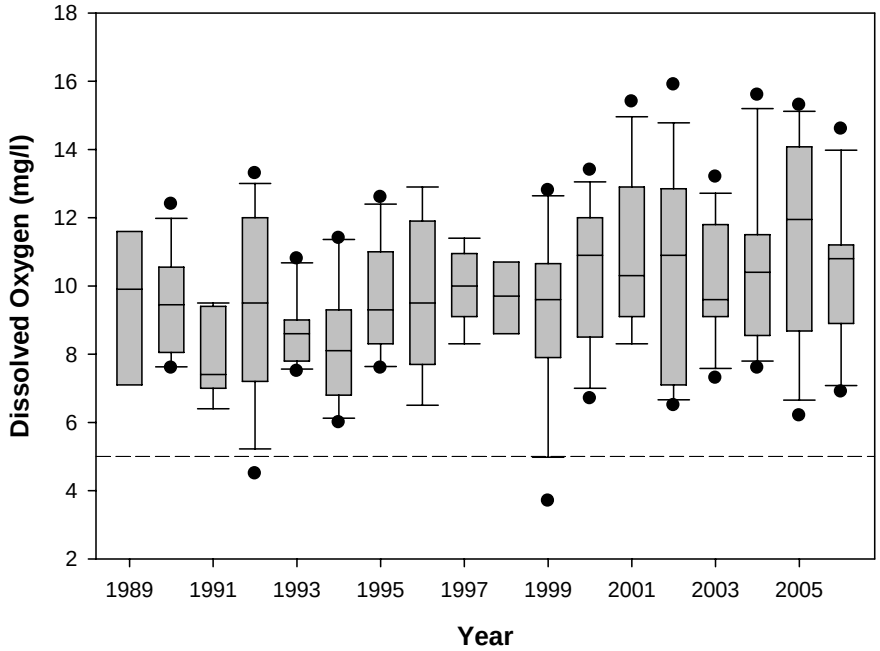

Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
J8910000
Chlorophyll a (µg/l)
140
120
100
80
60
40
20
0
1989
1991
1993
1995
1997
1999
2001
2003
2005
Year


Neuse River Estuary
Middle TMDL segment
Channel Marker 11
J8910000
Total Nitrogen (mg/l)
2.5
2.0
1.5
1.0
0.5
0.0
1989
1991
1993
1995
1997
1999
2001
2003
2005
Year

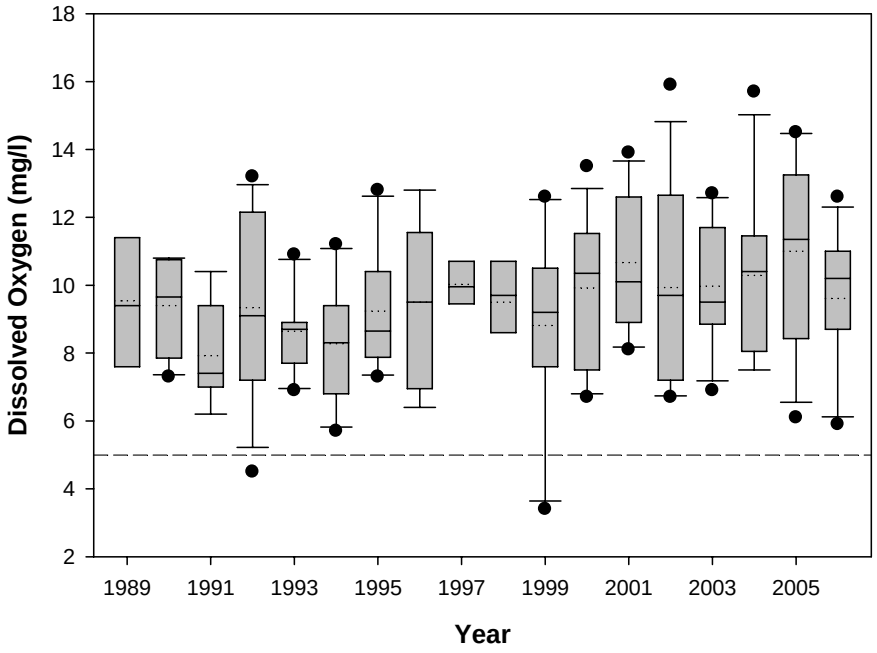
Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
J8910000



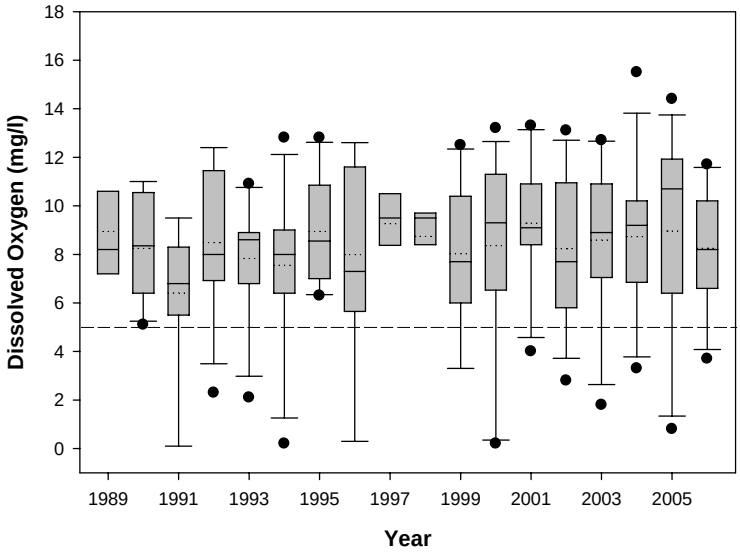
Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
J8910000
Dissolved Oxygen at 0.1 meters



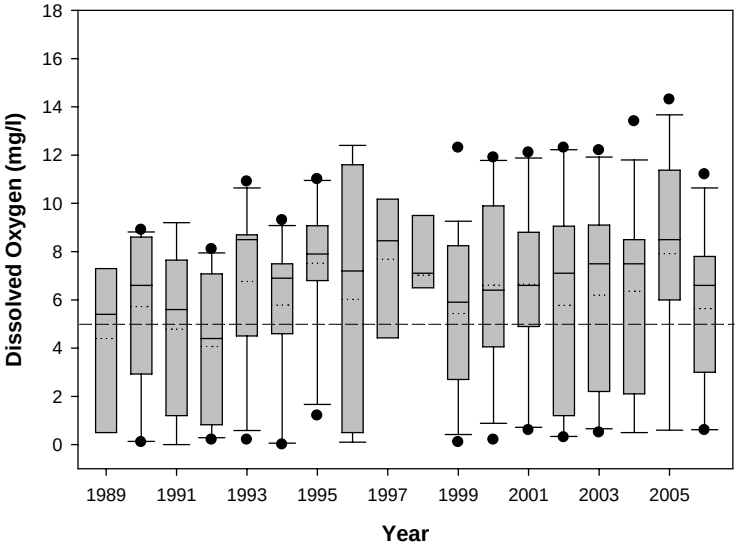
Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
J8910000
Dissolved Oxygen at 1.0 meters



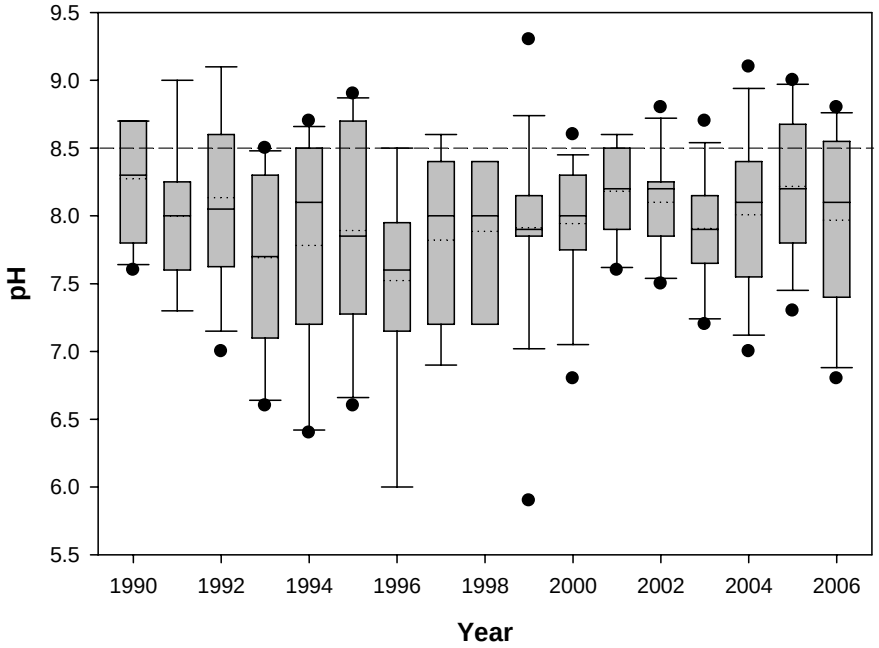
Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
J8910000
Dissolved Oxygen at 2.0 meters



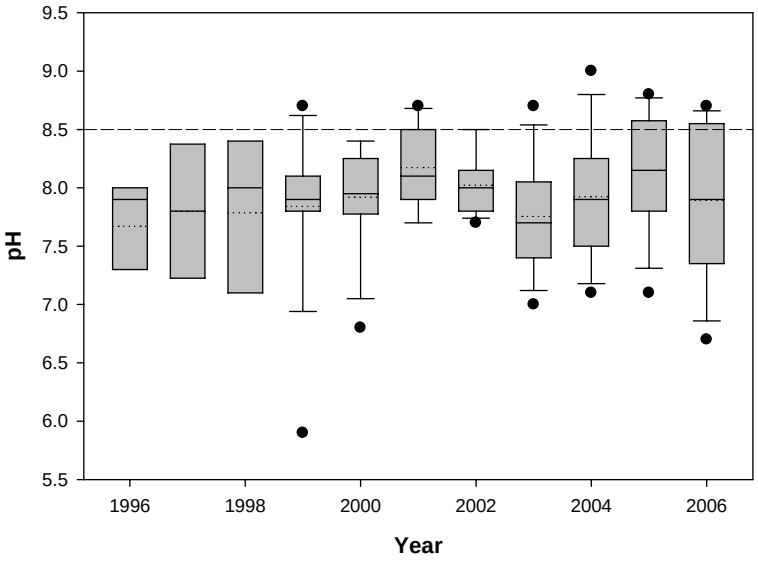
Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
J8910000
Dissolved Oxygen at 3.0 meters



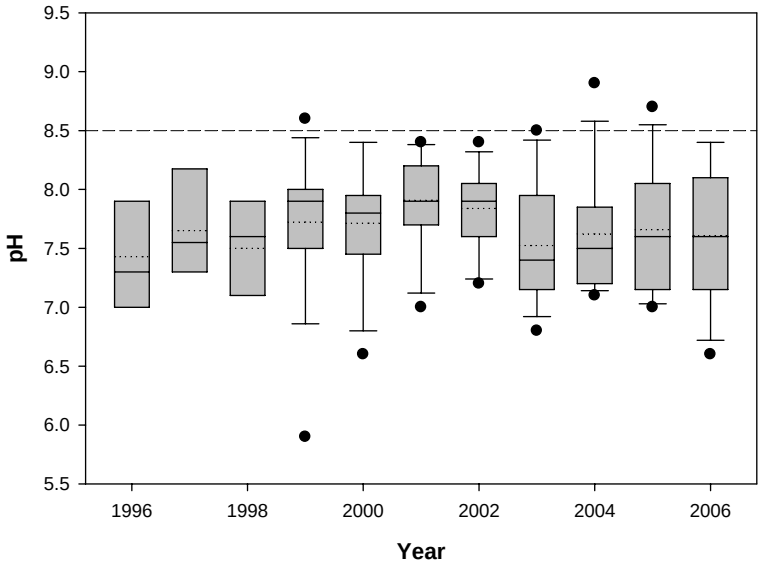
Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
J8910000
pH at 0.1 meter



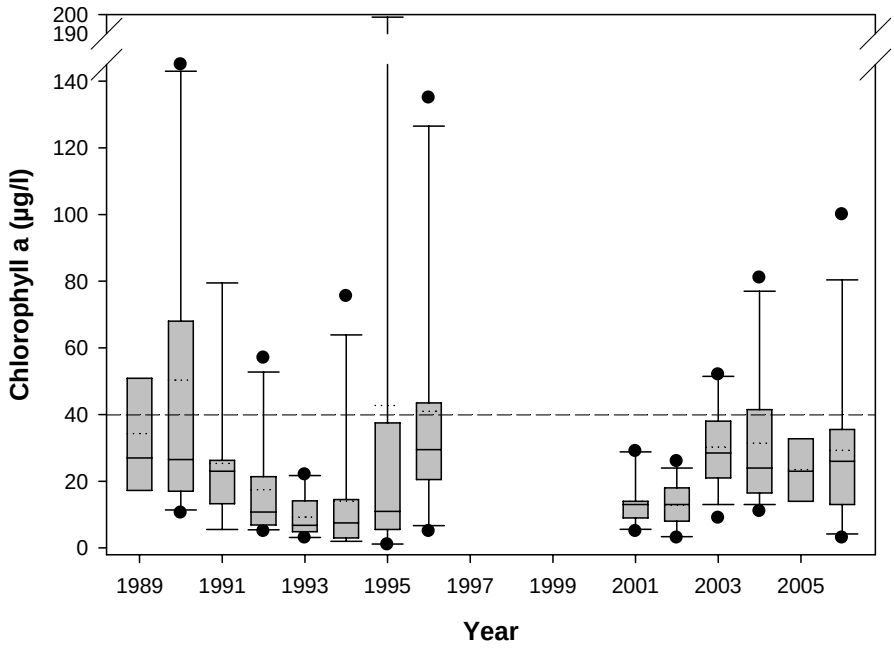
Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
J8910000
pH at 1.0 meters



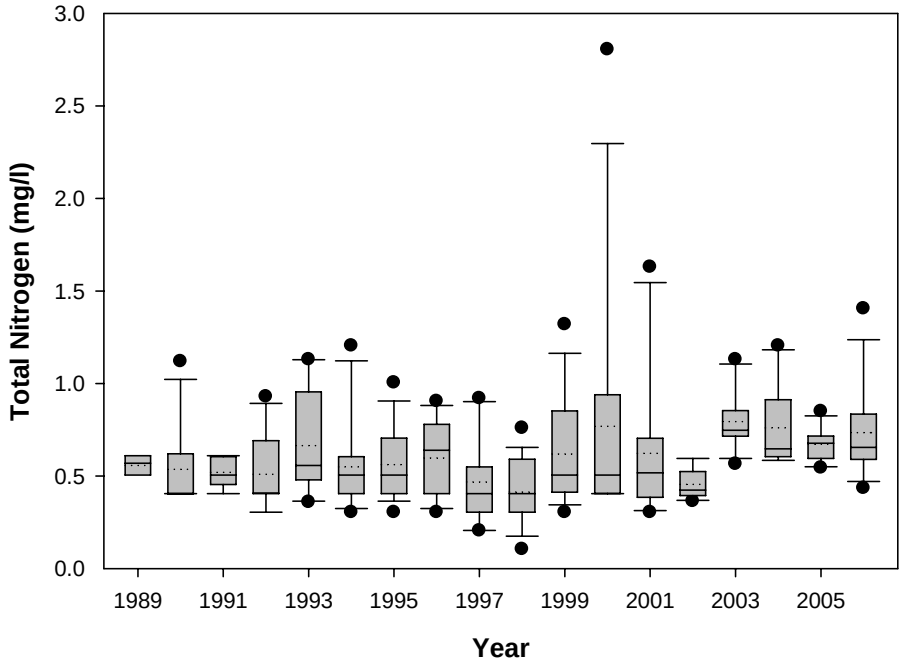
Neuse River Estuary
Middle TMDL Segment
Channel Marker 11
JA85/J8910000
pH at 2.0 meters



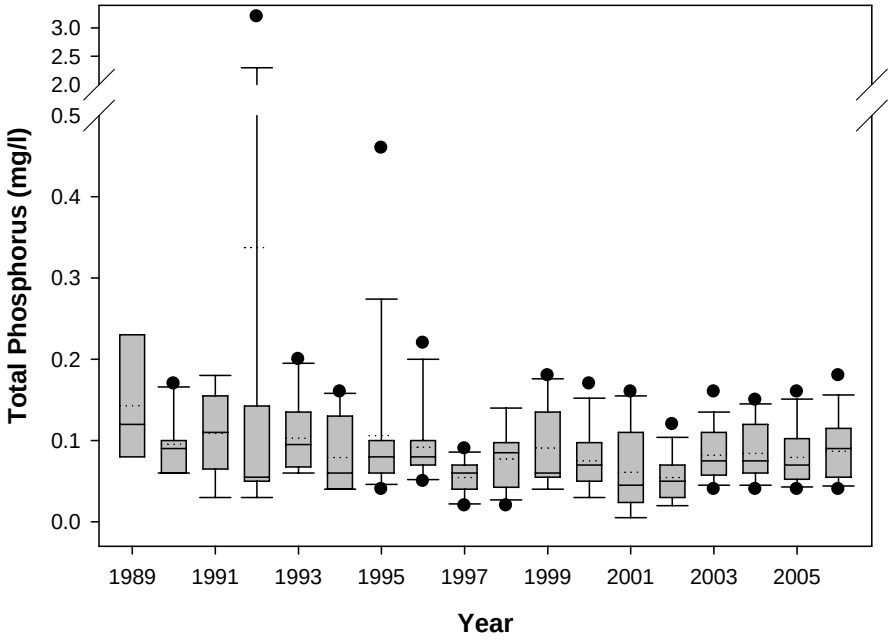
Neuse River Estuary
Lower TMDL Segment
Minnesott Beach
JA90/J9530000
Chlorophyll a



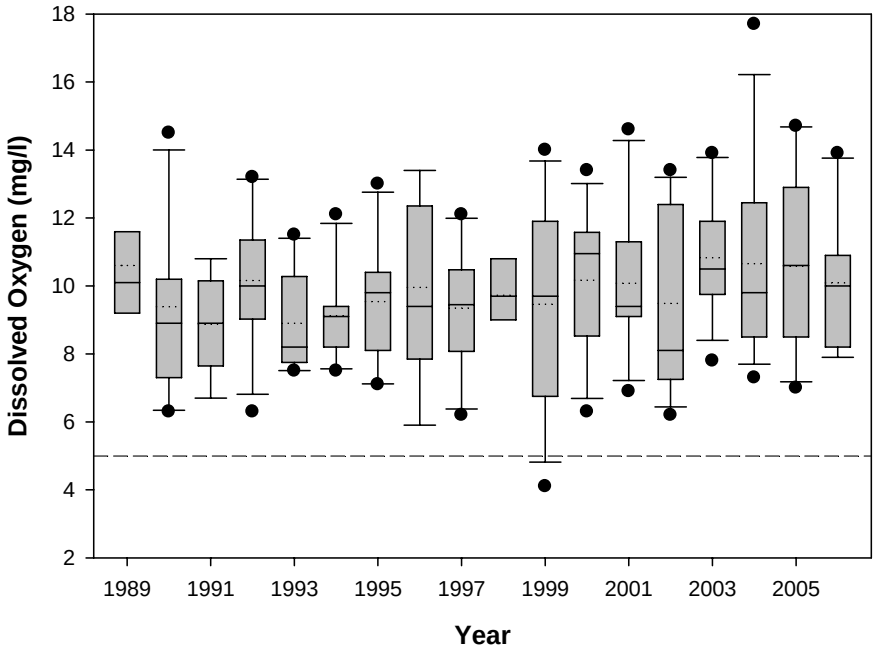
Neuse River Estuary
Lower TMDL segment
Minnesott Beach
JA90/J9530000
Total Nitrogen



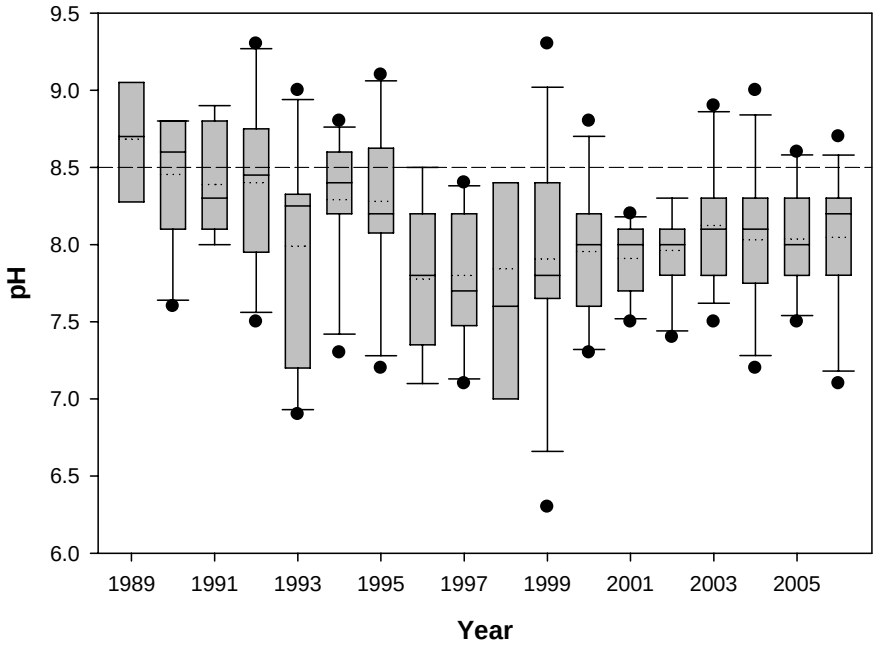
Neuse River Estuary
Lower TMDL Segment
Minnesott Beach
JA90/J9530000
Total Phosphorus



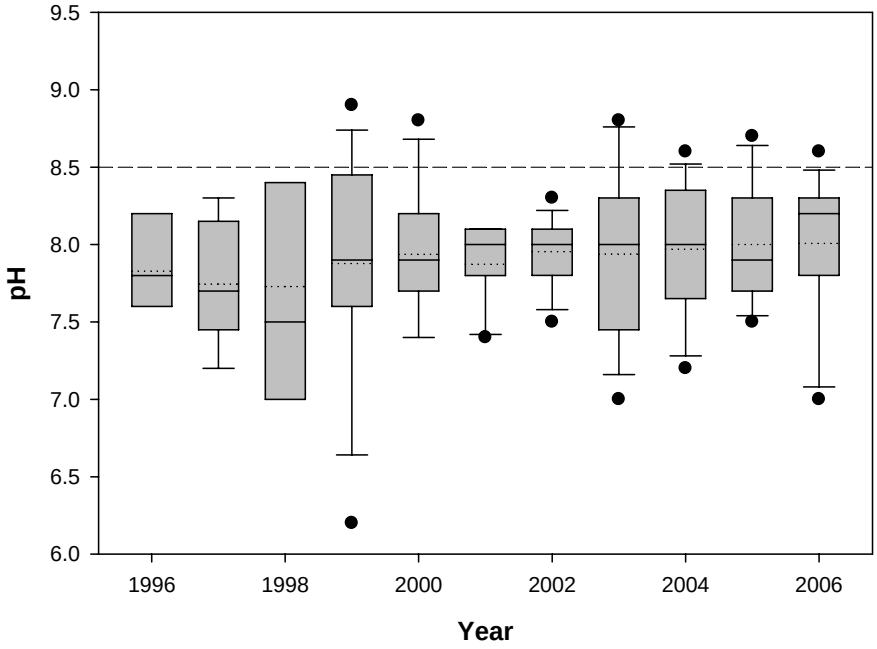
Neuse River Estuary
Lower TMDL Segment
Minnescott Beach
JA90/J8900800
Dissolved Oxygen at 0.1 meters



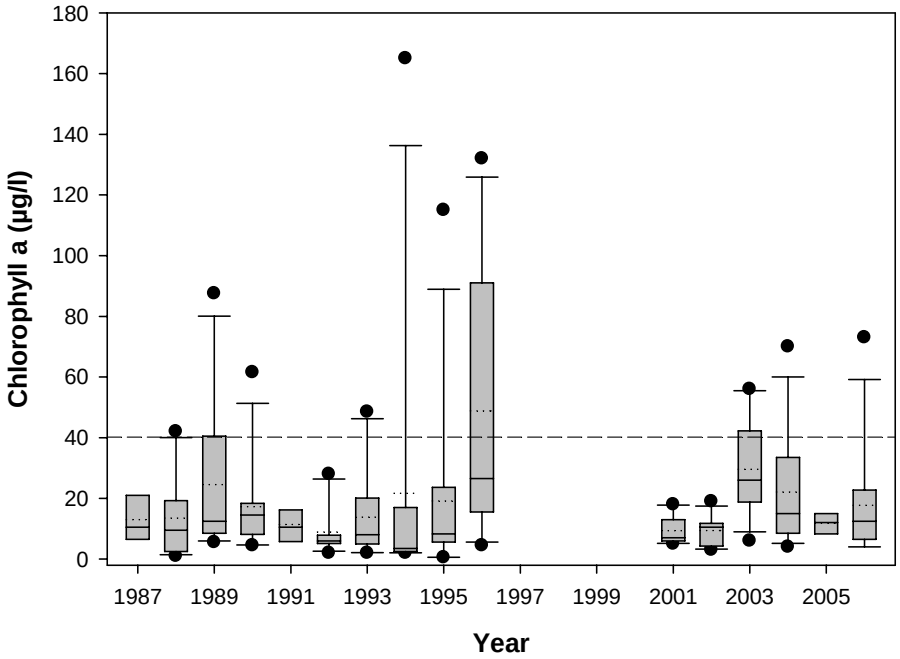
Neuse River Estuary
Lower TMDL Segment
Minnesott Beach
JA90/J9530000
pH at 0.1 meter



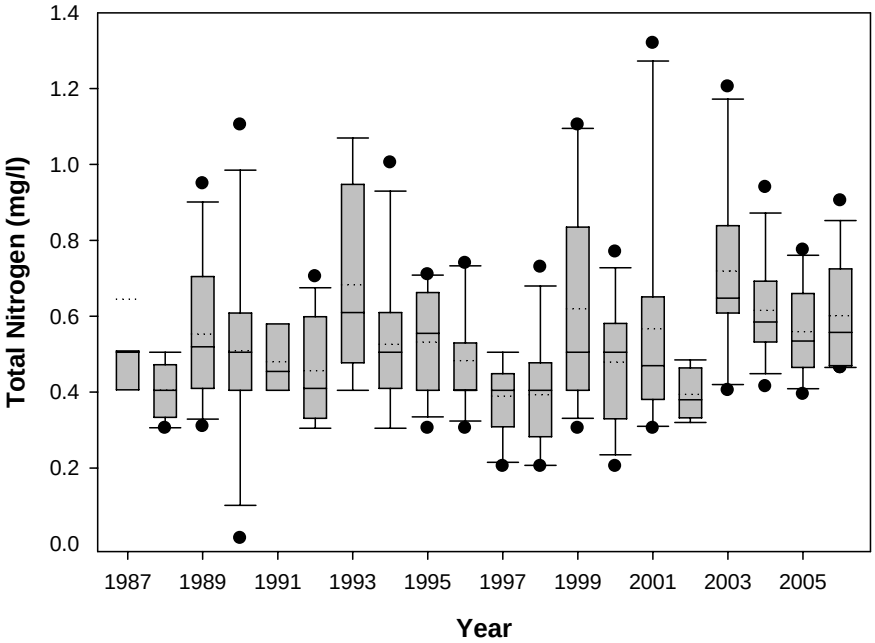
Neuse River Estuary
Lower TMDL Segment
Minnesott Beach
JA90/J9530000
pH at 1.0 meters



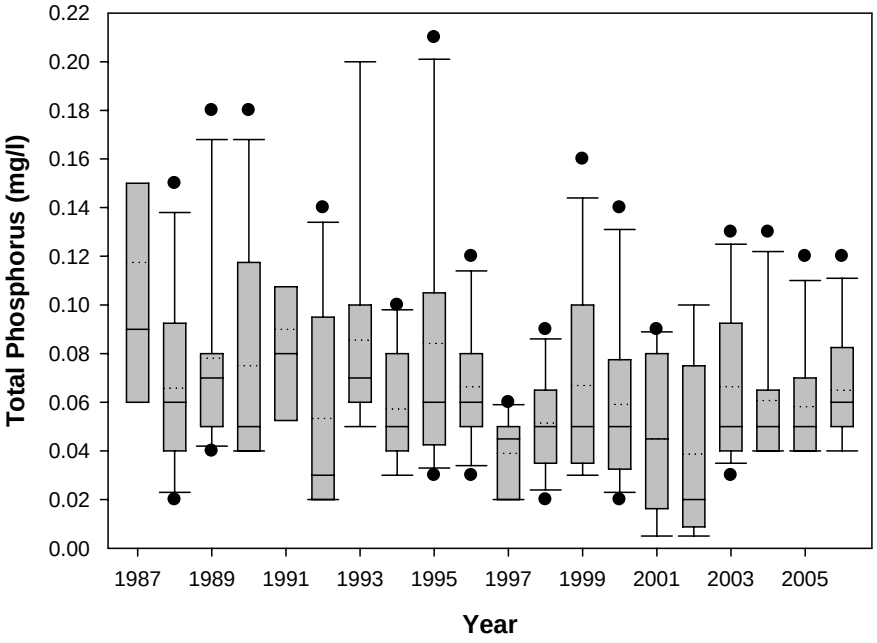
Neuse River Estuary
Lower TMDL Segment
Oriental
JA95/J9810000
Chlorophyll a



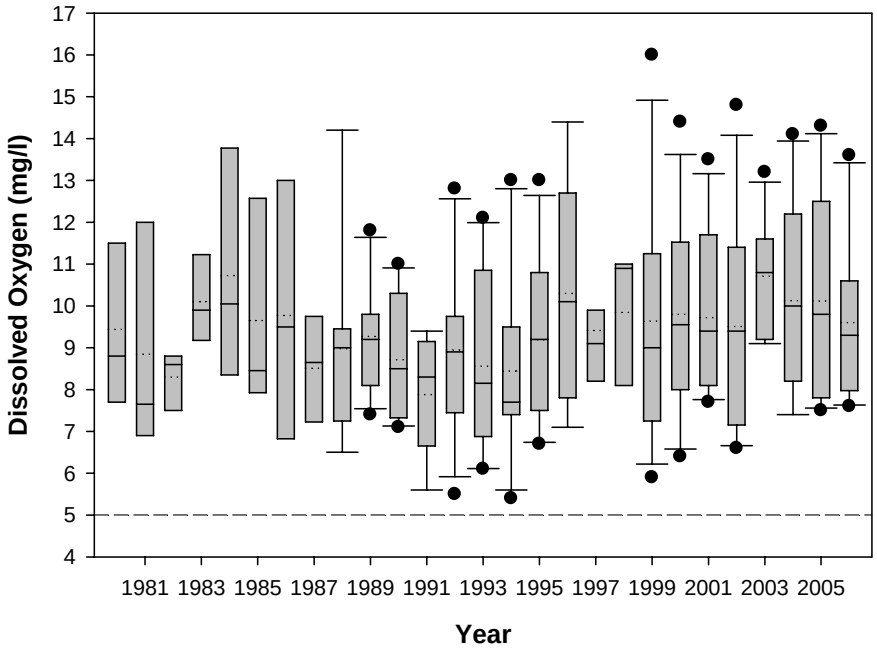
Neuse River Estuary
Lower TMDL segment
Oriental
JA95/J9810000
Total Nitrogen



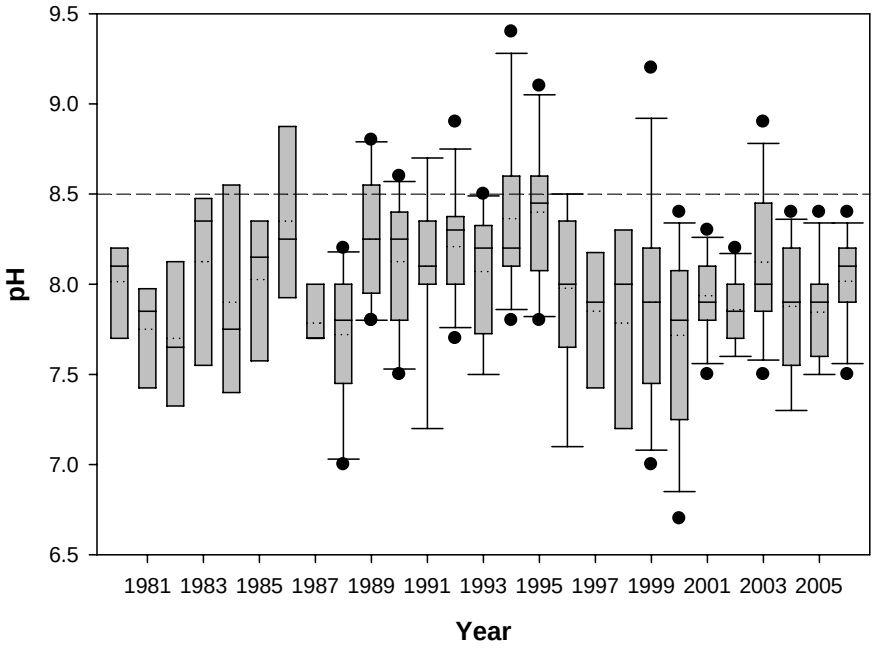
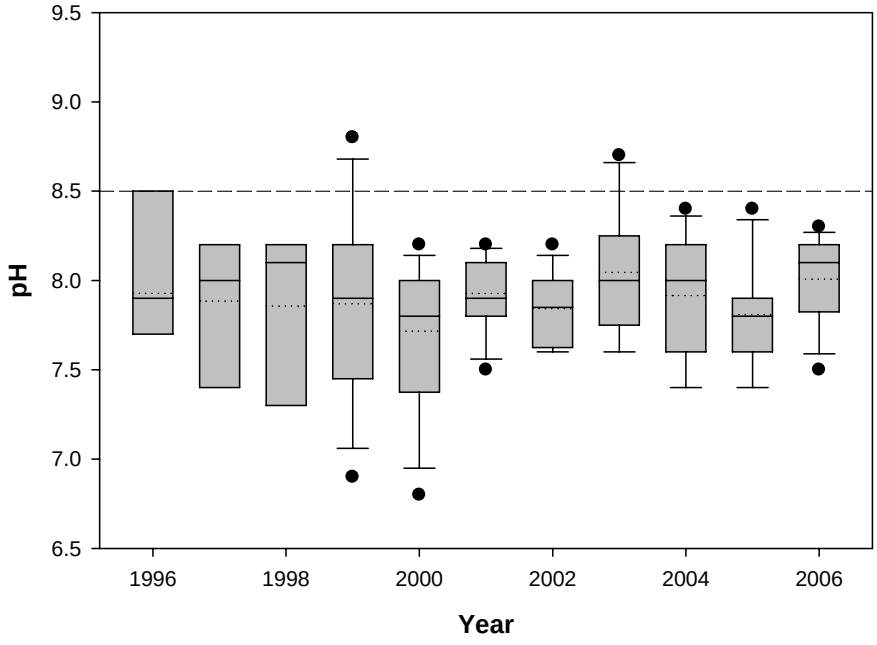
Neuse River Estuary
Lower TMDL Segment
Oriental
JA95/J9810000
Total Phosphorus



Neuse River Estuary
Lower TMDL Segment
Oriental
JA95/J9810000
Dissolved Oxygen at 0.1 meters



Neuse River Estuary
Lower TMDL Segment
Oriental
JA95/J9810000
pH at 0.1 meter



Neuse River Estuary
Lower TMDL Segment
Oriental
JA956/J9810000
pH at 1.0 meters