Temporal and Spatial Analysis of Water Quality and Landscape Characteristics for Albemarle Sound, North Carolina

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Abstract

Albemarle Sound, a lagoonal estuarine system on the North Carolina coast, has experienced a large decline in recreational and commercial fisheries over the years and managers are concerned about water quality, including the impacts of nutrient enrichment, or eutrophication. In an effort to help the United States Geological Survey improve its water quality monitoring network, this report compiles and analyzes over 40 years of historic data for the sound using three approaches.

Based on the current monitoring program and available historic data collected, five chemical and biological water quality parameters were chosen to characterize the water quality in Albemarle Sound: chlorophyll-a (Chl-a), dissolved oxygen (DO), turbidity, inorganic nitrogen (nitrate and nitrate) as N and phosphate-phosphorus as P. This project 1) statistically analyzes the relationships between water quality parameters within and among sub-sections of the Sound; 2) combines multiple sources of LULC data into sub-sections to better understand water quality drivers; 3) develops a GIS-based user interactive toolkit to identify the sensitive location(s).

Statistical and geospatial analyses show: 1) Overall, water quality in Albemarle Sound is good over time. 2) Seasonal effects may influence parameter values in some parts of the sound. 3) In light of inorganic nitrogen and phosphate-phosphorus levels, we may pay more attention to the North and South sections, as these two sections were more vulnerable to nutrient problems in history. 4) There are major differences in landscape characteristics between sections, offering some explanation for differences in water quality, and 5) There are some signals in the average concentrations of the five water quality parameters from 2006-2013, indicating that terrestrial drivers such as CAFO animal density and percent cultivated area could be important for water quality in the Albemarle Sound. This report provides fundamental guidance that can be used to inform both management plans and future studies in Albemarle Sound.

Contents

Introduction 5
Methods 9
  Water quality monitoring data collection 9
  Division of sound into regions 9
  Identification of long-term trends 10
  Water quality relationships and levels 10
  Geospatial analysis of LULC 13
  Interactive geospatial toolkit 15
Results 17
  Temporal and seasonal trends 17
  Water quality relationships and levels 24
  Comparison of parameter levels between sections 26
  LULC change summary 28
  Differences in current landscape characteristics between sections 29
Discussion 36
  Long-term trends 36
  Water quality relationships and levels 38
  LULC analysis 39
    Wetlands and forests 39
    Developed and cultivated areas 40
    Modified shorelines and CAFO animal density 40
Limitations and Conclusions 42
Acknowledgements 44
Faculty 44
References 45
Appendix A – Correlation Plots of Water Quality by Section 47
Appendix B – Q-Q Plots of Water Quality Parameters 59
Appendix C – Maps and LULC Summary and Analysis 60
Appendix D – LULC and water quality analysis (30 simple linear regressions) 63

Introduction

Excessive inputs of nitrogen and phosphorus from anthropogenic sources are a common problem along developed coastlines (Cloern, 2001). While nutrients are vital to support life, excess nutrients can accelerate the growth of phytoplankton (Scavia & Bricker, 2006). The life span of phytoplankton is short. When phytoplankton die, their decomposition depletes dissolved oxygen and secretes certain toxins, leading to significant reductions of other species, damaging the aquatic ecosystems and causing a phenomenon known as eutrophication (Pinckney, Paerl, Tester, & Richardson, 2001). Although estuaries tend to develop into a eutrophic stage due to natural processes, human activities have greatly accelerated this process (Goldman & Horne, 1983). Consequently, understanding trends in nutrient concentrations and the relationship of specific human activities to aquatic nutrients is essential in coastal management and eutrophication control.

There are many sources of nutrients in watersheds. Excess nutrients in a water body often come from runoff of fertilizer residues that are applied on agricultural lands and domestic gardens. Human wastewater from leaking septic systems and discharge of wastewater treatment facilities may also contain large amounts of nitrogen and phosphorus, which could contribute to the nutrient loads of a water body (Goldman & Horne, 1983). Therefore, eutrophication is often exacerbated by human activity within the watershed, especially as this activity relates to intensive land use and land cover change. Mapping the percentage of land use and land cover (LULC) type in source area watersheds has been shown to correlate to both water and sediment quality in regional or landscape studies (Crosbie and Chow-Fraser, 2011), and can provide important clues as to the source of nutrient enrichment in an estuary.

While nutrients are usually the cause of algal blooms, the negative effects of eutrophication are a direct result of algal growth and death. The respiration of oxygen by algae, as well as their consumers can deplete oxygen levels in the water column. Additionally, algae groups secrete certain cyanotoxins, which are extremely toxic to other species in the water body (Dittmann and Wiegand, 2006; Codd, Morrison, Metcalf, 2005). Death of other species due to either lack of oxygen or cyanotoxins will increase the activity of decomposers, which will further deplete the oxygen and ultimately create an environment with fewer algal species. For this reason it is important to understand the occurrence and distribution of harmful algal blooms in individual estuary systems.

Eutrophication is one of the primary water quality issues that concern natural resource managers of an important estuary on the coast of North Carolina, the Albemarle Sound. It is a shallow, low salinity estuary separated from the ocean by barrier islands, to which the Chowan and Roanoke Rivers drain (Moorman, n.d.). Since little water flows into the sound from the Pamlico Sound to the south, the majority of water inflows are from these freshwater rivers (Giese, Wilder, Parker, 1985). The system is economically important because it provides critical habitat for several commercial fisheries, and many of these populations are significantly below historic levels (Moorman n.d.). While this has been addressed by moratoriums on over-fishing in this area, there is still worry that water quality is preventing the recovery of many species.

Although a comprehensive study of historical trends in water quality in the Albemarle Sound has not been completed since the early 1990s (Harned and Davenpot, 1990), multiple studies have been performed on the adjacent lower Pamlico Estuary. These prior studies in both the 1990s and the 2000s have discovered correlations between water quality parameters and land use in the Neuse River estuary over time frames of 5 years to several decades (Stanley, 1996; Glasgow & Burkholder, 2000; Burkholder et al., 2006). A similar long-term analysis of changing land-use effects on surface water quality conducted for the Neuse River Basin (Rothenberger, Burkholder, Brownie, 2009) incorporated other aspects of LULC such as density of animals in CAFOs (concentrated animal feeding operations) into a nutrient loading model for the Pamlico.

Recent summaries of water quality for the Albemarle Sound, including preliminary analysis of various water quality constituents, was completed in 2012 as part of the Albemarle Pamlico National Estuary Partnership (APNEP) Ecosystem Based Assessment. Also, the NC Department of Water Quality's Basin-wide assessments are published every 5 years, but neither of these reports provided a comprehensive assessment of historic water quality from a geographic standpoint.

Several studies in the Albemarle-Pamlico Estuary have shown that multiple factors, not simply nutrient inputs, are related to harmful algal blooms, and that weather patterns are critical drivers of water quality trends (Burkholder et al., 2006; Glasgow & Burkholder, 2000). Hurricanes were found to temporarily decrease incidences of algal blooms, perhaps because of the scouring out of cysts (Burkholder et al., 2006; Glasgow & Burkholder, 2000). In addition, it is well known that nutrient loading is positively correlated with runoff. Drought has been shown to decrease nutrient loads, while wet years can increase delivery of nutrients to an estuary system (Burkholder et al., 2006). This confounds the search for long-term trends. The importance and effects of these variables on a given estuary vary widely, and it is therefore necessary to study each estuarine system separately to thoroughly understand its dynamics. The tributaries within an estuary can have different inputs from their watersheds, and different water residence times. Residence time is a measure of how long water remains in an area before being flushed out to sea. This metric has been shown to be one of the most important factors affecting water quality in the Albemarle.

The Albemarle Sound demonstration project for the National Monitoring Network of U.S. Coastal Waters and Tributaries (conducted by the U.S. Geological Survey, USGS) is currently operating a monitoring program to learn more about the dynamics of the estuary. In addition to gathering long-term data, the program aims to determine where the research gaps are, conduct more monitoring to help address these gaps, and compare the Albemarle monitoring network to the design of the well-established National Monitoring Network (Moorman, n.d.). The goal of this project is to assist in compiling and analyzing previously collected data to help inform future data collection, data analysis, and management decisions.

To determine whether the Albemarle Sound may be affected by excess nutrients inputs and therefore at risk to symptoms of eutrophication, this study will examine three general factors: water quality, nutrients, and land cover/land use. These three factors are interconnected: land use as a driver of nutrient inputs to the sound; nutrients as a direct cause of eutrophication that can be traced back to anthropogenic sources in the landscape; and water quality parameters as indicators of eutrophication. While a great deal of research has informed the study of eutrophication, it is by nature a localized phenomenon. This study aims to identify how the process of eutrophication unfolds in Albemarle Sound. We believe that, although the sound is a single, connected body of water, its varying depth, mixing, and flow patterns cause its behavior to vary both spatially and temporally.

Since the sound is well mixed, many of its tributaries have low flow, and data was not collected for each tributary evenly, we chose to examine spatial patterns by geographic region, rather than tributary. By comparing water quality between these regions, as well as the relationship between parameters within regions, we aimed to determine if there are differences in water quality dynamics between regions. To determine whether local land cover and land use has an effect on water quality by region, simple linear regressions were performed for each water quality parameter. Finally, by examining trends in water quality over a 40 year monitoring record, we address the hypothesis that increasing agriculture and development in the area is having a long-term negative affect on water quality

Based on the current monitoring program and available historic data collected, five chemical and biological water quality parameters were chosen to characterize the water quality in Albemarle Sound: chlorophyll-a (Chl-a), dissolved oxygen (DO), turbidity, inorganic nitrogen (nitrate and nitrate) as N and phosphate-phosphorus as P. The identification of historic levels of these parameters helps us to better evaluate the eutrophication trends as well as their drivers with respect to biochemical conditions in the estuary. We hypothesized that sections of the sound with higher nutrient concentrations would also have an increased occurrence of algal blooms (high chlorophyll-*a* concentrations) and a depressed oxygen concentration. We further hypothesized that high nutrient concentrations would coincide with spikes in turbidity level, as nutrients and other pollutants are often carried into the sound through overland flow from contributing areas.

Based on available data, literature reviews, and research interests of our client, we focused on four LULC types as well as modified shorelines and CAFO animal density in our quantitative analysis of landscape characteristics and water quality. We hypothesized that LULC types such as wetland and forest cover would have a negative relationship with nutrients, turbidity, and chlorophyll-*a* while having a positive relationship with dissolved oxygen. We hypothesized the opposite relationships for LULC types such as cultivated and developed area, as they are thought to contribute nutrients to waterbodies from fertilizer and sewage inputs. We hypothesized the same for modified shorelines, as they are often associated with increased urban development. Lastly, we predicted CAFO animal density would be positively correlated to nutrients, algal blooms, and increased turbidity as demonstrated by studies in neighboring river basins.

In order to improve management of the Sound, it is necessary to gain a better understanding of how the estuary is affected by regional land use/land cover, nutrient enrichment, and climate/tidal events. In addressing our hypotheses, this report summarizes and analyzes important environmental data relevant to future monitoring and research projects as well as management decisions. A detailed discussion of research gaps and additional research ideas can be found in the conclusion section of this report.

Methods

Water quality monitoring data collection

Publicly available water quality data for the Albemarle Sound watershed was downloaded from the EPA's STORET database (available at www.epa.gov/storet). While several different agencies' data was obtained via STORET, the majority of the data was collected by North Carolina's Department of Water Quality (DWQ). Only data from this agency was used for this project, to ensure consistency. Only five parameters were chosen for this project, based on their high frequency of measurement and relevance to eutrophication. For each parameter, only data measured in the same units were included, with the exception of turbidity. Turbidity was measured in both NTU and FTU, and these were considered equivalent (USGS 1998). The resulting pool of 41,322 data points was used for this project.

When inorganic nitrogen concentrations were below the detection minimum, one half of the lowest detection level was used (0.005 mg/l). Dissolved oxygen had no minimum detection, therefore all values (including zeroes) were retained. For all other parameters, the minimum detection level was unknown, and therefore all non-detect samples were converted to zeroes.

Division of sound into regions

The sound was split into six geographic regions, using HUC 10 and HUC 12 boundaries delineated by the USGS. The regions were created based on general flow, salinity, and wind patterns in the sound to help differentiate how unique combinations of these physical variables in each section may affect water quality dynamics. The expert opinion of USGS staff was used to determine which HUC boundaries should be used. Traditional HUC 10 watershed areas were not used because they were at too fine a resolution compared to the rest of our data, and we believe that rapid mixing within the Sound makes such fine delineation within the Sound not applicable to this study.

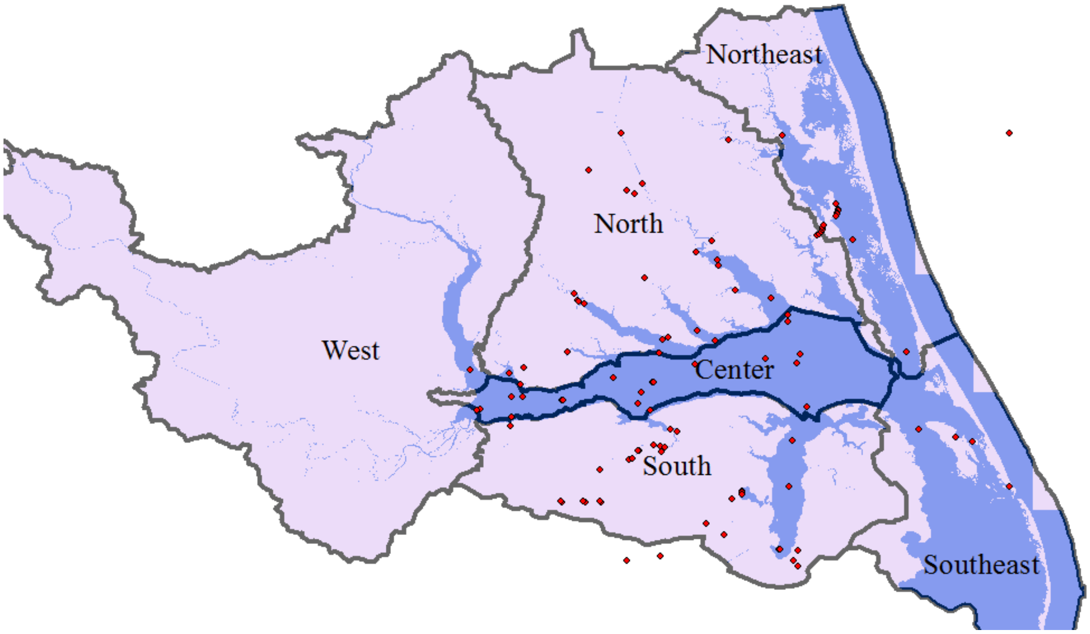


Figure 1. Map of sections created and used for geographic analyses. Red dots indicate a sampling point.

Identification of long-term trends

To fill water quality research gaps for the Albemarle Sound, we assessed the occurrence of chl-a, DO, turbidity, inorganic nitrogen and phosphate-phosphorus through time. To examine seasonal trends, we split the year into summer and winter sections. The period of April to September in each year is counted as summer time, showing as 01 in the X axis in the graphs; and the other months are counted as wintertime in that year. For each parameter, the data was grouped by section, and plotted by season over time. This information will help determine trends in water quality parameters for the sound and identify any sub-watersheds susceptible to water quality issues, as well as how well the long-term sites represent the sound as a whole.

Water quality relationships and levels

Data for each geographic section was imported into R, where the merge command was used to match measurements of two parameters taken at the same station, time, date and depth (Figure 2). Within each section, every possible pairwise match for the five parameters of interest was performed. This resulted in 10 datasets for each section of the Sound. The distributions of parameters within these subsets were non-normal. The distribution of dissolved oxygen was nearly symmetrical, while other parameters were right skewed, even after log transformation. All log transformations were also shifted up by 1 unit, making original values of 0 equal to 0 in logged plots. The correlation coefficient for each pairwise comparison was calculated and tested for significance with the non-parametric Kendall's tau method. Kendall's tau was chosen over Spearman's rho test as suggested by Gilpin (1993) and Roberts & Kunst (1990), especially because the data had ties. Plots of pairwise comparisons for each section were created to visualize trends (Appendix A). A true correlation matrix could not be created because the data for each pair-wise comparison was different. Global correlations for the entire sound were also calculated and displayed.

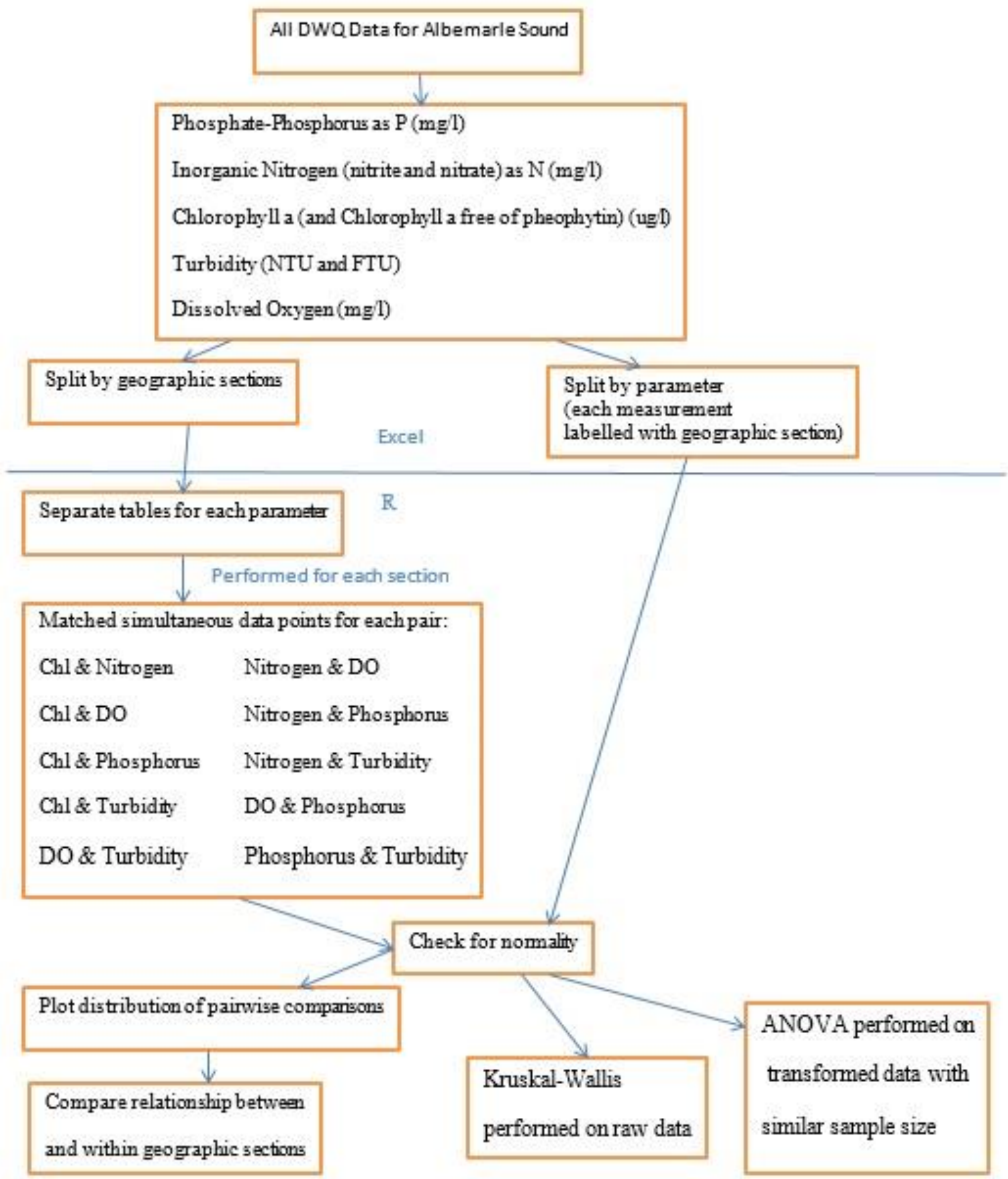


Figure 2. Schematic of data management for water quality analysis

Comparison of parameter levels between sections

Data were aggregated by parameter of interest, and tested for normality (Figure 2). The Kruskal-Wallis rank sum test was used to determine if water quality parameter levels varied between sites. Data were non-normal and had different variances; therefore, an ANOVA could not be performed to compare the level of each parameter between sites (Appendix B). While the ANOVA test is robust to non-normality and heteroscedasticity, the widely varying sample sizes prevented the use of an ANOVA across all sites (Zar 2006). Tests to determine homoscedasticity could not be performed because of differing sample sizes. For sections with acceptable normality and heteroscedasticity, and similar sample size, an ANOVA was performed to determine if the two sites differed for each water quality parameter. North and South sections had similar sample sizes, as did Northeast and Southeast. This enabled us to test whether latitudinal differences are important factors for water quality.

Geospatial analysis of LULC

All geospatial analysis for the LULC portion of this project was completed using ArcGIS 10.1 and 10.2. All geospatial data was projected into NAD 83 UTM Zone 18N prior to analysis. To evaluate land use and land cover for all of the watersheds contributing flow to the Albemarle Sound, NCLD raster images classified to Anderson Level II were downloaded for the three available time periods: 1992, 2001, 2006. Hydrology and hydrography data were obtained from the National Hydrography Dataset (NHD) and contributing watershed boundaries were obtained from the Watershed Boundary Dataset (WBD), contained inside the NHD. All NHD and WBD were derived from the best available elevation data.

To characterize landscape change over time, all LULC values from the three time periods were extracted for each of the 12 contributing HUC 8 watersheds. No higher-detail change analysis was performed or summarized for this project as there were no large-scale changes over this time period, and preliminary analysis of historical water quality trends did not indicate any significant changes for which a terrestrial driver might be located. Thus, the remainder of the analysis focused on the most recently available data from the USGS 2006 NLCD (2011 NLCD was published immediately after the completion of this project).

In order to further investigate the influence of these values on water quality trends, the LULC data was extracted utilizing the same sections that were used to statistically evaluate the water quality parameters. However, the West section was further divided into West (Roanoke) and Northwest (Chowan) as these are two very different riverine systems and the client indicated a desire to investigate them separately in future projects. Even though the 2011 NCLD LULC values were available for these smaller geographic areas through NOAA's C-CAP, the 2006 data was used for this analysis in order to be consistent with the long-term change analysis for the entire contributing watershed area.

Vector (point and line) data was also used in the LULC analysis for Albemarle Sound. CAFO (Concentrated Animal Feeding Operation) locations were downloaded from NCDENR's DWR permit website. All CAFO locations are "active" (as of 2014) permits, and may or may not have been present during all time periods of corresponding LULC and water quality data, but given the lack of major change in the region, this data is sufficient. Density values for each section were calculated using ArcMap's Zonal Statistics tool, and were derived from the maximum allowable number of animals in each operation.

Data on the length of modified shoreline surrounding the Albemarle Sound was obtained from the NC Division of Coastal Management (DCM) Shoreline Modification Dataset, completed in 2012 from 2009 imagery. Modified shorelines, as defined by the DCM, are any shorelines "with observable engineered erosion control structures." (McVerry, 2012). Percent modified shoreline in each section and primary shoreline type was also determined using the Zonal Statistics tool.

Only a maximum of 14 water quality sampling sites within the Albemarle Sound and contributing watersheds monitored by the NCDENR DWQ were identified as temporally overlapping with the most current LULC data. Some water quality parameters were monitored at even less stations. Neither the beach sections (Northeast and Southeast) nor the Roanoke River section (West) had any monitoring sites with all five parameters for the necessary time period. The seven-year average (2006-2013) chlorophyll-*a*, dissolved oxygen, inorganic nitrogen, phosphate-phosphorus as P, and turbidity concentrations were calculated for each of these sites using Microsoft Excel Pivot Tables (table in Appendix C), and used as response variables in simple linear regressions with the six LULC parameters of interest as independent variables. Each parameter had approximately 1,000 values used for each average calculation, except for dissolved oxygen, which had nearly 4,700 and phosphate-phosphorus as P, which only had around 400 due to a change in data collection methodology after the year 2007.

Exact contributing areas for all of the sampling sites could not be determined in this project due to the difficulty of hydrologic analysis in this region, so percentage of LULC type at each site was classified by section for those sites not on flowlines (most sites). Percentage of modified shoreline contributing to each site was also classified by section, except for those sites located on NHD flowlines. Modified shoreline was classified for these sites by using the ArcMap Spatial Analyst extension to calculate the total shoreline contributing to a site, as well as the shoreline type. Lastly, the CAFO animal density at each sampling site was also classified by section, as many of these facilities were not located on mappable flowlines.

Interactive geospatial toolkit

Advanced geospatial analysis was used, including GIS Modeling, Structured Query Language (SQL) and Python, in order to develop a user-interactive and distributable toolkit for the client. The toolkit enables users to easily select the input variables and parameters to get the water quality distribution and sites' geographic information in ArcGIS maps. The purpose is to identify any sensitive location(s) in Albemarle Sound regarding a specific water quality parameter from both a temporal and spatial perspective. Specifically, Tool 1 and Tool 2 demonstrate the monitoring sites, in which every site represents the maximum and minimum value of each record year, respectively, of a particular water quality parameter over the history. Tool 3 estimates the continuous distribution of the user-selected parameter for the entire Albemarle Sound in a particular year based on the relevant sampling sites. This toolkit is designed to be user-friendly interface, distributable and easily modified in future.

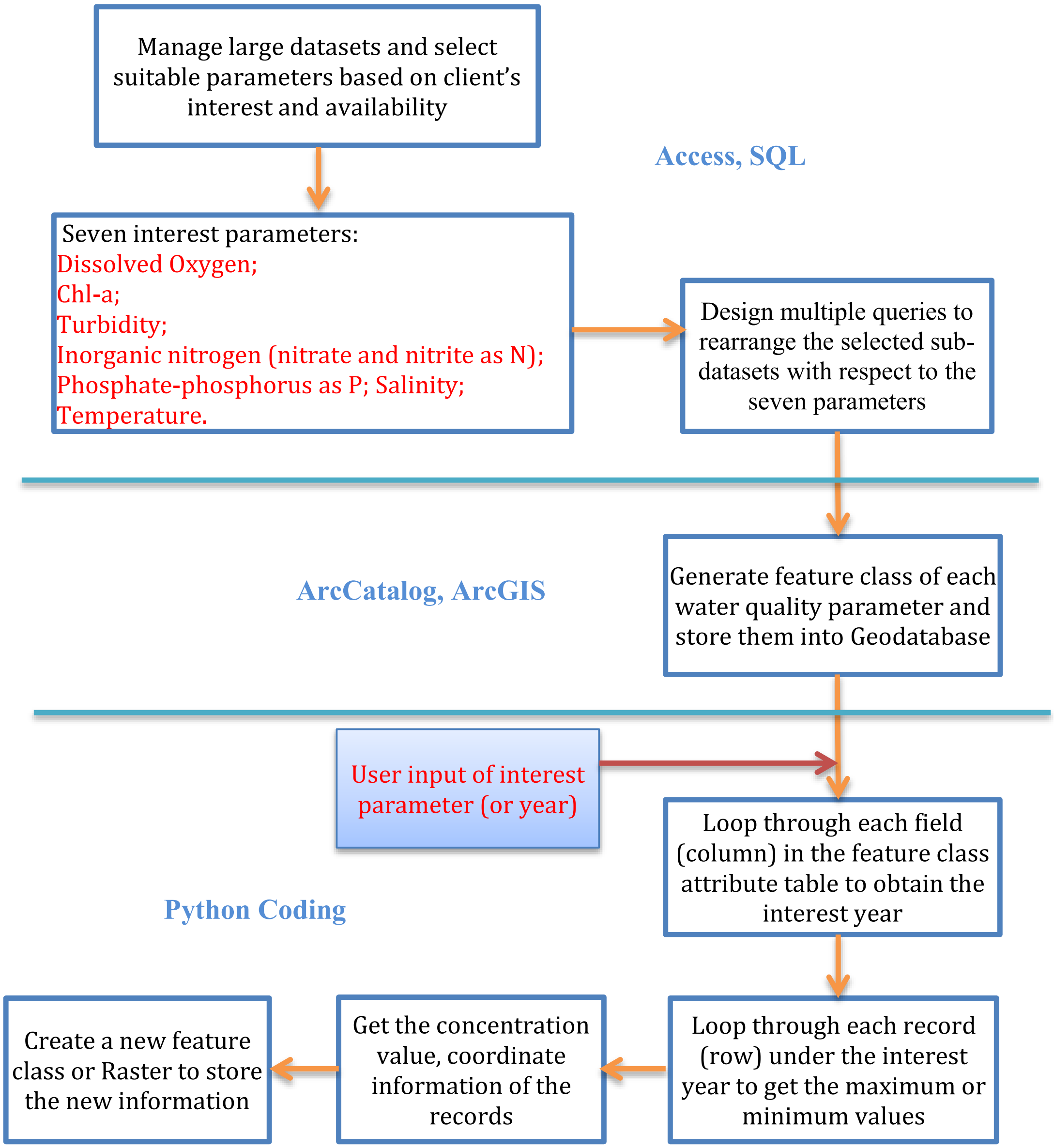


Figure 3. General workflow of ArcToolbox design

Results

Temporal and seasonal trends

Figure 4 shows the temporal and seasonal trends of Chl-a in all six sections. We can see that Chl-a was monitored through different time periods in different sections, among which the South section of Albemarle Sound has the greatest amount of sample years, followed by the Center section. Other the other hand, the Chl-a monitoring activities were very limited in West and Southeast sections of Albemarle Sound – there were only five seasonal sampling points on Southeast section, and 14 seasonal sampling points on West section. Seasonal patterns were observed in all geographic locations. Almost all the concentration peaks happened in summer time; and low concentration level happened in wintertime. Also, based on the available data, most of the values are between zero and 20ug/L; the West and Southeast part of Albemarle Sound had quite low and stable Chl-a concentration temporally (less than 10 ug/L), indicating the eutrophication problem may not be a concern in Albemarle Sound, especially West and Southeast parts.

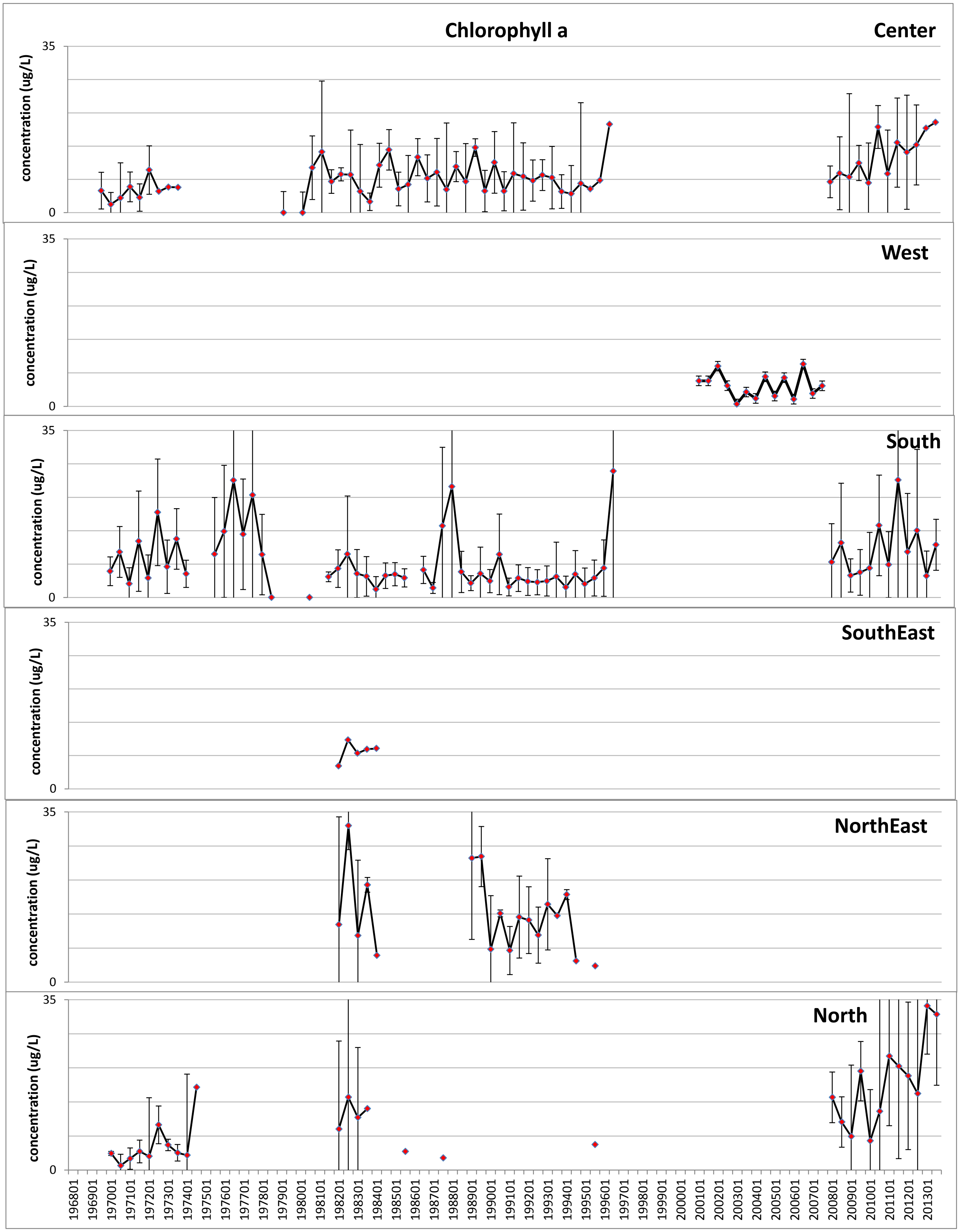


Figure 4. Temporal and seasonal trends of Chlorophyll a

Figure 5 shows the temporal and seasonal trends of DO in six sections of Albemarle Sound. Comparing with the monitoring history of Chl-a, DO has been monitored more consistently and continuously through time. The North section of Albemarle Sound has the most amount of sample years (from 1968 summer time to 2013 summer time), following by south and Center sections. Generally, the seasonal levels have not changed dramatically in the last 40 years in all six sections. No obvious increase or decrease in DO has been identified. Clear temporal and seasonal patterns are present, which is opposite to Chl-a seasonal pattern - high DO concentrations happened in winter time, and low DO levels were measured in summer time in the same year no matter its geographic locations. Also, based on the available data, most of the values are between 6 mg/L and 10 ug/L, which is larger than the threshold 5mg/L that EPA recommended, indicating the water quality in the whole Albemarle Sound is relatively good over time in terms of DO.

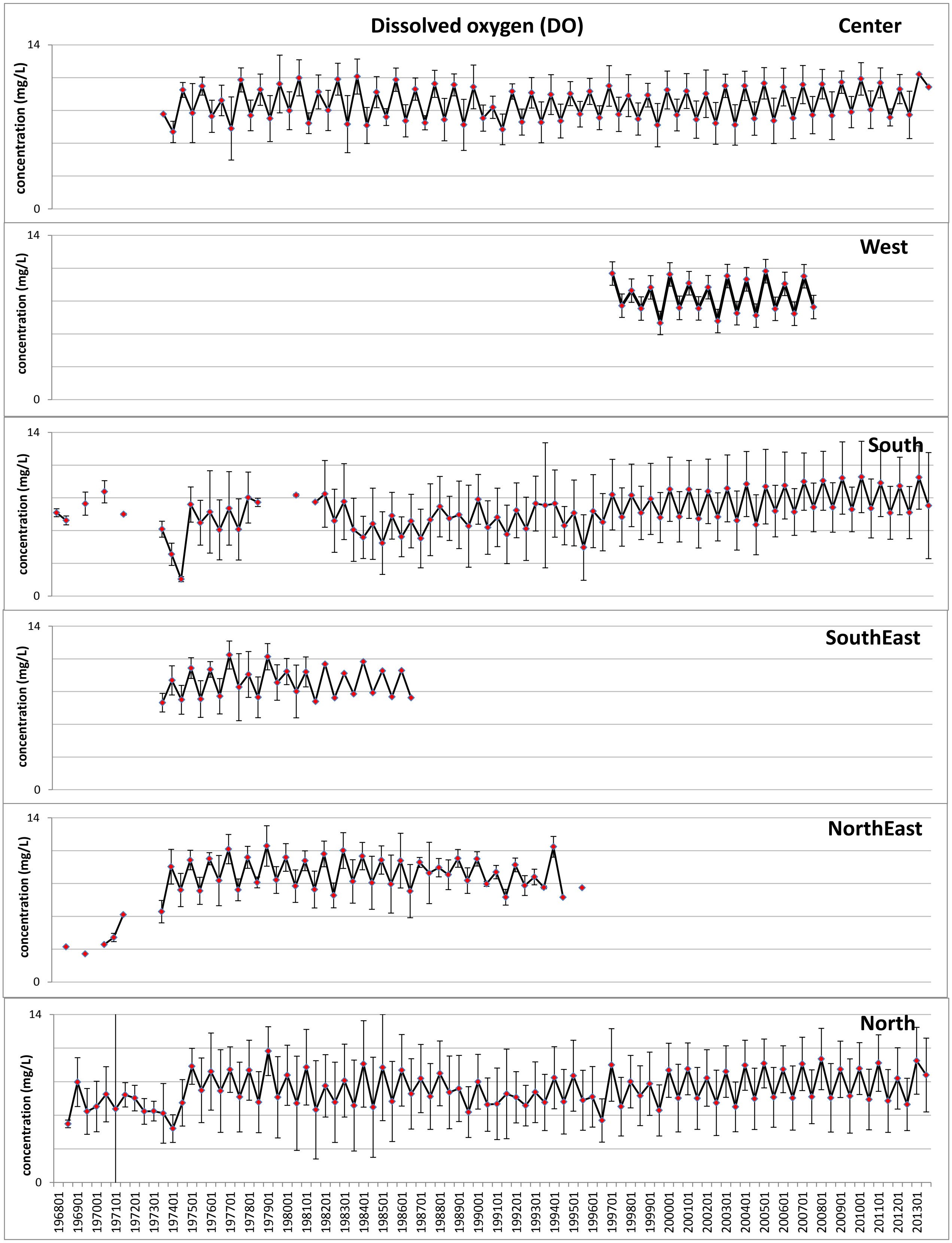


Figure 5. Temporal and seasonal trends of dissolved oxygen

Turbidity was monitored through different time periods in different sections, among which the West and Southeast section of Albemarle Sound have the least turbidity values over time (around 5 FTU or so, Figure 6). Other parts of Albemarle Sound have the temporal patterns fluctuating between 5 FTU and 15 FTU. There is no obvious seasonal pattern in the graphs – some peaks happened in wintertime, and others happened in summer time.

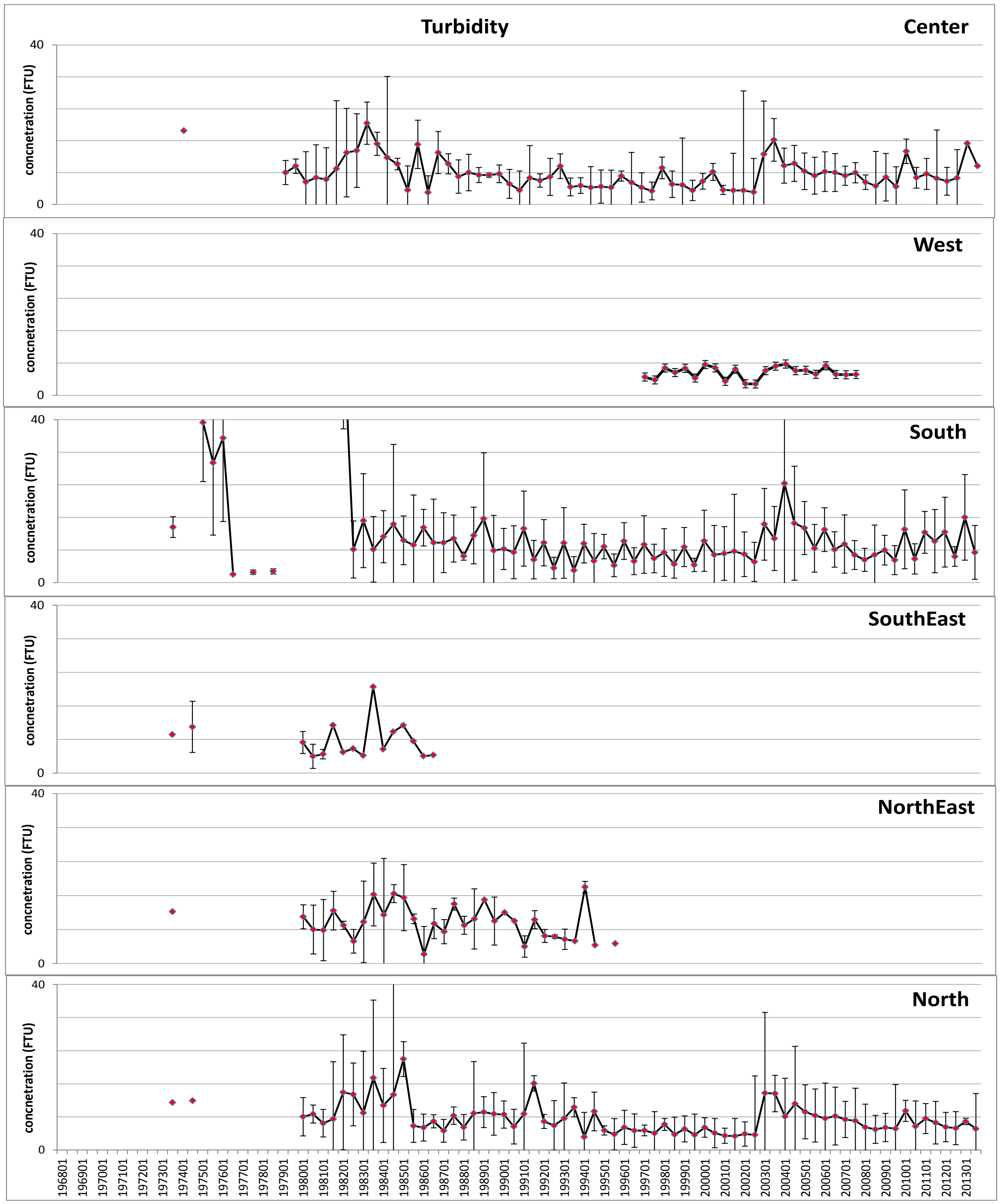


Figure 6. Temporal trends of turbidity

Unlike the similar temporal trends happened in all six sections in terms of Chl-a, DO and turbidity, there are clear differences of concentration level in different places in Albemarle Sound. Specifically, the South has the largest and varied seasonal values (from 0.2 to >2 mg/L) through years, following by North part, concentration ranging from 0.1 to > 1 mg/L). On the other hand, most of the values in other parts are only less than 0.2 mg/L all the time. Temporal and seasonal patterns were observed in all sections – concentration peaks happened in summer time; and low concentration levels happened in winter.

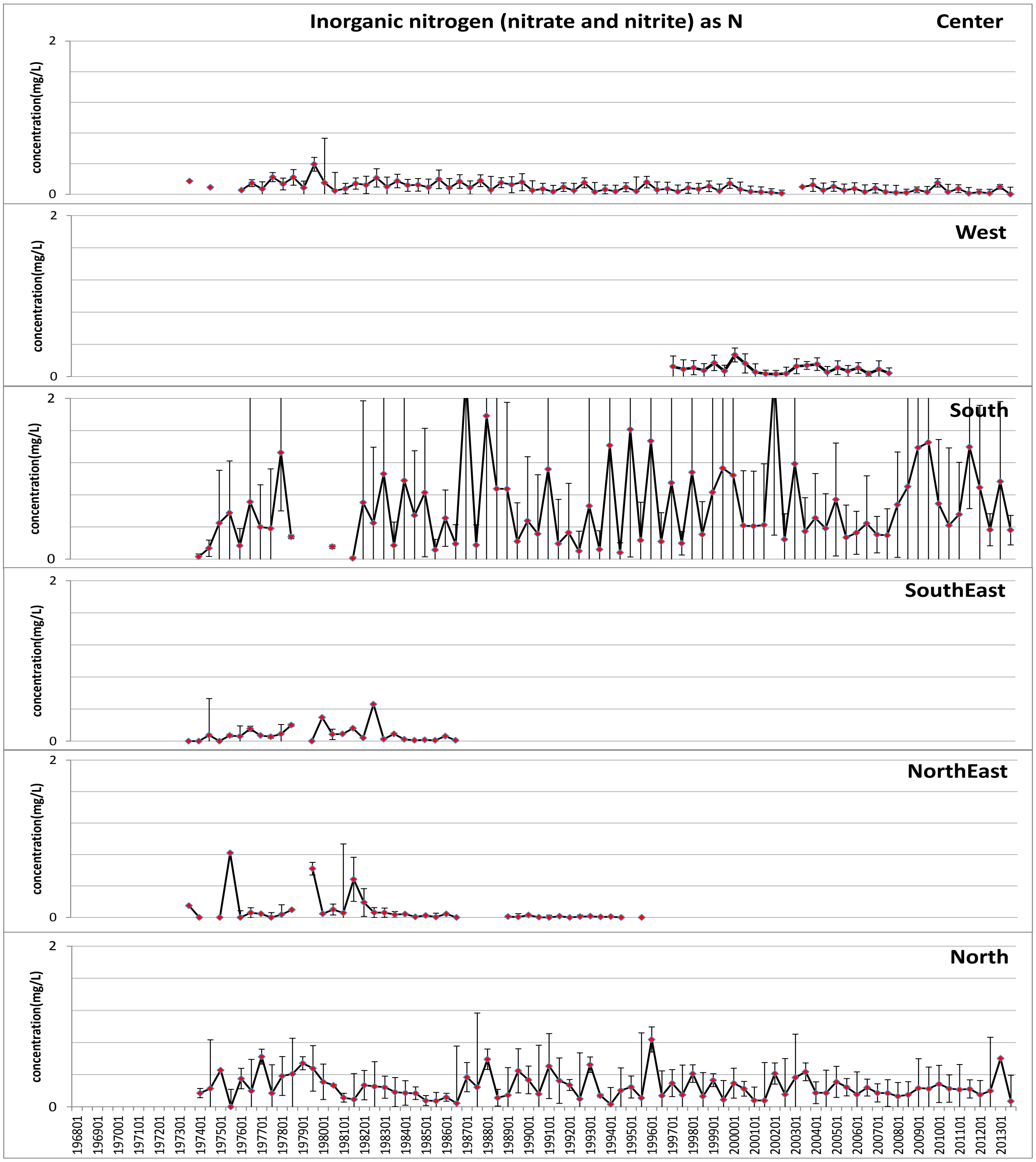


Figure 7. Temporal and seasonal trends of inorganic nitrogen (nitrate and nitrite) as N

Phosphate-phosphorus levels in the North and South part of Albemarle Sound have the largest and fluctuated values over time – most of the values measured in North are of the peaks happened in summer time, others happened in wintertime. Throughout the history, phosphate-phosphorus level has not changed much over years, especially for Southeast and West part of Albemarle Sound. No obvious increase or decrease is observed.

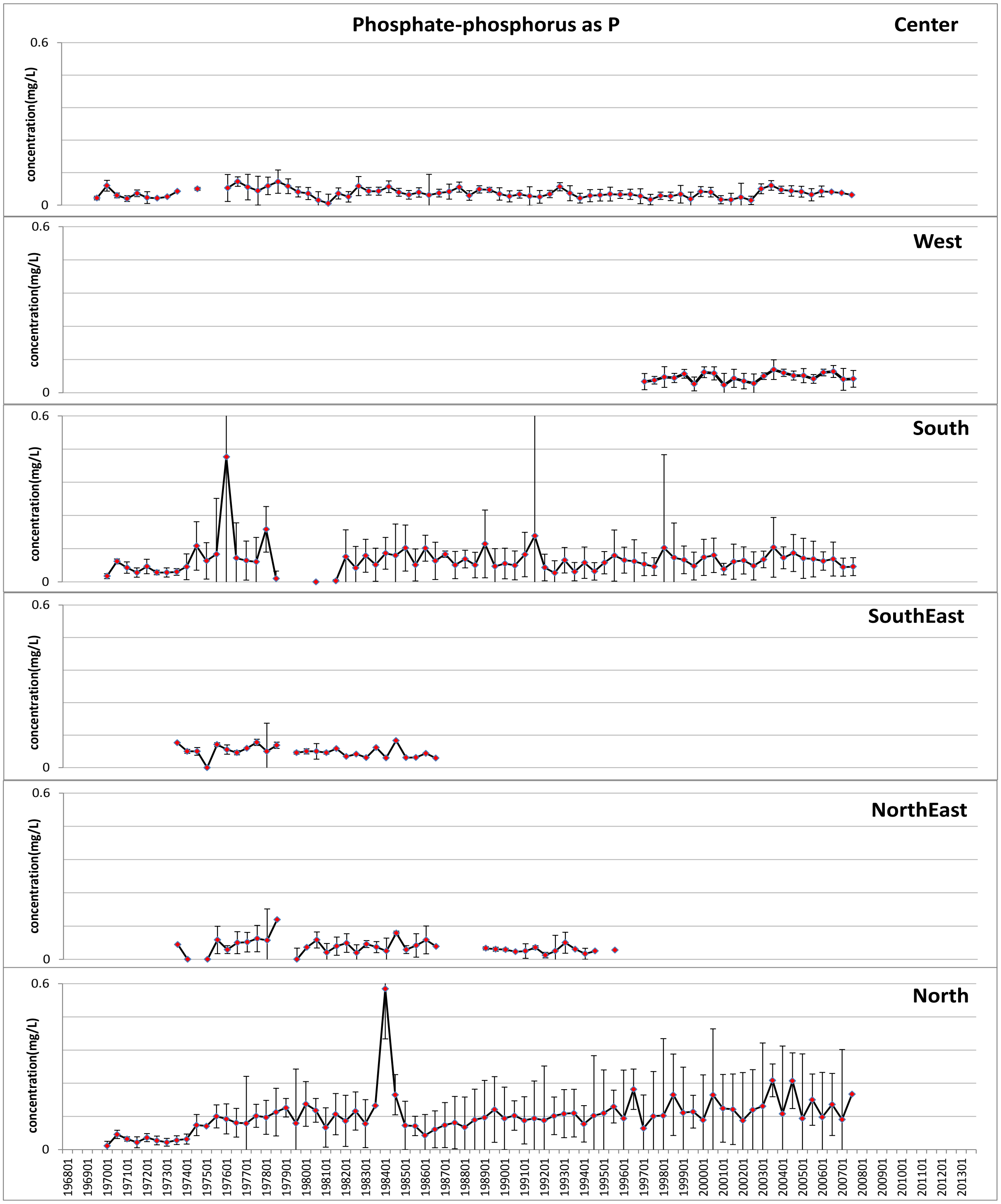


Figure 8. Temporal trends of inorganic phosphate-phosphorus as P

Water quality relationships and levels

Summary statistics of water quality data: Each parameter chosen for this study had at least 4,900 data points collected. While the data are left-censored because of detection limits, we thought it useful to display the summary statistics of each parameter (Table 1). The number of samples that exceeded the environmental standards set by North Carolina for aquatic life is also listed. Turbidity was the most often-exceeded parameter, while nitrogen was rarely over the state limit.

Table 1. Summary statistics for water quality parameters

Parameter	Min	1st Quartile	Median	3rd Quartile	Max	Mean	Standard Deviation	Number of Samples	NC Water Quality Standards	Exceed-ances	Percent exceedance
Chlorophyll a (ug/l)	0.00	2.88	6.00	12.00	460.00	10.08	18.208	5699	<40	184	3.2%
Dissolved Oxygen (mg/l)	0.00	7.20	8.40	10.10	73.00	8.446	2.471	20772	>5	1524	7.3%
Inorganic Nitrogen (mg/l)	0.000	0.000	0.060	0.185	490.00	0.291	6.273	6147	No Standard	No Standard	No Standard
Phosphate-Phosphorus as P (mg/l)	0.000	0.030	0.050	0.080	26.00	0.076	0.397	5517	No standard	No standard	No standard
Turbidity (NTU/FTU)	0.00	3.500	5.600	9.200	180.00	7.805	8.401	4902	25 NTU	153	3.1%

Global Relationships: The Kendall tau tests revealed many significant relationships between parameters at the global level (Figure 9). A positive relationship was found between phosphate-phosphorus and both Chl-a and inorganic nitrogen concentrations (tau = 0.065 and tau = 0.35, respectively). DO was negatively correlated with both inorganic nitrogen and phosphate-phosphorus at the global scale (tau = -0.028 and tau = -0.173, respectively). Turbidity was positively correlated with inorganic nitrogen and phosphate-phosphorus concentration (tau = 0.298 and tau = 0.322, respectively). High Chl-a concentrations were associated with low inorganic nitrogen levels (tau = -0.152).

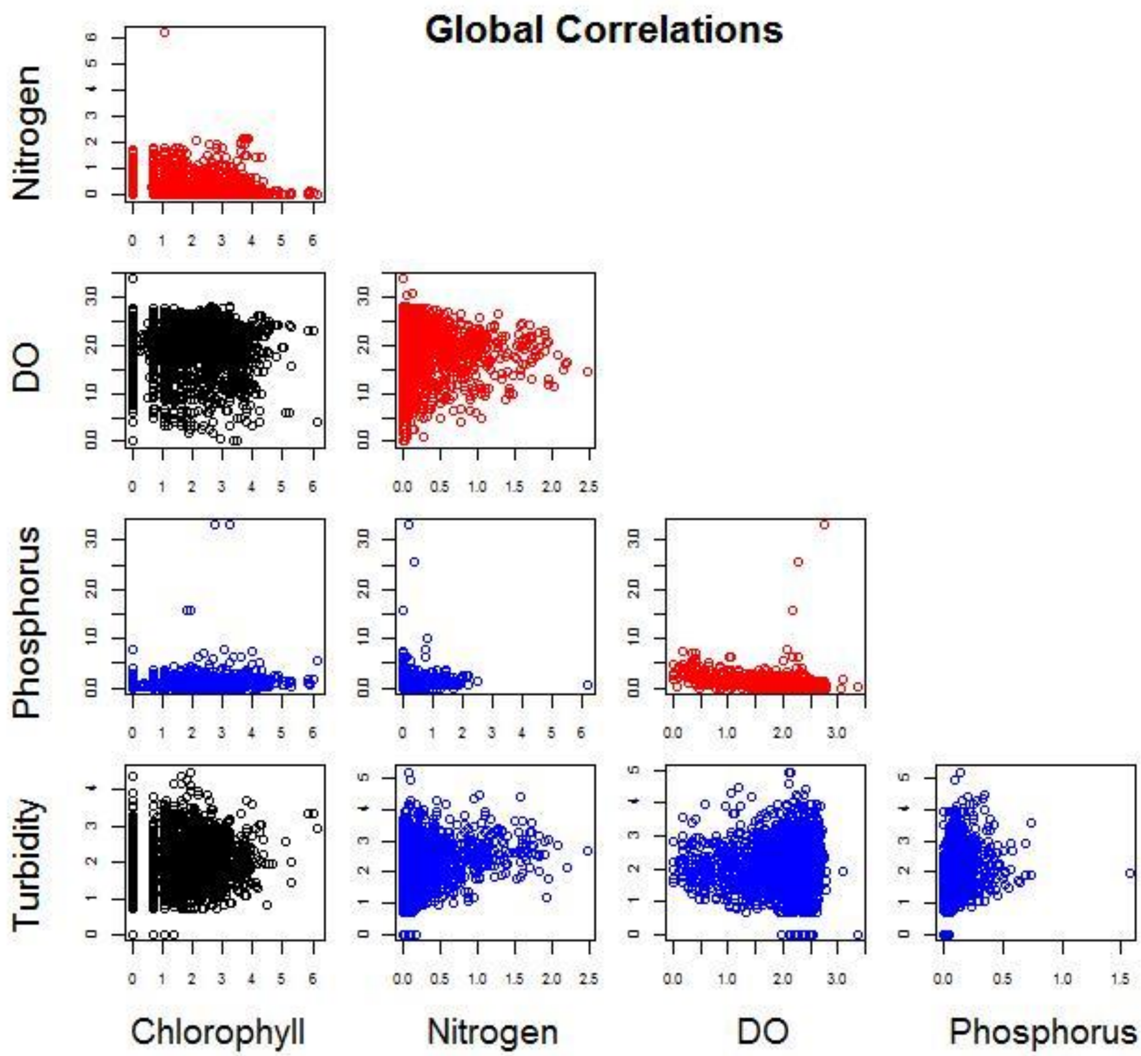
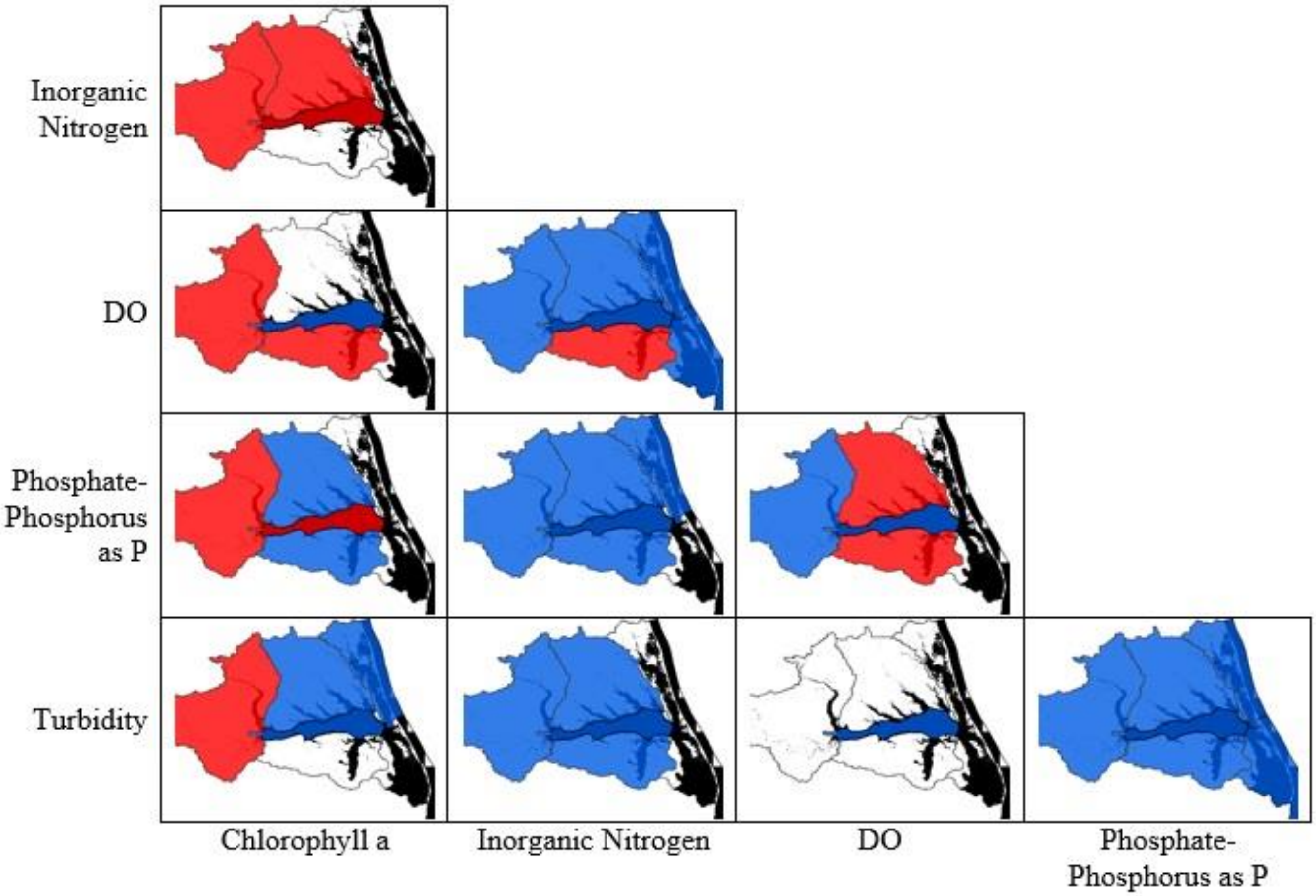


Figure 9. Correlations between parameters measured at the same depth, time, and station (All values have been log transformed, after having the integer 1 added to avoid irrational numbers. Plots with red points indicate a negative correlation. Plots with blue points indicate positive correlations. Plots with black points indicate no relationship.)

Regional differences: Some pairs of parameters had fairly consistent relationships across sections, mainly relationships between nutrients and turbidity. However, relationships between DO, inorganic nitrogen, and Chl-a concentrations had different directions in different sections (Figure 10). Significant correlations ($p \leq 0.05$) were found in most sections for pairs of parameters such as inorganic nitrogen by DO, and phosphate-phosphorus by turbidity. However, other pairs were only linked in some regions, such as dissolved oxygen by turbidity. Pairwise correlation plots for each section are contained in Appendix A.

Figure 10. Significant correlations between parameters in each region (Blue colored regions have a positive correlation for that pair of parameters, while red colored regions have a negative correlation for that pair. If a region is not shaded in the map, the relationship was not significant at the $p \leq 0.05$ level.)



Comparison of parameter levels between sections

For all 5 parameters considered, there were regional differences in levels (Table 2). While we cannot determine where the differences lie with the Kruskal-Wallis test, visual inspection of logged values across sites can provide additional information (Figure 11). The North and South sections had different concentrations of DO ($F=35.46$, $p=2.73*10^{-9}$), while the Northeast and Southeast were the same ($F=0.57$, $p=0.45$). Similar results were found for inorganic nitrogen and phosphate-phosphorus (Table 3). However, Northeast and Southeast did have different turbidity levels (Table 3).

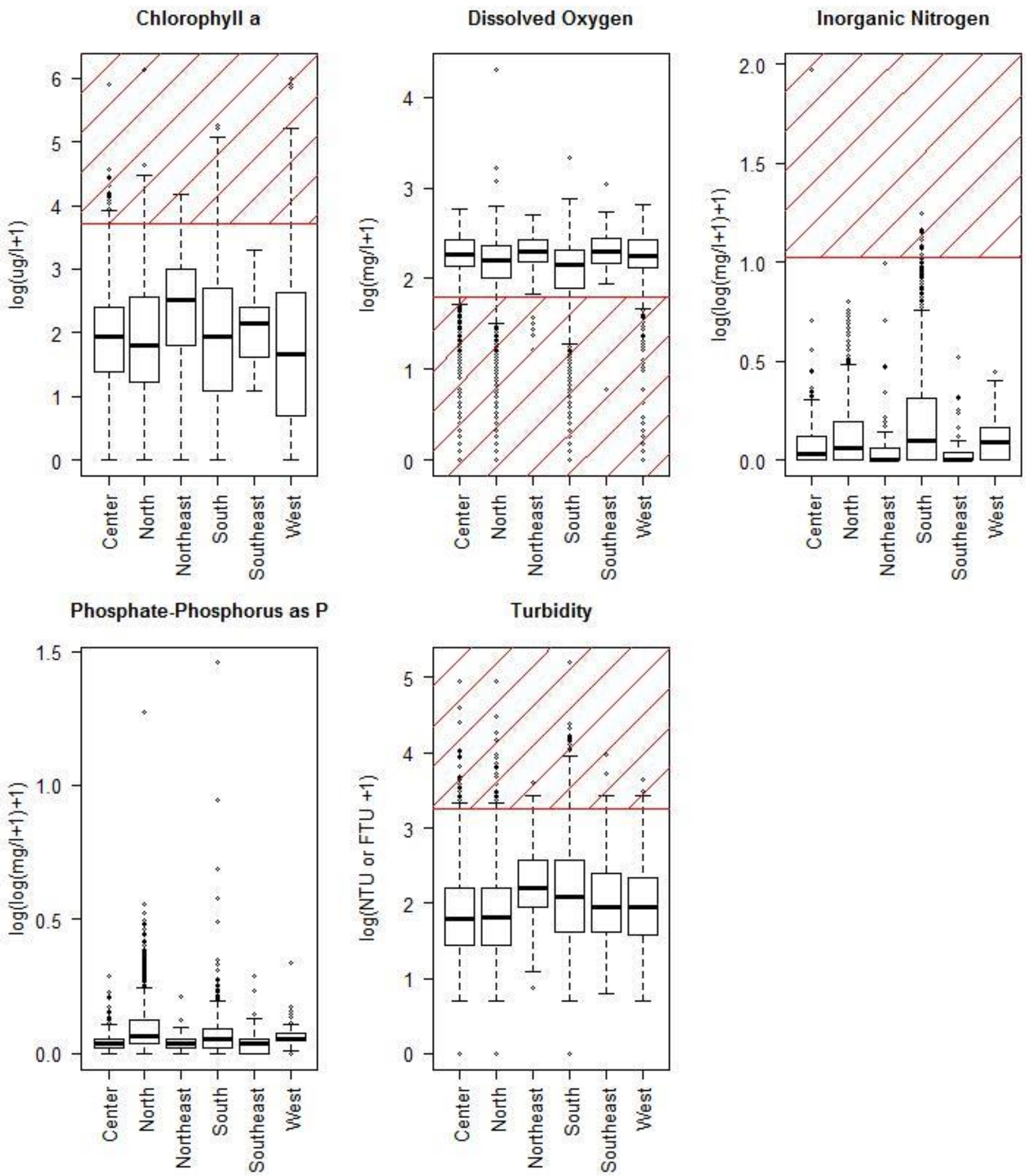


Figure 11. Log transformed water quality measurements in different regions.

Table 2. Statistics of Kruskal-Wallis test for difference between sections for each parameter (A significant difference indicates that at least one section is different from at least one other section.)

Parameter	Degrees of freedom	Chi-squared	P value
Chlorophyll a	5	63.4341	$2.367*10^{-12}$
Dissolved Oxygen	5	914.8359	$<2.2*10^{-16}$
Inorganic Nitrogen	5	620.2428	$<2.2*10^{-16}$
Phosphate-P as P	5	688.1217	$<2.2*10^{-16}$
Turbidity	5	178.4928	$<2.2*10^{-16}$

Table 3. Statistical results of ANOVA tests to determine different levels between latitudinal regions with similar sample sizes (The sections being comparing are noted in the left-most column.)

Sections	Parameter	Degrees of freedom		Sum of Squares	Mean Square	F value	P value
North versus South	Dissolved Oxygen	Section	1	7.9	7.896	35.46	$2.73*10^{-9}$
		Residuals	6695	1490.8	0.223		
	Inorganic Nitrogen	Section	1	16.1	16.080	142.9	$<2*10^{-16}$
		Residuals	2900	326.4	0.113		
	Phosphate-P as P	Section	1	0.65	0.6505	42.87	$7.04*10^{-11}$
		Residuals	2584	39.21	0.015		
	Turbidity	Section	1	33.8	33.78	77.72	$<2*10^{-16}$
		Residuals	2365	1027.1	0.43		
Northeast versus Southeast	Dissolved Oxygen	Section	1	0.024	0.02398	0.57	0.45
		Residuals	576	24.222	0.04205		
	Inorganic Nitrogen	Section	1	0.075	0.07456	3.519	0.0617
		Residuals	274	5.805	0.02119		
	Phosphate-P as P	Section	1	0.0002	0.0001906	0.115	0.735
		Residuals	272	0.4518	0.0016612		
	Turbidity	Section	1	2.55	2.553	8.925	0.00319
		Residuals	185	52.92	0.286		

LULC change summary

LULC for 1992, 2001, and 2006 was summarized for each HUC 8 unit contributing to the Albemarle Sound and mapped to display the spatial distribution (Appendix C). All forest, wetland, developed, and cultivated classes were combined for comparison between dates. Since the 1992 and 2001 data were classified using slightly different algorithms, combining these classes allows for more robust comparison across time periods.

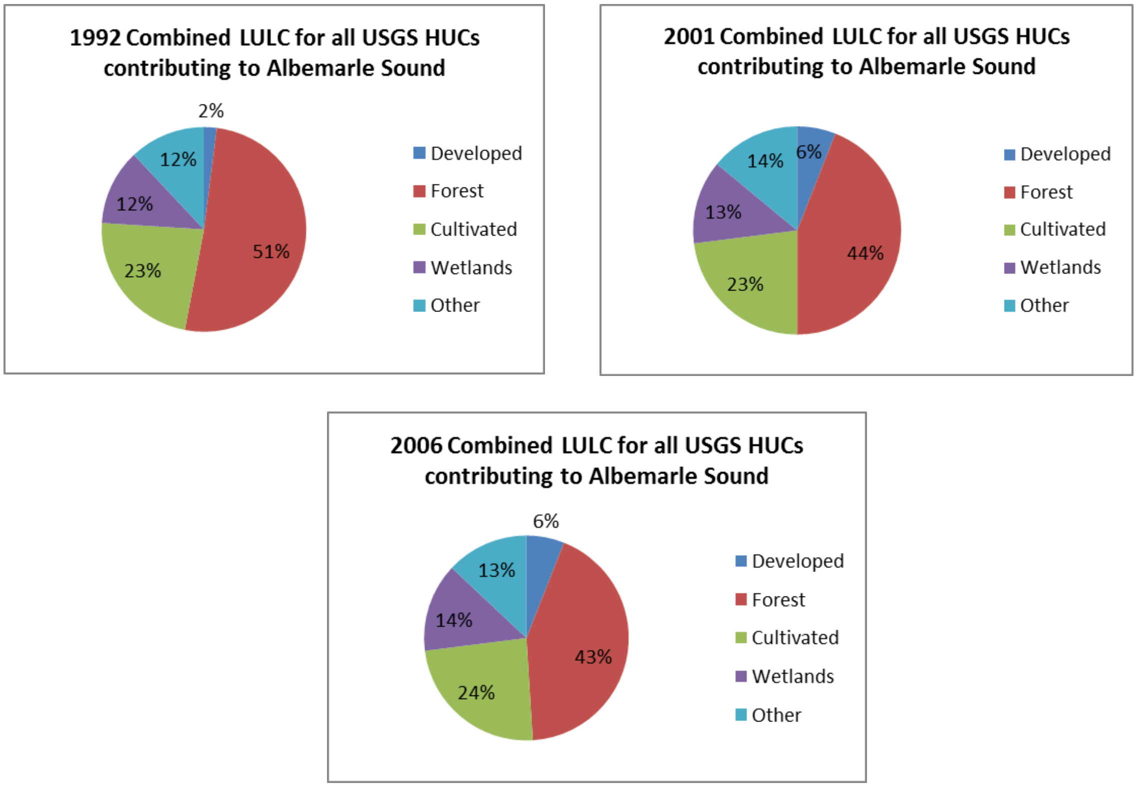


Figure 12. The percentage of LULC type from 1992, 2001, and 2006 for the entire contributing watershed area associated with Albemarle Sound.

As shown from the graphs, there was little LULC change in the study area from 1992-2006, with the most change occurring in the developed and forested areas. Developed area grew by 4% and forested area was reduced by 8%. Cultivated areas saw relatively no change, and wetlands increased by 2%. This increase in wetland cover could be the result of increased development in the region, requiring mitigation, or creation of wetlands, to comply with Section 404 of the Clean Water Act.

Differences in current landscape characteristics between sections

The 2006 LULC values for the six sections of Albemarle Sound used in this part of the analysis were very different from those calculated for the entire contributing watershed area. These sections make up roughly 13,300 km^2 or 5,000 mi^2 (less than half of the total contributing area) but could exert a stronger influence on water quality parameters measured in and around the sound due to their close proximity and high density of shoreline, a direct connection between the land and the environment. Each section does not contribute the same amount of drainage area to the Albemarle, and their relative contributions are evident in the map of the region below. To account for the differences in area, other LULC data is reported in percentage of total area or density, as well as the raw values.

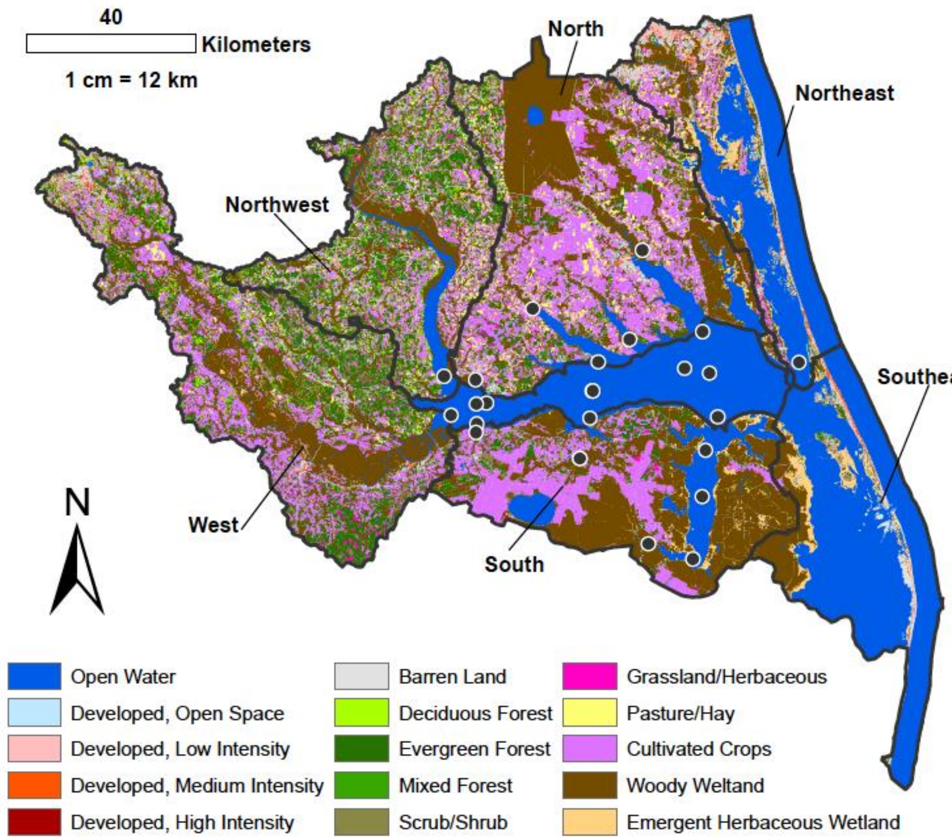


Figure 13. 2006 NCLD LULC values for each of the six contributing sections to the Albemarle Sound including the water quality sampling sites with temporally overlapping data.

As seen in Figure 13, there is a significant difference in percentage of LULC type for all six study sections. The most variable classes were also the four most intensive land uses for the purpose of our project: wetlands (all types), forests (all types), cultivated areas, and developed areas (all types).

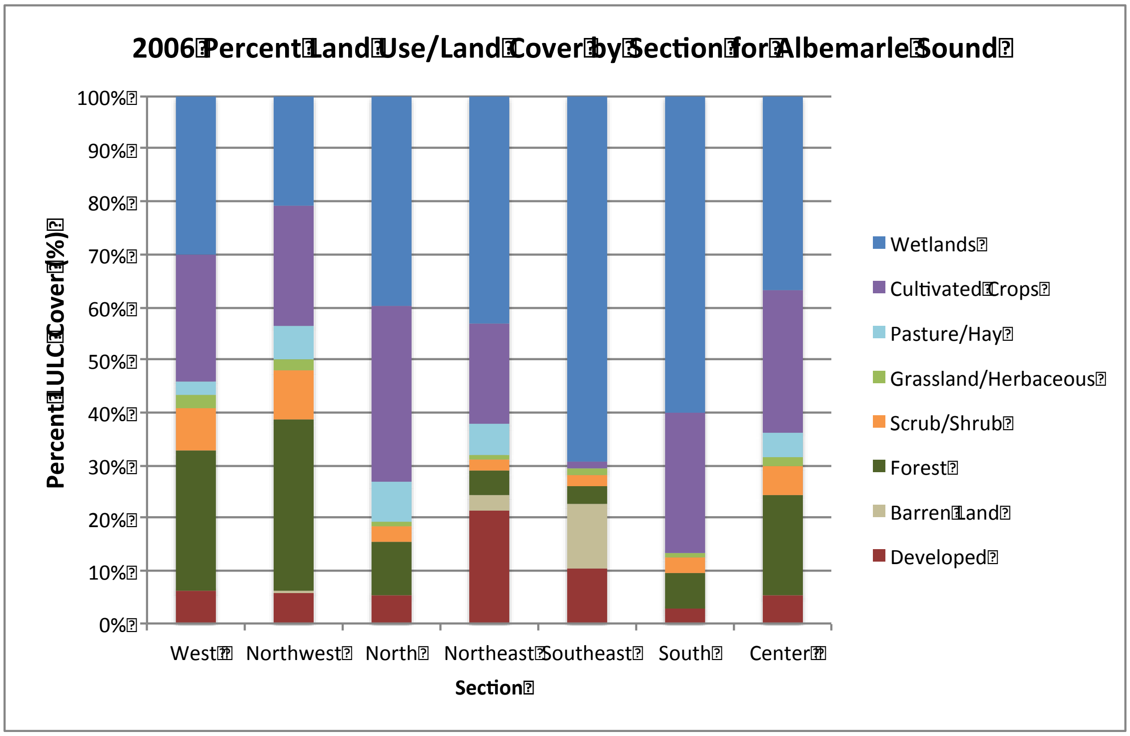


Figure 14. The percentage of each LULC type for the sections of Albemarle Sound.

As shown in Figure 14, the Southeast beach section had the largest percentage of wetlands, and the smallest percentage of forest. The Northwest (Chowan River) section, however, had the least amount of wetlands and the greatest percentage of forests. The Southeast section also had the least amount of cultivated area, while the North section had the largest percentage of cultivated area. Lastly, the Northeast beach section had the largest percentage of developed area, while the South section still remains the least developed of all six sections of Albemarle Sound. While the differences in 2006 LULC type alone could explain some of the differences in water quality among these sections, it is likely that other variables also play an important role in determining dominant water quality trends in these sections.

Much like the 2006 LULC data, major differences can also be seen when examining the length of modified shoreline in each of the sections (Figure 15).

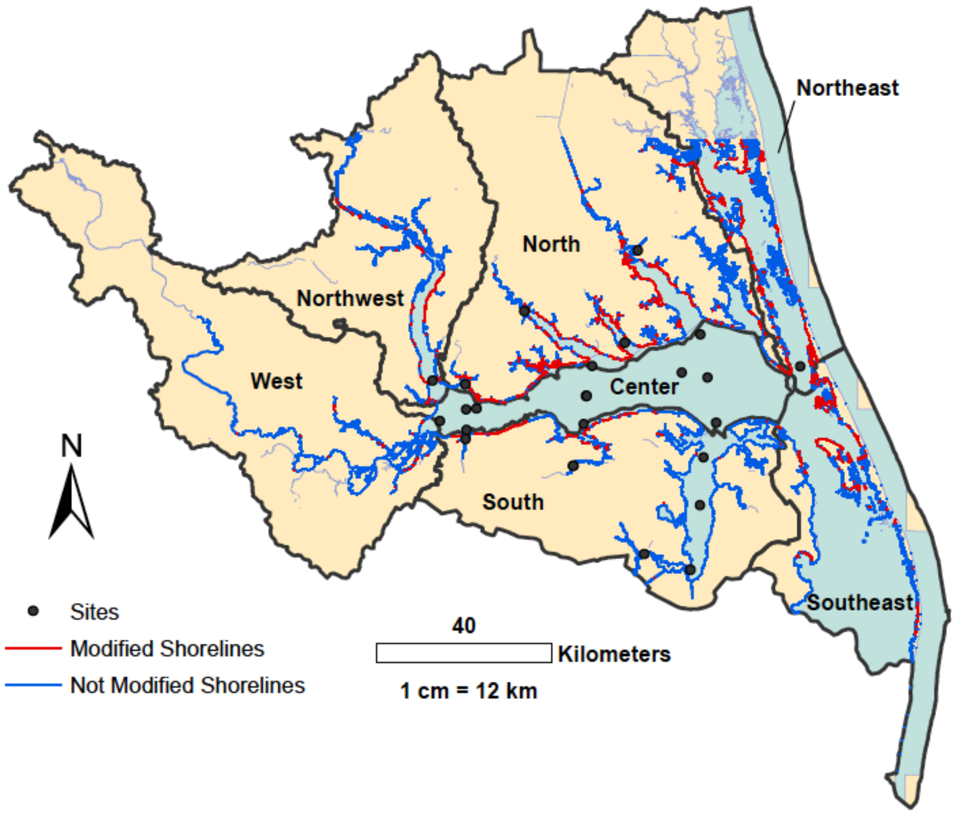


Figure 15. Modified and non-modified shorelines for the Albemarle Sound as defined by the DCM Shoreline Modification Dataset.

As shown in Figure 16 the North section had the longest distance of modified shorelines, but it also contained the greatest length of shoreline, modified and non-modified, of any of the sections. The West (Roanoke River) section had the shortest length of modified shoreline out of all of the sections. Figure 17 shows the same information, but reported as a percentage of total section shoreline. In this case, the sections are slightly less variables, and the North section has the same percentage of modified shorelines as the Northeast and Southeast sections, but twice the percentage of the South section. The West section still has the smallest percentage of modified shoreline out of total shoreline.

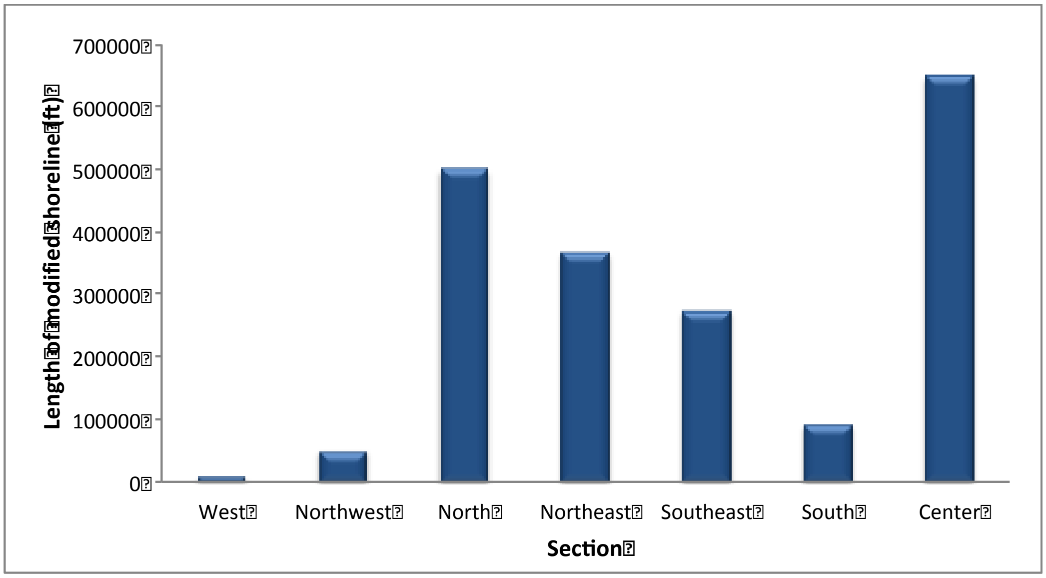


Figure 16. Length of modified shoreline (ft) for all six sections.

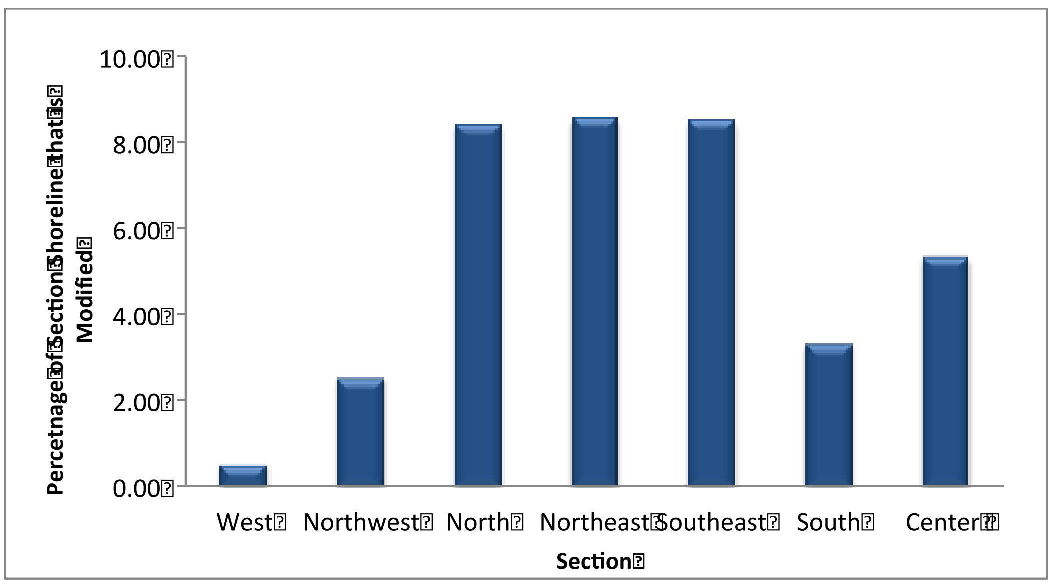


Figure 17. Percentage of shoreline in each section that is modified.

It should be noted that while the sections differ greatly in the length of modified shoreline, there is still a relatively small percentage (<10%) of modified shoreline in each section and the most common shoreline type for Albemarle Sound is overwhelmingly swamp/forest.

Similar differences between sections could also be observed from the active CAFO permit data. Only four of the six sections contain CAFOs, so no data is reported for the Northeast and Southeast (beach) sections (Figure 18).

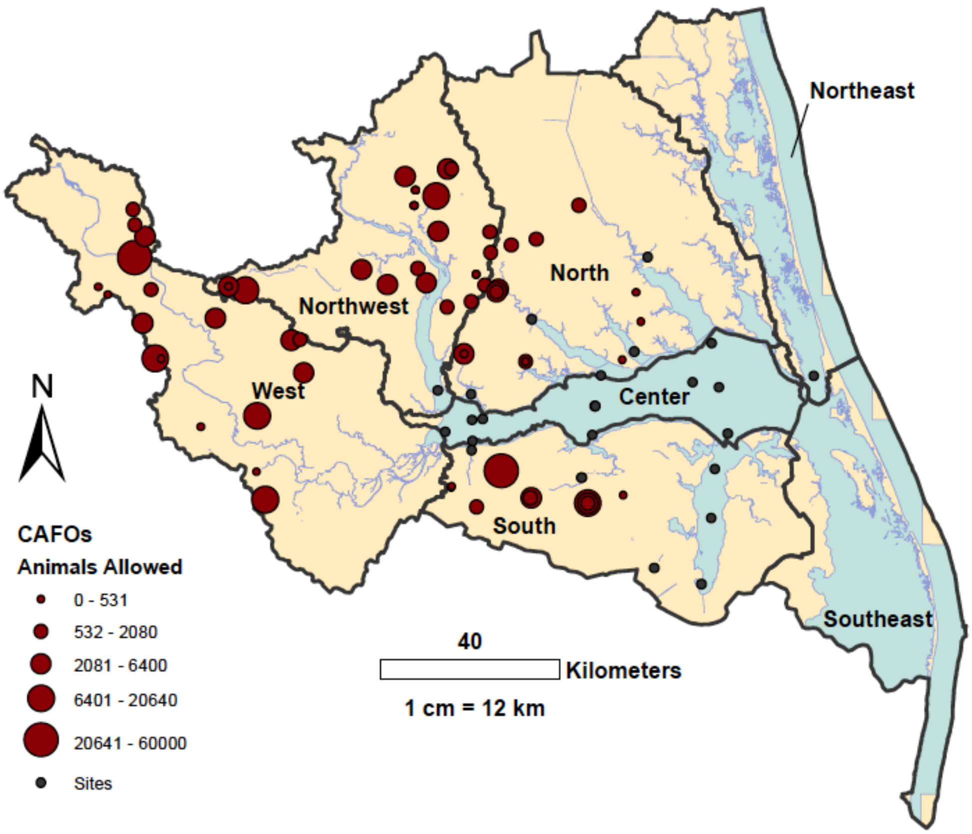


Figure 18. CAFOs in sections of Albemarle Sound, active permits as of January 2014.

Almost all of the CAFOs are swine operations, with a very small percentage of cattle operations. There is one large poultry operation in the West section, but it was not included in the density calculations for consistency purposes. Densities are based on total allowable animals and therefore may not reflect the current conditions in these facilities at all times. However, it is reasonable to assume that these facilities operate at full occupancy as much as possible to maximize profits.

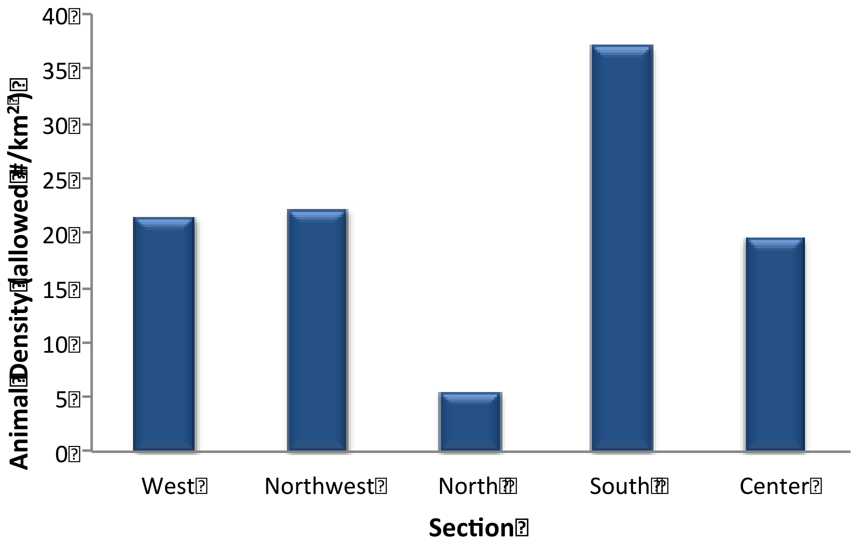


Figure 19. Shows the density (animals/km2) of animals in CAFOs for each section.

As shown in Figure 19, the South section has the highest density of animals per km^2 than any other section, with seven times as many animals per area unit as the North section. The West and Northwest sections have almost the exact same animal density, but as previously stated, the West section does contain a poultry operation that was not considered in this summary.

Summarizing these relevant landscape variables for each contributing section to the Albemarle Sound is not only important for understanding the terrestrial spatial variation but also the spatial variation in the water quality parameters and their relationships to each other. To address our hypotheses regarding signals from the landscape in water quality data, we performed thirty simple linear regressions as described in our methods.

Landscape characteristics and water quality (all graphs in Appendix D)

Given the coarse spatial resolution of our dataset, the overall strength of the relationships we examined was relatively weak, with an average R^2 value of only 0.22. However, we did observe some interesting and meaningful relationships between the LULC parameters and the average concentrations of the relevant water quality parameters, including those that were predicted in our hypotheses and some that were not (Table 4).

Table 4. R^2 values of all simple linear regressions (Blue indicates a relationship with a positive direction, and red indicates a negative direction.)

LULC	Dissolved Oxygen	Chlorophyll-*a*	Inorganic Nitrogen	Phosphate-Phosphorus as P	Turbidity
% Wetland	0.33	0.14	0.33	0.10	0.34
% Forest	0.30	0.31	0.26	0.07	0.14
% Developed	0.33	0.07	0.37	0.12	0.32
% Cultivated	0.02	0.43	0.00	0.04	0.05
% Shoreline modified	0.49	0.00	0.49	0.28	0.23
CAFO animal density	0.24	0.04	0.28	0.02	0.42

The strongest observed relationships in this analysis were between percent of modified shoreline and dissolved oxygen (positive direction) and inorganic nitrogen (negative direction), both with R^2 values of 0.49. We also observed a relatively strong (R^2 =0.43) positive relationship between percent cultivated area and average chlorophyll-a concentration as well as CAFO animal density and average turbidity levels (R^2 = 0.42). Other relationships were also observed, but with decreasing strength, such as decreasing chlorophyll-a concentration with increasing percent forest cover and increasing inorganic nitrogen with increasing percent developed area. The strength of the relationships between the landscape variables and the phosphate-phosphorus as P data was the weakest, probably due to the limited number of samples.

Discussion

Long-term trends

The West and Southeast parts of Albemarle Sound had quite low and stable chlorophyll-a concentrations temporally (less than 10 ug/L), indicating the eutrophication problem may not be a concern in Albemarle Sound, especially in these parts. However, due to the limited availability of the historic monitoring data for chlorophyll-a, there are long-period monitoring gaps in all of the sections. Also, the standard deviation error suggests that there are large variations among the sample sites measured during summer or wintertime in one section, or the variations may be attributed to the difference of measured values in the sample activities through summer or wintertime.

Due to the limited availability of the historic monitoring data for DO, the standard deviation error is moderately large, especially for the North and South parts, suggesting the uncertainty of the estimation we made based on the historical data. Similar to chlorophyll-a, there are many potential explanations for the large variations, such as the variation between different sites measured in the same area in the same season, and the variation between different sample activities in one site in the same season.

All but 3.1% of turbidity measurements met EPA standards, which suggests that turbidity is not a concern for Albemarle Sound, and the seasonal turbidity has not changed much over time. However, due to limitations in the period of record for the historic monitoring data of turbidity, the standard deviation is moderately large, especially for the Center, North and South sections, suggesting estimations based on this data may be uncertain. There are many potential explanations for the large variations, such as the variation between different sites measured in the same area in the same season, and the variation between different sample activities in one site in the same season.

Generally, inorganic nitrogen concentration peaks occurred in wintertime and decreased in summertime, then increased again in the following wintertime. Throughout history, the inorganic nitrogen level has been somewhat stable. However, the results may suggest that the South section of Albemarle Sound has a history of water quality issue with respect to inorganic nitrogen compared with other sections of the sound. Limited data availability led to a high standard deviation in south section, and most values extend beyond the graph scale. This may mislead the temporal trend and the estimation we made.

While no clear trends were observed in phosphorus, the high concentrations in the North and South parts of Albemarle Sound may suggest a history of water quality problems with respect to phosphate-phosphorus compared with other sections. The error in the North and South sections is quite large, indicating less certainty in our estimation based on the graphs larger than 0.1 mg/L. On the other hand, phosphorus concentrations in other parts are less than 0.1 mg/L all the time. There are no obvious patterns in terms of season impact – some of the peaks happened in summertime, others happened in wintertime. Throughout history, phosphate-phosphorus level has not changed much, especially for the Southeast and West parts of Albemarle Sound. No obvious increase or decrease is observed. The standard deviation error is quite large in the North and South sections, indicating high variability.

Water quality relationships and levels

The positive relationship between phosphorus and chlorophyll-a, and negative relationship between phosphorus and dissolved oxygen supports the belief that phosphorus is the limiting nutrient of the Sound. In a phosphorus-limited system, high phosphorus levels would cause a spike in productivity, which increases chlorophyll-a levels. Generally dissolved oxygen is depleted once the new phytoplankton growth dies back, so the presence of low oxygen levels during times of high chlorophyll-a could represent the beginning of the die-back period. However, having only instantaneous, point-in-time data does not allow us to examine the temporal coupling of parameters. We know what occurred at the same point in time but cannot tell if oxygen or phosphorus were increasing or decreasing at that point in time. The positive correlation between turbidity with phosphorus and nitrogen levels suggest that nutrient pollution comes from sediment runoff, since fertilizer often contains both nutrients.

Low dissolved oxygen levels when nutrient concentrations are high demonstrate that the Albemarle Sound could be affected by eutrophication. Differences in the magnitude and direction of parameter relationships between sections indicate that geographic locations within the Sound function in different ways. A particularly interesting trend is the opposite relationship between dissolved oxygen and phosphorus in the Center section of the sound compared with the North and South branches. Areas along the edges of the sound display the expected reduction in oxygen when phosphorus is high. Phosphorus appears to be driving eutrophication processes in the North and South sections. When phosphorus is high, DO is low, and chlorophyll-a is high, indicating harmful enrichment. It is unclear why high oxygen and phosphorus concentrations occur together in the Center section.

By comparing the water quality in sections across all time scales, it is clear that regional differences in the Sound are important. Differences between the North and South regions of the Sound may be evidence of wind impacts on circulation. Prevailing winds can easily mix and move water across the Sound, causing upwelling in the downwind region, which could be the cause eutrophication in the North and South. The lack of importance of latitude in the eastern, more saline regions of the Sound may be an effect of their greater connectivity with oceanic waters. The mixing from ocean tides and currents may be the cause of similarity of the Northeast and Southeast regions. In the future, the North and South sections should be monitored more thoroughly because they are most vulnerable to eutrophication.

LULC analysis

The analysis of landscape characteristics increased our understanding of the differences between the sections of Albemarle Sound by adding a terrestrial component. While simply summarizing the percentages of LULC type, modified shorelines, and CAFO animal density by section can provide important insight on terrestrial drivers of water quality in these areas, it is not enough to adequately address our hypotheses regarding specific land uses and resulting concentrations of the water quality parameters. However, despite their limitations and relatively low strength of the observed relationships, the results of the simple linear regressions can begin to answer these questions.

Wetlands and forests

The results from the simple linear regressions with our water quality parameters and percent wetland cover were the exact opposite of what we predicted with our hypotheses. According to our analysis, higher percentages of wetland cover actually cause increases in nutrients, turbidity, and chlorophyll-a, which is not an effect supported by the literature. While these results could be caused lack of temporal and spatial resolution of the data, these unexpected results could also be caused by the species of nutrients we are measuring, since our data did not include measurements of total phosphorus and total nitrogen. This would not explain the unexpected chlorophyll-a results, however. It could be that the percentage of wetland cover simply has no relative effect on chlorophyll-a concentrations, and changes in this parameter are primarily driven by some other landscape variable or combination of variables.

Unlike wetland cover, the regression analyses with percent forest cover did, in fact, support some of our initial hypotheses. We found that dissolved oxygen does have a positive relationship with percent forest cover, and chlorophyll-a shows a negative relationship. Interestingly, despite the expected relationship being observed with chlorophyll-a concentrations, the same was not observed for nutrients and turbidity. Again, a likely cause of this is the fact that we don't have measurements for total phosphorus and total nitrogen. The unexpected results could also be caused by the extremely coarse and spatially biased resolution of the water quality data. It could also be that some other landscape variable or combination of variables has more of an effect on these particular water quality parameters than percent forest cover.

Developed and cultivated areas

Almost all of the regression analyses with percent developed and percent cultivated area yielded unexpected results, with the exception of percent cultivated area and chlorophyll-a concentrations, which showed a relatively strong positive relationship with an R^2 value of 0.43. This is the relationship that we expected to see since it is well documented that intensive commercial agriculture contributes large amounts of nutrients through runoff from excess fertilizer. It is interesting that while we observed this expected relationship with chlorophyll-a, the same relationship was not observed with cultivated area and nutrient concentrations. In fact, no relationships whatsoever were observed between cultivated area and the other parameters. Again, this could be due to the fact that we are only measuring part of the total phosphorus and total nitrogen concentrations. It could also be that the temporal resolution of the water quality data was too coarse to detect changes in nutrient concentrations related to land use and land cover. The unexpected relationships observed between percent developed area and the water quality parameters could perhaps be explained by this, as well. It is more likely, however, that since there is very little development in the sections of Albemarle Sound, this area is simply not exerting as much influence on water quality as other landscape variables.

Modified shorelines and CAFO animal density

The regressions with modified shorelines and CAFO animal density also yielded mixed results as it relates to our initial hypotheses. For modified shorelines, every relationship that was predicted turned out to be the exact opposite. Especially for the parameters of dissolved oxygen and inorganic nitrogen (with R^2 values near 0.5), this could indicate that building erosion control structures has little control on the water quality in each section. Or, it could indicate that our water quality sampling sites were simply not physically close enough to the modified shorelines for the average concentrations of our parameters to be affected.

The results from the regression analyses with CAFO animal density conformed more to our original predictions. As expected, turbidity levels were shown to increase with increasing CAFO animal density in each section ($R^2 = 0.42$). It is very well documented that animal waste contributes significant amounts of suspended solids to surface waters, increasing turbidity. Furthermore, our analyses also confirmed our hypotheses that increasing CAFO animal density correlates to increasing nutrient concentrations, but this relationship was only observed with inorganic nitrogen and not with phosphate-phosphorus as P. This difference could be the result of the lack of phosphorus data compared to inorganic nitrogen data. Or, this difference could be explained by the fact that phosphorus is preferentially retained in soil while nitrogen is more easily transported through the water column. These results could also be skewed by the fact that we do not have data for total phosphorus or total nitrogen. The negative relationship observed between dissolved oxygen and CAFO animal density was also predicted, as increasing nutrient enrichment from these facilities can stimulate algal blooms that cause dissolved oxygen concentrations to drop. However, there was no relationship observed between CAFO animal density and chlorophyll-a, so this explanation may not be sufficient. Perhaps this is the result of poor spatial and temporal resolution, or perhaps there is another variable or combination of variables that exerts a stronger influence on the water quality data.

LULC and water quality in sections of Albemarle Sound

Based on the results of the LULC and water quality analysis, we may conclude that sections of the sound with higher percentages of cultivated area could be at a higher risk of elevated chlorophyll-a concentrations and potentially algal blooms. While the observed relationship was not statistically robust, the signal is strong enough to suggest that managers may benefit from monitoring these sections (i.e. North and South sections) more closely for nutrient enrichment problems related to agriculture. In the same vein, managers may also benefit from closely monitoring sections with higher CAFO animal density for elevated turbidity levels. In this case, The South section should be considered extremely vulnerable to sediment pollution as it contains the largest density of animals in CAFOS. Even though high turbidity levels are not a direct cause of eutrophication, sediments often carry a suite of pollutants with them as they are transported through the surface water system.

Limitations and Conclusions

While many insights about the internal functioning of Albemarle Sound can be drawn from this project, we were limited in our statistical power by inconsistencies in the data. While there is a multitude of data points for the Albemarle Sound for the last 40 years, changing methodologies have rendered some data incomparable. Changing detection limits, new laboratory techniques, and changes in nutrient quantification strategies all caused some data to be unusable for this study.

Quantifying different species of nutrients in different years makes it difficult to examine change, since conversions between species are usually not possible. We recommend that the current method of measuring nutrients, total nitrogen and total phosphorus, be continued because of its ecological significance. However, the older measurements should still be collected as well, to enable long-term studies. In addition, some of the longest running stations were eliminated in recent decades. Even when the same measurement, such as dissolved oxygen, was measured consistently, quantification was sometimes by volume, and sometimes by mass.

The lack of discharge data in the tributaries of the sound is perhaps the most restrictive problem. Determination of nutrient loads is impossible, and precipitation impacts on concentration are difficult to determine. In addition to these specific problems encountered during this study, the standard statistical difficulties with left-censored water quality data are present.

The spatial resolution of water quality sampling sites from this particular dataset was particularly limiting. The majority of the sampling stations that collected all five parameters of interest and coincided temporally with our period of study were heavily clustered around the Center section. Less sampling work was completed for the further upstream parts of our study sections, making it more challenging to draw explicit connections between land use and land cover and water quality measurements. Furthermore, there is currently no standard, easy-to-reproduce method for delineating exact contributing areas for sampling sites located several miles from the shore of the sound. This also weakens the relationships that can be observed between LULC and water quality variables since the majority of the water quality data is sampled further offshore.

Considering the temporal performance of all five parameters we chose in different parts of Albemarle Sound, we could discover several things: 1) Overall, water quality in Albemarle Sound is good over time. 2) Different seasons may influence the values of some parameters in some parts of the sound. 3) In light of inorganic nitrogen and phosphate-phosphorus, we may pay more attention on the North and South sections of Albemarle Sound, as these two sections were more vulnerable to nutrient problems in history. 4) There are major differences in landscape characteristics between sections, offering some explanation for differences and water quality, and 5) There are some signals in the average concentrations of the five water quality parameters from 2006-2013, indicating that terrestrial drivers such as CAFO animal density and percent cultivated area could be important drivers for water quality in the Albemarle Sound.

While limited in scope, this project reveals geographic and temporal scale water quality dynamics in Albemarle Sound. We hope that this data can be used to inform further projects, and help the USGS improve the monitoring program in the Sound. By synthesizing many different sources of data, we aimed to maximize the usage of available data on the Sound. We hope that other studies will include wind and discharge models to draw more conclusions from this massive historical database of information on the Albemarle Sound.

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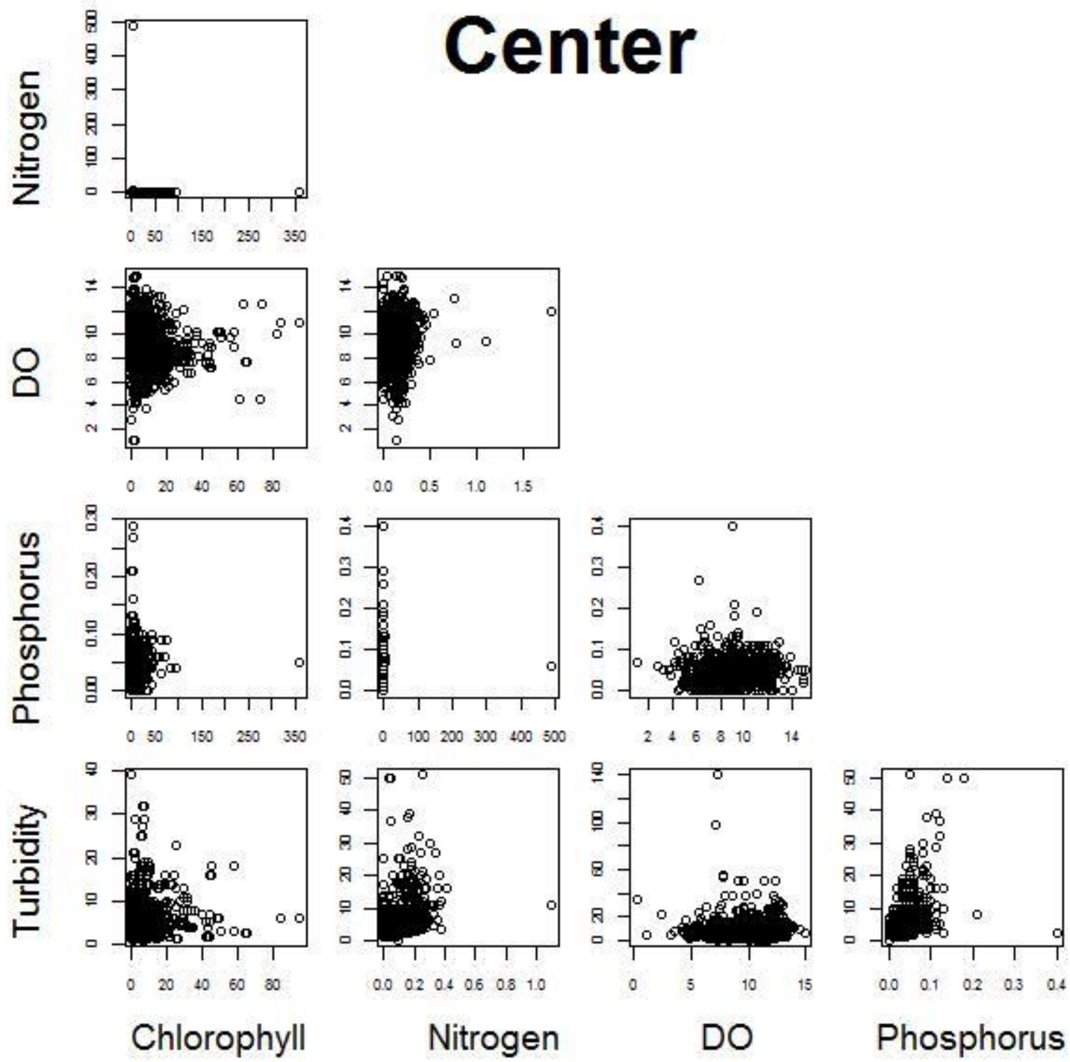
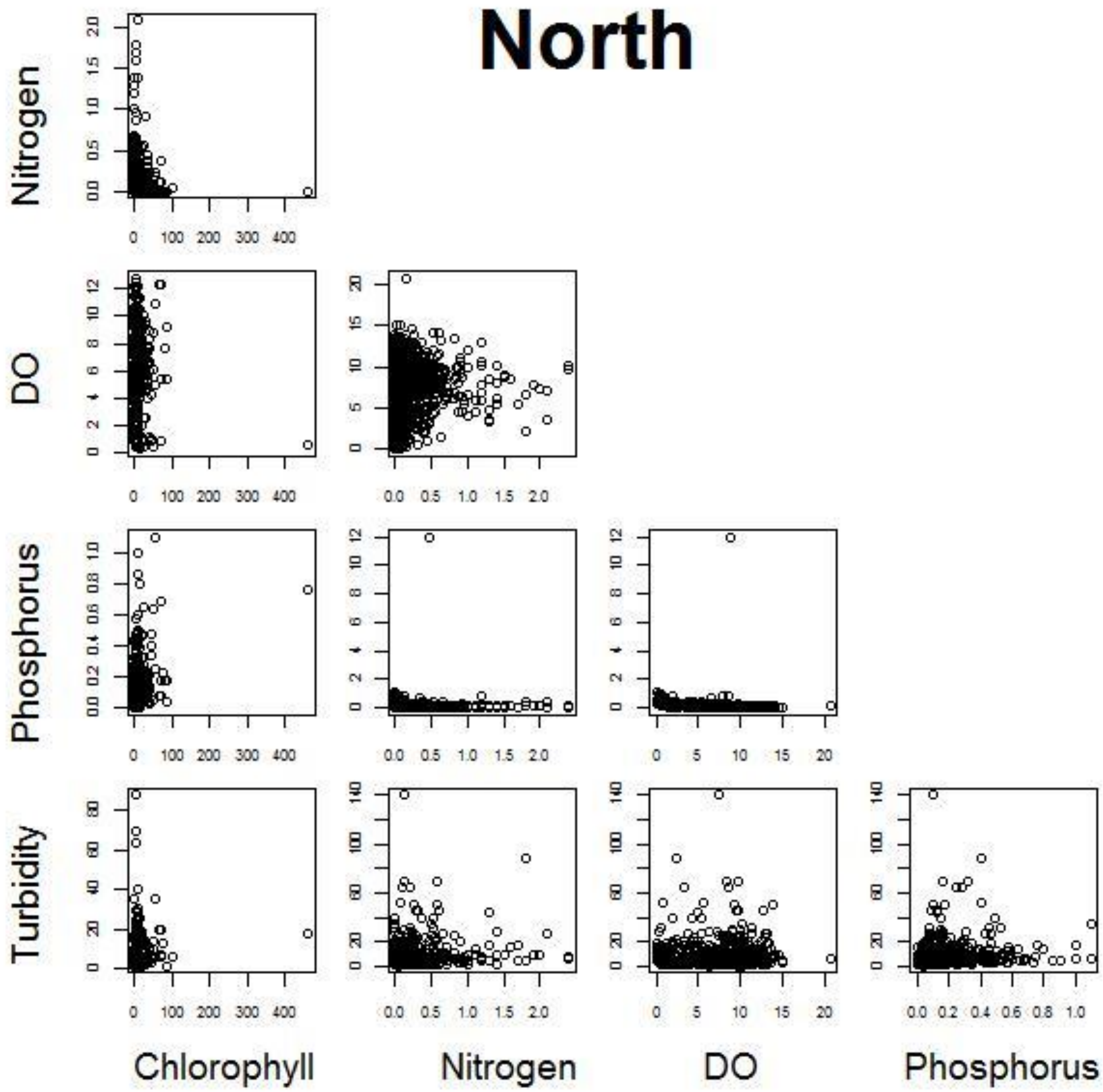
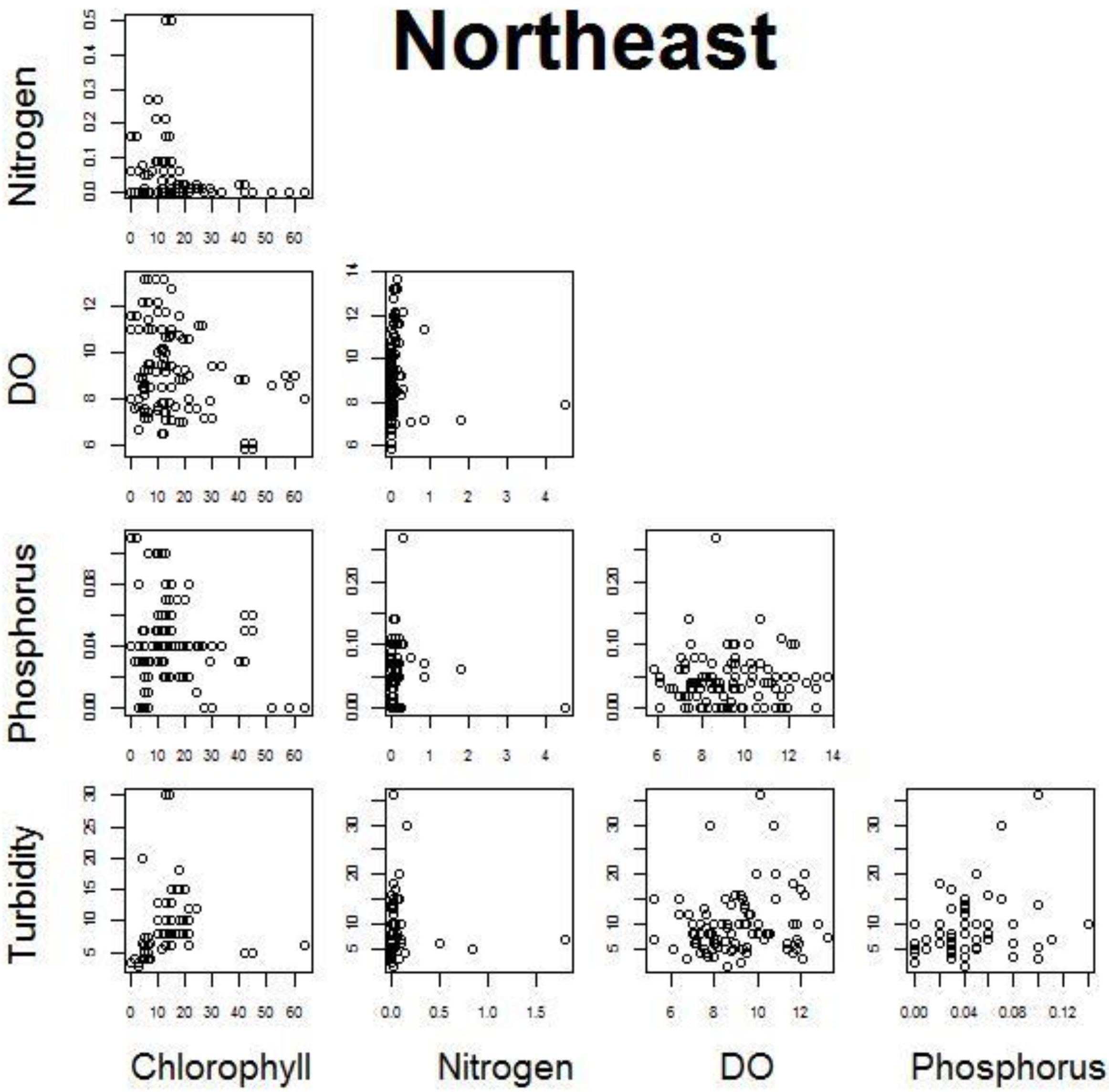
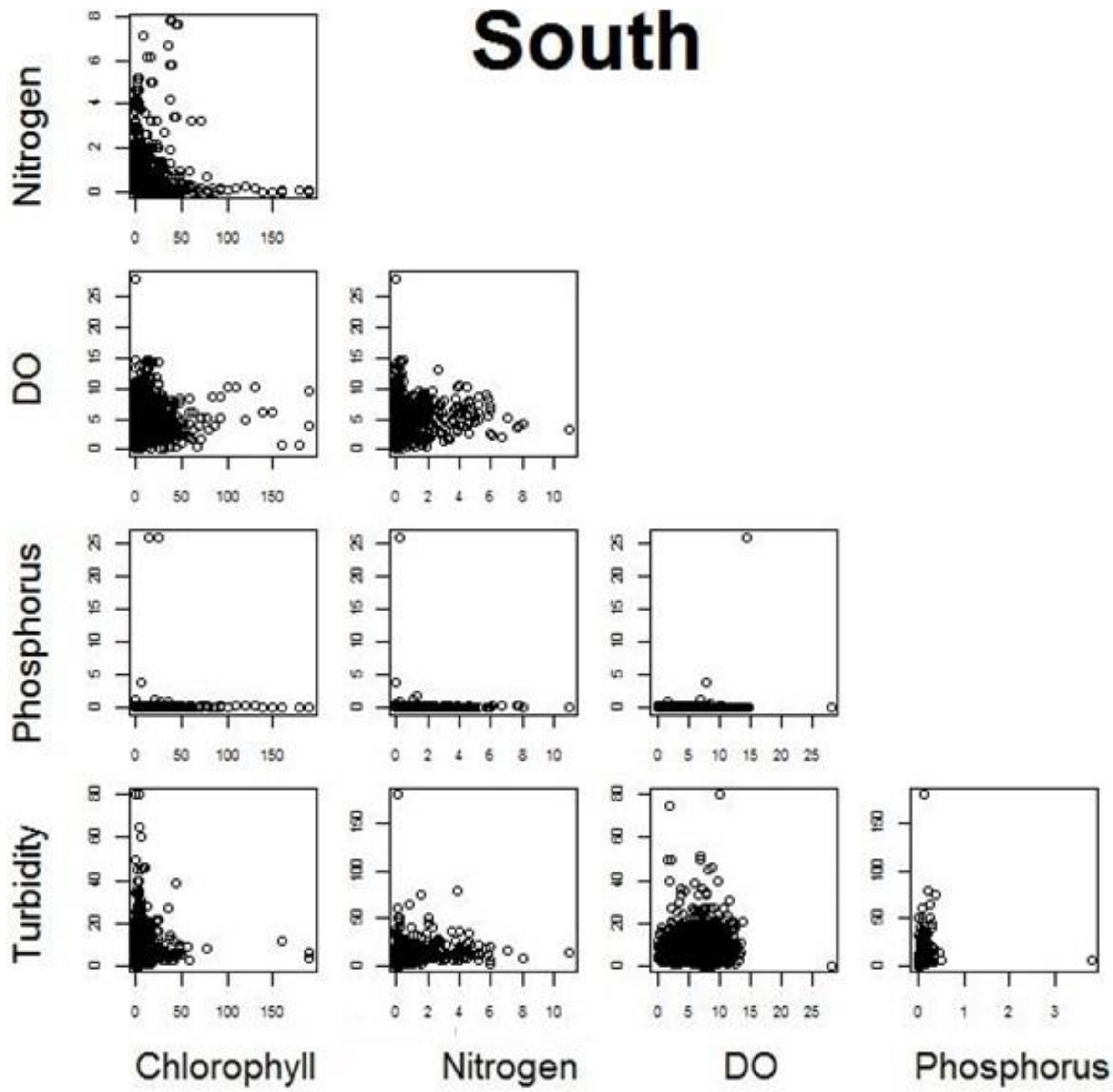
Appendix A – Correlation Plots of Water Quality by Section

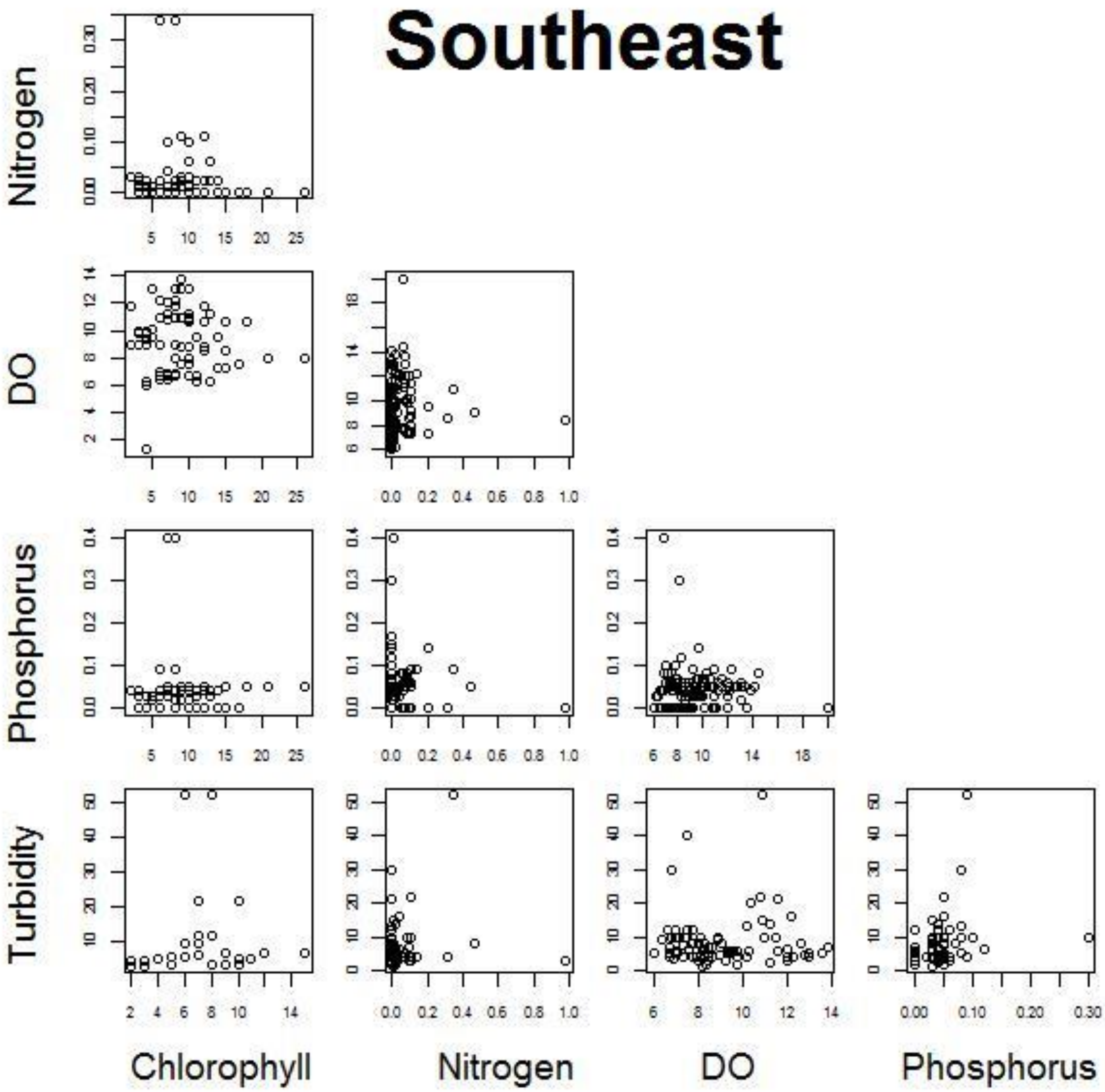


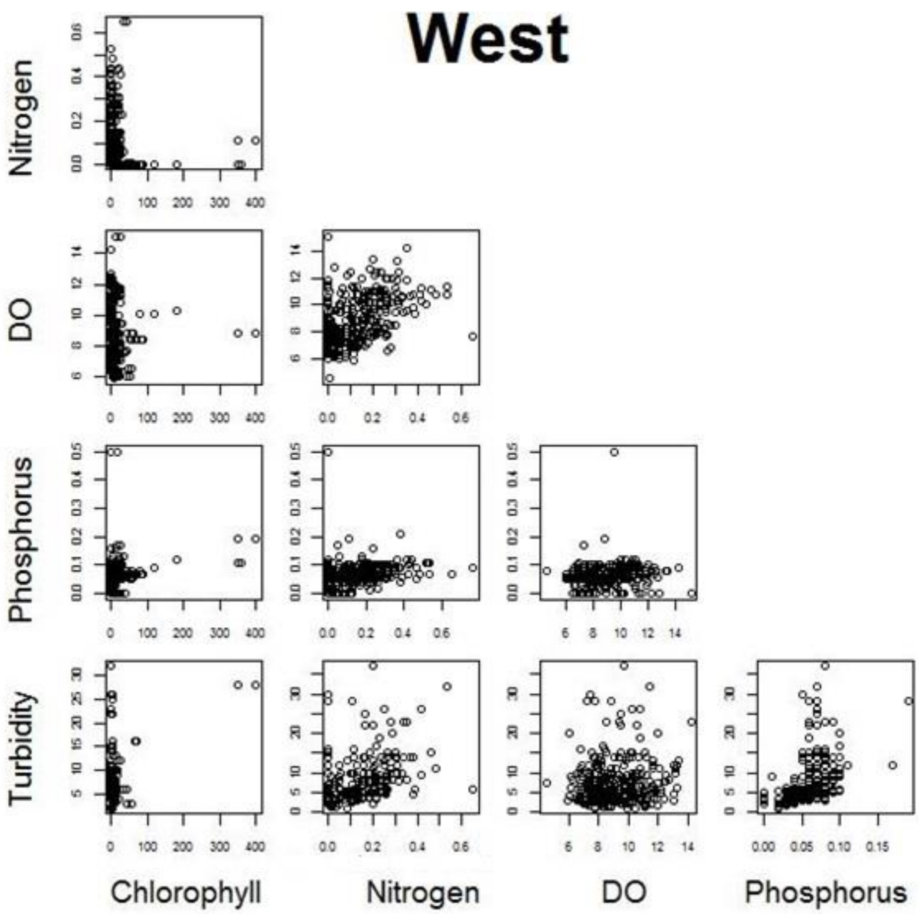

North
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

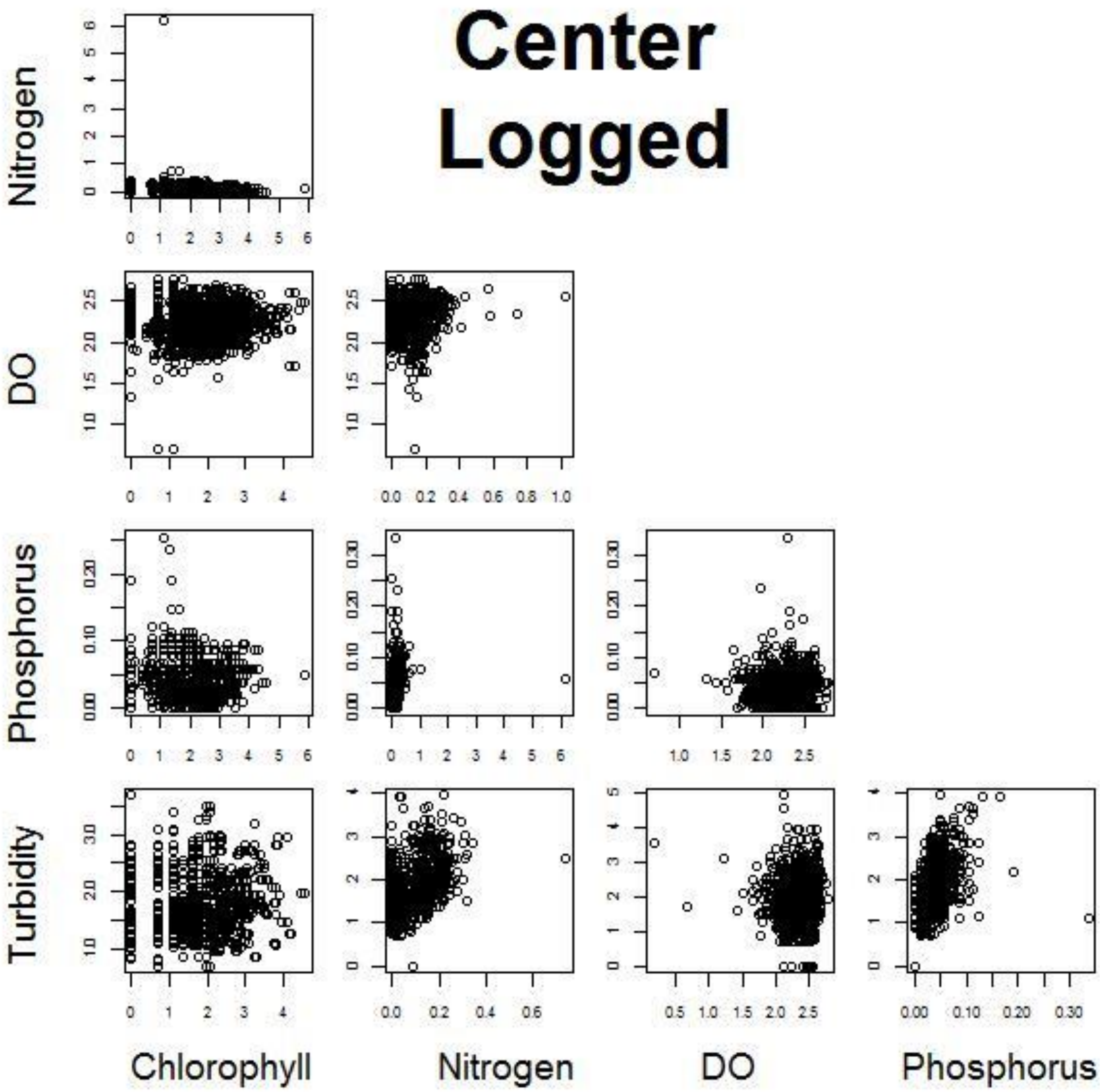


Northeast
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

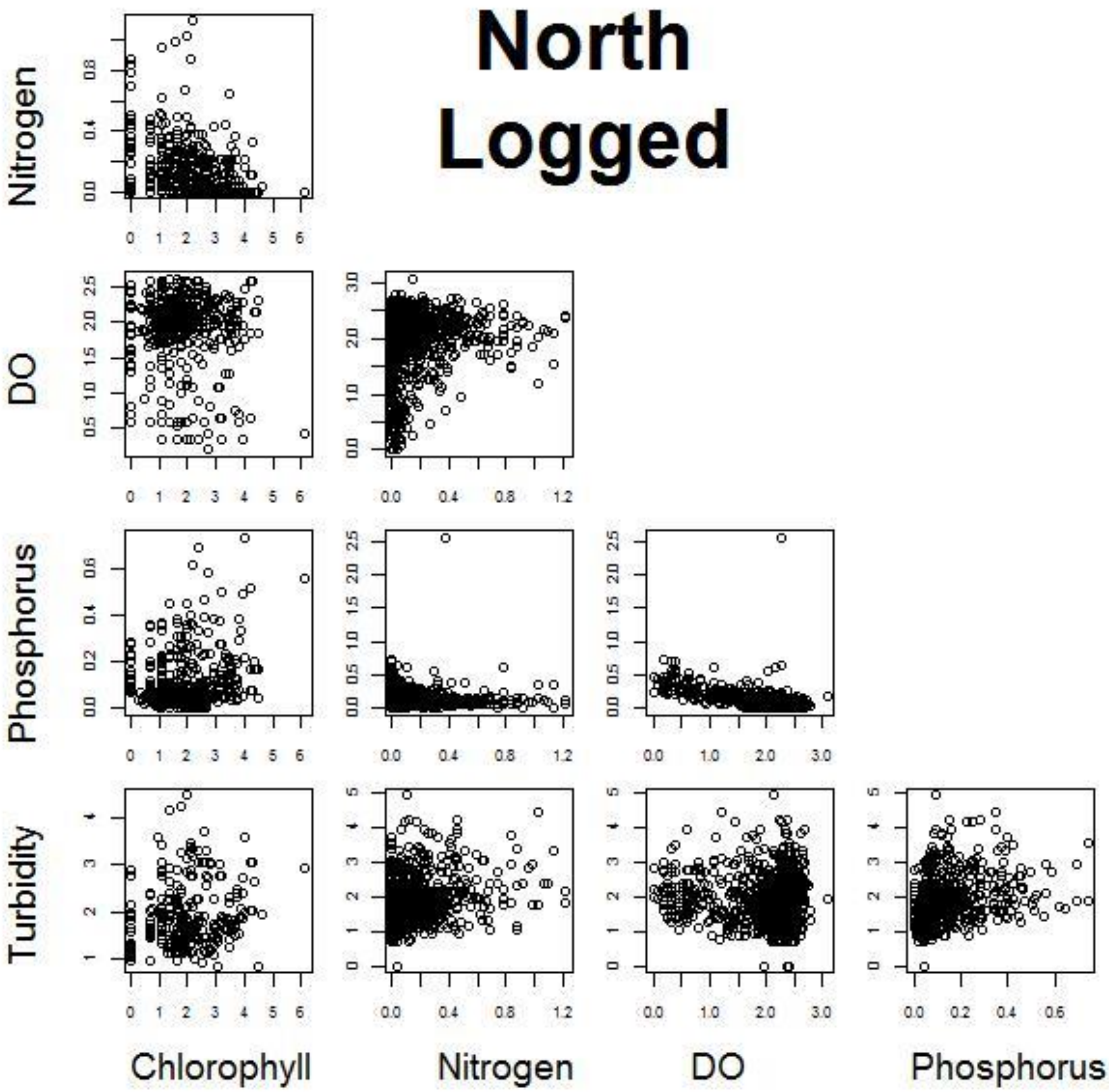

South
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

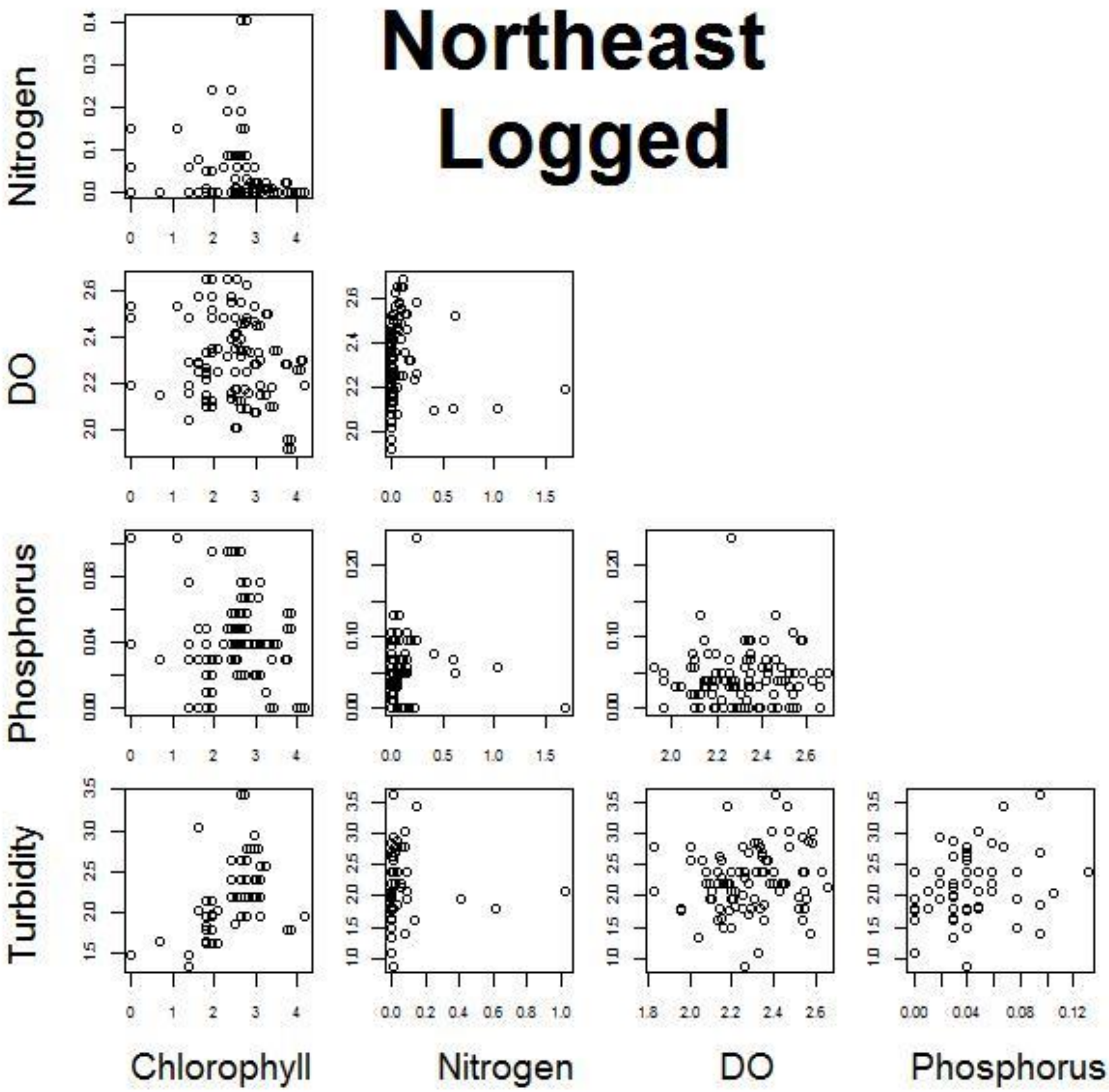

Southeast
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

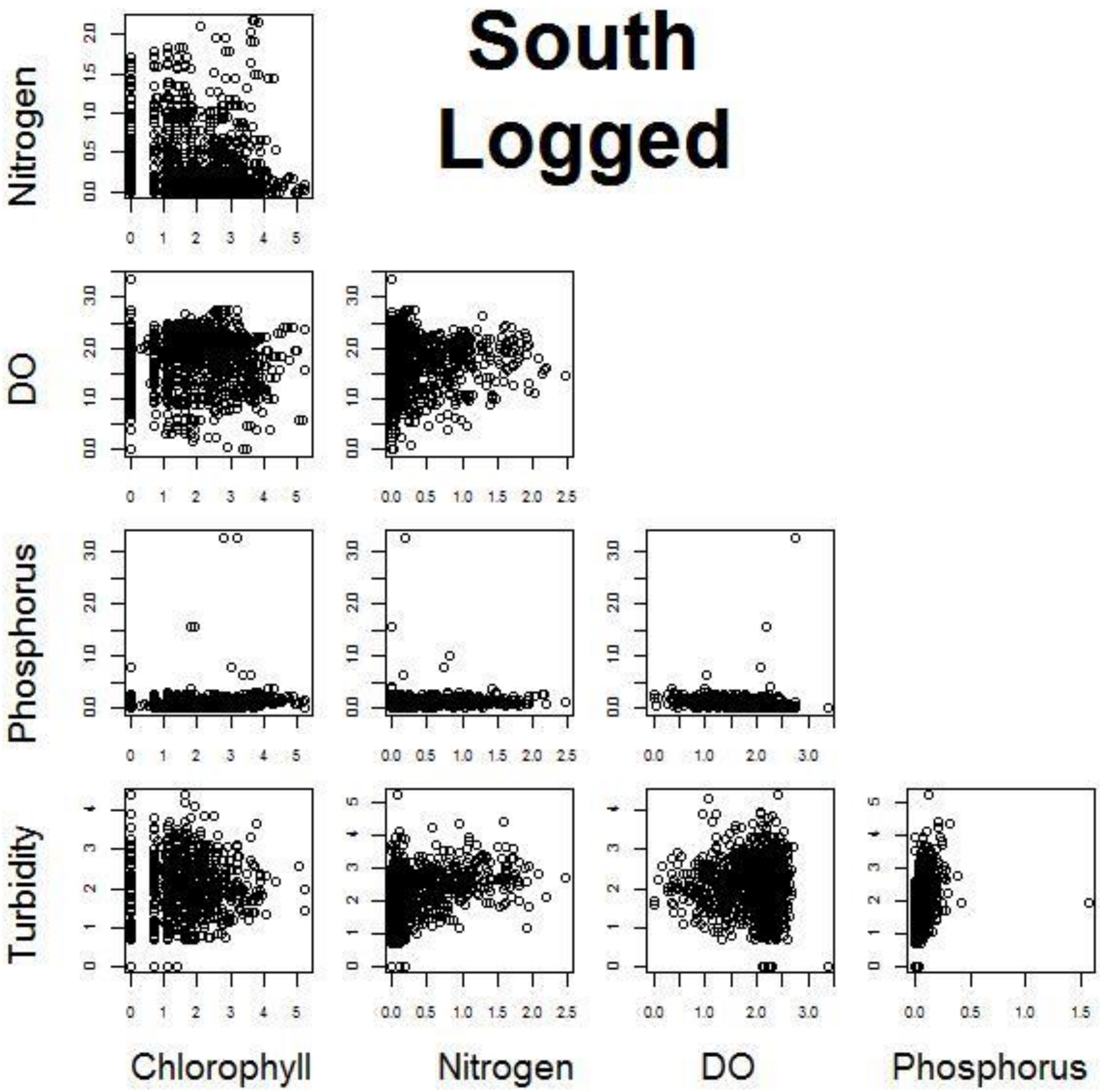

West
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

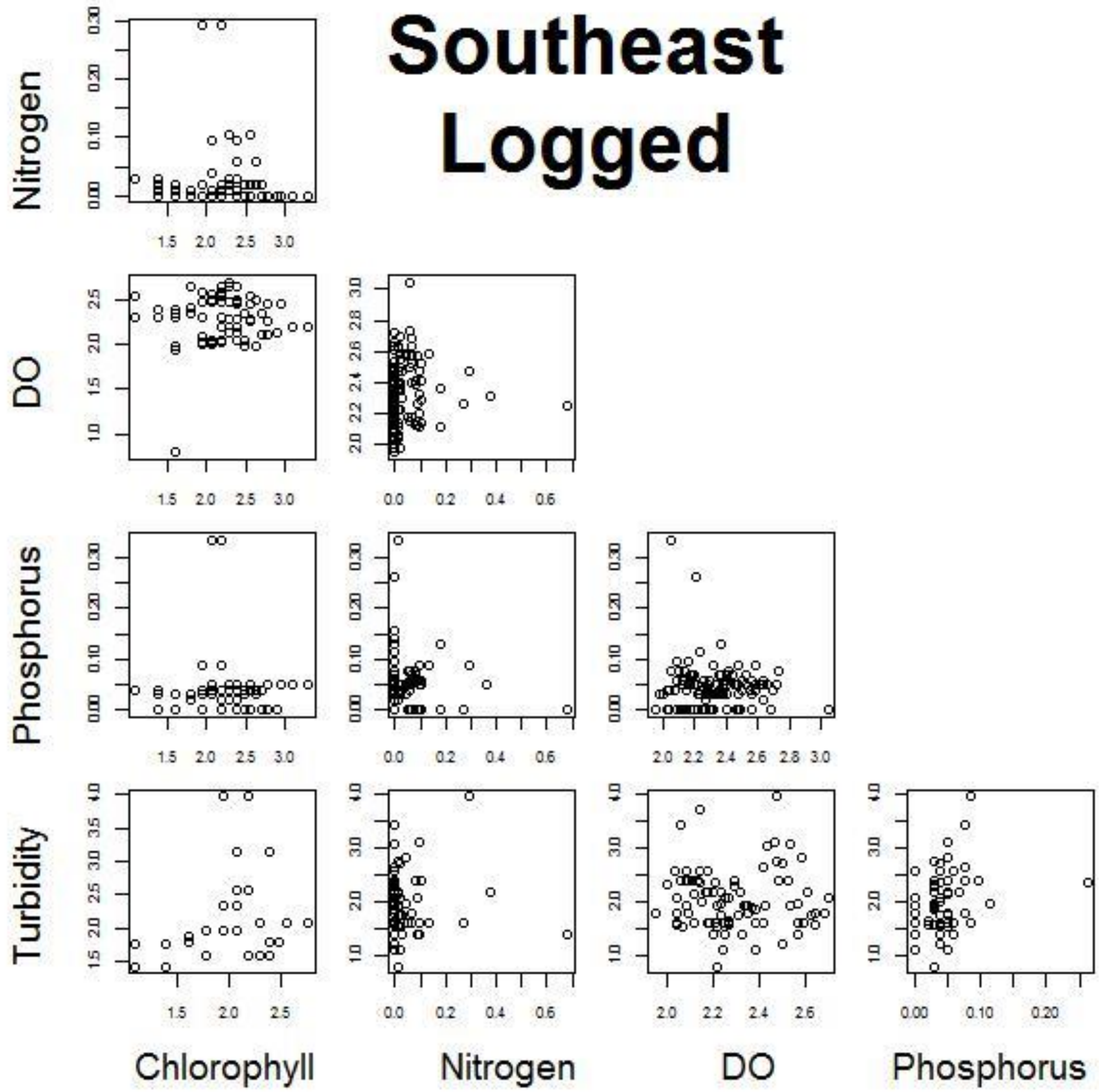


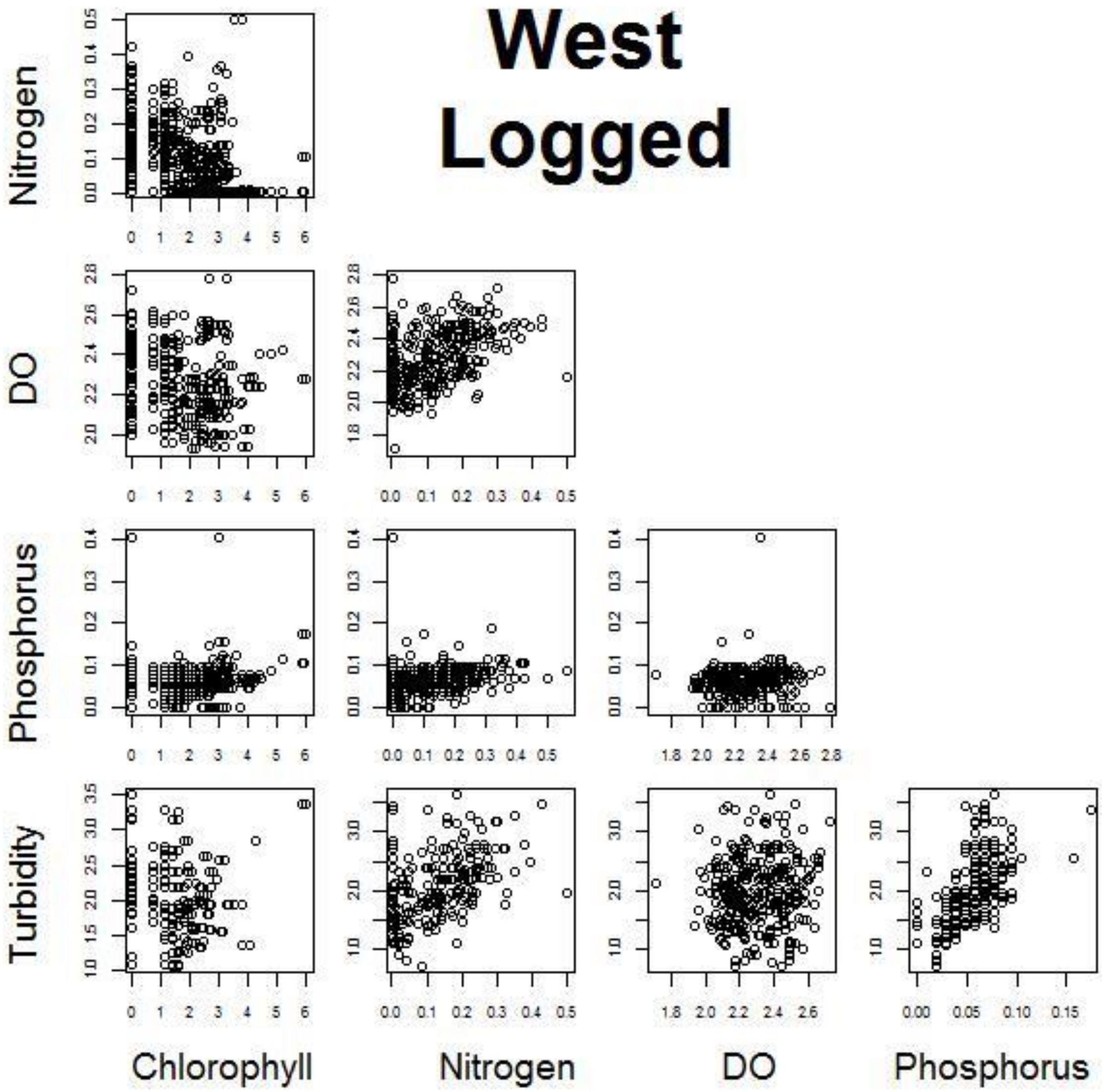
Center
Logged
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus


North Logged
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

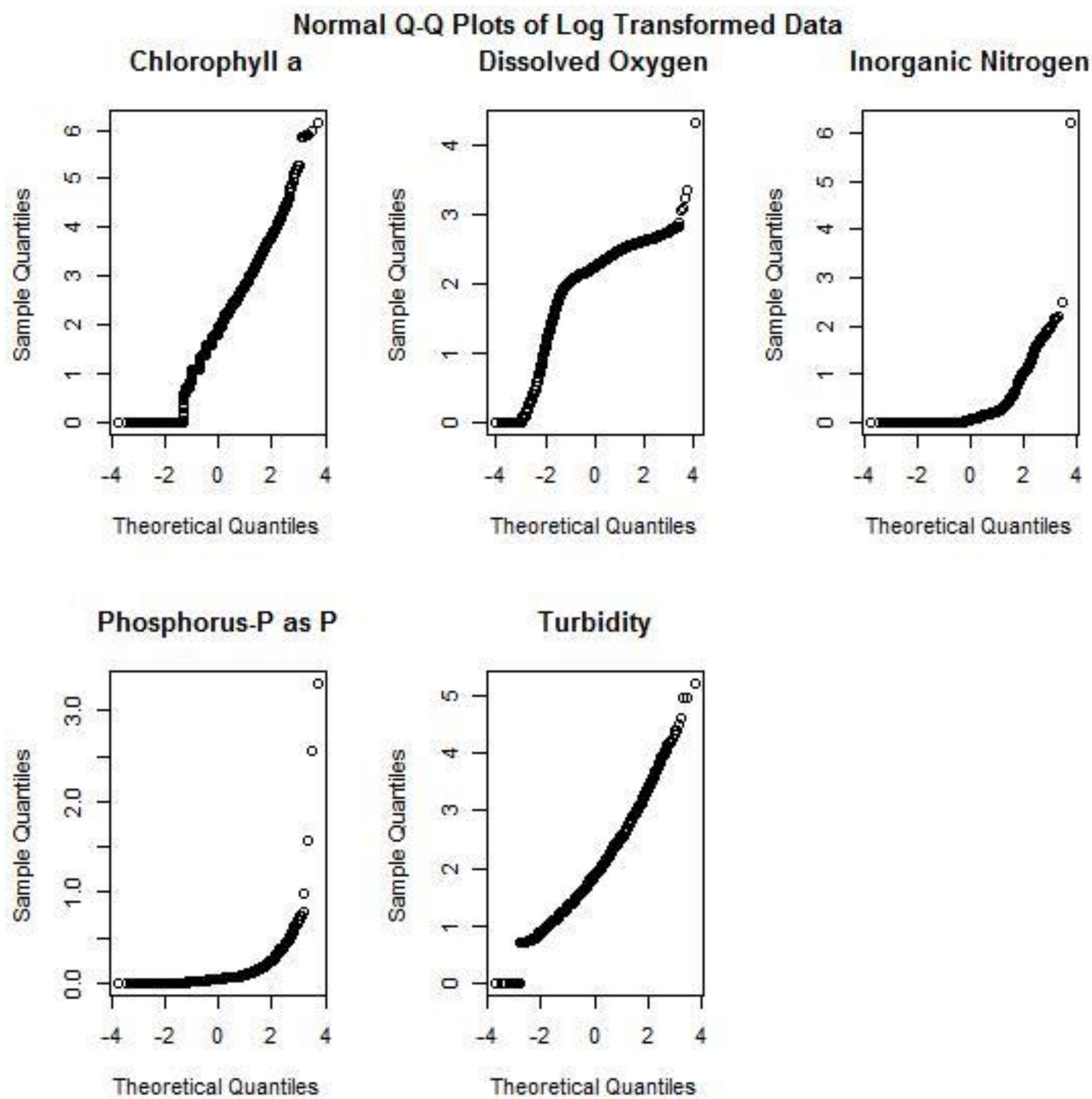

Northeast
Logged
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus


South
Logged
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

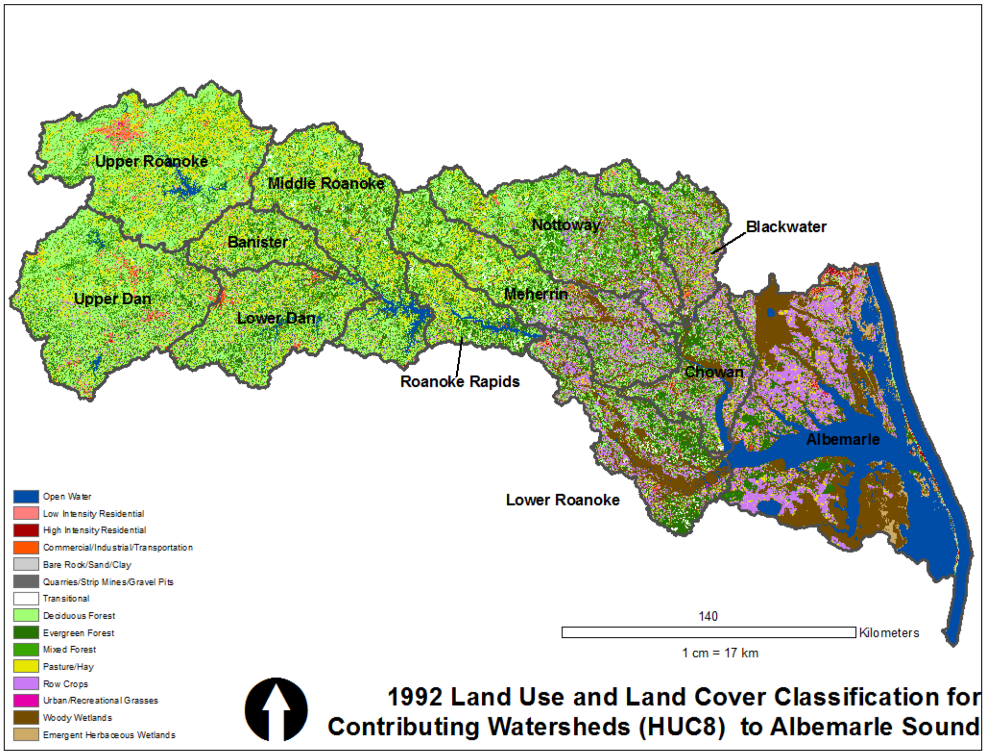

Southeast
Logged
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

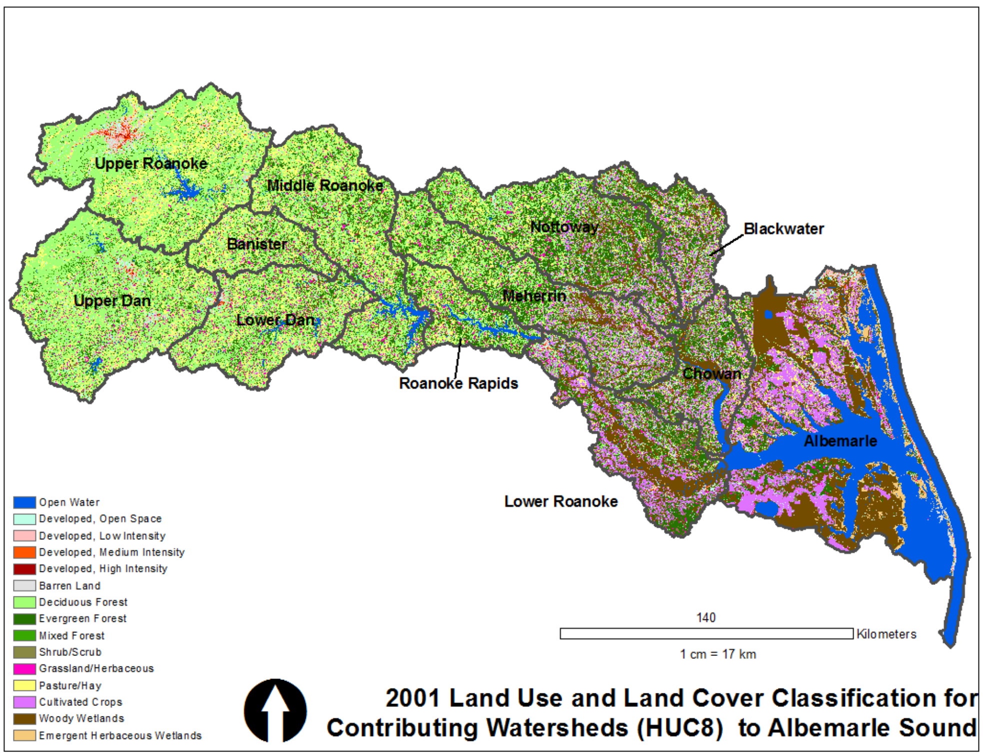

West
Logged
Nitrogen
DO
Phosphorus
Turbidity
Chlorophyll
Nitrogen
DO
Phosphorus

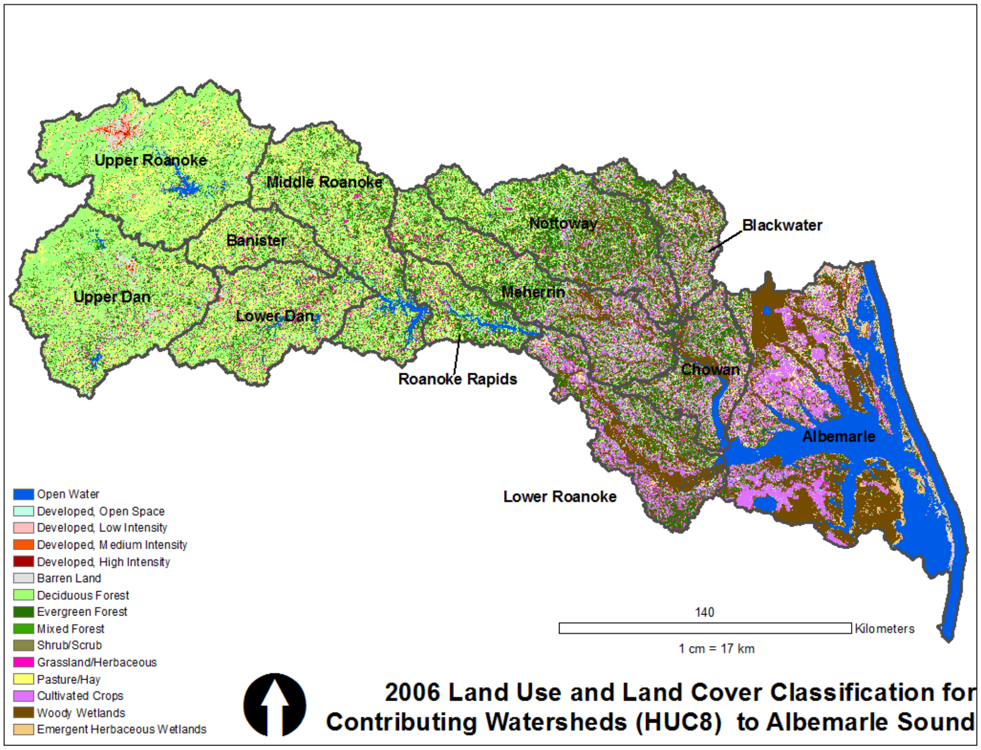
Appendix B – Q-Q Plots of Water Quality Parameters

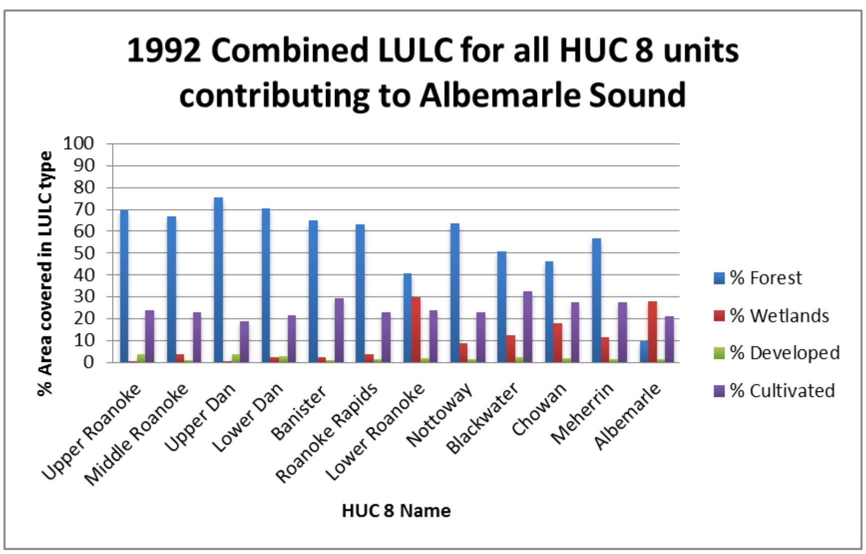


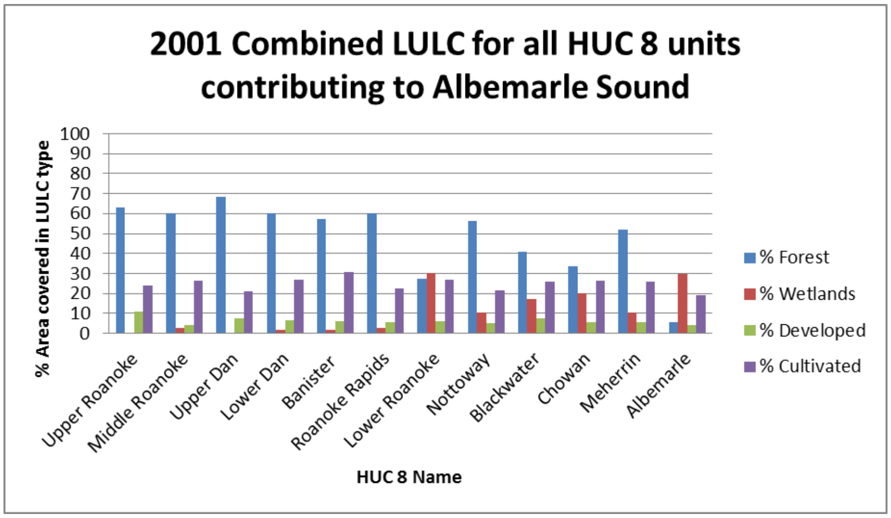
Appendix C – Maps and LULC Summary and Analysis






Upper Roanoke
Middle Roanoke
Banister
Upper Dan
Lower Dan
Nottoway
Blackwater
Meherrin
Roanoke Rapids
Chowan
Albemarle
Lower Roanoke
Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grassland/Herbaceous
Pasture/Hay
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands
140
Kilometers
1 cm = 17 km
2006 Land Use and Land Cover Classification for
Contributing Watersheds (HUC8) to Albemarle Sound


1992 Combined LULC for all HUC 8 units
contributing to Albemarle Sound
% Area covered in LULC type
100
90
80
70
60
50
40
30
20
10
0
Upper Roanoke
Middle Roanoke
Upper Dan
Lower Dan
Banister
Roanoke Rapids
Lower Roanoke
Nottoway
Blackwater
Chowan
Meherrin
Albemarle
HUC 8 Name
% Forest
% Wetlands
% Developed
% Cultivated



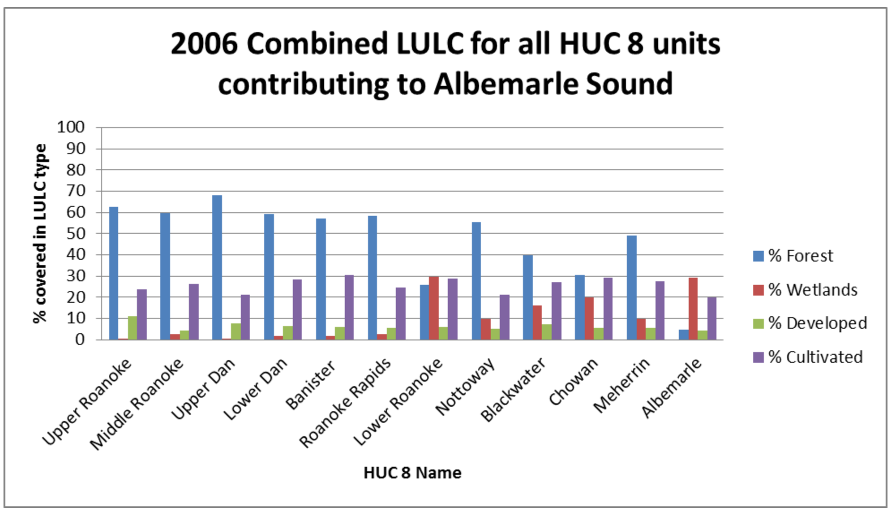
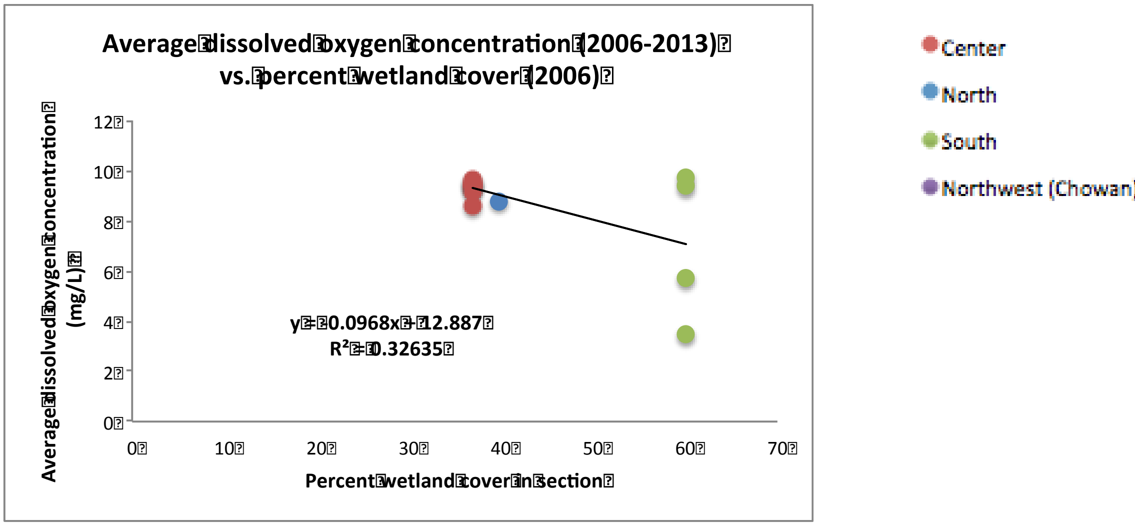
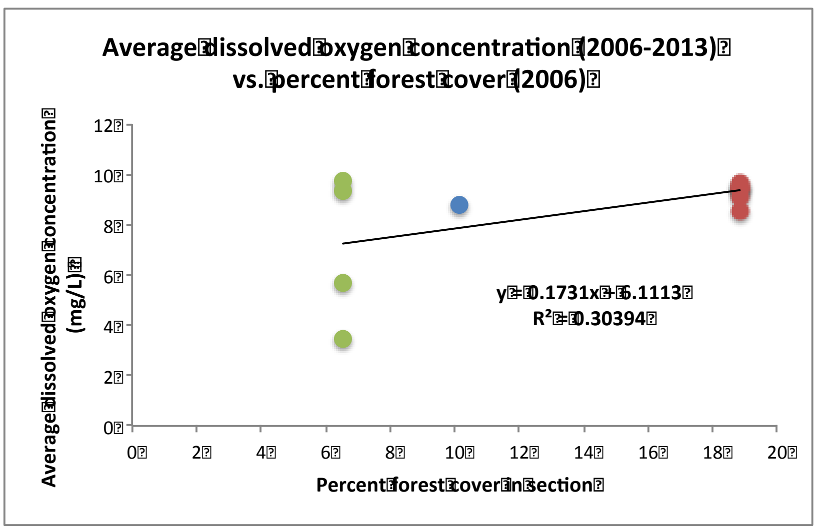


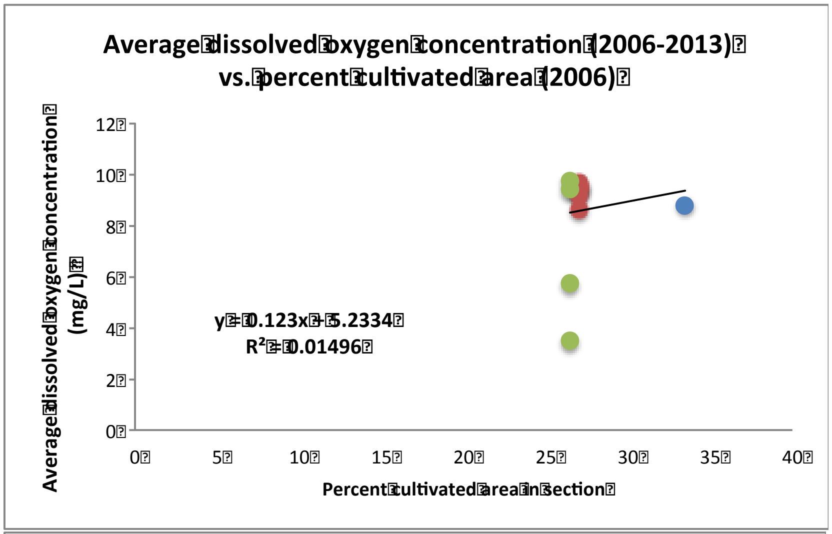
Table Summary of LULC data by section (not showing Center section as it is a combination of West, Northwest, North, and South sections).

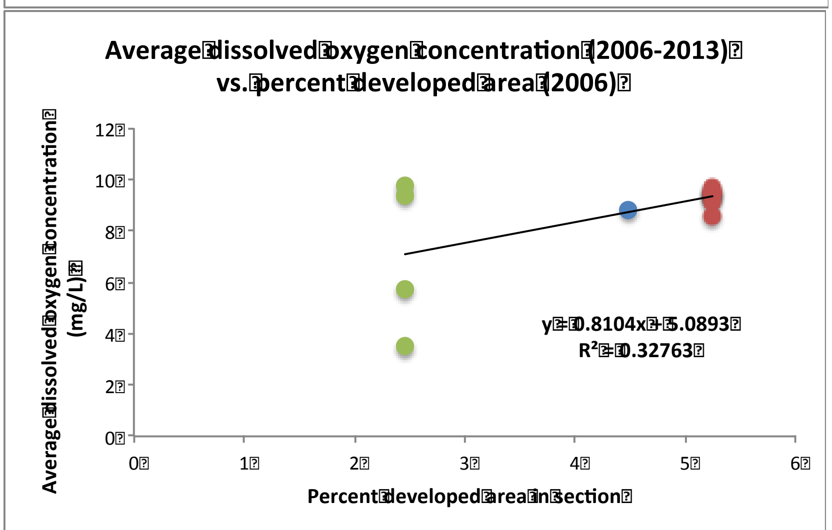
LULC Type	West	% Area	NW	% Area	North	% Area	NE	% Area	SE	%	South	%
Developed, Open Space	185328	5.00	133008	5.45	169721	4.49	93868	4.64	22291	4.25	56938	2.46
Developed, Low Intensity	33395	0.90	8957	0.37	25551	0.68	68906	3.40	20424	3.89	6106	0.26
Developed, Medium Intensity	9221	0.25	2644	0.11	6911	0.18	28069	1.39	11863	2.26	404	0.02
Developed, High Intensity	2745	0.07	440	0.02	1052	0.03	2606	0.13	1015	0.19	12	0.00
Barren Land	3537	0.10	1435	0.06	4604	0.12	26998	1.33	63447	12.09	5661	0.24
Deciduous Forest	176722	4.77	153183	6.28	81999	2.17	17270	0.85	1207	0.23	7578	0.33
Evergreen Forest	728722	19.67	554942	22.74	266991	7.07	21045	1.04	15064	2.87	132844	5.74
Mixed Forset	71375	1.93	84892	3.48	34680	0.92	3150	0.16	1392	0.27	10881	0.47
Scrub/Shrub	295008	7.96	234456	9.61	100616	2.66	22245	1.10	11775	2.24	65956	2.85
Grassland/Herbaceous	102558	2.77	51803	2.12	39511	1.05	6443	0.32	4921	0.94	23810	1.03
Pasture/Hay	94944	2.56	152198	6.24	278650	7.38	53819	2.66	69	0.01	1046	0.05
Cultivated Crops	885735	23.91	551756	22.61	1264594	33.47	170034	8.40	7546	1.44	612065	26.46
Woody Wetland	1076177	29.05	504644	20.68	1453669	38.48	249520	12.33	212485	40.49	1285930	55.60
Emergent Herbaceous Wetlands	38998	1.05	6387	0.26	49641	1.31	144059	7.12	151252	28.82	103672	4.48
TOTAL	**3704465**	**100**	**2440745**	**100**	**3778190**	**100**	**2023771**	**100**	**524751**	**100**	**2312903**	**100**

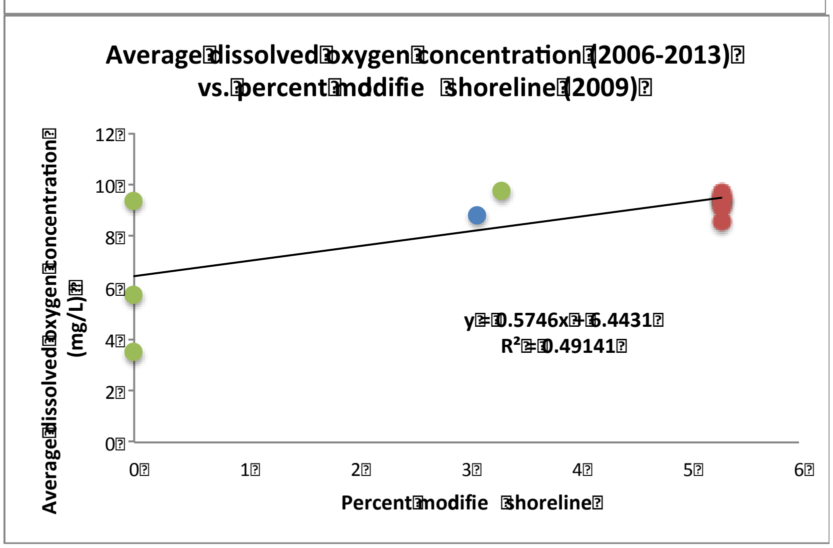
Appendix D – LULC and water quality analysis (30 simple linear regressions)

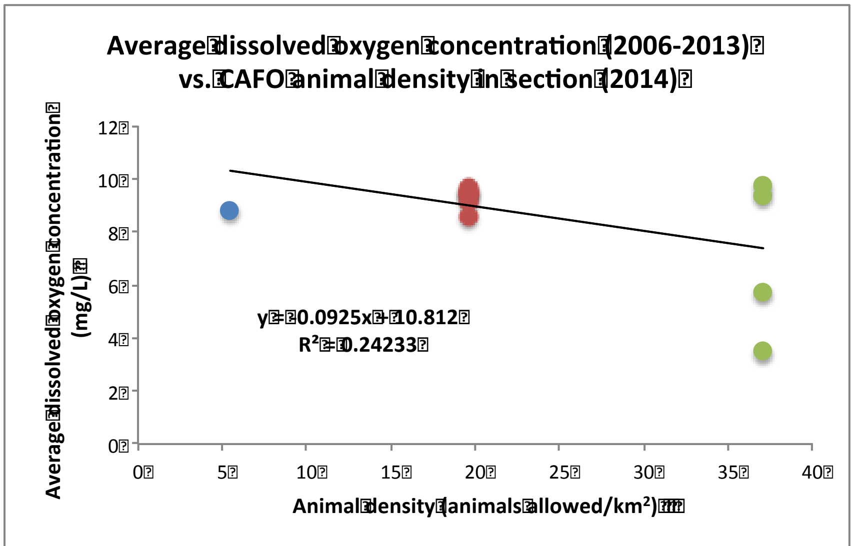


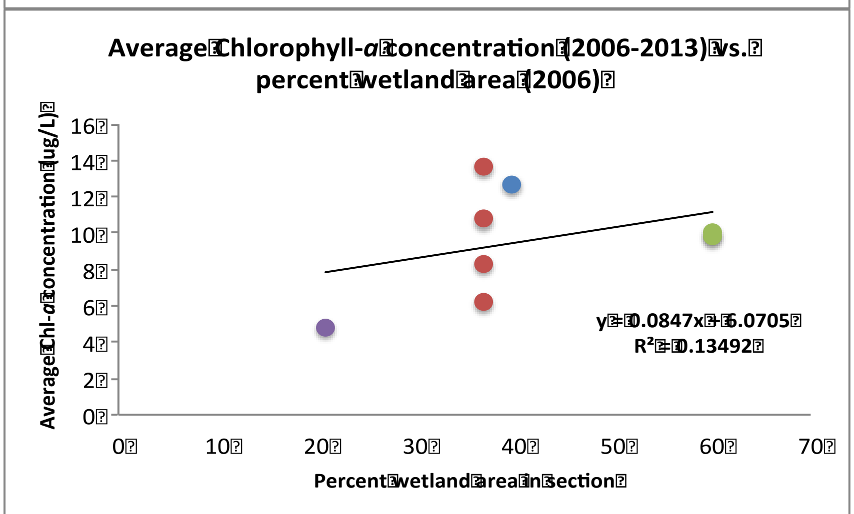


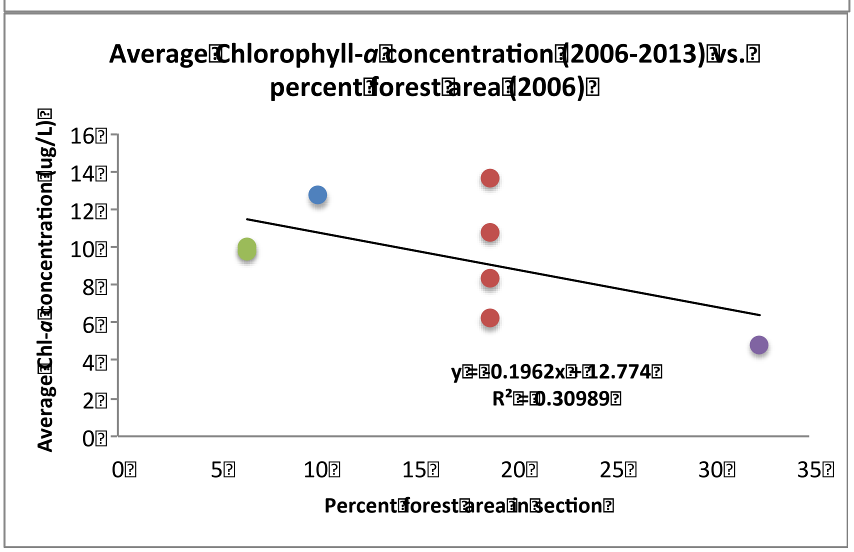

Average dissolved oxygen concentration (2006-2013)
vs. percent cultivated area (2006)
Average dissolved oxygen concentration (mg/L)
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
Percent cultivated area in section
y = 0.123x + 5.2334
R² = 0.01496

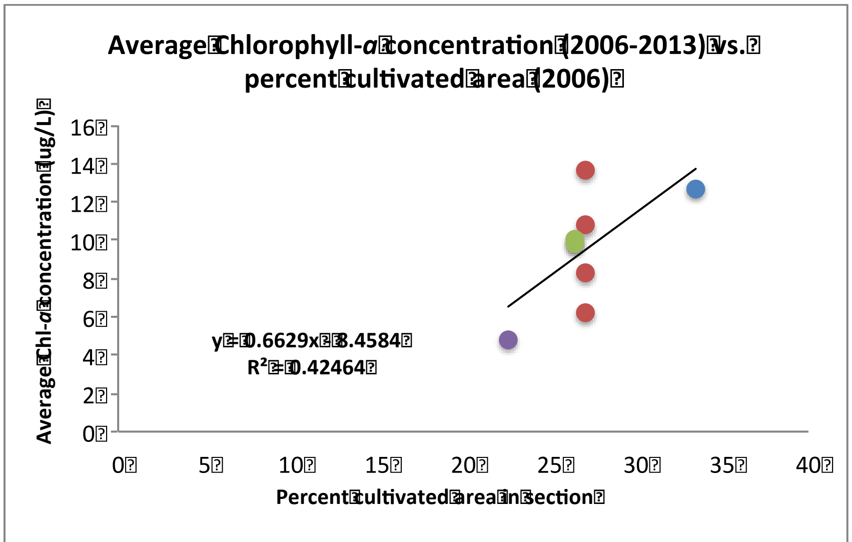

Average dissolved oxygen concentration (2006-2013)
vs. percent developed area (2006)
Average dissolved oxygen concentration (mg/L)
12
10
8
6
4
2
0
0
1
2
3
4
5
6
Percent developed area in section
y = 0.8104x + 5.0893
R² = 0.32763


Average dissolved oxygen concentration (2006-2013)
vs. percent modifie shoreline (2009)
Average dissolved oxygen concentration (mg/L)
12
10
8
6
4
2
0
0
1
2
3
4
5
6
Percent modifie shoreline
y = 0.5746x + 6.4431
R² = 0.49141

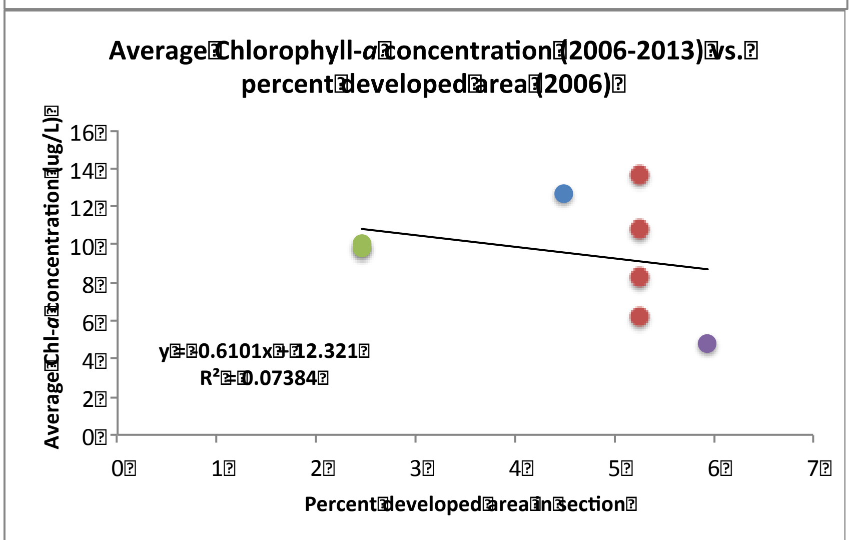

Average dissolved oxygen concentration (2006-2013) vs. CAFO animal density in section (2014)
Average dissolved oxygen concentration (mg/L)
y = -0.0925x + 10.812
R^2 = 0.24233
Animal density (animals allowed/km^2)
0
2
4
6
8
10
12
0
5
10
15
20
25
30
35
40


Average Chlorophyll-*a* concentration (2006-2013) vs. percent wetland area (2006)
Average Chl-*a* concentration (ug/L)
y = 0.0847x + 6.0705
R^2 = 0.13492
Percent wetland area in section
0
2
4
6
8
10
12
14
16
0
10
20
30
40
50
60
70

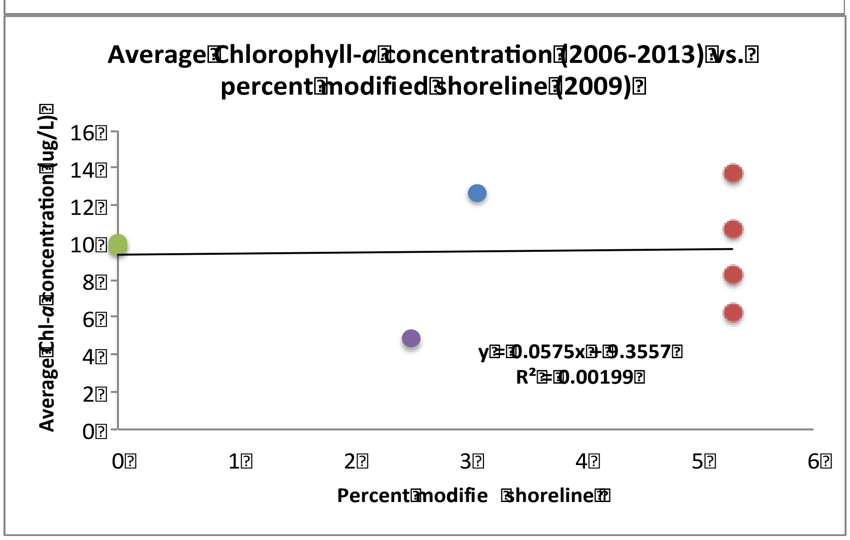

Average Chlorophyll-*a* concentration (2006-2013) vs. percent forest area (2006)
Average Chl-*a* concentration (ug/L)
y = -0.1962x + 12.774
R^2 = 0.30989
Percent forest area in section
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35



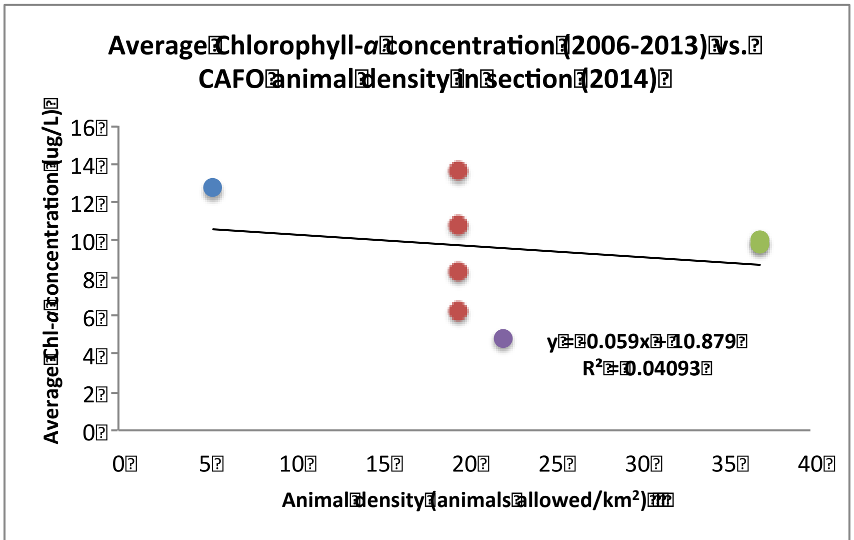
Average Chlorophyll-*a* concentration (2006-2013) vs. percent cultivated area (2006)
Average Chl-*a* concentration (ug/L)
0
2
4
6
8
10
12
14
16
y = 0.6629x 8.4584
R² = 0.42464
0
5
10
15
20
25
30
35
40
Percent cultivated area in section



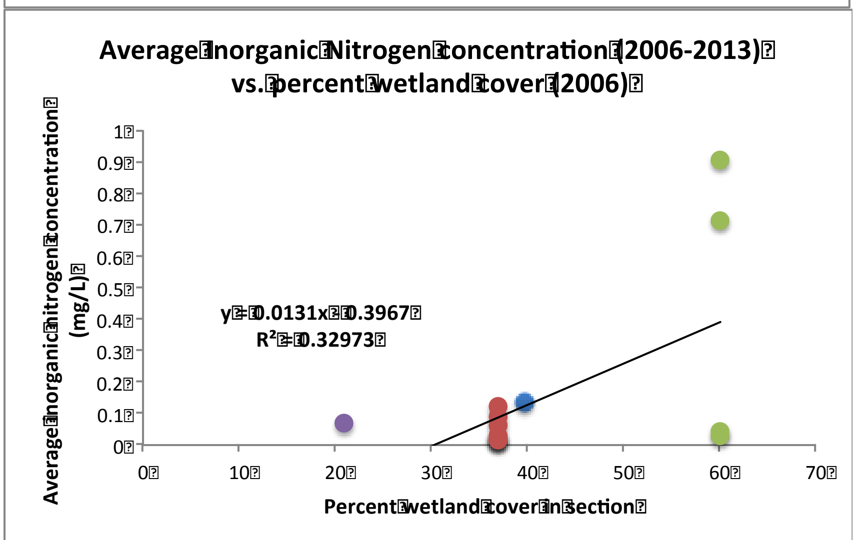
Average Chlorophyll-*a* concentration (2006-2013) vs. percent developed area (2006)
Average Chl-*a* concentration (ug/L)
0
2
4
6
8
10
12
14
16
y = 0.6101x + 12.321
R² = 0.07384
0
1
2
3
4
5
6
7
Percent developed area in section



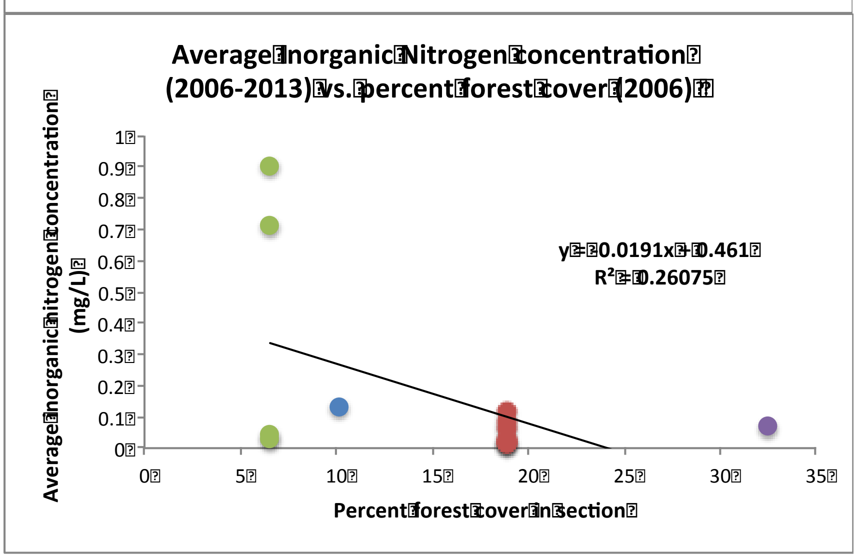
Average Chlorophyll-*a* concentration (2006-2013) vs. percent modified shoreline (2009)
Average Chl-*a* concentration (ug/L)
0
2
4
6
8
10
12
14
16
y = 0.0575x + 9.3557
R² = 0.00199
0
1
2
3
4
5
6
Percent modifie shoreline



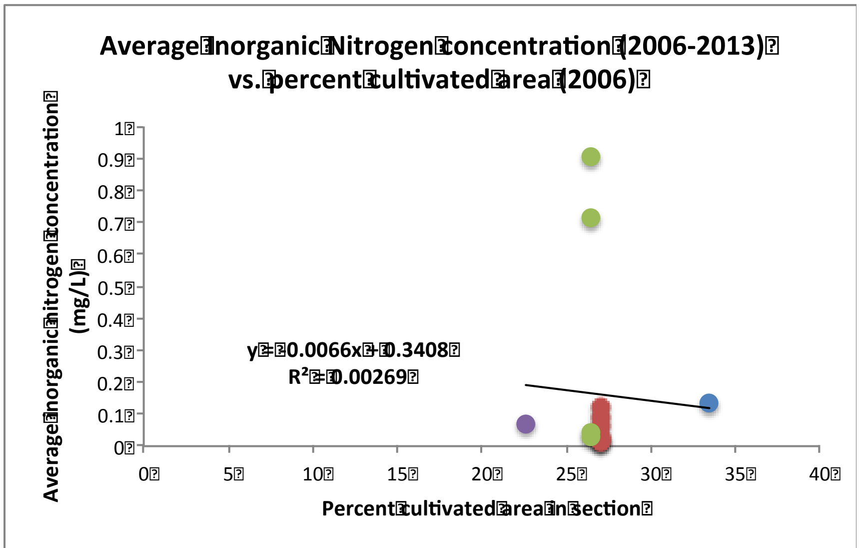
Average Chlorophyll-*a* concentration (2006-2013) vs. CAFO animal density in section (2014)
Average Chl-*a* concentration (ug/L)
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
Animal density (animals allowed/km²)
y = -0.059x + 10.879
R² = 0.04093

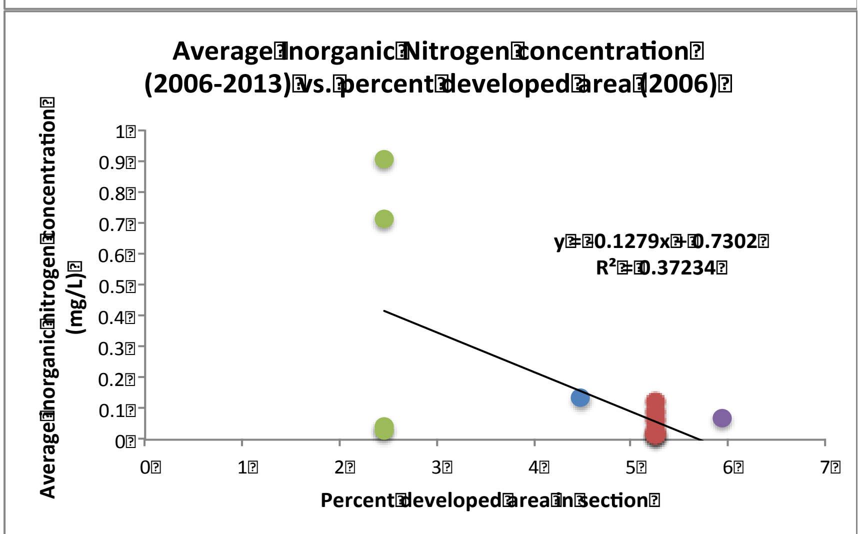


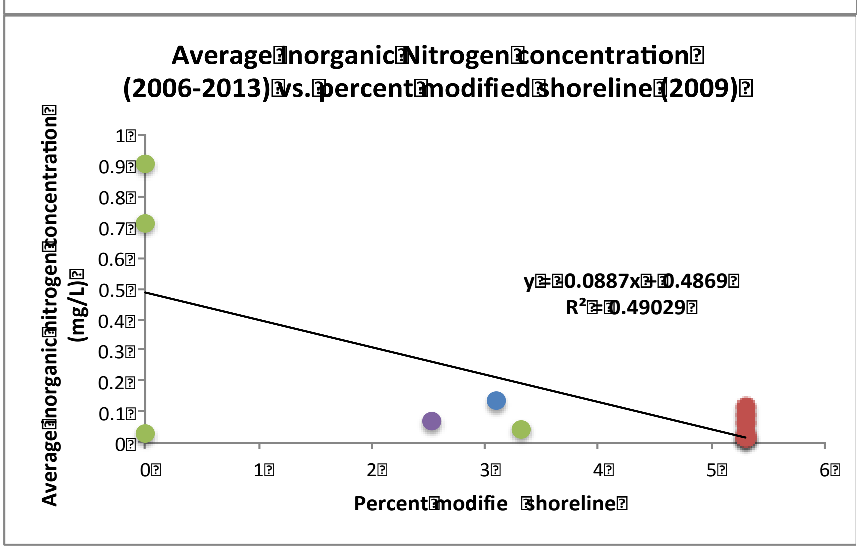
Average Inorganic Nitrogen concentration (2006-2013) vs. percent wetland cover (2006)
Average inorganic nitrogen concentration (mg/L)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
Percent wetland cover in section
y = 0.0131x - 0.3967
R² = 0.32973

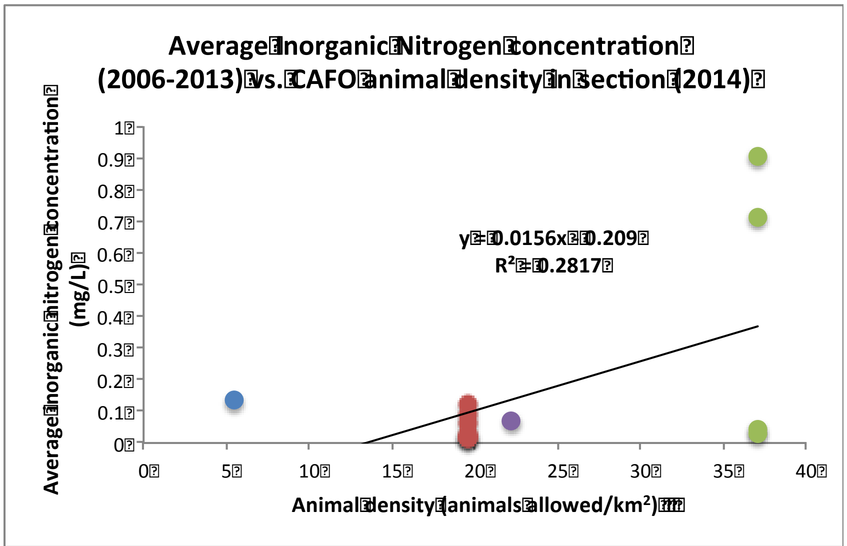


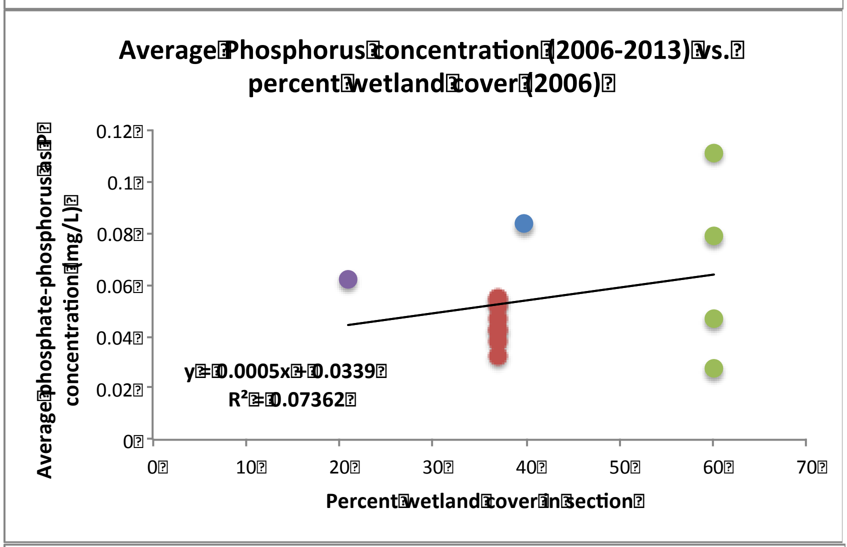
Average Inorganic Nitrogen concentration (2006-2013) vs. percent forest cover (2006)
Average inorganic nitrogen concentration (mg/L)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
Percent forest cover in section
y = -0.0191x + 0.461
R² = 0.26075

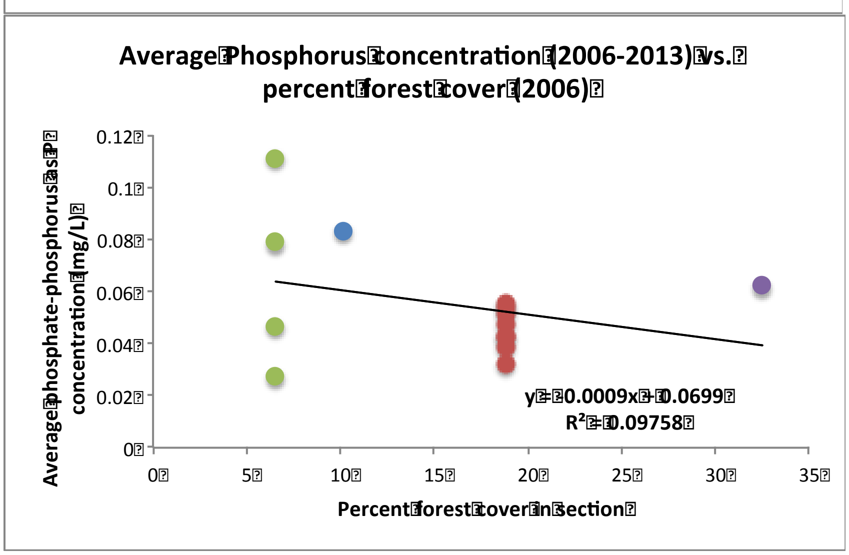

Average Inorganic Nitrogen concentration (2006-2013) vs. percent cultivated area (2006)
Average Inorganic nitrogen concentration (mg/L)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
y = 0.0066x + 0.3408
R² = 0.00269
0
5
10
15
20
25
30
35
40
Percent cultivated area in section

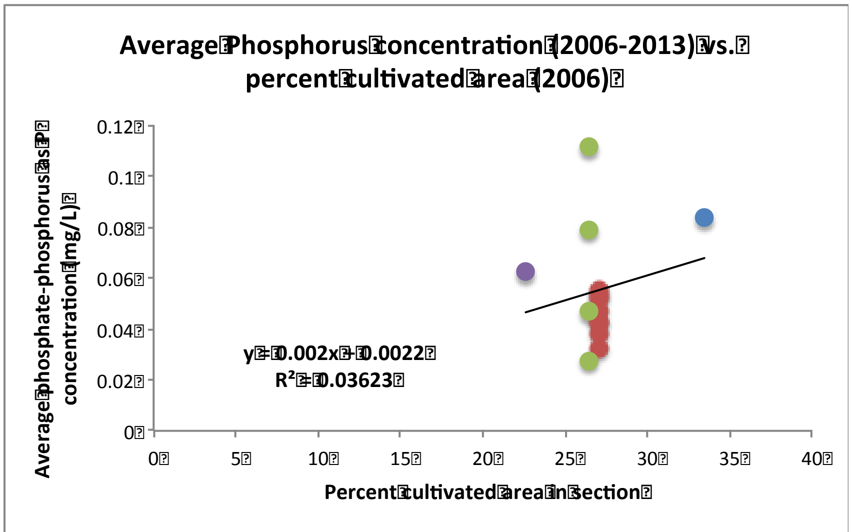

Average Inorganic Nitrogen concentration (2006-2013) vs. percent developed area (2006)
Average Inorganic nitrogen concentration (mg/L)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
y = 0.1279x + 0.7302
R² = 0.37234
0
1
2
3
4
5
6
7
Percent developed area in section

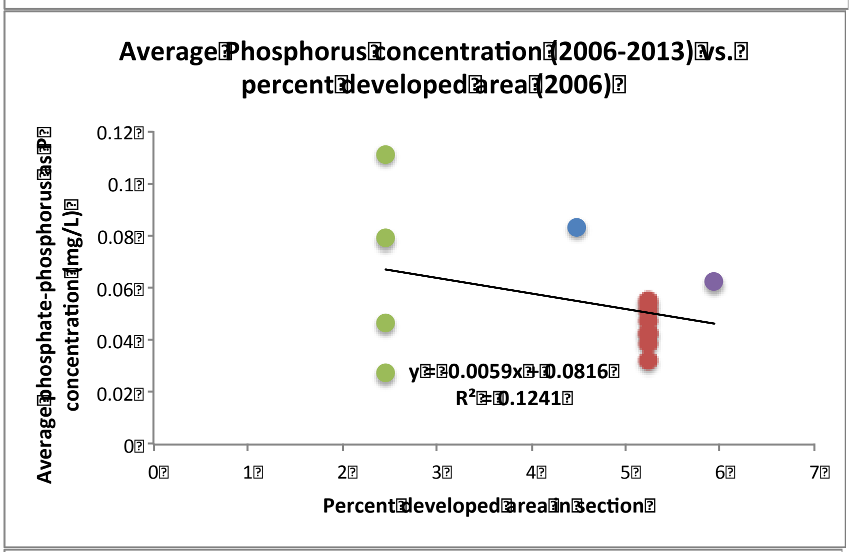

Average Inorganic Nitrogen concentration (2006-2013) vs. percent modified shoreline (2009)
Average Inorganic nitrogen concentration (mg/L)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
y = 0.0887x + 0.4869
R² = 0.49029
0
1
2
3
4
5
6
Percent modifie shoreline

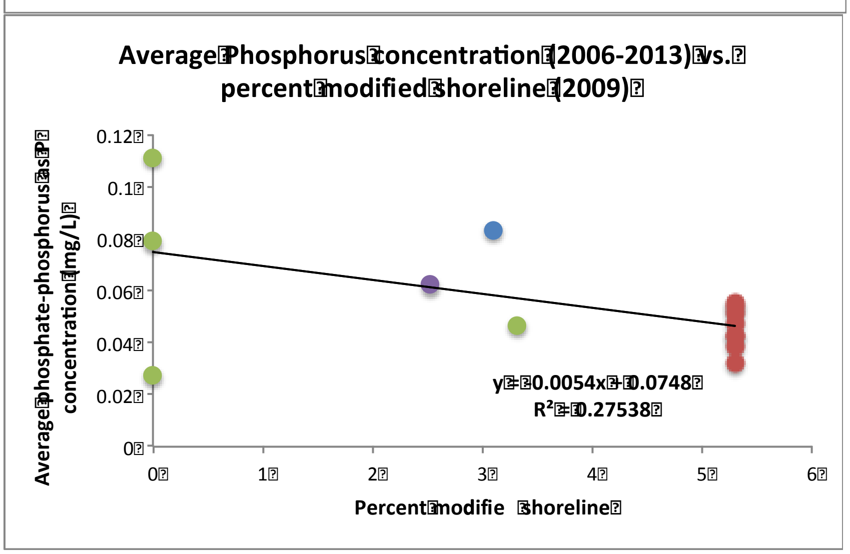

Average Inorganic Nitrogen concentration (2006-2013) vs. CAFO animal density in section (2014)
Average inorganic nitrogen concentration (mg/L)
y = 0.0156x - 0.209
R² = 0.2817
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
Animal density (animals allowed/km²)

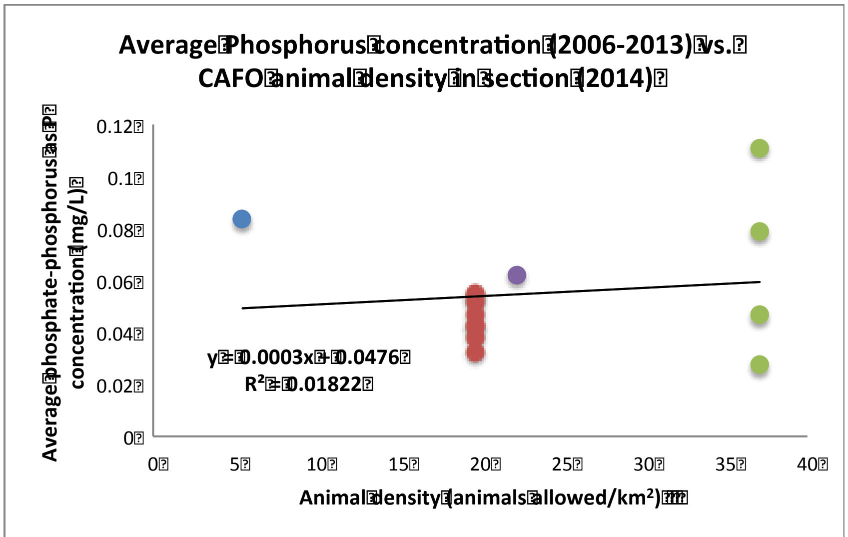

Average Phosphorus concentration (2006-2013) vs. percent wetland cover (2006)
Average phosphate-phosphorus as P concentration (mg/L)
y = 0.0005x + 0.0339
R² = 0.07362
0
0.02
0.04
0.06
0.08
0.1
0.12
0
10
20
30
40
50
60
70
Percent wetland cover in section

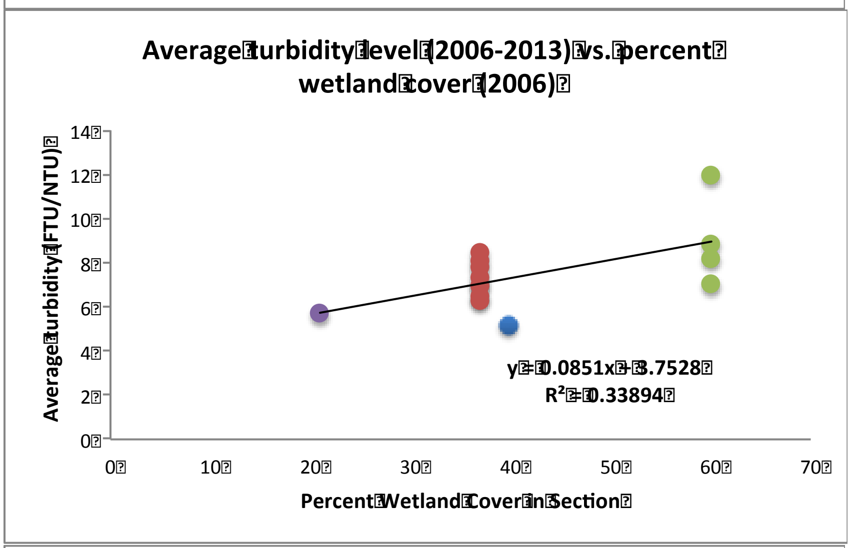

Average Phosphorus concentration (2006-2013) vs. percent forest cover (2006)
Average phosphate-phosphorus as P concentration (mg/L)
y = -0.0009x + 0.0699
R² = 0.09758
0
0.02
0.04
0.06
0.08
0.1
0.12
0
5
10
15
20
25
30
35
Percent forest cover in section

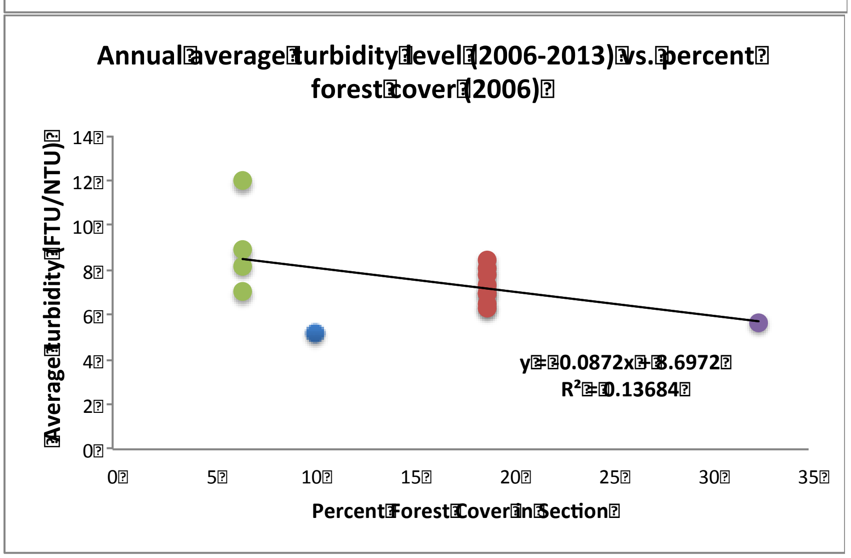

Average Phosphorus concentration (2006-2013) vs. percent cultivated area (2006)
Average phosphate-phosphorus as P concentration (mg/L)
0.12
0.1
0.08
0.06
0.04
0.02
0
y = 0.002x + 0.0022
R² = 0.03623
0
5
10
15
20
25
30
35
40
Percent cultivated area in section

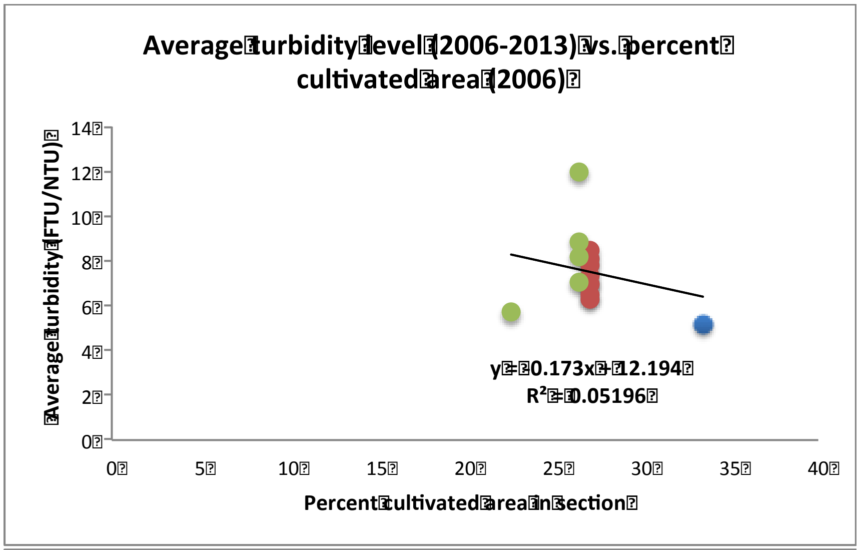

Average Phosphorus concentration (2006-2013) vs. percent developed area (2006)
Average phosphate-phosphorus as P concentration (mg/L)
0.12
0.1
0.08
0.06
0.04
0.02
0
y = -0.0059x + 0.0816
R² = 0.1241
0
1
2
3
4
5
6
7
Percent developed area in section

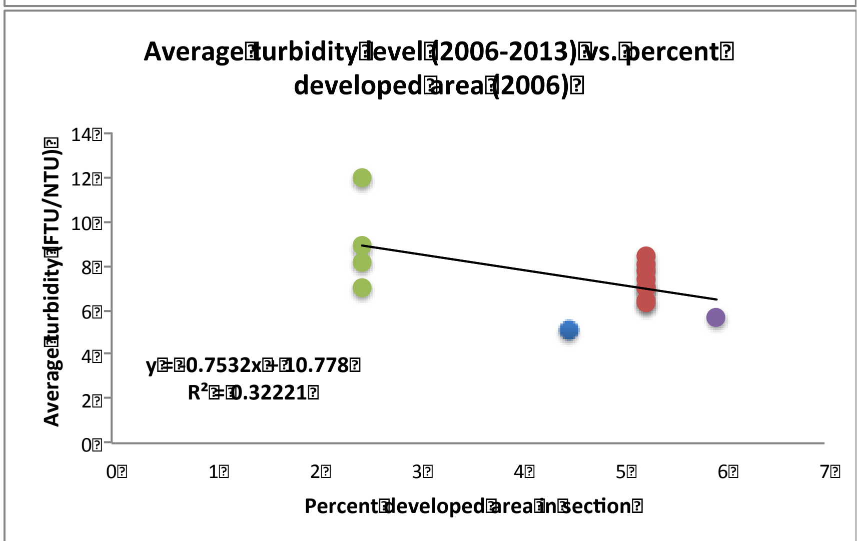

Average Phosphorus concentration (2006-2013) vs. percent modified shoreline (2009)
Average phosphate-phosphorus as P concentration (mg/L)
0.12
0.1
0.08
0.06
0.04
0.02
0
y = -0.0054x + 0.0748
R² = 0.27538
0
1
2
3
4
5
6
Percent modifie shoreline

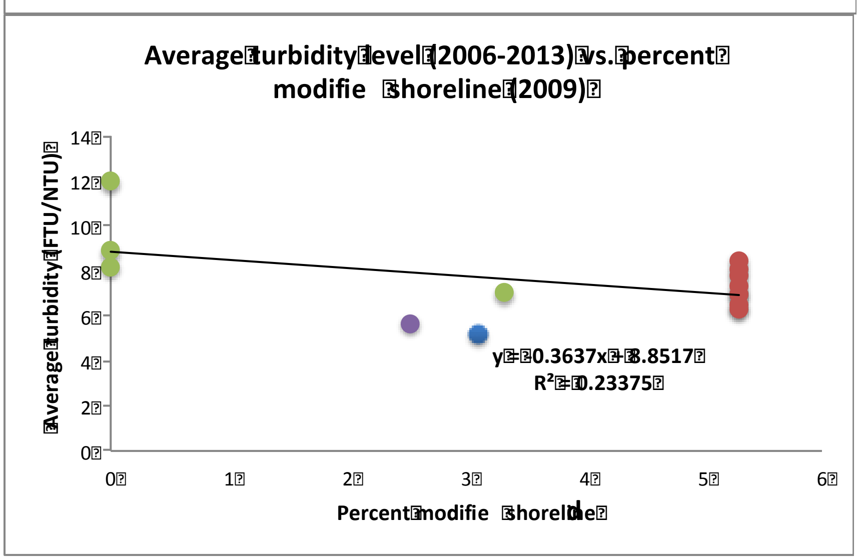

Average Phosphorus concentration (2006-2013) vs. CAFO animal density in section (2014)
Average phosphate-phosphorus as P concentration (mg/L)
0.12
0.1
0.08
0.06
0.04
0.02
0
y = 0.0003x + 0.0476
R² = 0.01822
0
5
10
15
20
25
30
35
40
Animal density (animals allowed/km²)

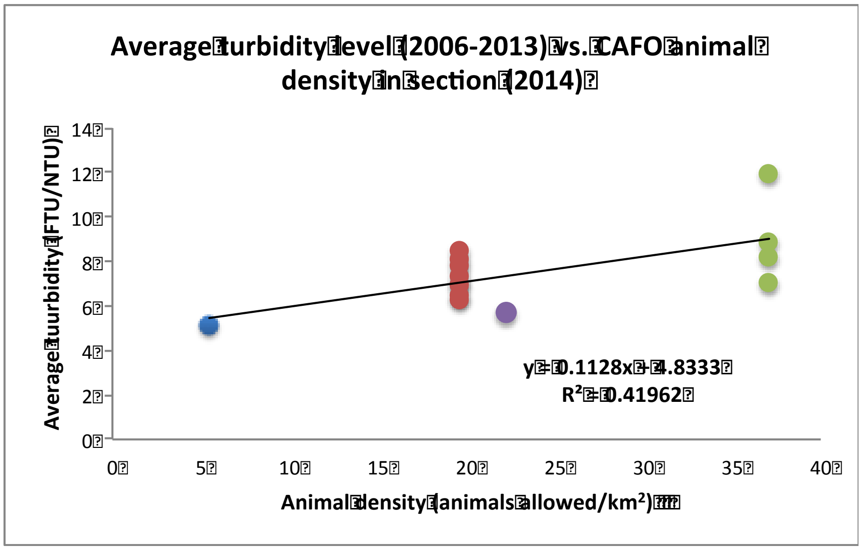

Average turbidity level (2006-2013) vs. percent wetland cover (2006)
Average turbidity (FTU/NTU)
14
12
10
8
6
4
2
0
y = 0.0851x + 3.7528
R² = 0.33894
0
10
20
30
40
50
60
70
Percent Wetland Cover in Section


Annual average turbidity level (2006-2013) vs. percent forest cover (2006)
Average turbidity (FTU/NTU)
14
12
10
8
6
4
2
0
y = -0.0872x + 8.6972
R² = 0.13684
0
5
10
15
20
25
30
35
Percent Forest Cover in Section


Average turbidity level (2006-2013) vs. percent cultivated area (2006)
Average turbidity (FTU/NTU)
14
12
10
8
6
4
2
0
y = -0.173x + 12.194
R² = 0.05196
0
5
10
15
20
25
30
35
40
Percent cultivated area in section


Average turbidity level (2006-2013) vs. percent developed area (2006)
Average turbidity (FTU/NTU)
14
12
10
8
6
4
2
0
y = -0.7532x + 10.778
R² = 0.32221
0
1
2
3
4
5
6
7
Percent developed area in section


Average turbidity level (2006-2013) vs. percent modified shoreline (2009)
Average turbidity (FTU/NTU)
14
12
10
8
6
4
2
0
y = -0.3637x + 8.8517
R² = 0.23375
0
1
2
3
4
5
6
Percent modified shoreline


Average turbidity level (2006-2013) vs. CAFO animal density in section (2014)
Average tuurbidity (FTU/NTU)
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
y = 0.1128x + 4.8333
R² = 0.41962
Animal density (animals allowed/km²)