ENVIRONMENTAL QUALITY OF WILMINGTON AND NEW HANOVER COUNTY WATERSHEDS, 2009

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CMS Report 10-01
Center for Marine Science
University of North Carolina Wilmington
Wilmington, N.C. 28409
www.uncw.edu/cmsr/aquaticecology/tidalcreeks

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Map of New Hanover County Watersheds
(Courtesy Matt Hayes, Wilmington Stormwater Services)

Executive Summary

This report represents combined results of Year 11 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The program involved 9 watersheds and 24 sampling stations. In this summary we first present brief water quality overviews for each watershed from data collected between January and December 2009.

Barnards Creek – Barnards Creek drains into the Cape Fear River Estuary. It drains a 4,161 acre watershed that consists of about 17% impervious surface coverage, and a population of approximately 12,600. There was one station sampled in this watershed during 2009, lower Barnard's Creek at River Road. Based on 23 samples collected during 2009, there was only one algal bloom, and minor turbidity problems. Dissolved oxygen was below the state standard on 39% of occasions sampled. Fecal coliform bacteria exceeded the NC standard of 200 CFU / 100 mL on 35% of the sampling trips; in general water quality in this creek was poor in 2009.

Bradley Creek – Bradley Creek drains a watershed of 4,631 acres, including much of the UNCW campus, into the Atlantic Intracoastal Waterway (ICW). The watershed contains about 23% impervious surface coverage. Three sites were sampled, all from shore. In 2009 there were no problems with turbidity or algal blooms exceeding the state standard. Average dissolved oxygen was good to fair at the three sites. The three sites sampled were all rated poor due to high fecal coliform bacteria, with the south branch site on Wrightsville Avenue, BC-SB, having especially high counts. We note that construction activity has been ongoing upstream of BC-NB, the north branch site on Wrightsville Avenue.

Burnt Mill Creek – Burnt Mill Creek drains a 4,252 acre watershed which is extensively urbanized (36% impervious surface coverage) into Smith Creek. Three locations were sampled during 2009. This creek has very poor water quality, with large algal blooms occurring on several occasions at two of the three sites sampled, and major issues with high fecal coliform counts, with two of the three sites exceeding the human contact standard > 83% of occasions sampled. These levels of pollution have characterized the system for the past several years. On a positive note, dissolved oxygen concentrations were greatly improved in 2009 compared to the previous several years.

The effectiveness of Ann McCrary wet detention pond on Randall Parkway as a pollution control device for upper Burnt Mill Creek was mixed in 2009. Comparing inflows to outflows, there was a significant decrease in fecal coliform bacteria, and a significant increase in dissolved oxygen and pH. However, there were no significant decreases in nutrients. Several water quality parameters showed a worsening in pollutant levels along the creek from where it exited the detention pond to the downstream Princess Place sampling station, including dissolved oxygen, fecal coliform bacteria, nitrogen and phosphorus.

Futch Creek – Futch Creek is situated on the New Hanover-Pender County line and drains a 3,106 acre watershed into the ICW. UNC Wilmington was not funded to regularly sample this creek in 2009. The County employed a consulting firm to sample this creek and data are available on the County website.

Greenfield Lake – This lake drains a watershed of 2,551 acres, covered by about 36% impervious surface area. This urban lake has, over the years, suffered from low dissolved oxygen, algal blooms, periodic fish kills and high fecal bacteria counts. The lake was sampled for physical parameters at three tributary sites and for all parameters at three in-lake sites. The three tributaries of Greenfield Lake (near Lake Branch Drive, Jumping Run Branch, and Lakeshore Commons Apartments) all suffered from low dissolved oxygen problems.

From 2005 to 2009 several steps were taken by the City of Wilmington to restore viability to the lake. Sterile grass carp were introduced to the lake to control (by grazing) the overabundant aquatic macrophytes, and four SolarBee water circulation systems were installed in the lake to improve circulation and force dissolved oxygen from the surface downward toward the bottom. Also, on several occasions a contract firm and City staff applied herbicides to further reduce the amount of aquatic macrophytes. These actions led to a major reduction in aquatic macrophytes lake wide. In 2009 there was good to fair dissolved oxygen at two of the lake stations (especially nearest the SolarBees), but low dissolved oxygen concentrations were common at GL-2340, in the upper lake, as well as the tributary stream stations.

Algal blooms are periodically problematic in Greenfield Lake, and have occurred during all seasons, but are primarily a problem in spring and summer. In 2007 algal blooms were not as common as in previous years, but In 2008 algal blooms exceeding the North Carolina water quality standard increased. In 2009 several blooms exceeding the state standard occurred (at GL-P and GL-YD); however, on average, overall bloom activity in the lake showed a slight decrease from 2008. In 2007-2009 there was a statistically significant relationship within the lake between chlorophyll *a* and BOD5, meaning that the algal blooms are likely an important cause of low dissolved oxygen in this lake, along with stormwater runoff of BOD materials into the streams feeding the lake. Thus, a challenge for Greenfield Lake is to continue to reduce the frequency and magnitude of the algal blooms, which will lead to continuing dissolved oxygen improvements. High fecal coliform counts continue to impact the lake, particularly Station GL-2340. Non-point source pollution control should be targeted to reduce nitrogen, suspended materials and fecal bacteria to the lake.

Hewletts Creek – Hewletts Creek drains a large (7,435 acre) watershed into the Intracoastal Waterway. This watershed has about 19% impervious surface coverage. In recent years this system has been plagued by a number of sewage spills. In 2009 the creek was sampled at four tidal sites and one non-tidal freshwater site. There were only two incidents of low dissolved oxygen seen in our sampling; in July and September; one at SB-PGR (the south branch at Pine Grove Rd.) and one at MB-GLR (middle branch at Pine Grove Rd.); although none were severe (below 3.6 mg/L). Turbidity was low and no major algal blooms were seen at these stations in 2009. Fecal coliform bacterial pollution continued to impact Hewletts Creek in 2009, with all stations with the exception of HC-3 exceeding the North Carolina standard of 200 CFU/100 mL 33% of the time or more.

Howe Creek – Howe Creek drains a 3,518 acre watershed into the ICW. This watershed hosts a population of approximately 4,230 with about 19% impervious surface coverage. Three stations were sampled in Howe Creek in 2009. Only one major algal bloom was seen, at the uppermost station HW-DT in May. Both upper stations, HW-DT and HW-GP were rated poor due to high fecal coliform bacteria counts, exceeding the state standard on 83% or more of the times sampled. The lower station HW-FP was rated fair, exceeding the standard on one occasion only. Dissolved oxygen concentrations were fair in Howe Creek in 2009. Since wetland enhancement was performed in 1998 above Graham Pond the creek below the pond at Station HW-GP has had fewer and smaller algal blooms than before the enhancement.

Motts Creek – Motts Creek drains a watershed of 3,328 acres into the Cape Fear River Estuary. This creek was sampled 23 times at one station at River Road in 2009 as a result of funding from the private sector. Dissolved oxygen concentrations were below the state standard of 5.0 mg/L on 39% of the sampling occasions in 2009. Neither turbidity nor suspended solids were problematic in 2009, and there was only one algal bloom encountered in the sampling. However, fecal coliform bacteria contamination was a major problem in Motts Creek, with the State standard of 200 CFU/100 mL exceeded on 74% of the occasions sampled; failing septic systems in upper areas of the creek have been considered by County Health authorities to be one source of this contamination. Thus, in 2009 this creek showed poor water quality based on dissolved oxygen issues and major fecal coliform problems.

Pages Creek – Pages Creek drains a 3,039 acre watershed into the ICW. UNC Wilmington was not funded to regularly sample this creek in 2008 or 2009. The County employed a consulting firm (Coastal Planning & Engineering) to sample this creek and data are available on the County website. Elevated fecal coliform bacteria counts in upper creek areas near Bayshore Drive (PC-BDUS and PC-BDDS) were found during sampling by this group. The New Hanover County Water Quality Roundtable, of which UNCW and Coastal Planning & Engineering are both members, expressed concern over the elevated fecal coliform bacteria counts in Pages Creek. As such, in fall 2008 UNCW was contracted by Coastal Planning & Engineering to perform bacteria source tracking using molecular-based methods at two upper creek sites. Both sites, during all four months, showed excessive fecal bacteria counts, either from fecal coliform bacteria or *Enterococcus* bacteria, or both. Fecal bacteria numbers were considerably higher at both sites during or shortly after rain events. Station PC-BDDS had on average higher fecal bacteria counts than did PC-BDUS. Optical brightener concentrations indicated that, at least in some periods, either sewage or septic system leachate was polluting the creek waters. Molecular-based bacterial source tracking methods, PCR and T-RFLP, indicated the presence, sometimes substantial, of human fecal bacteria in Pages Creek at both sites during all four months. There was a considerable ruminant contribution to the fecal bacteria in upper Pages Creek as well. Likely ruminant sources are deer, which are certainly present in the watershed, and horses if there any boarded in the watershed. A number of unidentified peaks were also found, indicating other potential sources to those we listed above. These data collectively indicate that upper Pages Creek has a fecal bacteria problem with stormwater runoff (as exemplified by the ruminant signal and elevated bacteria counts during rain events). There is also clearly a human infrastructure problem as well, either derived from the pump stations present at the sites (particularly at PC-BDDS), leaking sewer lines, or possibly failing septic systems if they are present in the upper Pages Creek watershed. At times, rainfall coincided with elevated optical brighteners and human fecal source signals indicating potential leaks in the sanitary sewer system.

Smith Creek – Smith Creek drains into the lower Northeast Cape Fear River just upstream of where it merges with the Cape Fear River. It has a watershed of 13,896 acres that has about 28% impervious surface coverage, with a population of about 26,000. One estuarine site on Smith Creek proper, SC-CH, was sampled by UNCW under the auspices of the Lower Cape Fear River Program (LCFRP) 2009. Overall the water quality in 2009 can be described as good, with no violations of NC water quality standards.

Whiskey Creek – Whiskey Creek is the southernmost large tidal creek in New Hanover County that drains into the ICW. It has a watershed of 2,095 acres, a population of about 7,100, and is covered by approximately 19% impervious surface area. One station, on Masonboro Loop Road, was sampled from shore along this creek in 2009. This site had low to moderate nutrient concentrations and no algal bloom problems. Dissolved oxygen was substandard (4.3 mg/L) only in July. Fecal coliform bacteria counts were generally good at this site in 2009.

Water Quality Station Ratings – The UNC Wilmington Aquatic Ecology Laboratory utilizes a quantitative system with four parameters (dissolved oxygen, chlorophyll *a*, turbidity, and fecal coliform bacteria) to rate water quality at our sampling sites. If a site exceeds the North Carolina water quality standard for a parameter less that 10% of the time sampled, it is rated Good; if it exceeds the standard 10-25% of the time it is rated Fair, and if it exceeds the standard > 25% of the time it is rated Poor for that parameter. We applied these numerical standards to the water bodies described in this report, based on 2009 data, and have designated each station as good, fair, and poor accordingly (Appendix B).

Fecal coliform bacterial conditions for the entire Wilmington City and New Hanover County Watersheds system (21 sites sampled for fecal coliforms) showed 10% to be in good condition, 14% in fair condition, but **76%** in poor condition. Dissolved oxygen conditions system-wide (24 sites) showed 42% of the sites were in good condition, 33% were in fair condition, and 25% were in poor condition. For algal bloom presence, measured as chlorophyll *a*, 80% of the 20 stations sampled were rated as good, 0% as fair and 20% as poor (all in Greenfield Lake or Burnt Mill Creek). In terms of turbidity 93% of the 24 sites sampled were rated as good, 17% as fair and 0% as poor. It is important to note that the two water bodies with the worst water quality in the system also have the most developed watersheds with the highest impervious surface coverage; Burnt Mill Creek – 36% impervious coverage; Greenfield Lake – 36% impervious coverage.

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1.0 Introduction

In 1993 scientists at the UNC Wilmington Center for Marine Science Research began studying five tidal creeks in New Hanover County. This project, funded by New Hanover County, the Northeast New Hanover Conservancy, and UNCW, yielded a comprehensive report detailing important findings from 1993-1997, and produced a set of management recommendations for improving creek water quality (Mallin et al. 1998a). Data from that report were later published in the peer-reviewed literature (Mallin et al. 2000a; Mallin et al. 2001) and were used 2006-2008 by the N.C. General Assembly (Senate Bill 1967) as the scientific basis to redefine low density coastal areas as 12% impervious surface coverage instead of the previously used 25% impervious cover. In 1999-2000 Whiskey Creek was added to the matrix of tidal creek watersheds analyzed in our program.

In October 1997 the Center for Marine Science began a project (funded by the City of Wilmington Engineering Department) with the goal of assessing water quality in Wilmington City watersheds under base flow conditions. Also, certain sites were analyzed for sediment heavy metals concentrations (EPA Priority Pollutants). In the past twelve years we have produced combined Tidal Creeks – Wilmington City Watersheds reports (Mallin et al. 1998b; 1999; 2000b; 2002a; 2003; 2004; 2006a; 2007; 2008; 2009a). In fall 2007 New Hanover County decided to stop funding UNCW sampling on the tidal creeks. In the present report we present results of sampling conducting during 2009, with principal funding by the City of Wilmington. In fall 2008 we were pleased to obtain funding from a private company dedicated to environmentally sound development, the Newland Corporation. The Newland Corporation is designing and building a large residential project called River Lights along River Road between Barnards and Motts Creeks. Through this funding we have reinitiated sampling of Motts and Barnards Creeks along River Road. There has been no construction near either creek as of yet related to this project, thus water quality at our Barnards and Motts Creek stations reflect current upstream development and construction activities. Also, in 2008-2009 a consulting firm, Coastal Planning & Engineering of North Carolina, Inc., funded UNCW to conduct bacterial source tracking in upper Pages Creek, with the results published within this report.

Water quality parameters analyzed in these nine watersheds include water temperature, pH, dissolved oxygen, salinity/conductivity, turbidity, total suspended solids (TSS), nitrate, ammonium, total Kjeldahl nitrogen (TKN), total nitrogen (TN), orthophosphate, total phosphorus (TP), chlorophyll *a* and fecal coliform bacteria. Biochemical oxygen demand (BOD5) is measured at selected sites.

1.1 Water Quality Methods

Samples were collected on six occasions at most locations within the Wilmington City watersheds from January through November 2009. Field parameters were measured at each site using a YSI 6920 Multiparameter Water Quality Probe (sonde) linked to a YSI 650 MDS display unit. Individual probes within the instruments measured water temperature, pH, dissolved oxygen, turbidity, salinity, and conductivity. YSI Model 85 and 55 dissolved oxygen meters were also used on occasion. The instruments were calibrated prior to each sampling trip to ensure accurate measurements. The UNCW Aquatic Ecology laboratory is State-Certified for field measurements (temperature, conductivity, dissolved oxygen and pH) and for laboratory chlorophyll *a* measurements. Samples were collected on-site for analysis of ammonium, nitrate+nitrite (referred to within as nitrate), total Kjeldahl nitrogen (TKN), orthophosphate, total phosphorus, total suspended solids (TSS), fecal coliform bacteria, and chlorophyll *a*.

The analytical method used by the UNCW Aquatic Ecology Laboratory to measure chlorophyll *a* (EPA Method 445.0) is based on Welschmeyer (1994) and US EPA (1997). Chlorophyll *a* concentrations were determined from the 1.0 micrometer glass fiber filters used for filtering samples for nitrate+nitrite and orthophosphate analyses. All filters were wrapped individually in aluminum foil, placed in an airtight container and stored in a freezer. During the analytical process, the glass filters were separately immersed in 10 ml of a 90% acetone solution and allowed to extract the chlorophyll from the material for three hours; filters were ground using a Teflon grinder prior to extraction. The solution containing the extracted chlorophyll was then analyzed for chlorophyll *a* concentration using a Turner AU-10 fluorometer. This method uses an optimal combination of excitation and emission bandwidths that reduces errors in the acidification technique.

Nutrients (nitrate, ammonium, total Kjeldahl nitrogen, total nitrogen, orthophosphate, and total phosphorus) and total suspended solids (TSS) were analyzed by a state-certified contract laboratory using EPA and APHA techniques. We also computed inorganic nitrogen to phosphorus molar ratios for relevant sites (N/P). Fecal coliform concentrations were determined using a membrane filtration (mFC) method (APHA 1995).

For a large wet detention pond (Ann McCrary Pond on Burnt Mill Creek) we collected data from input and outfall stations. We used these data to test for statistically significant differences in pollutant concentrations between pond input and output stations. The data were first tested for normality using the Shapiro-Wilk test. Normally distributed data parameters were tested using the paired-difference t-test, and non-normally distributed data parameters were tested using the Wilcoxon Signed Rank test. Statistical analyses were conducted using SAS (Schlotzhauer and Littell 1987).

For comparative purposes, North Carolina water quality standards are listed in Appendix A.

2.0 Barnards Creek

Snapshot
Watershed area: 4,161 acres (1,684 ha)
Impervious surface coverage: 17%
Watershed population: Approximately 12,600
Overall water quality: Poor
Problematic pollutants: Low dissolved oxygen; high fecal bacteria counts

The water quality of lower Barnard's Creek is an important issue as single family and multifamily housing construction has occurred upstream of Carolina Beach Rd. in the St. Andrews Dr. area and along Independence Boulevard near the Cape Fear River. Another major housing development (River Lights) is breaking ground for the area east of River Road and between Barnards and Motts Creeks, although no project construction has occurred near Barnards Creek. In 2009 we collected data at a station located on Barnards Creek at River Road (BNC-RR), that drains part of this area (Fig. 2.1). Samples were collected approximately two times per month during 2009. We also have extensive data on this site under a previous funding arrangement from 1999 – 2007 (see the following website for reports on-line: http://www.uncwil.edu/cmsr/aquaticecology/TidalCreeks/Index.htm.

Barnards Creek was sampled on 23 occasions during 2009. BNC-RR had an average salinity of 6.2 ppt with a range of 0.1-14.4 ppt. This station had dissolved oxygen levels ranging from 2.3-11.1, with 39% of the samples yielding readings that fell below the 5.0 mg/L North Carolina standard for dissolved oxygen in brackish waters (Fig. 2.2). Turbidity on average was moderate (15 NTU), and exceeded the state standard for estuarine waters of 25 NTU 17% of the times sampled. Average total suspended solids concentrations were likewise moderate during 2009 (Table 2.1). There is no North Carolina ambient standard for TSS, but our large coastal data sets indicate that values above 25 mg/L are generally high, and we found such concentrations on four of 23 occasions sampled.

Concentrations of nitrate, ammonium and orthophosphate were among the highest in streams and tidal creeks of similar salinities in the Wilmington area (Table 2.1). The mean N/P ratio indicates that phytoplankton production is limited primarily by phosphorus loading in this creek. There was only one algal bloom seen in our 2009 sampling, of 33 µg/L as chlorophyll *a* (Table 2.1).

Average BOD5 was low to moderate for urban streams with mean of 1.4 mg/L and a maximum value of 3.0 mg/L (Mallin et al. 2006a; 2007; 2008). However, fecal coliform counts exceeded the state standard on 35% of the sampling occasions (Fig. 2.3). The geometric mean was well below the state standard (129 CFU/100 mL).

Table 2.1. Mean and standard deviation of water quality parameters in Barnards Creek watershed, January – December 2009. Fecal coliforms as geometric mean; N/P ratio as mean (n = 23 for all parameters).

Parameter BNC-RR	mean (st. deviation)	range
Salinity (ppt)	6.2 (4.4)	0.1-14.4
DO (mg/L)	6.2 (2.6)	2.3-1.1
Turbidity (NTU)	15 (9)	4-36
TSS (mg/L)	16.1 (10.1)	3-40
Nitrate (mg/L)	0.29 (0.15)	0.11-0.42
Ammonium (mg/L)	0.14 (0.15)	0.01-0.70
TN (mg/L)	0.94 (0.37)	0.41-1.92
Phosphate (mg/L)	0.04 (0.01)	0.01-0.06
TP (mg/L)	0.11 (0.04)	0.05-0.25
N/P molar ratio	23.8	
Chlorophyll *a* (µg/L)	8.4 (7.4)	1.0-33.0
BOD5	1.4 (0.5)	0.9-3.0
Fecal coliform bacteria (/100 mL)	129	5-7,000

Figure 2.1 Barnards Creek watershed

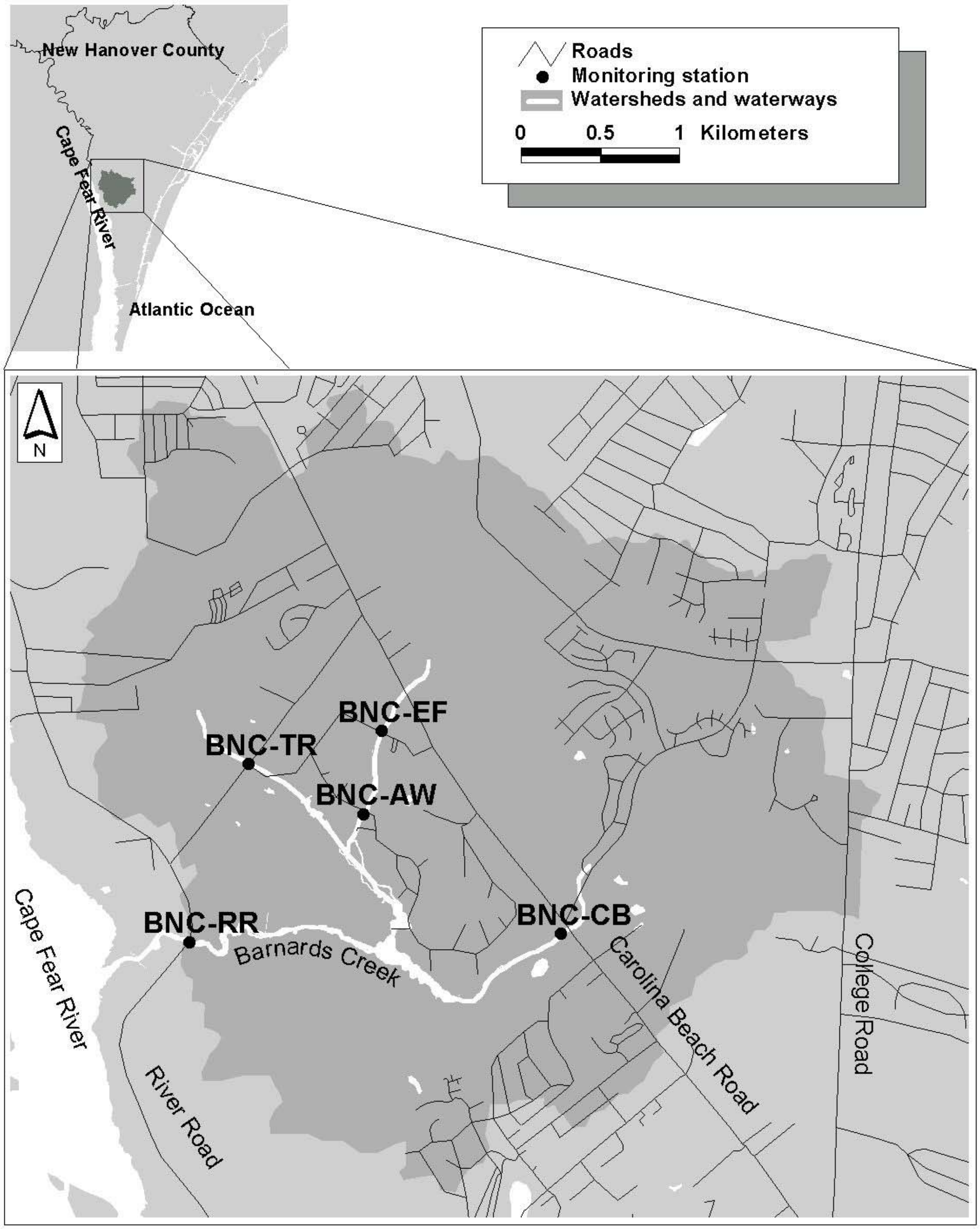


Figure 2.2. Dissolved oxygen concentrations in lower Barnards Creek at River Road, 2009

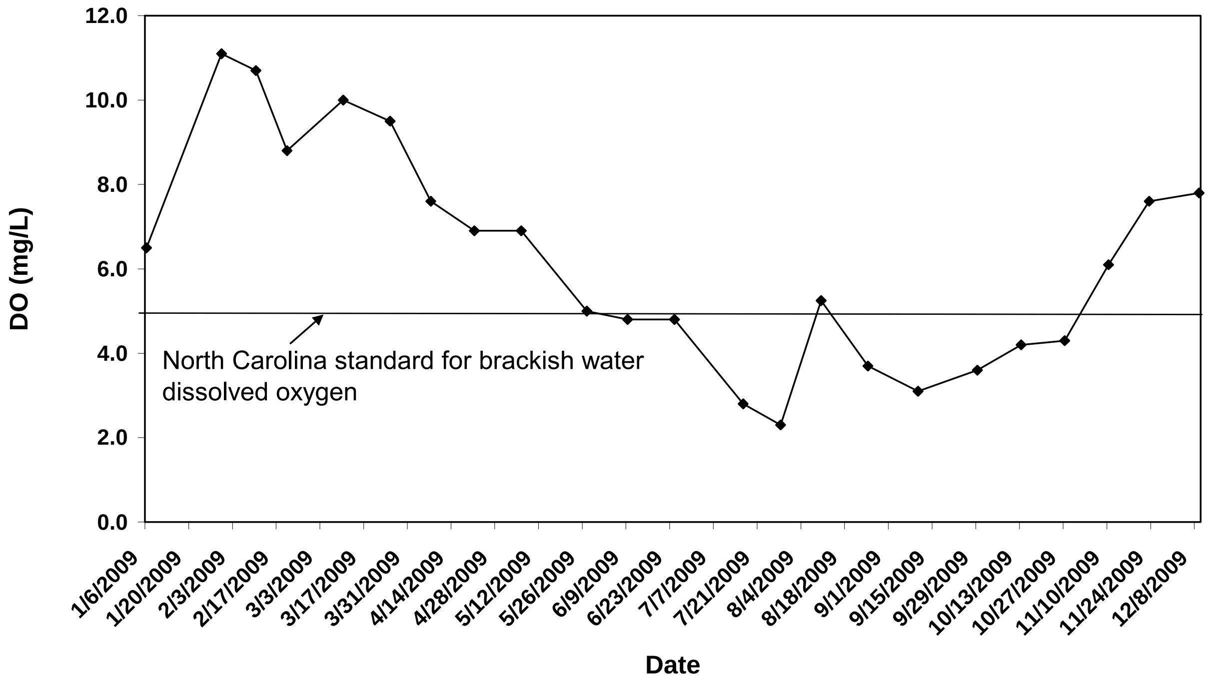
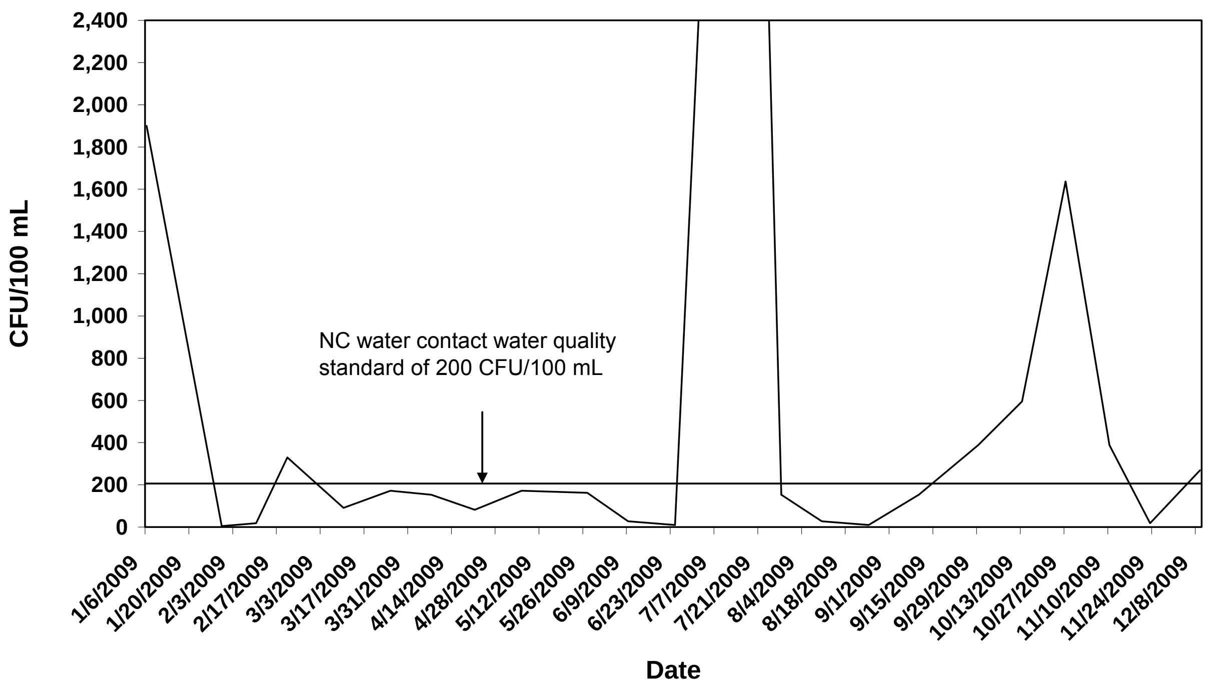


Figure 2.3. Fecal coliform bacteria counts in lower Barnards Creek at River Road, 2009



3.0 Bradley Creek

Snapshot
Watershed area: 4,631 acres (1,874 ha)
Impervious surface coverage: 23%
Watershed population: Approximately 16,720
Overall water quality: fair-poor
Problematic pollutants: fecal bacteria, occasional low dissolved oxygen, occasional algal blooms

The Bradley Creek watershed has been a principal location for Clean Water Trust Fund mitigation activities, including the purchase and renovation of Airlie Gardens by the County. The ongoing redevelopment of the former Duck Haven property bordering Eastwood Road is of great concern in terms of its potential water quality impacts to the creek. This creek is one of the most polluted in New Hanover County, particularly by fecal coliform bacteria (Mallin et al. 2000a). Three upstream stations (BC-SB, BC-NB and BC-CA) were sampled in the past year, both fresh and brackish (Fig. 3.1).

Turbidity was not a major problem during 2009; the standard of 25 NTU was not exceeded on any sampling occasion (Table 3.1). Total suspended solids (TSS) was elevated on one occasion; in July when it was 20 mg/L at BC-NB (there are no NC ambient standards for TSS). There were only minor issues with low dissolved oxygen (hypoxia) upstream, with one station (BC-NB) having DO < 5.0 mg/L on only one occasion each during the six sampling occasions (Appendix B).

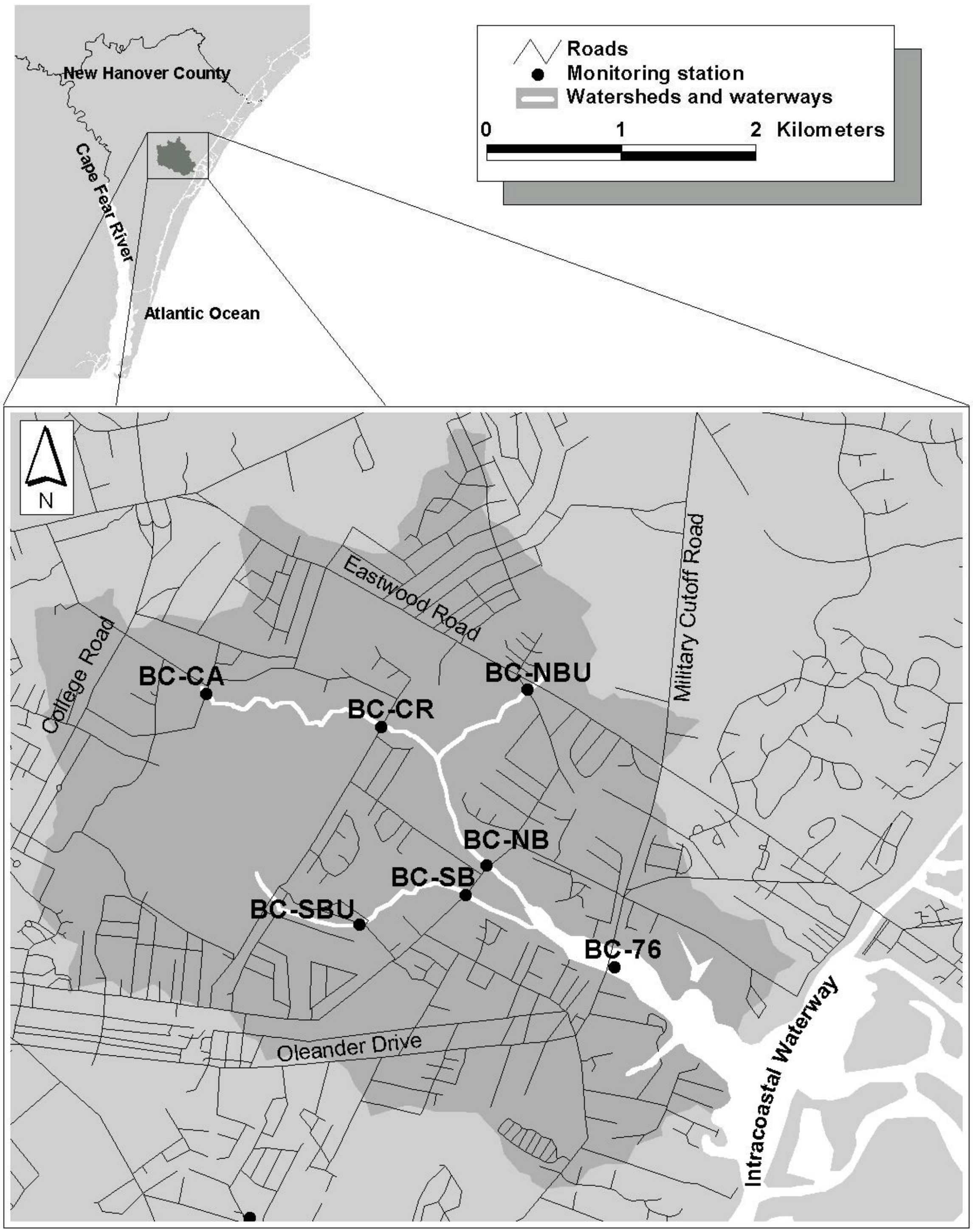
Ammonium concentrations were low on all sampling occasions. Nitrate concentrations were highest at station BC-CA, and slightly increased from the previous year at all sites (Table 3.1). Total nitrogen concentrations were low to moderate at all times sampled. Orthophosphate concentrations were low in all samples in 2009, while total phosphorus was low at BC-CA and moderate at BC-NB and BC-SB. Bradley Creek did not host algal blooms exceeding the state standard in 2009.

Fecal coliform bacteria counts were excessive at all three upstream stations during all seasons, with the NC standard being exceeded on at least 50% of occasions sampled at all sites. The geometric means of the fecal coliform counts ranged from under the standard (127 CFU/100 mL) at BC-NB to >2X the standard (469 CFU/100 mL) at BC-SB (Table 3.1).

Table 3.1 Water quality parameter concentrations at Bradley Creek sampling stations, 2009. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 6 months.

Station	BC-CA	BC-NB	BC-SB
Salinity	0.1 (0.0)	22.5 (9.0)	12.1 (11.1)
(ppt)	0.1-0.1	8.2-33.2	1.6-27.5
Dissolved Oxygen	7.9 (0.7)	6.9 (1.8)	7.2 (1.5)
(mg/L)	7.1-9.0	4.7-9.1	5.0-9.2
Turbidity	2 (3)	5 (3)	5 (3)
(NTU)	0-8	2-9	1-11
TSS	4 (3)	9 (6)	7 (4)
(mg/L)	1-7	3-20	1-12
Nitrate	0.342 (0.028)	0.043 (0.044)	0.042 (0.032)
(mg/L)	0.290-0.360	0.010-0.100	0.010-0.080
Ammonium	0.014 (0.007)	0.012 (0.007)	0.011 (0.007)
(mg/L)	0.005-0.020	0.005-0.020	0.005-0.020
TN	0.525 (0.211)	0.237 (0.155)	0.320 (0.193)
(mg/L)	0.290-0.760	0.100-0.420	0.100-0.580
Orthophosphate	0.012 (0.004)	0.012 (0.004)	0.012 (0.004)
(mg/L)	0.010-0.020	0.010-0.020	0.010-0.020
TP	0.025 (0.018)	0.032 (0.018)	0.040 (0.024)
(mg/L)	0.010-0.050	0.010-0.050	0.010-0.080
N/P	72.3	11.6	9.8
	80.3	6.1	9.4
Chlorophyll *a*	2.7 (3.3)	4.0 (3.3)	7.2 (6.7)
(μg/L)	0.1-9.0	1.0-8.0	1.0-16.0
Fecal coliforms	469	127	269
(CFU/100 mL)	136-2,100	10-1,000	37-637

Figure 3.1. Bradley Creek watershed and sampling sites.



4.0 Burnt Mill Creek

Snapshot
Watershed area: 4,252 acres (1,721 ha)
Impervious surface coverage: 36%
Watershed population: Approximately 25,500
Overall water quality: poor
Problematic pollutants: Fecal bacteria, algal blooms, low dissolved oxygen, high sediment PAH and lead concentrations

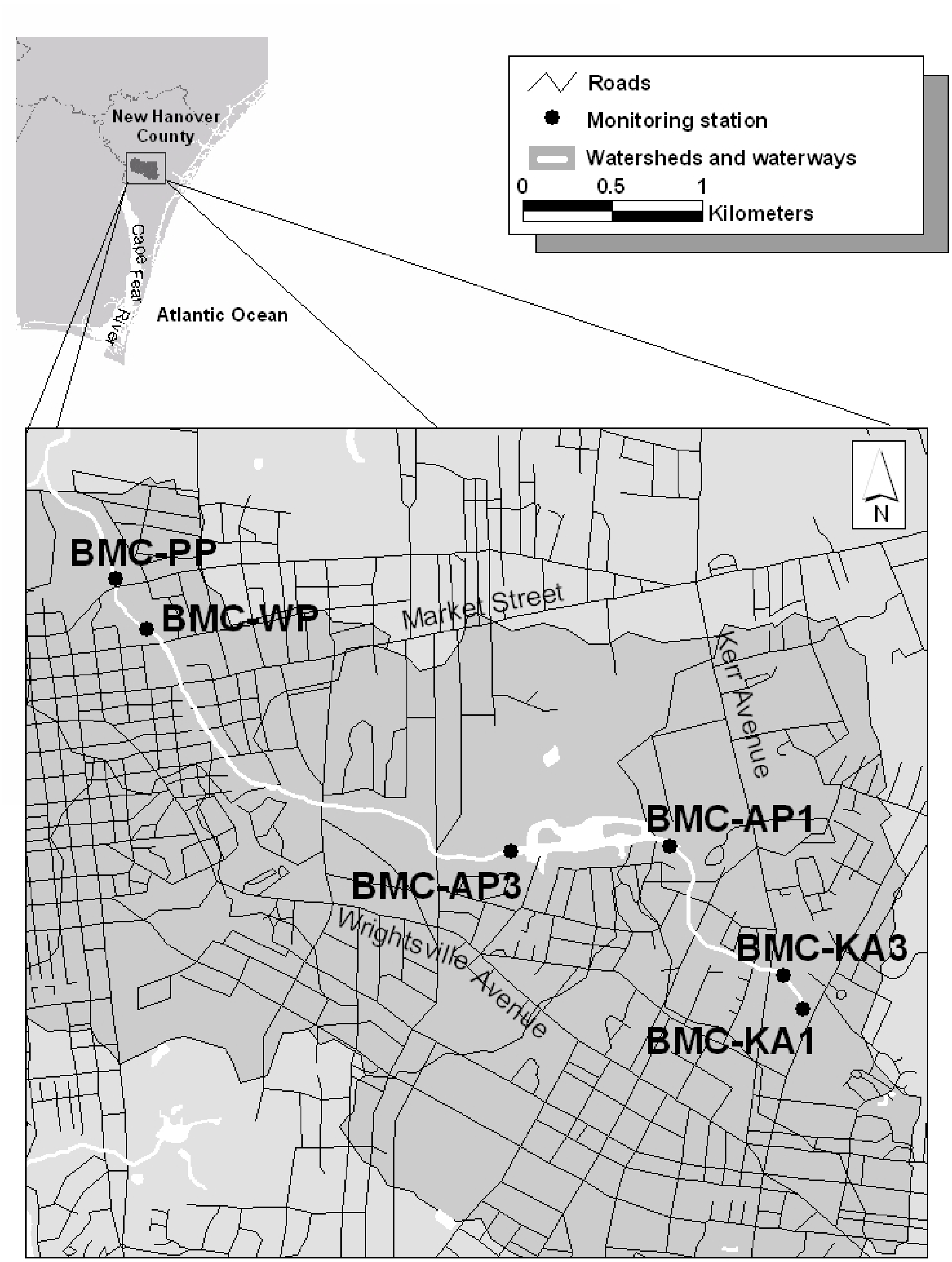
Introduction

In 1997 the City of Wilmington contracted with the Aquatic Ecology Laboratory at the UNC Wilmington Center for Marine Sciences to begin citywide water quality sampling. Since then the Burnt Mill Creek watershed (Fig. 4.1) has been sampled just upstream of Ann McCrary Pond on Randall Parkway (BMC-AP1), and about 40 m downstream of the pond outfall (BMC-AP3). Ann McCrary Pond is a large (28.8 acres) regional wet detention pond draining 1,785 acres, with an apartment complex at the upper end near BMC-AP1. The pond itself periodically hosts thick growths of submersed aquatic vegetation, with *Hydrilla verticillata, Egeria densa, Alternanthera philoxeroides, Ceratophyllum demersum* and *Valliseneria americana* having been common at times. There have been efforts to control this growth, including addition of triploid grass carp as grazers. The ability of this detention pond to reduce suspended sediments and fecal coliform bacteria, and its failure to reduce nutrient concentrations, was detailed in a scientific journal article (Mallin et al. 2002b). Numerous waterfowl utilize this pond as well. Another station is on the creek at the bridge at Princess Place (BMC-PP - Fig. 4.1). Recent water quality results of these continuing studies have been published in technical reports and scientific journals (Mallin et al. 2006a; Mallin et al. 2007; Mallin et al. 2008; Mallin et al. 2009a; Mallin et al. 2009b).

Methods

<u>Sampling Sites</u>: During 2009 samples were collected from three stations on the main body of the creek (Fig. 4.1). Ann McCrary Pond, a large regional wet detention pond on Randall Parkway was sampled just upstream (BMC-AP1) and about 40 m downstream (BMC-AP3) of the pond (Fig. 4.1). Several km downstream of Ann McCrary Pond is Station BMC-PP, located at the Princess Place bridge over the creek, respectively (Fig. 4.1). This is a main stem station in what is considered to be the mid-to-lower portion of Burnt Mill Creek, in a mixed residential and retail area.

Figure 4.1. Burnt Mill Creek watershed and water quality sampling sites.



Results and Discussion

The Upper Creek

About one km downstream from Kerr Avenue along Randall Parkway is the large regional wet detention pond known as Ann McCrary Pond. Data were collected at the input (BMC-AP1) and outflow (BMC-AP3) stations on six occasions in 2009. The state standard for turbidity in freshwater is 50 NTU; there was only one exceedence of this value at both BMC-AP1 and BMC-AP2 in our 2009 samples. Suspended solids concentrations were high on only one occasion at BMC-AP1 and low to moderate at BMC-AP3 leaving this large regional pond, with no statistical difference between inflow and outflow (Table 4.1). Fecal coliform concentrations entering Ann McCrary Pond at BMC-AP1 were high (Table 4.1), possibly a result of pet waste runoff from the apartment complex and runoff from urban upstream areas (including the Kerr Avenue wetland). Over the sampling period five of the six samples collected at BMC-AP1 had counts exceeding 200 CFU/100 mL, but only one of the samples from BMC-AP3 exceeded the standard. There was a statistically significant, 86% reduction (geometric mean) in fecal coliform abundance between the inflow and outflow of the pond (Table 4.1).

There were no major algal blooms at BMC-AP1 that exceeded the North Carolina water quality standard of 40 µg/L during the study, whereas at BMC AP-3 there were two major algal blooms that exceeded the State standard, and two lesser blooms. Statistically, there were no significant differences in chlorophyll *a* concentrations or nutrient concentrations exiting the pond compared with entering the pond (Table 4.1). It is likely that inputs of nutrients enter the pond from a suburban drainage stream midway down the pond, short circuiting the ability of the pond to remove nutrients. Also, intensive waterfowl use of the pond, particularly at a tributary near the outfall, may have contributed to nitrogen and phosphorus loading in the lower pond and along its shoreline. However, the concentrations of nutrients entering the pond were not high to begin with. Dissolved oxygen significantly increased through the pond (by 28% on average), probably because of in-pond photosynthesis and aeration by passage over the final dam at the outfall. There was a significant increase in pH, probably due to utilization of CO_2 during photosynthesis in the pond. At no sampling occasion did dissolved oxygen (DO) fall below the North Carolina standard in our 2009 samples.

Lower Burnt Mill Creek: The Princess Place location (BMC-PP) was the only lower creek station sampled in 2009. One parameter that is key to aquatic life health is dissolved oxygen. In contrast to previous years, dissolved oxygen at BMC-PP in 2009 was not substandard on any sampling occasion. Total suspended solids (TSS) concentrations have no ambient state standard. Based on our long term observances in the lower Cape Fear River basin, for the lower Coastal Plain a reasonable TSS "interest concentration" is 25 mg/L. This concentration was exceeded on only one occasion (May – 33 mg/L) in the lower creek.

However, the lower creek was prone to algal bloom formation, with chlorophyll *a* concentrations on three of six occasions exceeding 50 µg/L at BMC-PP (Table 4.1). As mentioned, the North Carolina water quality standard for chlorophyll *a* is 40 µg/L. Algal blooms can cause disruptions in the food web, depending upon the species present (Burkholder 2001).

An important question is what drives algal bloom formation in Burnt Mill Creek? Nutrient concentrations were unremarkable at BMC-PP. Examination of inorganic nitrogen to phosphorus ratios (Table 4.1) shows that median N/P ratios are 14.9. In waters where the N/P ratio is well below 16 (the Redfield Ratio for algal nutrient composition) it is generally considered that algal production is limited by the availability of nitrogen (i.e. phosphorus levels are sufficient); where N/P ratios are well above 16, additions of phosphate should encourage algal blooms. If such values are near the Redfield Ratio, inputs of either N or P could drive an algal bloom. Thus, there is a need for control of inputs of both N and P to help reduce algal blooms in lower Burnt Mill Creek.

Table 4.1. Water quality data in Burnt Mill Creek, 2009, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as median.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	7.2 (0.9) 6.2-8.5	10.0 (1.8)* 7.8-11.7	7.4 (1.4) 5.1-9.0
Cond. (μS/cm)	213 (91) 77-280	226 (82) 67-292	522 (328) 90-1,067
pH	7.2 (0.3) 6.8-7.6	7.8 (0.5)* 7.2-8.4	7.3 (0.2) 7.1-7.5
Turbidity (NTU)	12 (19) 3-50	18(21) 1-59	13 (6) 4-21
TSS (mg/L)	13 (16) 1-44	10 (4) 3-16	13 (11) 2-33
Nitrate (mg/L)	0.187 (0.122) 0.080-0.410	0.057 (0.086) 0.010-0.230	0.165 (0.091) 0.040-0.300
Ammonium (mg/L)	0.080 (0.045) 0.010-0.300	0.045 (0.039) 0.010-0.120	0.052 (0.020) 0.030-0.080
TN (mg/L)	0.665 (0.335) 0.250-1.710	0.6654 (0.335) 0.200-1.110	2.028 (2.701) 0.180-7.400
OrthoPhos. (mg/L)	0.018 (0.013) 0.010-0.040	0.018 (0.013) 0.010-0.040	0.032 (0.015) 0.010-0.050
TP (mg/L)	0.077 (0.069) 0.020-0.200	0.063 (0.034) 0.010-0.110	0.128 (0.111) 0.040-0.350
N/P molar ratio	34.3	7.8	14.9
Chlor. *a* (μg/L)	6.3 (5.9)* 2.0-18.0	40.7 (40.6) 4.0-116.0	65.3 (84.4) 7.0-232.0
FC (CFU/100 mL)	1,116 91-34,000	159* 28-21,000	1,940 350-32,000

* Statistically significant difference between inflow and outflow at $p<0.05$; ** $p < 0.01$.

Important from a public health perspective are the excessive fecal coliform bacteria counts, which maintained geometric means at BMC-PP well in excess of the State standard for human contact waters (200 CFU/100 mL). Fecal coliform counts were greater than the State standard on 100% of occasions sampled at Princess Place. It is notable that fecal coliform bacteria counts increased along the passage from BMC-AP3 (geometric mean 159 CFU/100 mL) to the Princess Place location (geometric mean 1,940 CFU/100 mL; Fig. 4.2). It is likewise notable that nutrient concentrations increased from the outflow from Ann McCrary Pond downstream to the lower main stem station (Fig. 4.3).

Figure 4.2. Fecal coliform bacteria geometric means for Burnt Mill Creek, 2009

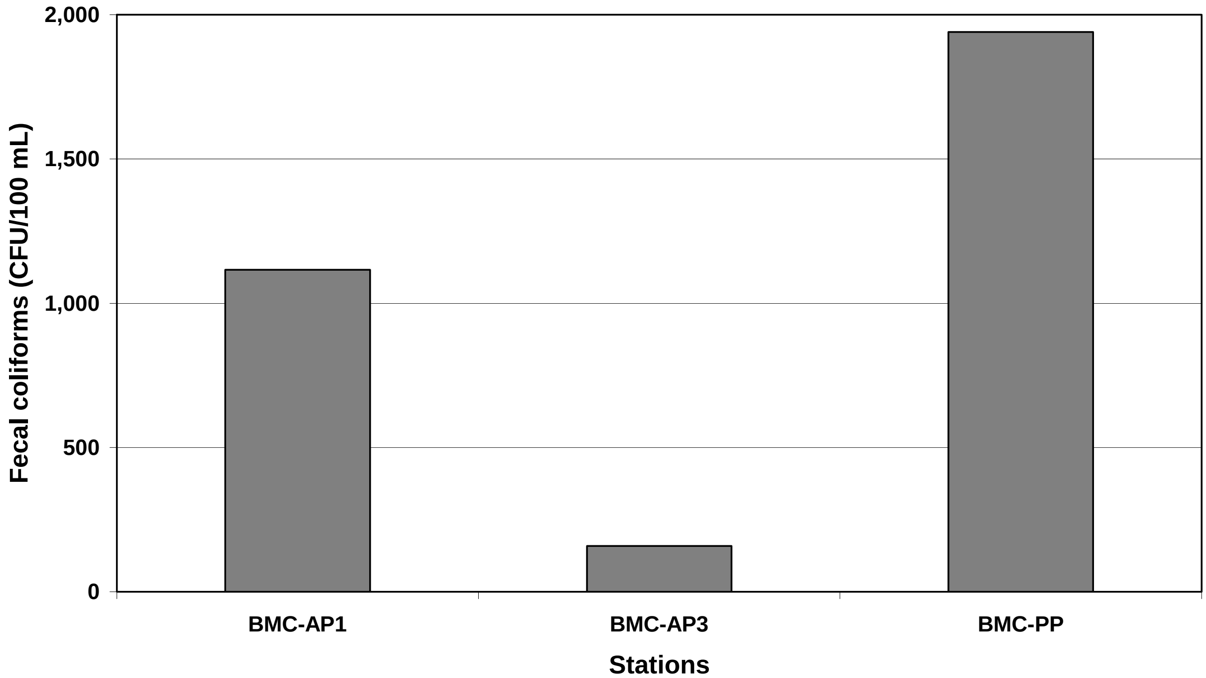
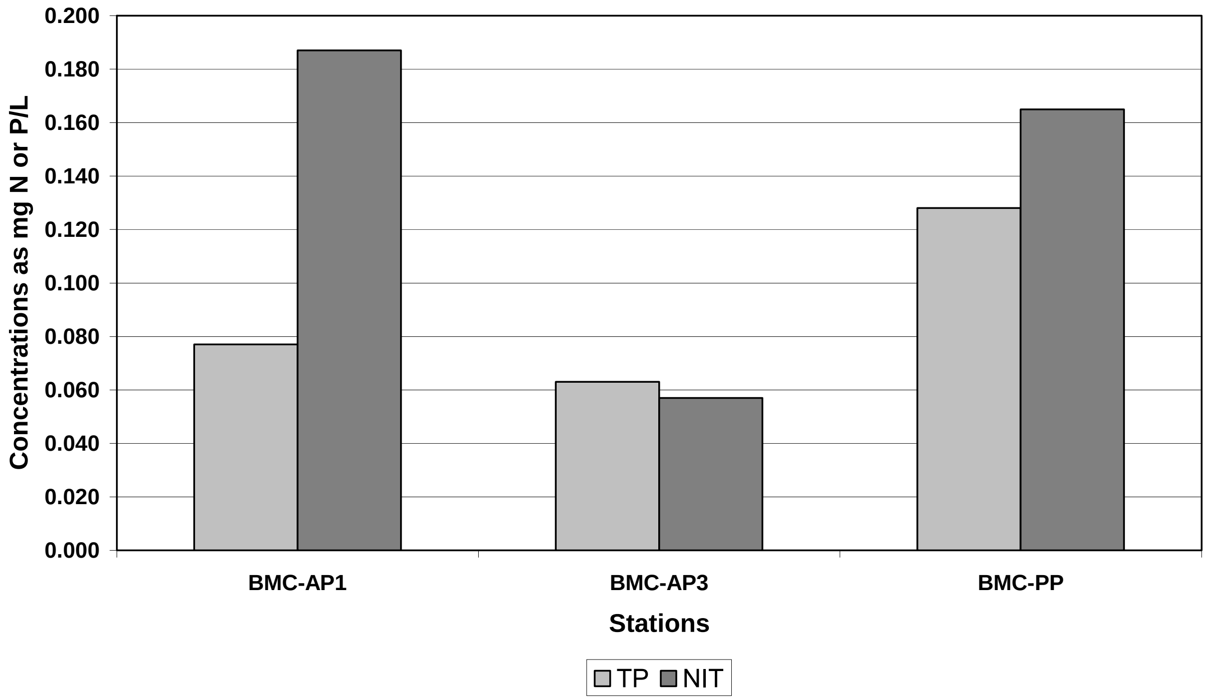


Figure 4.3. Average total phosphorus and nitrate concentrations by station for Burnt Mill Creek, 2009



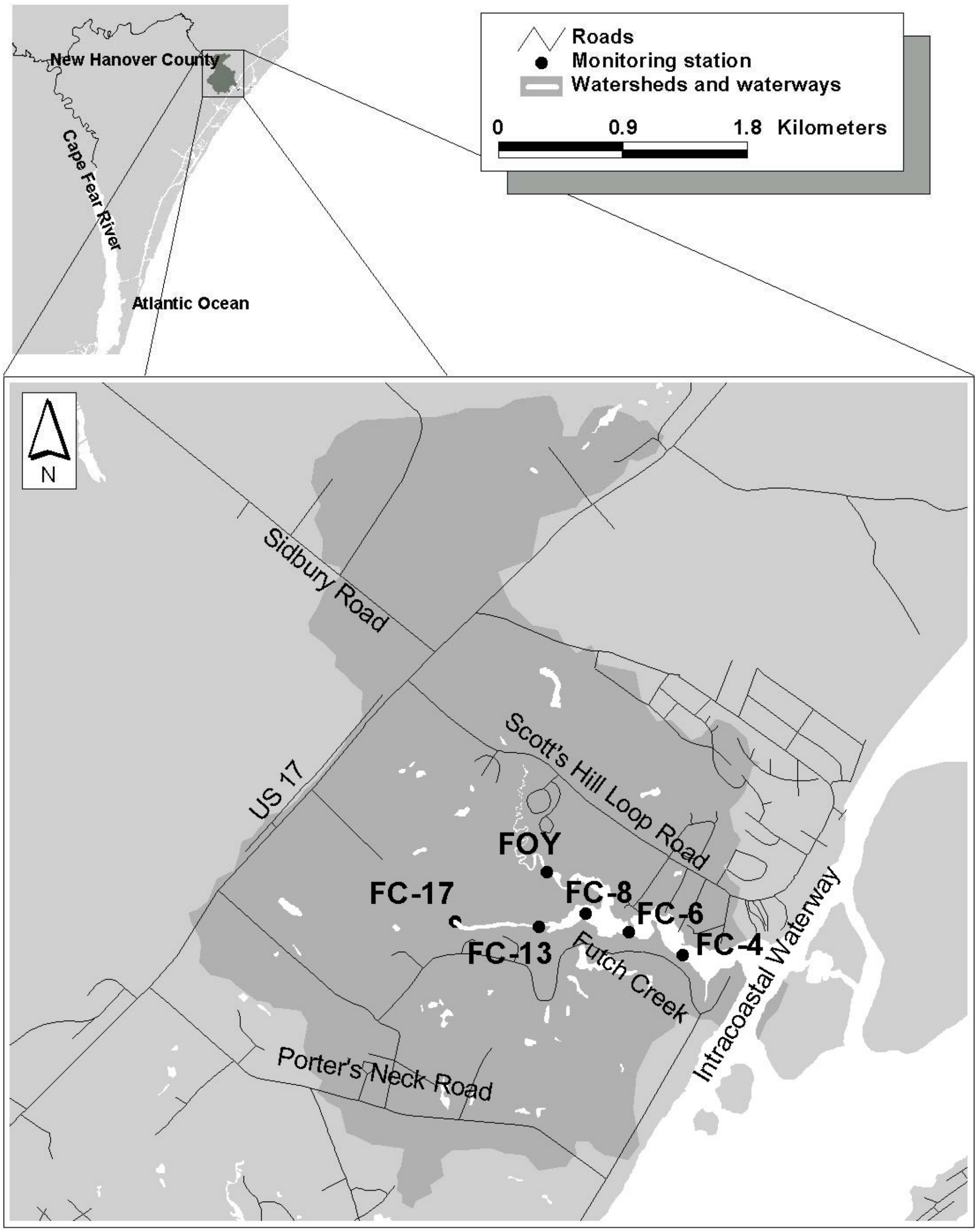
To summarize, in most years Burnt Mill Creek has problems with low dissolved oxygen (hypoxia) at some of the stations, but in 2009 dissolved oxygen (DO) was within standard at all sites and on all sampling occasions. Algal blooms remained an important problem in the creek during 2009. The N/P ratios in the creek indicate that inputs of either nitrogen or phosphorus are likely to stimulate algal bloom formation, depending upon season and inputs. It is notable that nutrient concentrations increase from the lower portion of the regional Randall Parkway wet detention pond as one moves downstream toward the lower creek. An important human health issue is the high fecal bacteria counts found at most sampling stations, with the exception of BMC-AP3 below the detention pond. As NPDES point source discharges are not directed into this creek, the fecal bacteria (and nutrient) loading appears to be caused either by non-point source stormwater runoff, illegal discharges, or leakage from sanitary sewer lines.

5.0 Futch Creek

Snapshot
Watershed area: 3,247 acres (1,314 ha)
Impervious surface coverage: >11%
Watershed population: 1,720 (New Hanover County only)

Six stations were sampled by the University of North Carolina Wilmington in Futch Creek from 1993 through 2007. UNCW was not funded by the County to sample Futch Creek in 2008 or 2009. We present the above information and map below purely for informational purposes. Water quality information for 2008-2009 is available on the County Planning Department website:
http://www.nhcgov.com/AgnAndDpt/PLNG/Pages/WaterQualityMonitoring.aspx.

Figure 5.1. Futch Creek watershed and sampling sites.



6.0 Greenfield Lake Water Quality

Snapshot
Watershed area: 2,551 acres (1,032 ha)
Impervious surface coverage: 36%
Watershed population: 12,270 Overall water quality: Poor, improving
Problematic pollutants: Fecal bacteria, low dissolved oxygen in tributaries and the upper lake, algal blooms

Three tributaries of Greenfield Lake were sampled for physical field parameters only in 2009 (Table 6.1, Fig. 6.1). All three tributaries suffered from hypoxia, with GL-LB (creek at Lake Branch Drive) and GL-LC (creek beside Lakeshore Commons) both showing average concentrations below the state standard (DO < 5.0 mg/L). However, the hypoxia was not as severe as in 2008. Dissolved oxygen levels were below the state standard of 5.0 mg/L on three occasions each (Table 6.1; Appendix B). Turbidity concentrations were generally low in the tributary stations, with no exceedences of the freshwater standard of 50 NTU (Table 6.1).

Table 6.1. Mean and (standard deviation) / range of selected field water quality parameters in tributary stations of Greenfield Lake, 2009. n = 6.

Parameter	GL-JRB	GL-LB	GL-LC
DO (mg/L)	5.1 (2.2) 2.2-8.0	4.6 (2.7) 2.7-7.8	4.6 (1.7) 2.4-6.4
Turbidity (NTU)	5 (4) 0-10	8 (10) 1-27	9 (7) 0-17

Three in-lake stations were sampled (Table 6.2). Station GL-2340 represents an area receiving a considerable influx of urban/suburban runoff, GL-YD is downstream and receives some outside impacts, and GL-P is at Greenfield Lake Park, away from inflowing streams but in a high-use waterfowl area (Fig. 6.1). Low dissolved oxygen was only a problem at GL-2340, with concentrations below the state standard of 5.0 mg/L on two of six occasions (see Section 6.1). Turbidity was below the state standard on all sampling occasions, and suspended solids were low to moderate except for high TSS (46 mg/L) at GL-YD and 29 mg/L at GL-2340 in September. Fecal coliform concentrations were problematic at all three sites in the lake, exceeding the State standard on five of six sampling occasions at GL-2340, two times at GL-YD, and three times at GL-P. During July 2009 fecal coliform counts were 54,000 CFU/100 mL at GL-2340, 12,000 CFU/100 mL at GL-YD and 5,300 CFU/100 mL at GL-P.

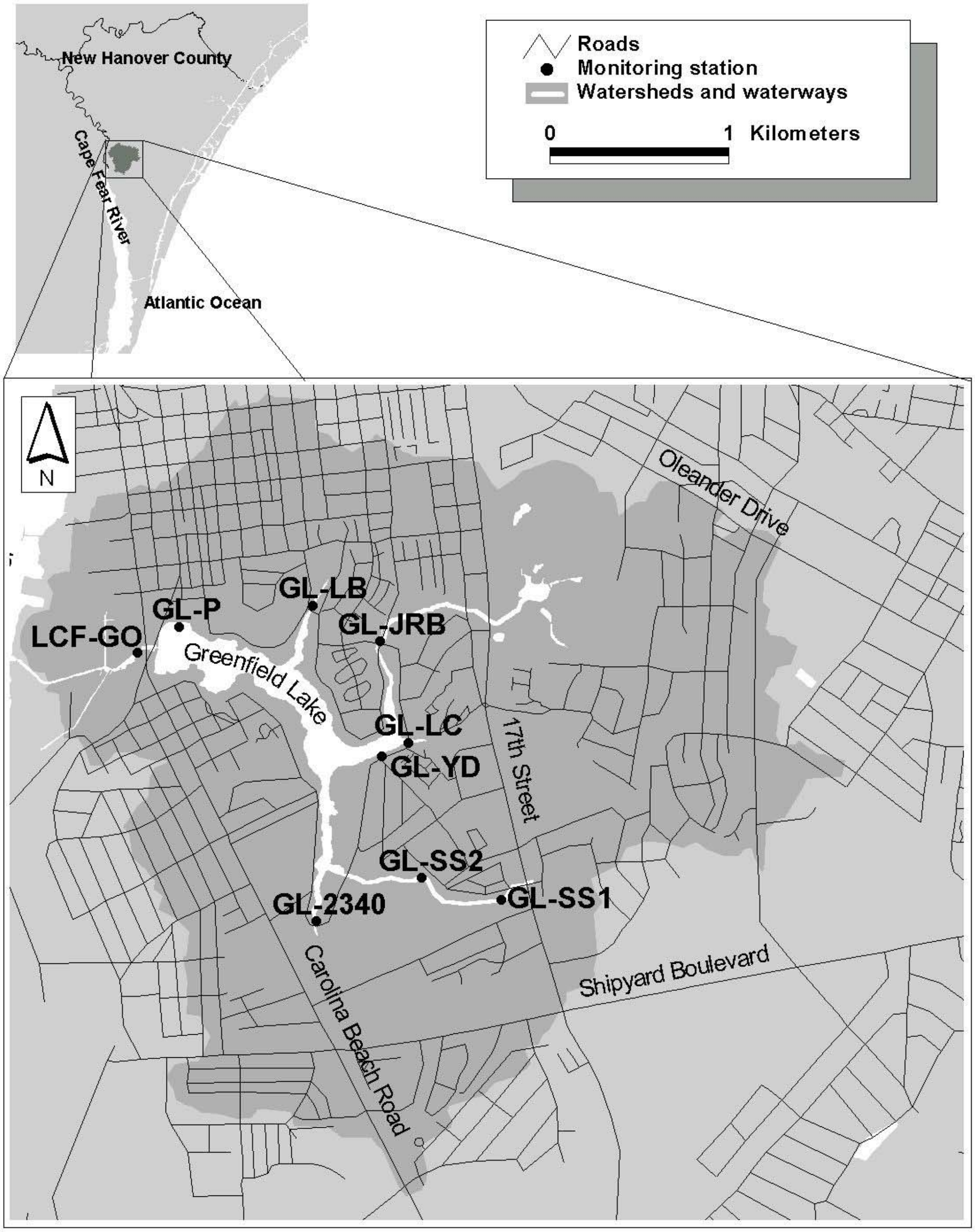
Nitrogen concentrations were generally highest at GL-YD, with lower concentrations at GL-P and GL-2340; total nitrogen concentrations were generally similar to 2008. Ammonium levels in the lake were generally low except for a pulse of ammonium in May 2009. Total phosphorus concentrations were highest at GL-YD among stations, and none of the phosphorus values were remarkable (Table 6.2). Inorganic N/P molar ratios can be computed from ammonium, nitrate, and orthophosphate data and can help determine what the potential limiting nutrient can be in a water body. Ratios well below 16 (the Redfield ratio) can indicate potential nitrogen limitation, and ratios well above 16 can indicate potential phosphorus limitation (Hecky and Kilham 1988). Based on the median N/P ratios (Table 6.2), phytoplankton growth in Greenfield Lake was limited by nitrogen except in the uppermost station GL-2340. Our previous bioassay experiments indicated that nitrogen was usually the limiting nutrient in this lake (Mallin et al. 1999).

Phytoplankton blooms are periodically problematic in Greenfield Lake (Table 6.1), and usually consist of green or blue-green algal species, or both together. These blooms have occurred during all seasons, but are primarily a problem in spring and summer. Three blooms exceeding the North Carolina water quality standard of 40 μg/L of chlorophyll *a* occurred at both GL-YD and GL-P in 2009, with no violations of standard at GL-2340. Average biochemical oxygen demand (BOD5) was generally high (> 3.0 mg/L) at all three stations in the lake (Table 6.1). The elevated BOD was in part driven by organic detritus created by the algal blooms (Mallin et al. 2006; see also subsequent section, Fig. 6.7) and likely also by stormwater runoff inputs (Mallin et al. 2009). Elevated BOD contributes directly to lower dissolved oxygen concentrations. Thus, during 2009 Greenfield Lake was impaired by large algal blooms, high fecal coliform counts and low dissolved oxygen concentrations, although the latter parameter continues to be better than the 2003-2004 pre-restoration period, and was better than in 2008 (see Section 6.1A). The tributary stations were also impaired by low dissolved oxygen, but to a lesser extent than in previous years. These same problems have occurred in the lake for several years (Mallin et al. 1999; 2000; 2002; 2003; 2004; 2005; 2006; 2007; 2008).

Table 6.2. Mean and (standard deviation) / range of water quality parameters in Greenfield Lake sampling stations, 2009. Fecal coliforms given as geometric mean, N/P ratio as median; n = 6 samples collected.

Parameter	GL-2340	GL-YD	GL-P
DO (mg/L)	5.6 (2.8) 1.6-10.4	8.2 (3.9) 4.9-14.6	4.6 (1.7) 2.4-6.4
Turbidity (NTU)	4 (3) 0-8	5 (7) 0-18	6 (5) 1-14
TSS (mg/L)	10 (12) 1-29	12 (17) 1-46	6 (4) 1-11
Nitrate (mg/L)	0.25 (0.13) 0.02-0.38	0.07 (0.07) 0.01-0.15	0.02 (0.04) 0.01-0.09
Ammonium (mg/L)	0.06 (0.04) 0.02-0.11	0.12 (0.15) 0.01-0.41	0.10 (0.15) 0.01-0.39
TN (mg/L)	0.73 (0.22) 0.43-1.02	1.80 (1.68) 0.64-5.00	0.94 (0.53) 0.30-1.90
OrthoPhosphate (mg/L)	0.03 (0.01) 0.01-0.03	0.02 (0.02) 0.01-0.04	0.04 (0.03) 0.01-0.08
TP (mg/L)	0.07 (0.03) 0.03-0.12	0.11 (0.07) 0.05-0.24	0.09 (0.05) 0.06-0.17
N/P molar ratio	27.5	14.9	4.6
Fec. col. (CFU/100 mL)	447 19-54,000	118 10-12,000	260 37-5,300
Chlor. *a* (µg/L)	8.2 (11.8) 1.0-32.0	55.3 (59.0) 3.0-157.0	39.8 (42.4) 3.0-117.0
BOD5	3.5 (5.2) 0.9-14.0	4.3 (3.3) 1.6-9.0	3.1 (1.2) 1.7-4.8

Figure 6.1 Greenfield Lake watershed



6.1 A Continuing Assessment of the Efficacy of the 2005-2009 Greenfield Lake Restoration Measures

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Introduction

Greenfield Lake is a 37 ha blackwater system located in the City of Wilmington, North Carolina. It was first dammed and filled as a millpond in 1750, and purchased for a city park in 1925. It has an average depth of 1.2-1.5 m, it is about 8,530 m around the shoreline, and its watershed drains approximately 1,032 ha (2,551 acres). The lake has one outfall, but is fed by six perennial inflowing streams (as well as intermittent ditches). The lake is surrounded by a watershed that is comprised mainly of residential, office, institutional and commercial areas, with an overall watershed impervious surface coverage of 36%.

In recent decades a number of water quality problems have become chronic within the lake, including high fecal coliform bacterial counts, low dissolved oxygen problems, nuisance aquatic macrophyte growths, algal blooms and fish kills. Some of these problems are typically related to eutrophication, a process driven by loading of excessive nutrients to a body of water. The State of North Carolina Division of Water Quality considers the lake to have a problem with aquatic weeds (NCDENR 2005). Periodic phytoplankton blooms have occurred in spring, summer and fall. Some of the most frequent bloom forming taxa are the cyanobacterium *Anabaena cylindrica* and the chlorophytes *Spirogyra* and *Mougeotia* spp. The free-floating macrophyte *Lemna* sp. (duckweed) is frequently observed on the surface, and below a massive *Lemna* bloom in summer 2004 dissolved oxygen concentrations at the park station were nearly anoxic. In-situ monitoring instruments have demonstrated that dissolved oxygen concentrations can decrease by as much as 45% at night compared with daytime DO measurements.

In 2005 several steps were taken by the City of Wilmington to restore viability to the lake (David Mayes, City of Wilmington Stormwater Services, personal communication). During February one thousand sterile grass carp were introduced to the lake to control (by grazing) the overabundant aquatic macrophytes. During that same month four SolarBee water circulation systems were installed in the lake to improve circulation and force dissolved oxygen from the surface downward toward the bottom. Finally, from April through June 2005 a contract firm applied the herbicide Sonar to further reduce the amount of aquatic macrophytes. On March 29-31 2006 City crews applied 35 gallons of K-Tea algaecide and on July 18 applied 6.3 gallons of habitat aquatic herbicide. A contract firm stocked the lake with 500 additional grass carp on April 4, 2006 and applied 40 gallons of Nautique aquatic herbicide on April 25, and treated the lake with Nautique again on July 31, 2007. The firm also added 200 more grass carp March 28, 2007, but no further fish were added in 2008. City crews added spot applications of herbicide in April, September, October and November 2007 and April, May and June

2008. Herbicide was also added in March, April, July, August and September 2009 in various locations.

Since 1998 the University of North Carolina Wilmington's Aquatic Ecology Laboratory, located at the Center for Marine Science, has been performing water quality sampling and associated experiments on Greenfield Lake. The City of Wilmington Stormwater Services has funded this effort. Monitoring of various physical, chemical, and biological parameters has occurred monthly. These data allow us to perform a assessment of the effectiveness of the City's lake restoration efforts by comparing summer data from 2003 and 2004 (before restoration efforts) with data from the summers of 2005 through 2009 (after restoration efforts have been ongoing).

Results

To assess the results so far we have chosen several parameters to examine over time. One parameter that is only estimated visually is surface coverage by nuisance macrophyte vegetation. In the summers of 2003 and 2004 extensive mats of duckweed (*Lemna* sp.), mixed with algae and other vegetation covered large areas of the lake's surface, with visible estimates for some coves exceeding 95% coverage. In summer of 2005 surface coverage was minimal; with most lake areas 95% clear of surface mats. Some coverage returned in 2006 and minimal coverage was seen in 2007 through 2009.

Dissolved oxygen (DO): During 2003 and 2004 hypoxia (DO < 4.0 mg/L) was common in surface waters. Areas beneath thick *Lemna* mats were anoxic (DO of zero) or nearly so, especially at GL-P, the main Park area (Fig. 6.1). Following the onset of herbicide addition in April 2005, the May DO (mean of the three in-lake stations) showed a distinct decrease; however, it subsequently rose in June and remained at or above the State standard of 5 mg/L through the rest of the summer of 2005 (Fig. 6.2). In summer of 2006 the average lake DO levels decreased compared with 2005, but were still higher than in 2003 and 2004 (Fig. 6.2). This was because Station GL-2340 experienced low DO levels from 1.2 to 3.8 mg/L from July through September, although the other two in-lake stations (GL-P and GL-YD) maintained good DO levels. In 2007 through 2009 GL-2340 continued to have poor, but improving dissolved oxygen problems and the other two in-lake stations had generally good dissolved oxygen (Table 6.2).

Turbidity: Turbidity was not excessive in the lake during the two years prior to restoration efforts (Mallin et al. 2006). It has remained low (well below the North Carolina standard) following these efforts throughout 2009 (Table 6.2).

Ammonium: Ammonia, or ammonium is a common degradation product of organic material, and is an excretory product of fish and other organisms. The addition of grass carp and the herbicide usage did not raise ammonium concentrations in the lake for several years (Fig. 6.3). However, in early 2008 there was a large increase in average ammonium lake-wide, which decreased in late spring (Fig. 6.3). There were no herbicide sprayings immediately before this pulse, and no fish kills, so the reason for this remains unknown. In 2009 there were generally low ammonium levels except for an unusually large peak in July, which subsequently decreased (Fig. 6.3). There was no herbicide application within three months prior to this 2009 ammonium peak.

Nitrate: Nitrate is an inorganic form of nitrogen that is known to enter the lake during rainfall and runoff periods (Mallin et al. 2002). The concentration of nitrate in the lake does not appear to have been influenced by the restoration efforts (Table 6.2). Nitrate concentrations are generally impacted by stormwater runoff, and the low rainfall in 2007 likely provided minimal nutrient inputs to the lake. During 2008 there was a sharp increase in nitrate concentrations, especially in the upper and middle lake stations, which we suspect was largely stormwater runoff-driven. Concentrations in 2009 were highest at GL-2340 but otherwise unremarkable (Table 6.2).

Total nitrogen: Total nitrogen (TN) is a combination of all inorganic and organic forms of nitrogen. Mean concentrations and concentrations at individual stations appeared to show no overall trend over time, although we noted an unusually large peak in May of 2009 (Table 6.2; Fig. 6.4).

Orthophosphate: Orthophosphate is the most common inorganic form of phosphorus, and is utilized as a key nutrient by aquatic macrophytes and phytoplankton. Orthophosphate concentrations have not experienced any major changes in the water column either before (Mallin et al. 2006a) or after the restoration effort (Table 6.2). Earlier research found that a significant quantity of phosphorus in the lake is contributed by waterfowl through excretion.

Total phosphorus: Total phosphorus (TP) is a combination of all organic and inorganic forms of phosphorus in the water. Although pulses of TP occurred in summer 2005 and spring 2006, they were similar in magnitude to pulses of TP seen in 2003 and 2004 (Fig. 6.5). Pulses in 2007 were smaller than the previous years (Figure 6.5). In 2008 there was a jump in TP, which may in part by caused by high phytoplankton biomass and the phosphorus locked up as cell tissue (see next section). Another reason may include increased runoff of phosphorus into the lake with increased rainfall. In 2009 there was decreased TP compared with 2008, although it was not as low as in 2007.

Chlorophyll *a*: Chlorophyll *a* is the principal measure used to estimate phytoplankton biomass (algal bloom strength) in water bodies. As mentioned above, algal blooms have been a common occurrence in this lake. They are generally patchy in space, usually occurring at one or two stations at a time. However, in summer 2005 extensive phytoplankton blooms occurred at all three in-lake stations, with levels well exceeding the State standard of 40 µg/L (Fig. 6.6). Blooms continued throughout 2006 as well (Fig. 6.6). A positive signal was that blooms within the lake in 2007 were fewer than in previous years (Fig. 6.6), either because of continuing restoration efforts or lower stormwater driven inputs of nitrate to feed the blooms. Unfortunately the latter was the likely explanation, as in 2008 the blooms returned in force (Fig. 6.6; also see previous section). In 2009 several blooms exceeding the state standard occurred (at GL-P and GL-YD); however, on average, overall bloom activity in the lake showed a slight decrease from 2008 (Fig. 6.6). The overall reduction in macrophytes coverage may also encourage phytoplankton growth because there is less competition for nutrients, and less shading of the water column by the macrophytes cover.

Algal blooms are the result of nutrient inputs, either from outside the lake or from release from decaying material. Algal blooms, when they die, cause a BOD (biochemical oxygen demand) load (Mallin et al. 2006b). This is organic material that natural lake bacteria feed on and multiply, using up dissolved oxygen in the lake as they do so. We performed regression analysis on our 2007 chlorophyll *a* concentrations with the corresponding BOD concentrations for the three in-lake stations, and found that, statistically speaking, approximately 40% of the variability in Greenfield Lake BOD was caused by algal blooms. We performed similar analysis using our 2008 chlorophyll *a* and BOD data (Fig. 6.7). The results showed a significant positive correlation between the two parameters, although regression analysis indicated that only 26% of the variability in dissolved oxygen was accounted for by chlorophyll *a* in 2008. In 2009 this regression was again highly significant ($p = 0.017$) and chlorophyll explained about 31% of the variability in BOD5. Thus, the algal blooms can lead to low dissolved oxygen in the lake, but there are other factors that contribute as well. Research conducted on Burnt Mill Creek, Smith Creek, and Prince Georges Creek (Mallin et al. 2009) showed that BOD was also strongly correlated with watershed rainfall and TSS concentrations, indicating that runoff of oxygen-demanding materials (organic waste, debris, various chemicals) can make a significant contribution to reducing dissolved oxygen in aquatic systems.

<u>Fecal coliform bacteria</u>: Fecal coliform bacteria are commonly used to provide an estimate of the human or animal derived microbial pollution in a water body. Greenfield Lake is chronically polluted by high fecal coliform counts, well exceeding the state standard of 200 CFU/100 mL during many months (Table 6.2; Fig. 6.8). In summer 2005 there were particularly large fecal coliform counts at each in-lake station, though the individual stations did not have pulses during the same months. Excessive fecal coliform counts occurred to a lesser degree in 2006 in the lake, mainly at GL-2340 (Table 6.2). In 2007 high fecal coliform counts occurred within the lake on about 43% of the occasions sampled (Fig. 6.8). In 2008 the lake was highly polluted by fecal coliforms (Fig. 6.8), with stormwater runoff likely the principal source. In September 2008 at the upper station, GL-2340, there was a high concentration (60,000 CFU/100 mL) of fecal coliform bacteria. City staff was unaware of any sewage spills in that area, so the source remains unknown. In 2009 there were again high counts (Table 6.2) especially for July (Fig. 6.8) with other months not unusually high. Fecal coliform counts are not expected to be influenced by the type of restoration efforts currently ongoing in the lake.

Discussion

A risk that is taken when applying herbicides to lakes is the creation of biochemical oxygen demand (BOD) from decomposing organic matter that is a product of dead or dying plant material. As mentioned above, this would serve to drive the lake DO concentrations downward. DO levels in summer 2005 were nearly twice what they were during summers of 2003 and 2004, and DO levels in 2006 were also higher than 2003 and 2004. It is very likely that the use of the SolarBee circulation systems maintained elevated DO even when there was an obvious BOD source. The in-lake station with lowest DO levels in 2006 was GL-2340, which is located quite a distance from the

SolarBees. This pattern continued into 2007, 2008 and 2009, but we note 2009 in general had better DO concentrations than in the previous two years.

Water column nutrient concentrations did not appear to change notably after the introduction of grass carp or use of herbicide. Certainly ammonium, an excretory and decomposition product would be expected to rise following the consumption and death of large quantities of plant material. Likewise phosphorus did not increase, although it is a common excretory product. However, ammonium (like orthophosphate) is readily used as a primary nutrient by phytoplankton. Nutrient addition bioassay experiments have demonstrated that phytoplankton in this lake is limited by nitrogen (Mallin et al. 1999). It is likely that ammonium produced by fish excretion or dying plant material was utilized by phytoplankton to produce the excessive algal blooms that characterized the lake in 2005 and 2006. The phytoplankton blooms were dominated by blue green algae (cyanobacteria) including species containing heterocysts. These species have the added ability to fix atmospheric nitrogen when phosphorus is replete. Thus, while large amounts of macrophyte material disappeared from the lake, some of the resultant nutrients were utilized by phytoplankton to produce the blooms. As mentioned, a problem with algal blooms is that when they die, they become labile forms of organic material, or BOD (Fig. 6.7). Published research has previously demonstrated that chlorophyll *a* in this lake is strongly correlated with BOD (Mallin et al. 2006b). Positive news from 2007 was that algal blooms were fewer than in previous years. This may have been due to the restoration efforts, less stormwater runoff during the drought, or some combination of the two. However, since the blooms returned in 2008 and 2009 it is likely that nitrogen loading from stormwater runoff is the principal factor controlling their magnitude and frequency of occurrence, with some nutrient contributions from plant decomposition following the ongoing spot herbicide treatments.

The continuing problems with high fecal coliform bacteria do not appear to be related to any of the restoration activities. Fecal coliform bacteria enter the environment from the feces of warm blooded animals, so it is possible that increases in waterfowl or dogs brought to the lake by their owners, or feral cats could lead to increased fecal coliform bacteria counts, but we have no data to support this speculation either way. Likewise on rare occasions large pulses of fecal bacteria have appeared in the lake or tributaries, potentially related to either sewage leaks or spills, or illicit connections.

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Mallin, M.A., L.B. Cahoon, M.H. Posey, V.L. Johnson, D.C. Parsons, T.D. Alphin, B.R. Toothman, M.L. Ortwine and J.F. Merritt. 2006a. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2004-2005*. CMS Report 06-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., V.L. Johnson, S.H. Ensign and T.A. MacPherson. 2006b. Factors contributing to hypoxia in rivers, lakes and streams. *Limnology and Oceanography* 51:690-701.

Mallin, M.A., V.L. Johnson and S.H. Ensign. 2009. Comparative impacts of stormwater runoff on water quality of an urban, a suburban, and a rural stream. *Environmental Monitoring and Assessment* 159:475-491.

NCDENR. 2005. Cape Fear River Basinwide Water Quality Plan (draft). North Carolina Department of Environment and Natural Resources, Division of Water Quality / Planning, Raleigh, NC, 27699-1617.

Figure 6.2. Average dissolved oxygen concentrations in Greenfield Lake, 2003-2009.

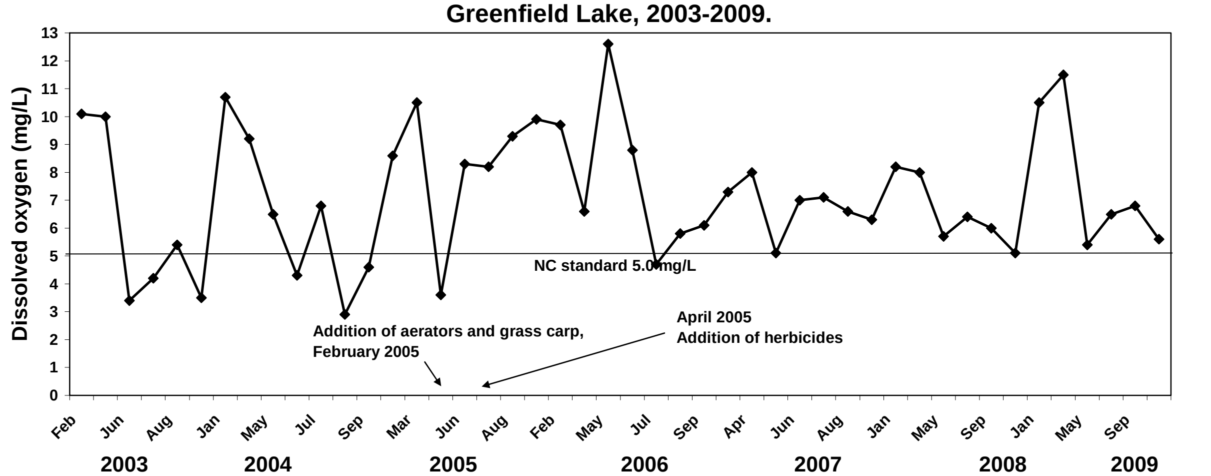


Figure 6.3. Average ammonium concentrations for Greenfield Lake, 2003-2009

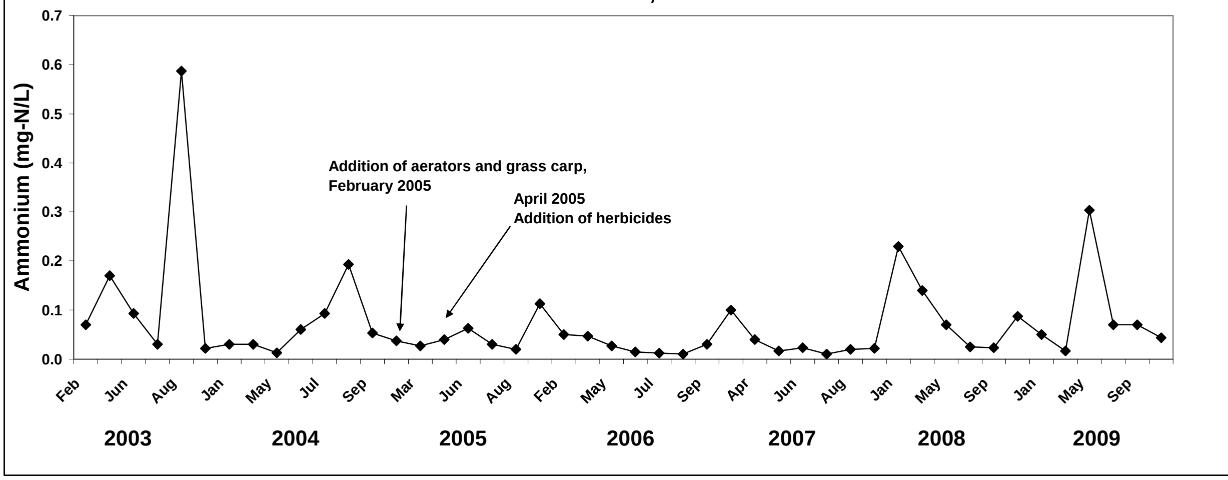
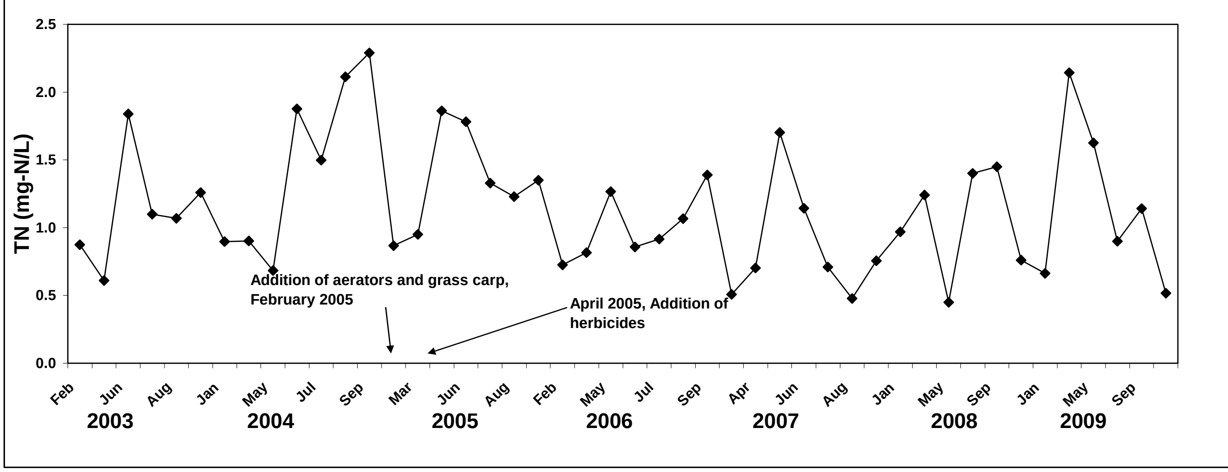


Figure 6.4. Average total nitrogen (TN) concentrations in Greenfield Lake, 2003-2009



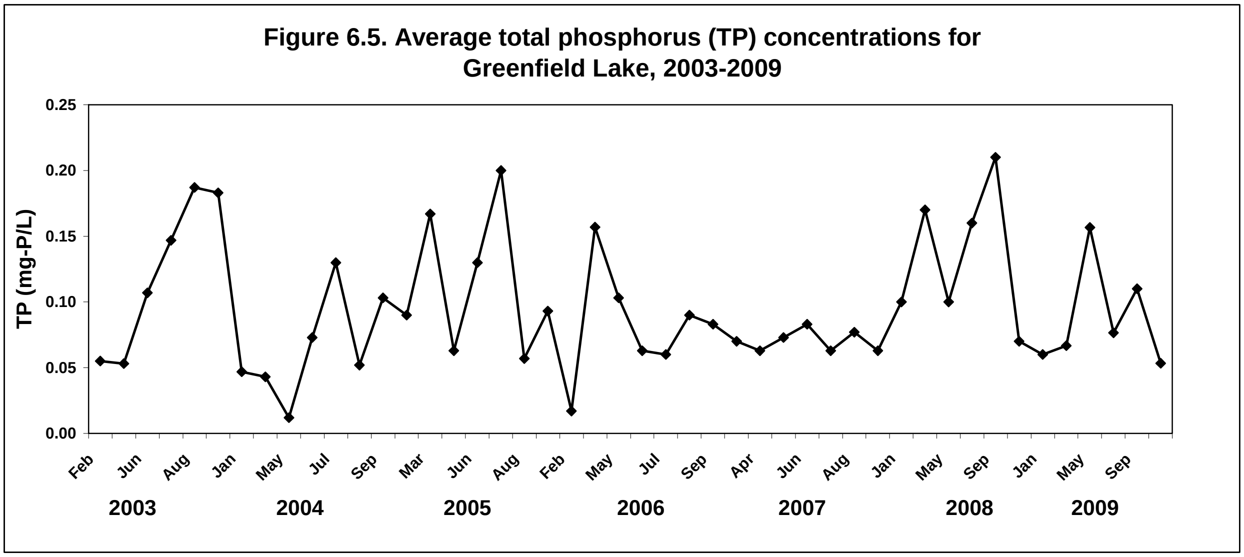


Figure 6.5. Average total phosphorus (TP) concentrations for Greenfield Lake, 2003-2009
TP (mg-P/L)
0.25
0.20
0.15
0.10
0.05
0.00
Feb
Jun
Aug
Jan
May
Jul
Sep
Mar
Jun
Aug
Feb
May
Jul
Sep
Apr
Jun
Aug
Jan
May
Sep
Jan
May
Sep
2003
2004
2005
2006
2007
2008
2009

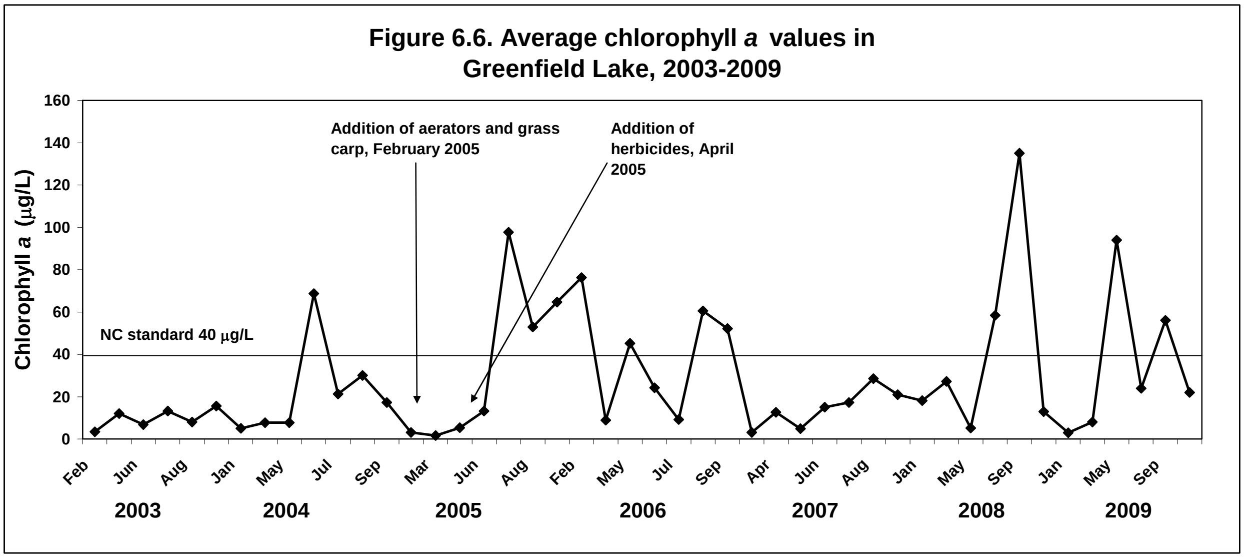


Figure 6.6. Average chlorophyll a values in Greenfield Lake, 2003-2009
Chlorophyll a (µg/L)
160
140
120
100
80
60
40
20
0
Addition of aerators and grass carp, February 2005
Addition of herbicides, April 2005
NC standard 40 µg/L
Feb
Jun
Aug
Jan
May
Jul
Sep
Mar
Jun
Aug
Feb
May
Jul
Sep
Apr
Jun
Aug
Jan
May
Sep
Jan
May
Sep
2003
2004
2005
2006
2007
2008
2009

Figure 6.7. BOD5 as a function of chlorophyll *a* in Greenfield Lake, 2009 (data from all three in-lake stations combined).

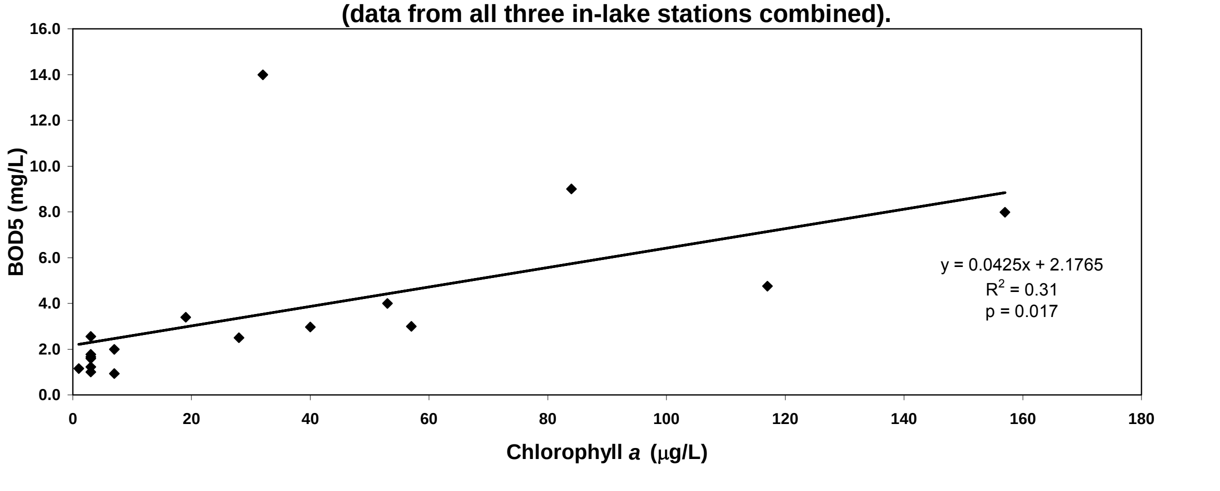
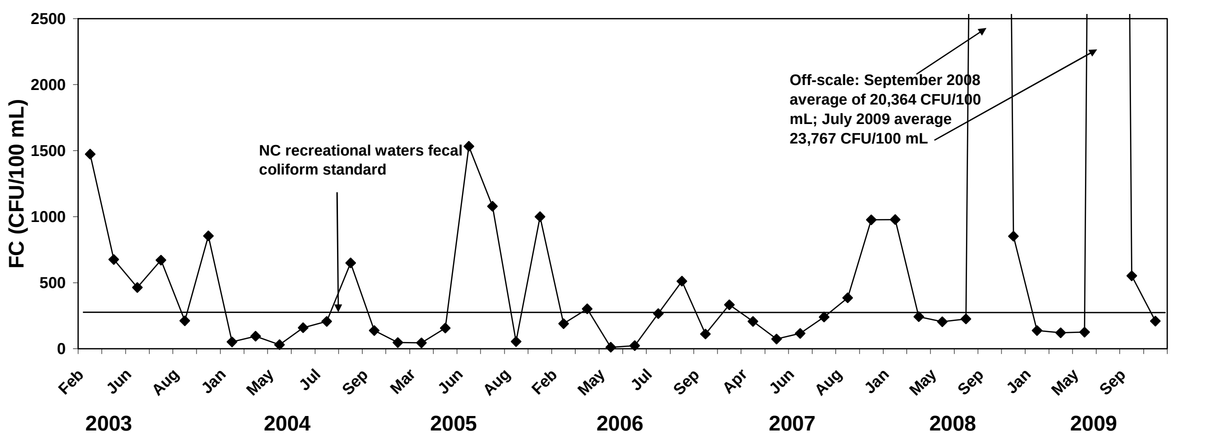


Figure 6.8. Average fecal coliform bacteria counts (FC) for Greenfield Lake, 2003-2009



7.0 Hewletts Creek

Snapshot
Watershed area: 7,435 acres (3,009 ha)
Impervious surface coverage: 19%
Watershed population: Approximately 21,350
Overall water quality: Fair
Problematic pollutants: minor algal blooms, high fecal bacteria, minor dissolved oxygen issues

Hewletts Creek was sampled at four tidally-influenced areas (HC-3, NB-GLR, MB-PGR and SB-PGR) and a freshwater stream station draining Pine Valley Country Club (PVGC-9 - Fig. 7.1). At the tidal stations the physical data indicated that turbidity was well within State standards during this sampling period during all sampling events, and TSS levels were below 20 mg/L at all times sampled (Table 7.2). There was only one incident of hypoxia (September at MB-GLR) in our 2009 samples. Nitrate concentrations were elevated leaving the golf course at PVGC-9 relative to the other stations (Tables 7.1 and 7.2). From there the next station is MB-GLR, which also receives inputs from the Wilmington Municipal Golf Courses (Fig. 7.1; Mallin and Wheeler 2000). Nitrate was still elevated there; however, none of the other stations had elevated nitrate concentrations. Ammonium concentrations were low at all sites. Orthophosphate concentrations were low, as were total phosphorus concentrations. The chlorophyll *a* data (Tables 7.1 and 7.2) showed that the Hewletts Creek samples were free of major algal blooms in 2009, with only one minor bloom in May at SB-PGR. This is positive news as algal blooms have been common in upper Hewletts Creek in the past (Mallin et al. 1998a; 1999; 2002a; 2004; 2005; 2006a; 2008).

Fecal coliform bacteria counts were high in most areas of the creek, except for HC-3. Counts exceeded State standards 100% of the time sampled at MB-PGR, 83% of the time at PVGC-9, 67% of the time at NB-GLR and 33% of the time at SB-PGR (Tables 7.1 and 7.2).

Table 7.1. Selected water quality parameters at upper and middle creek stations in Hewletts Creek watershed as mean (standard deviation) / range, 2009. Fecal coliform bacteria presented as geometric mean / range.

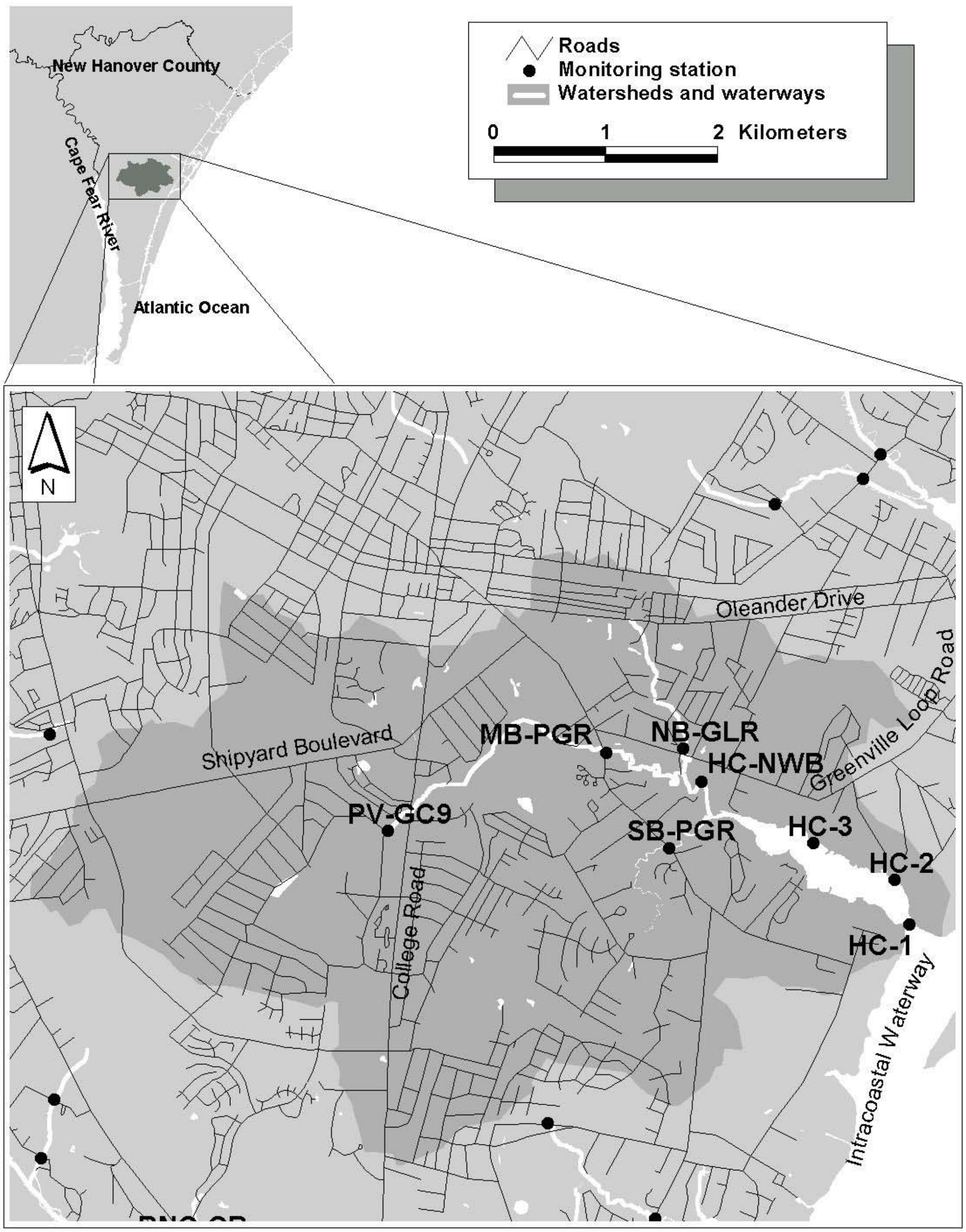
Parameter	PVGC-9	MB-PGR
Salinity (ppt)	0.1 (0) 0.1-0.1	2.2 (4.9) 0.1-12.2
Turbidity (NTU)	3 (2) 1-7	2 (2) 0-6
TSS (mg/L)	3 (2) 1-5	2 (2) 1-5
DO (mg/L)	6.8 (1.8) 5.0-9.5	7.3 (1.8) 4.3-9.3
Nitrate (mg/L)	0.942 (0.144) 0.690-1.120	0.333 (0.098) 0.170-0.440
Ammonium (mg/L)	0.038 (0.036) 0.005-0.100	0.018 (0.008) 0.010-0.030
TN (mg/L)	1.508 (0.134) 1.290-1.620	0.767 (0.295) 0.370-1.190
Orthophosphate (mg/L)	0.013 (0.005) 0.010-0.020	0.015 (0.002) 0.010-0.020
TP (mg/L)	0.032 (0.017) 0.010-0.060	0.028 (0.017) 0.010-0.060
Mean N/P Median	181.3 189.3	59.4 59.2
Chlorophyll *a* (µg/L)	7.2 (7.4) 2.0-22.0	2.7 (3.1) 1.0-9.0
Fecal col. (CFU/100 mL)	503 82-1,182	416 240-910

Table 7.2. Selected water quality parameters at stations in Hewletts Creek watershed, 2009, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 6 months.

Parameter	NB-GLR	SB-PGR	HC-3
Salinity (ppt)	18.7 (9.6) 7.6-29.9	25.7 (7.4) 15.5-33.5	33.2 (2.6) 29.3-35.7
Turbidity (NTU)	5 (4) 1-12	6 (6) 2-18	7 (8) 1-22
TSS (mg/L)	7 (4) 2-13	11 (5) 4-19	8 (6) 3-19
DO (mg/L)	7.1 (1.5) 5.2-9.7	6.8 (2.1) 3.6-9.5	7.7 (1.6) 5.5-9.7
Nitrate	0.063 (0.052) 0.010-0.150	0.025 (0.028) 0.010-0.080	0.010 (0.010) (mg/L) 0.010-0.010
Ammonium (mg/L)	0.009 (0.006) 0.005-0.020	0.006 (0.002) 0.005-0.010	0.005 (0.000) 0.005-0.005
TN (mg/L)	0.315 (0.191) 0.100-0.550	0.280 (0.223) 0.100-0.700	0.253 (0.122) 0.100-0.400
Orthophosphate (mg/L)	0.015 (0.005) 0.010-0.020	0.012 (0.004) 0.010-0.020	0.010 (0.000) 0.010-0.010
TP (mg/L)	0.037 (0.012) 0.020-0.050	0.033 (0.024) 0.010-0.070	0.020 (0.013) 0.010-0.040
Mean N/P ratio Median	10.9 7.2	9.8 9.4	3.3 3.3
Chlor *a* (µg/L)	6.2 (4.1) 2.0-12.0	6.7 (8.3) 1.0-23.0	2.8 (1.3) 2.0-5.0
Fecal coliforms (CFU/100 mL)	217 46-728	37 5-280	22 5-819

Dobo Property/Bethel Rd./JEL Wade Park wetland: The New Hanover County Tidal Creeks Advisory Board, using funds from the North Carolina Clean Water Management Trust Fund, purchased a former industrial area owned by the Dobo family in August 2002. This property was bought to be used as a passive treatment facility for the improvement of non-point source runoff drainage water before it enters Hewletts Creek. As such, the City of Wilmington contracted with outside consultants to create a wetland on the property for this purpose. Baseline data were needed to assess water quality conditions before and after the planned improvements. From January 2004 through late 2007 the UNCW Aquatic Ecology Laboratory sampled three inflowing creeks and the single outflowing creek. Construction of the wetland has been completed, so that sampling ceased in 2008. A series of rainfall events are presently being sampled to test the efficacy of the wetland in removing pollutants from runoff.

Figure 7.1 Hewletts Creek watershed



8.0 Howe Creek Water Quality

Snapshot
Watershed area: 3,518 acres (1,424 ha)
Impervious surface coverage: 19%
Watershed population: Approximately 4,230
Overall water quality: Fair-Poor
Problematic pollutants: Fecal coliform bacteria, some low dissolved oxygen

Howe Creek was sampled for physical parameters, nutrients, chlorophyll *a*, and fecal coliform bacteria at three locations during 2009 (HW-FP, HW-GP and HW-DT- Fig. 8.1). Turbidity was generally low and only exceeded the North Carolina water quality standard of 25 NTU at one site on one occasion, March at HW-DT (Table 8.1; Appendix B). Dissolved oxygen concentrations were fair, with HW-FP, HW-GP and HW-DT each below the standard of 5.0 mg/L on only one occasion (Appendix B). Nitrate and ammonium concentrations were low to moderate in 2009 (Table 8.2). Orthophosphate was generally low at the three sites.

Median inorganic molar N/P ratios were low, indicating that nitrogen was probably the principal nutrient limiting phytoplankton growth at all stations. Previously Mallin et al. (2004) demonstrated that nitrogen was the primary limiting nutrient in Howe Creek. There was one minor algal bloom of 39 µg/L as chlorophyll *a* at HW-DT, but the lower two stations did not experience algal bloom problems in 2009 (Table 8.2). Since wetland enhancement was performed in 1998 above Graham Pond the creek below the pond at HW-GP has had fewer and smaller algal blooms than before the enhancement (Fig. 8.2). For fecal coliform bacteria, the creek ranged from one exceedence of the water contact standard of 200 CFU/100 mL at the lower station HW-FP to 83% exceedence at HW-GP, to 100% exceedence (all six sampling occasions) at the upper station HW-DT, where the geometric mean was 3X the NC standard (Table 8.1; Fig. 8.3). Most troubling, the geometric mean fecal coliform count at HW-GP increased to the highest annual count we have seen since this project began in 1993; counts at HW-DT remained at high levels as well (Fig. 8.3).

Table 8.1. Water quality summary statistics for Howe Creek, 2009, as mean (st. dev.) / range. Fecal coliform bacteria as geometric mean / range.

Parameter	HW-FP	HW-GP	HW-DT
Salinity (ppt)	28.4(12.6) 3.3-35.7	18.4(10.5) 6.6-29.6	4.6(5.1_ 0.7-13.1
Dissolved oxygen (mg/L)	6.6(1.6) 4.3-9.3	6.1(1.8) 3.7-9.1	6.8(1.7) 4.3-9.4
Turbidity (NTU)	4(2) 1-8	9(4) 5-16	12(8) 4-28
TSS (mg/L)	12(6) 5-19	10(6) 4-17	9(3) 6-14
Chlor *a* (µg/L)	3.0(1.3) 1.0-4.0	6.5(5.1) 1.0-13.0	16.5(11.9) 6.0-39.0
Fecal coliforms (CFU/100 mL)	17 5-721	551 127-2,300	596 290-1,182

Figure 8.1. Howe Creek watershed and sampling sites.

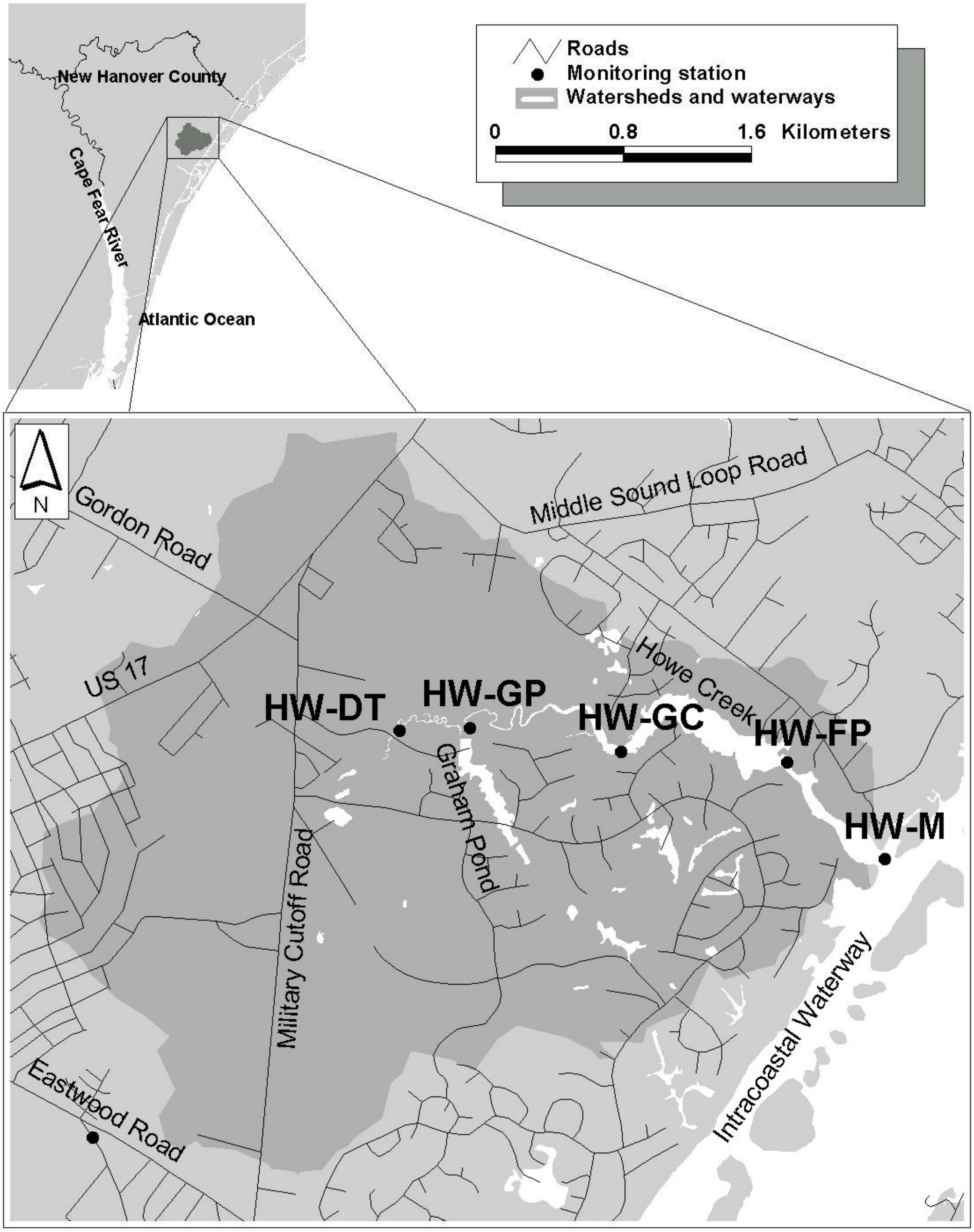


Figure 8.2. Chlorophyll *a* concentrations (algal blooms) in Howe Creek below Graham Pond before and after 1998 wetland enhancement in upper Graham Pond, 1993-2009.

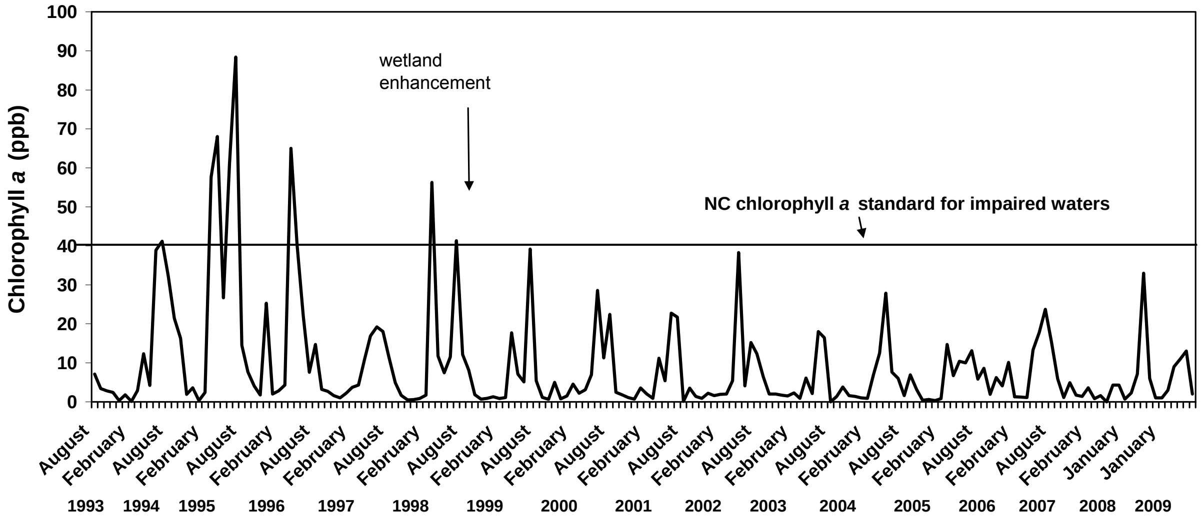
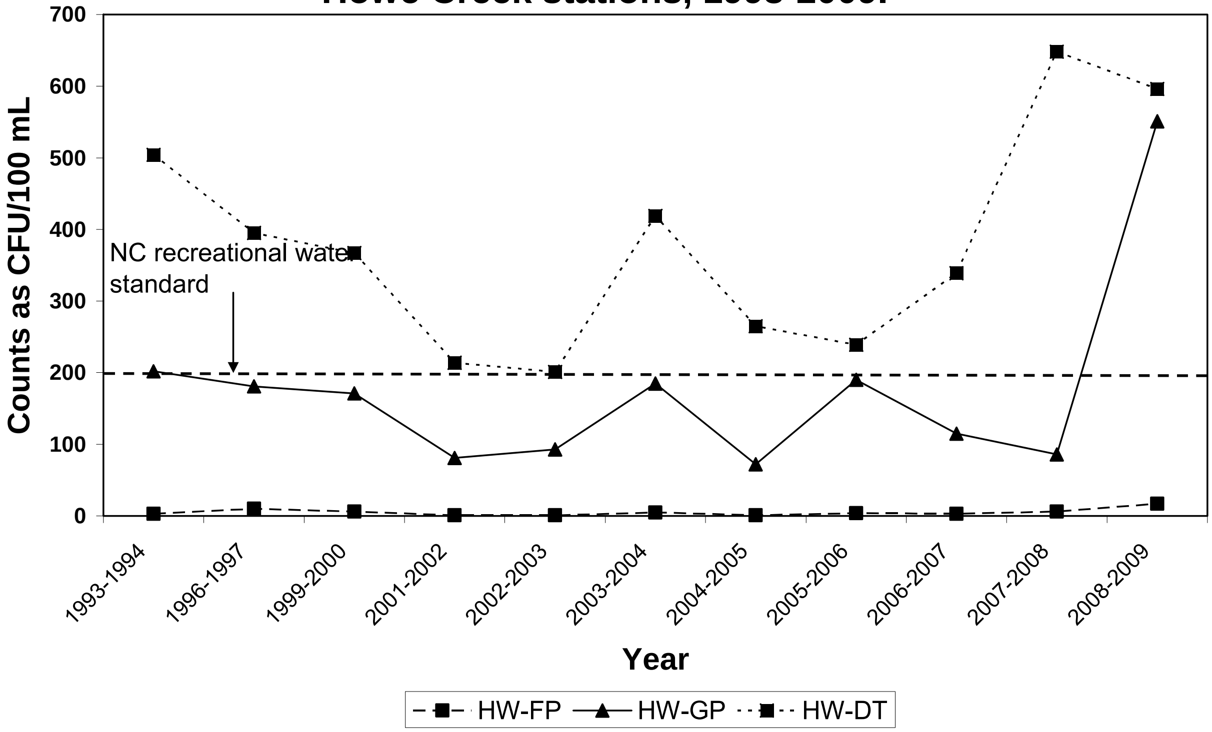


Table 8.2. Inorganic nutrient concentration summary statistics for Howe Creek, 2009, as mean (standard deviation) / range, N/P ratio as mean / median.

Parameter	HW-FP	HW-GP	HW-DT
Nitrate (mg/L)	0.013(0.008) 0.010-0.030	0.028(0.027) 0.010-0.080	0.097(0.103) 0.010-0.300
Ammonium (mg/L)	0.013(0.010) 0.005-0.030	0.032(0.025) 0.005-0.060	0.028(0.032) 0.005-0.090
Orthophosphate (mg/L)	0.012(0.004) 0.010-0.020	0.022(0.015) 0.010-0.040	0.023(0.010) 0.010-0.040
Molar N/P ratio	5.4 5.5	7.2 5.5	13.5 11.1

Figure 8.3. Fecal coliform counts over time for three Howe Creek stations, 1993-2009.



9.0 Motts Creek

Snapshot
Watershed area: 3,328 acres (1,347 ha)
Impervious surface coverage: 14%
Watershed population: 4,800
Overall water quality: poor
Problematic pollutants: Low dissolved oxygen; high fecal coliform bacteria

Motts Creek drains into the Cape Fear River Estuary (Fig. 9.1), and the creek area near River Road has been classified by the State of North Carolina as a Natural Heritage Site because of the area's biological attributes. These include the pure stand wetland communities, including a well-developed sawgrass community and unusually large flats dominated by *Lilaeopsis chinensis* and spider lily, with large cypress in the swamp forest. UNCW scientists sampled Motts Creek at the River Road bridge on 23 occasions during 2009 (Fig. 9.1). A large residential development (River Lights) is under construction upstream of the sampling site between Motts and Barnards Creeks; however, this development has no construction activity ongoing within a half-mile of Motts Creek. In recent years extensive commercial development has been occurring along Carolina Beach Road near its junction with Highway 421.

Dissolved oxygen concentrations were below the North Carolina brackish water standard of 5.0 mg/L on 39% of the occasions sampled (Fig. 9.2). Neither turbidity nor suspended solids were problematic in this period in 2009.

Total nitrogen, ammonium, nitrate, total phosphorus and orthophosphate levels were low to moderate, and the inorganic N/p ratio was 15, near the Redfield ratio. There was only one major algal bloom, of 35 µg/l of chlorophyll *a*, occurring in May (Table 9.1).

BOD5 was moderate for urban streams, yielding a mean value of 1.4 mg/L and a maximum value of 3.0 mg/L (Table 9.1). Fecal coliform contamination was a major problem in Motts Creek, with the geometric mean of 320 CFU/100 mL well above the State standard of 200 CFU/100 mL; the standard was exceeded on 74% of the sampling occasions in 2008 (Fig. 9.3). At meetings of the New Hanover County Water Quality Roundtable, personnel from the NHC Health Department noted that there have been periodic problems with septic tanks in upstream areas of Motts Creek. Samples collected by Coastal Planning & Engineering of North Carolina, Inc., have shown some very high counts in these upper areas. It is likely that elevated fecal coliforms generated upstream are also seen in our downstream samples from the River Road site.

Table 9.1. Selected water quality parameters at a station (MOT-RR) draining Motts Creek watershed before entering the Cape Fear Estuary, as mean (standard deviation) and range, January – December 2009. Fecal coliforms as geometric mean / range.

Parameter	MOT-RR	
	Mean (SD)	Range
Salinity (ppt)	2.7 (3.5)	0.2-11.7
DO (mg/L)	6.0 (2.1)	2.5-9.6
Turbidity (NTU)	10 (4)	0-18
TSS (mg/L)	10.1 (5.1)	4.0-21.0
Nitrate (mg/L)	0.21 (0.09)	0.07-0.44
Ammonium (mg/L)	0.06 (0.03)	0.02-0.13
Total nitrogen (mg/L)	0.73 (0.22)	0.21-1.14
Orthophosphate (mg/L)	0.04 (0.01)	0.01-0.06
Total phosphorus (mg/L)	0.07 (0.03)	0.03-0.12
Mean N/P ratio	14.9	
Chlor *a* (μg/L)	7.7 (8.0)	1.0-35.0
BOD5 (mg/L)	1.4 (0.6)	0.7-3.0
Fecal coliforms (CFU/100 mL)	320	5-2,400

Figure 9.1 Motts Creeks watershed

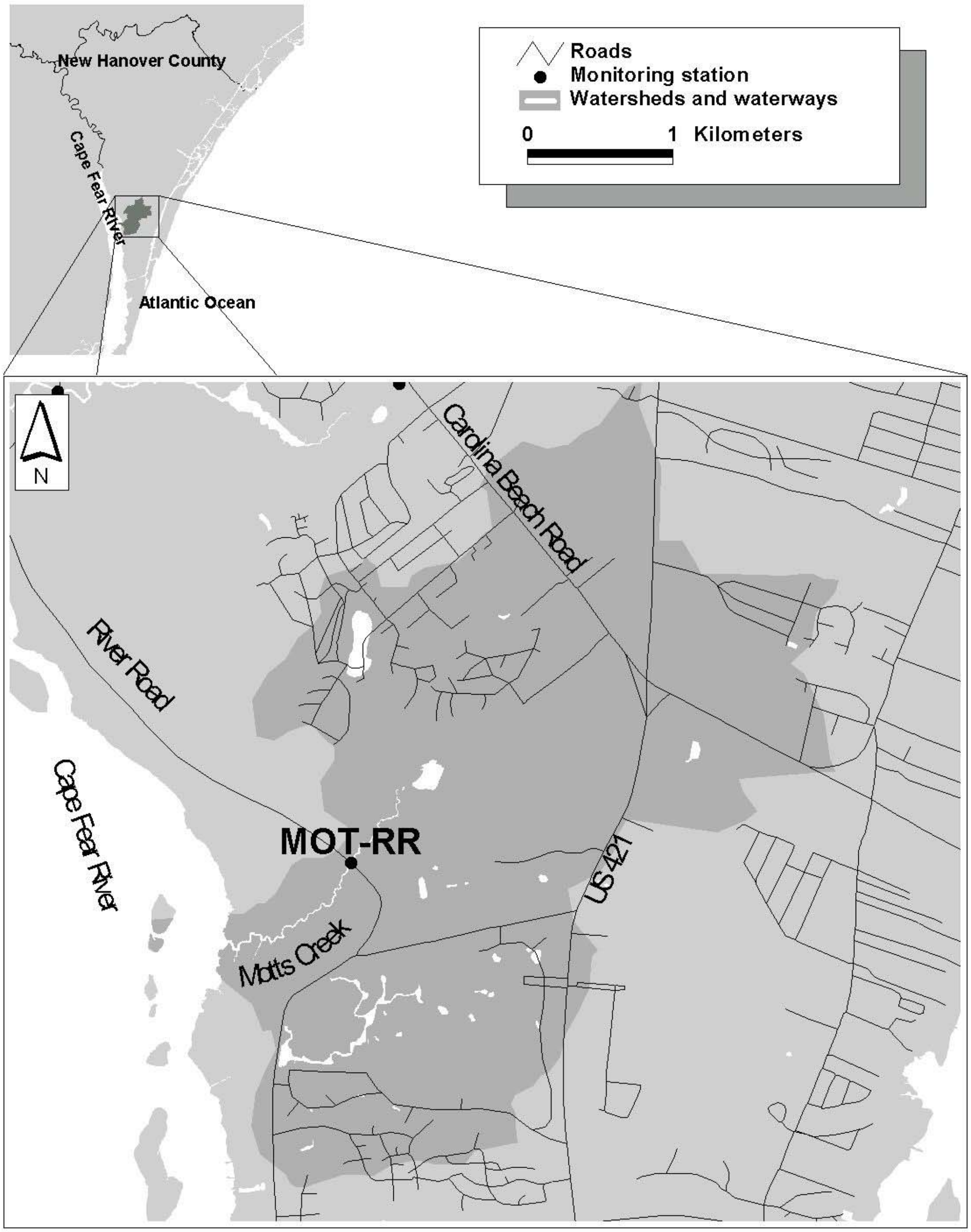


Figure 9.2. Dissolved oxygen concentrations in lower Motts Creek at River Road, 2009.

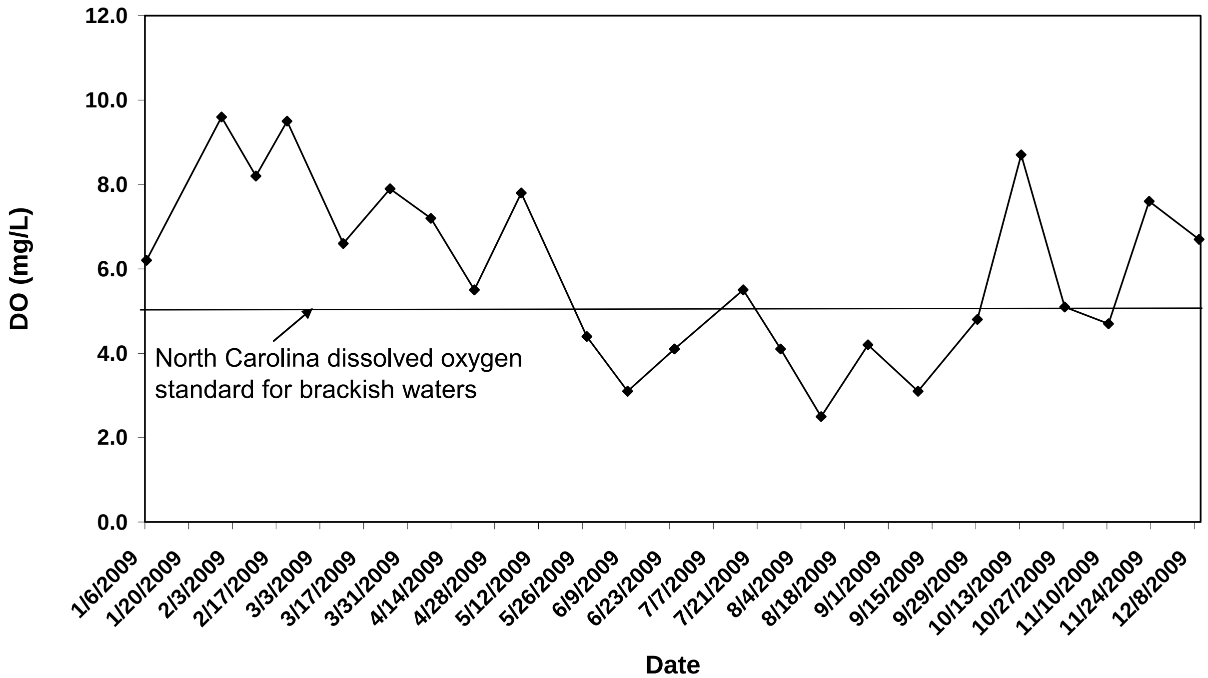
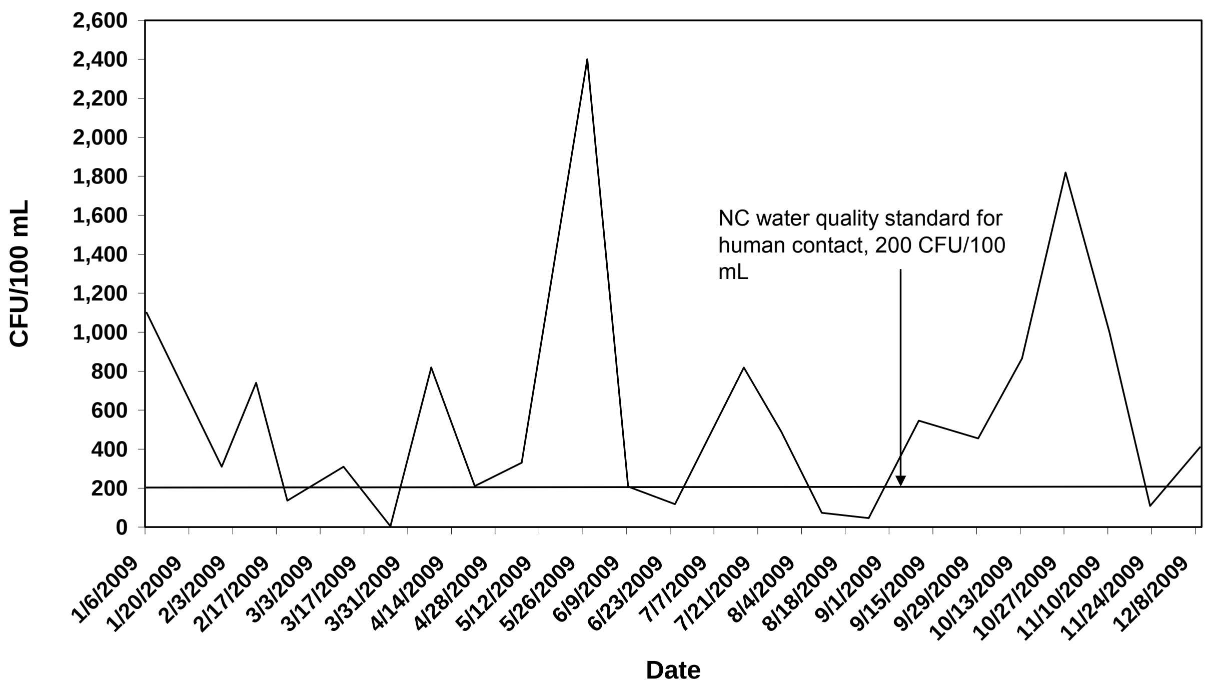


Figure 9.3. Fecal coliform counts in lower Motts Creek at River Road, 2009



10.0 Pages Creek

Snapshot
Watershed area: 4,100 acres (1,659 ha)
Impervious surface coverage: >13%
Watershed population: Approximately 4,600

The University of North Carolina Wilmington was not funded by the County in 2009 to sample Pages Creek. Subsequent County-sponsored sampling of this creek was performed by Coastal Planning & Engineering of North Carolina, Inc., with data and information for this creek available on the County Planning Department website: http://www.nhcgov.com/AgnAndDpt/PLNG/Pages/WaterQualityMonitoring.aspx. Elevated fecal coliform bacteria counts in upper creek areas were found during sampling by this group. The New Hanover County Water Quality Roundtable, of which UNCW and Coastal Planning & Engineering are both members, expressed concern over the elevated fecal coliform bacteria counts in Pages Creek. As such, in fall 2008 UNCW was contracted by Coastal Planning & Engineering to perform bacteria source tracking using molecular-based methods. The work was carried out as a collaborative effort between the Aquatic Ecology Laboratory, led by Dr. Michael Mallin, and Dr. Bongkeun Song of the UNCW Department of Biology and Marine Biology. The following chapter is from UNCW's final report to Coastal Planning & Engineering.

Pages Creek is a 3rd order tidal creek located in northern New Hanover County, North Carolina. Whereas most of the tidal creeks in the area are closed to shellfishing due to excessive fecal coliform bacteria counts, Pages Creek, along with nearby Futch Creek, remains partially open to shellfishing. This is likely a result of its low percentage of developed land, especially low percent impervious surface coverage, compared with other area tidal creeks (Mallin et al. 2000). For twelve years this creek was sampled as a part of the New Hanover County Tidal Creeks Program, funded by New Hanover County with sampling and analyses carried out by the Aquatic Ecology Laboratory at the University of North Carolina Wilmington's Center for Marine Science. That program indicated that some areas of the creek have periodically experienced fecal bacterial pollution, including the uppermost stations PC-BDUS and PC-H (Figure 10.1) and a tributary location PC-BDDS (Figure 10.1). Data from 1995, 2001 and 2007 showed periodic high concentrations (especially in 1995 and 2007) of fecal coliform bacteria exceeding the North Carolina recreational water standard of 200 colony-forming units (CFUs) per 100 mL of water (Table 10.1). Also, an elevated count found by UNCW in June 2007 at PC-H, near the headwaters prompted investigations by County planners and engineers that located a sewage pump station problem that was subsequently rectified. We note that human signals of fecal pollution have recently been identified from Pages Creek (Spivey 2008).

Table 10.1. Fecal coliform bacteria data (presented as geometric mean and range) for upper Pages Creek, North Carolina.

Year	1995	2001	2007
PC-BDUS	260 (40-3,001)	38 (10-140)	131 (29-1,040)
PC-BDDS	155 (17-1,020)	28 (3-126)	38 (21-1536)
PC-H	63 (10-575)	29 (7-200)	34 (21-309)

Site Description

Two stations were sampled in upper Pages Creek, PC-BDUS and PC-BDDS (Figure 10.1). PC-BDDS is located at the headwaters of a 1st order tributary to Pages Creek along its northern shore. This tributary is fed by a stormwater drainpipe that carries runoff water under Bayshore Drive from an adjacent suburban area (Figure 10.1). There is also a sewage lift station located at the sampling location.

PC-BDUS is located in the upper portion of Pages Creek, and is fed by a drainage ditch/intermittent stream that drains a large suburban area encompassing a portion of Bayshore Drive and a development across Highway 17 as well. There is also a sewage pump station located at this site, as well as a concrete boat ramp. A spring feeds the creek near this location as well.

Materials and Methods

Samples were collected by Coastal Planning & Engineering and UNCW personnel from each station on four separate dates in 2008: September 23, October 15, November 4, and December 11. The latter two samples were collected during or just after substantial rain events; the first two samples were collected in relatively dry periods. Water samples were collected at each station for mean fecal coliform and mean *Enterococcus* counts, optical brightener analysis, and DNA analysis for bacterial source tracking (BST).

Water samples for fecal coliform, *Enteroccocus*, and BST were collected in autoclaved 500mL Pyrex glass bottles at both stations. The samples were transported on ice and allowed to sit no longer than six hours before filtration. Upon return to the lab, the BST samples were filtered using autoclaved glassware and sterile Whatman GF/F 47mm filters, with a nominal pore size of 0.7μm. 500mL of water were filtered for each sample and the filters were stored at -20°C until DNA was extracted. The fecal coliform and *Enterococcus* samples were filtered using autoclaved glassware and sterile Millipore white gridded 47mm filters, with a nominal pore size of 0.45μm. For mean fecal coliform (MFC), these filters were placed in sterile petri dishes with pads soaked in MFC broth media, composed of MFC medium, distilled water, and Rosolic Acid solution (Rosolic Acid crystals dissolved in 0.2N NaOH). The plates were then sealed in plastic storage bags and incubated in a water bath at 44.5°C for 23 to 25 hours. For mean enterococcus (ME), the filters were placed in sterile petri dishes with ME agar, composed of ME agar media, nalidixic acid, and a 1% solution 2,3,5-triphenyl tetrazolium solution. The plates were also sealed in plastic storage bags and incubated in a water bath at 41.0°C for 47 to 49 hours. Both the MFC and ME samples were removed from the incubator after the specified period of time, colonies that formed on the gridded filters were counted, and the counts were reported as an average of the number of colony forming units (CFUs) per 100mL of water. See APHA (1995) for detailed methodologies.

DNA Extraction: DNA extraction was accomplished using the PowerSoil™ DNA Isolation Kit from MO BIO Laboratories, with the protocol slightly modified for extraction from a filter instead of a soil sample. A portion of the filter was ground using a PowerBead Tube and tissue grinder, and then the extraction was completed per manufacturer's instructions. The MO BIO PowerSoilTM DNA Isolation Kit uses a detergent to lyse the cells and release the DNA, and then uses several solutions to help precipitate materials that may reduce the purity of the DNA (such as non-DNA humics, cell debris, and proteins). The completed process results in 100µL of DNA for use in any downstream applications.

PCR: All of the samples were first amplified with the universal 16s rDNA primers to amplify the DNA of any bacteria present in the sample. These PCR products were then used as the template for the next PCR reaction for each sample. The second set of PCR reactions were then setup with a Bac32F/Bac708R primer pair, which are specific for Bacteroides 16S rDNA amplification (Bernhard and Field, 2000). The Bac32F primer was labeled with fluorescent tags (FAM labeled) for fingerprint analysis.

These PCR products were run on a 1% agarose gel to determine the presence or absence of the target segment of DNA and in order to separate the proper size bands from other amplified products. A GENECLEAN® Turbo Kit from Q-BIO gene was then used to purify these PCR products from agarose gel slices.

T-RFLP: In order to determine the concentration of purified PCR products, a Quant-iT™ DNA HS Assay from Invitrogen was used. The samples were read using a Qubit fluorometer, which provides a fluorescence measurement used in determining the concentration of DNA in the sample. The resultant information about the concentration of DNA present in each sample was then used to determine the needed formula for enzyme digestion. These reactions were incubated overnight at 37°C for digestion to occur.

The enzyme digested DNA fragments were precipitated and prepared for DNA fingerprint analysis, using an ABI PRISM® Genetic Analyzer. Upon completion of fingerprinting, each sample was represented by a profile. The profiles have representative peaks for different bacterial populations present in each sample. The size of each fragment present is indicated in base pairs, and these fragments can be matched to a database of known fragments of 16S rDNA for bacterial identification. This analysis was completed using the Microbial Community Analysis 3 (MiCA) T-RFLP Analysis Phylogenetic Assessment Tool (PAT) (http://mica.ibest.uidaho.edu/pat.php).

Optical brighteners, compounds added to laundry detergents, adsorb to clothing and form a light reflective layer creating the appearance of whiter whites and brighter colors. These compounds are excited by light in the near UV range (360-365nm) and emit light in the blue range (400-440nm). After light absorption, fluorescence is given off during the second excited state and can be measured by a fluorometer. In the United States, 97% of all laundry detergents contain one or both of two types of fluorescent whitening agents; FWA-1 also called DAS1 or FB-28, or FWA-2 referred to as DSBP or Tinopal CBS-X. Since household plumbing systems combine wastewater from toilets and washing machines, the presence of optical brighteners and fecal coliform bacteria in a waterway may indicate an input of human origin. Optical brightener samples were collected by filling Nalgene 125mL opaque collection bottles 10 cm below the surface facing into the stream. Collection bottles were acid washed and triple rinsed before sampling. Samples were refrigerated in the dark at 8º C and read within 8 days.

Fluorometry was performed with a laboratory fluorometer (Model 10-AU-000, Turner Designs, Sunnyvale, California). A kit was added to the fluorometer that included a lamp (10-049) emitting near UV light at 310-390 nm, a filter (10-069R) for the 300-400nm light range, and finally a 436 nm filter was added to greater decrease background fluorescence (Hartel 2007a). A standard curve was created using serial dilutions from 100 mg of Tide (Procter and Gamble, Cincinnati, Ohio) in one liter of deionized water. Tide is a commonly used laundry detergent known to contain optical brighteners. When the fluorometer was adjusted to an 80% sensitivity scale, the fluorometric value of 100 was equal to 100mg of Tide in 1 L of deionized water. The standard curve demonstrated that there was a linear relationship between the fluorometric response and detergent-sourced optical brighteners up to a reading of 100. Following field collections, each field sample was read on the fluorometer in triplicate at room temperature after 10 seconds to minimize degradation of optical brighteners by UV light (Hartel 2007b; Tavares et al. 2008). For optical brightener determination, the samples were allowed to warm to room temperature for approximately 30 minutes. Each sample was shaken and poured into a cuvette (about 1/3 full). The cuvette was then placed in the fluorometer modified as above for optical brightener measurement.

Results

Fecal coliform bacteria: Sampling indicated a fecal coliform bacterial pollution problem at Stations PC-BDUS and PC-BDDS in fall 2008 (Table 10.2). While both sites were polluted, PC-BDDS tended to have higher fecal coliform counts than PC-BDUS, especially during the rainy period collections

Enterococcus bacteria: The *Enterococcus* counts all exceeded the instantaneous standard of 104 CFU/100 mL (Table 10.2). During the rain dates the counts were especially high, 10-30X the standard. *Enterococcus* counts were on average higher than fecal coliform bacteria counts, likely a result of this indicator bacterium's greater tolerance to elevated salinity in estuaries. As a reference the instantaneous standard for marine recreational waters for *Enterococcus* is 104 CFU/100 mL.

Optical brighteners: Elevated optical brightener (OB) concentrations are a good indication of sewage or septic system pollution entering a water body (Hartel et al.

2007a). Based on our earlier investigations in local tidal creeks OB concentrations above 20 were correlated with high fecal coliform bacteria counts in reaches known to have been polluted by leaking sewer lines (Tavares et al. 2008). One sample, at PC-BDDS in November registered 43, which we consider a strong signal of human sewage (Table 10.2). The sample from that month from Station PC-BDUS was about 22, indicated a good probability of sewage influence (Table 10.2). Both stations sampled in December were >50, indicating sewage influences.

Table 10.2. Fecal coliform bacteria, *Enterococcus* bacteria, and optical brightener data for upper Pages Creek, September-December 2008.

Date	Fecal coliforms		Enterococcus		Optical brighteners	
	BDUS	BDDS	BDUS	BDDS	BDUS	BDDS
9/1/08	214	115	324	147	nd	nd
10/15/08	410	905	195	745	13.7	15.4
11/4/08*	765	2,320	1,720	2,970	21.8	43.1
12/11/08*	1,065	2,175	1,720	2,970	54.0	50.0
Average	614	1,379	1,517	1,759	29.8	36.2
Geomean	517	851	803	1,008		

nd = no data
* = rain sample

<u>Sources of fecal bacteria pollution</u>: There was a substantial human source detected in the fecal bacteria collected from upper Pages Creek in fall 2008 (Table 10.3). The human signal was higher at PC-BDDS than PC-BDUS. The human signal at PC-BDDS was elevated both during a dry period sampling (September) as well as during one of the wet period samplings (November).

In addition to the human sources, substantial ruminant source was also found; again, it was greater at PC-BDDS than PC-BDUS (Table 10.3).

Table 10.3. Human and ruminant source as a percent of fecal bacteria groups based on DNA fingerprint analysis of upper Pages Creek, September-December 2008.

	Human		Ruminant	
Date	BDUS	BDDS	BDUS	BDDS
9/1/08	17.2	30.7	18.7	42.1
10/15/08	13.2	12.6	13.9	18.2
11/4/08*	13.8	21.5	19.8	26.4
12/11/08*	ns	11.7	ns	18.1

ns = no species-specific peaks
* = rain sample

Conclusions

1) Both sites, during all four months, showed excessive fecal bacteria counts, either from fecal coliform bacteria or *Enterococcus* bacteria, or both.

2) Fecal bacteria numbers were considerably higher at both sites during or shortly after rain events. Average counts for the dry periods combined for fecal coliforms were 312 for PC-BDUS and 510 for PC-BDDS, respectively, while for the rainy periods they were 915 and 2,248 for those two stations. For *Enterococcus* average counts for PC-BDUS and PC-PDDS in dry periods were 260 and 446, respectively, while for those same sites in wet periods they were 2,775 and 3,075 CFU/100 mL.

3) Station PC-BDDS had on average higher fecal bacteria counts than did PC-BDUS.

4) Optical brightener concentrations indicated that, at least some periods, either sewage or septic system leachate was polluting the creek waters. What is especially perplexing is the elevated OB concentrations during the rain events in November and December. While elevated counts can be expected from stormwater runoff during rains, the elevated OB concentrations may point to a sewage system problem exacerbated by rainfall.

5) PCR and T-RFLP indicated the presence, sometimes substantial, of human fecal bacteria in Pages Creek at both sites during all four months.

6) There was a considerable ruminant contribution to the fecal bacteria in upper Pages Creek as well. Likely ruminant sources are deer, which are certainly present in the watershed, and horses if there any boarded in the watershed.

7) A number of unidentified peaks were also found, indicating other potential sources to those we listed above.

8) These data collectively indicate that upper Pages Creek has a fecal bacteria problem with stormwater runoff (as exemplified by the ruminant signal and high counts during rain events). There is also clearly a human infrastructure problem as well, either derived from the pump stations present at the sites (particularly at PC-BDDS), leaking sewer lines, or possibly failing septic systems if they are present in the upper Pages Creek watershed.

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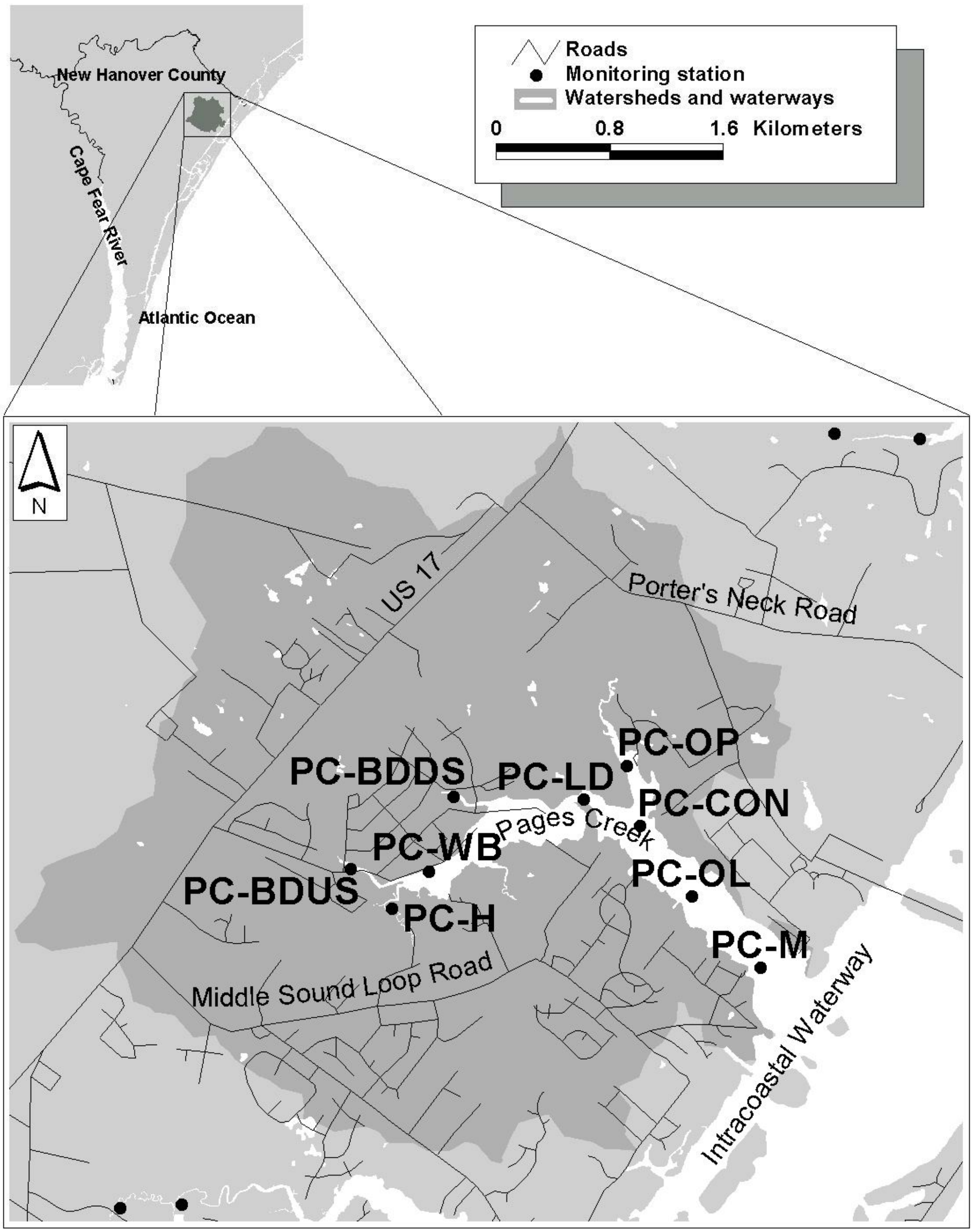
Figure 10.1. Pages Creek watershed and sampling sites.



11.0 Smith Creek

Snapshot
Watershed area: 13,896 acres (5,624 ha)
Impervious surface coverage: 28%
Watershed population: 25,904
Overall water quality: Good
Problematic pollutants: moderate turbidity, low dissolved oxygen

Smith Creek drains into the lower Northeast Cape Fear River just before it joins with the mainstem Cape Fear River at Wilmington (Fig. 11.1). The University of North Carolina Wilmington was not funded by the County to sample Smith Creek during 2009. However, one location on Smith Creek, SC-CH (Fig. 11.1) is sampled monthly by UNCW under the auspices of the Lower Cape Fear River Program for selected parameters (field physical parameters and fecal coliform bacteria) and these data are shown below (Table 11.1).

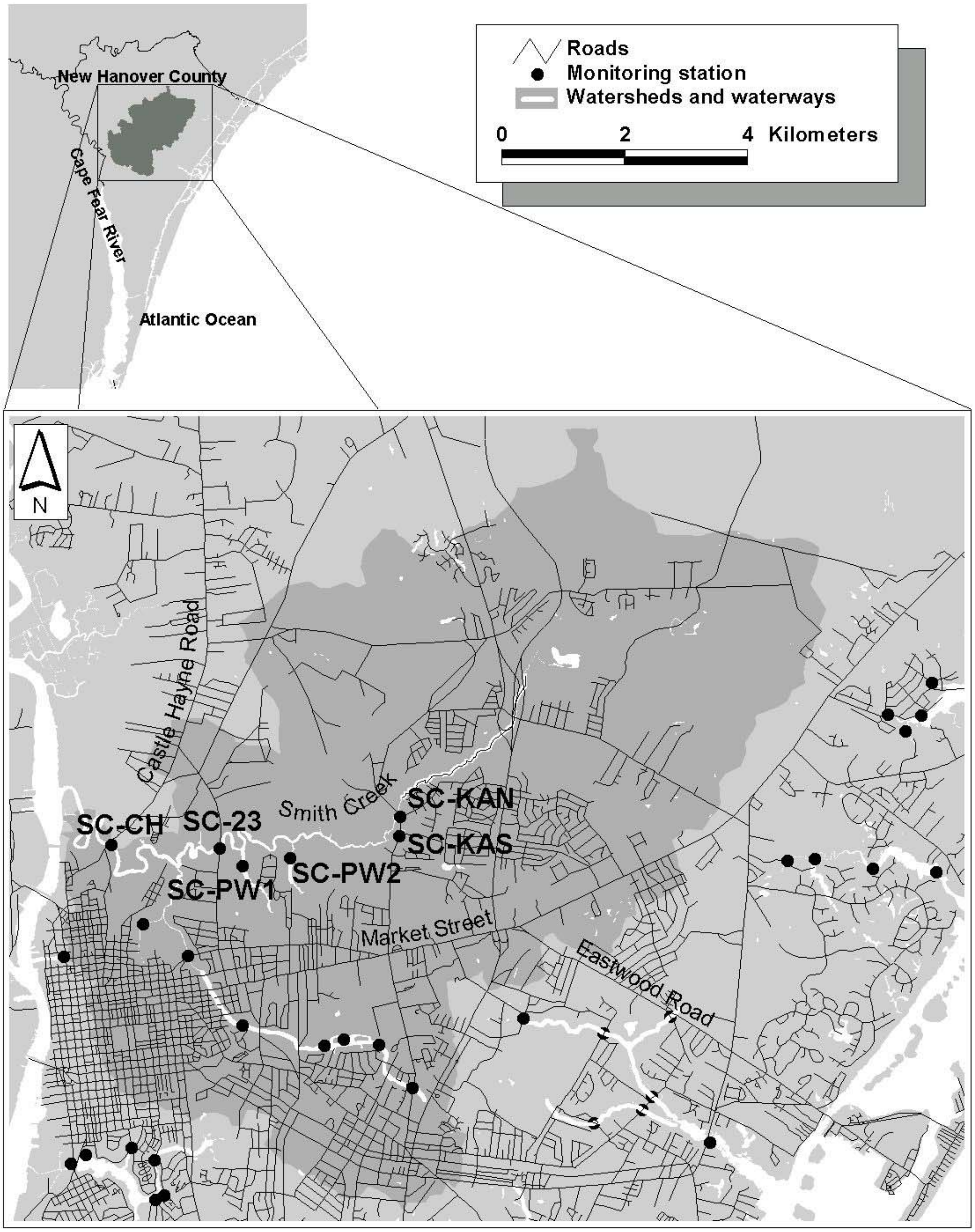
The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters is 4.0 mg/L, which was not violated in our 2009 samples. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded, although it ranged between 21 and 25 NTU on four occasions.

Fecal coliform bacteria concentrations did not exceed the standard of 200 CFU/100 mL on any sampling occasion at SC-CH in 2009, for a Good rating (Table 11.1).

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range, 2009, n = 12 months.

Parameter	SC-CH	
	Mean (SD)	Range
Salinity (ppt)	4.5 (4.9)	0.1-13.8
Dissolved oxygen (mg/L)	6.8 (2.3)	4.3-10.5
Turbidity (NTU)	17 (5)	8-25
Fecal col. /100 mL (geomean / range)	62	10-172

Figure 11.1 Smith Creek watershed



12.0 Whiskey Creek

Snapshot
Watershed area: 2,095 acres (848 ha)
Impervious surface coverage: 19%
Watershed population: 7,107
Overall Water Quality: Good
Problematic pollutants: Low dissolved oxygen on occasion

Whiskey Creek drains into the ICW. Sampling of this creek began in August 1999, at five stations. One station was dropped due to access issues in 2005; four stations were sampled until and including 2007; in 2008 this was reduced to one station, WC-MLR (from the bridge at Masonboro Loop Road – Fig. 12.1). Salinity at this station was relatively high, what scientists consider euhaline, ranging from 23 – 34 ppt and averaging about 30 ppt (Table 12.1).

Dissolved oxygen concentrations were below the State standard on only one of six sampling occasions at WC-MLR (Table 12.1), and that only mildly below standard. Turbidity was within state standards for tidal waters on all sampling occasions (Table 12.1; Appendix B). Algal blooms are relatively rare in this creek and there were no notable blooms detected in our 2009 sampling (Table 12.1). Nutrient concentrations were unremarkable at this station, and averages were somewhat lower than in 2008.

Fecal coliform bacteria were acceptable for human contact at this site and below the North Carolina standard of 200 CFU/100 mL. Whiskey Creek is presently closed to shellfishing by the N.C. Division of Marine Fisheries.

We note that our previous sampling showed that most water quality problems occurred near the headwaters of the creek rather than the middle section we currently sample.

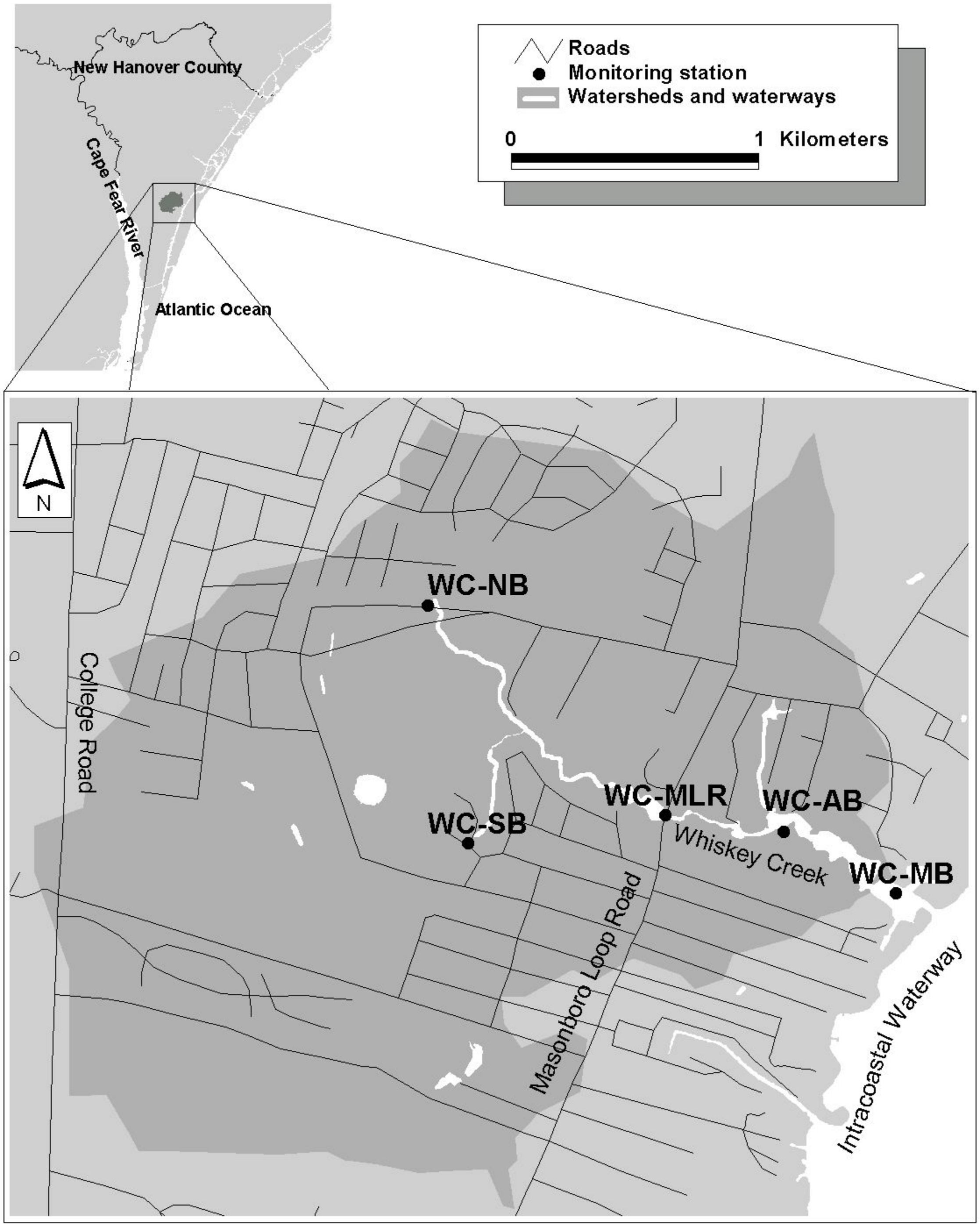
Table 12.1. Water quality summary statistics for Whiskey Creek, 2009, presented as mean (standard deviation) / range, fecal coliforms as geometric mean / range.

	Salinity (ppt)	DO (mg/L)	Turbidity (NTU)	TSS (mg/L)	Chlor *a* (µg/L)	FC CFU/100 mL
WC-MLR	29.8 (4.2) 22.5-33.9	6.7 (2.0) 4.2-9.7	7 (6) 1-17	12 (6) 4-19	5.2 (3.2) 2.0-10.0	32 5-127

Table 12.2. Nutrient concentration summary statistics for Whiskey Creek, 2009, as mean (standard deviation) / range, N/P ratio as mean / median.

	Nitrate (mg/L)	Ammonium (mg/L)	TN (mg/L)	Phosphate (mg/L)	TP (mg/L)	N/P ratio
WC-MLR	0.01 (0.01) 0.01-0.02	0.02 (0.03) 0.01-0.06	0.30 (0.17) 0.10-0.60	0.01 (0.01) 0.01-0.02	0.04 (0.02) 0.01-0.06	6.9 3.3

Figure 12.1. Whiskey Creek. Watershed and sampling sites.



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14.0 Acknowledgments

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15.0 Appendix A. North Carolina Water Quality standards for selected parameters (NCDEHNR 1996). We note that these standards are general, and differ with designated water body use. Details can be found at within the N.C. Division of Water quality website at: http://h2o.enr.state.nc.us/csu/documents/ncactable290807.pdf

Parameter	Standard
Dissolved oxygen	5.0 ppm (mg/L)
Turbidity	25 NTU (tidal saltwater) 50 NTU (freshwater)
Fecal coliform counts	14 CFU/100 mL (shellfishing waters), and more than 10% of the samples cannot exceed 43 CFU/100 mL. 200 CFU/100 mL (human contact waters)
Chlorophyll *a*	40 ppb (μg/L)

CFU = colony-forming units
mg/L = milligrams per liter = parts per million
μg/L = micrograms per liter = parts per billion

16.0 Appendix B. UNCW ratings of sampling stations in Wilmington watersheds based on 2008, where available, for chlorophyll *a*, dissolved oxygen, turbidity, and fecal coliform bacteria (human contact standard) based on North Carolina state chemical standards for freshwater or tidal saltwater, *fecal coliform based on contact standard.

G (good quality) – state standard exceeded in ≤ 10% of the measurements
F (fair quality) – state standard exceeded in 11-25% of the measurements
P (poor quality) – state standard exceeded in >25% of the measurements

Watershed	Station	Chlor *a*	DO	Turbidity	Fecal coliforms*
Barnard's Creek	BNC-RR	G	P	F	P
Bradley Creek	BC-CA	G	G	G	P
	BC-SB	G	G	G	P
	BC-NB	G	F	G	P
Burnt Mill Creek	BMC-AP1	G	G	F	P
	BMC-AP3	P	G	F	F
	BMC-PP	P	G	G	P
Greenfield Lake	GL-LC	-	P	G	-
	GL-JRB	-	P	G	-
	GL-LB	-	P	G	-
	GL-2340	G	P	G	P
	GL-YD	P	F	G	P
	GL-P	P	G	G	P
Hewletts Creek	HC-3	G	G	G	G
	NB-GLR	G	G	G	P
	MB-PGR	G	F	G	P
	SB-PGR	G	F	G	P
	PVGC-9	G	G	G	P
Howe Creek	HW-FP	G	F	G	F
	HW-GP	G	F	G	P
	HW-DT	F	F	F	P
Motts Creek	MOT-RR	G	P	G	P
Smith Creek	SC-CH	-	G	G	G
Whiskey Creek	WC-MLR	G	F	G	G

17.0 Appendix C. GPS coordinates for the Wilmington Watersheds Project sampling stations used during various years.

Watershed	Station	GPS coordinates	
Barnard's Creek	BNC-RR	N 34.15873	W 77.93795
Bradley Creek	BC-CA	N 34.23257	W 77.86658
	BC-CR	N 34.23077	W 77.85235
	BC-SB	N 34.21977	W 77.84578
	BC-SBU	N 34.21725	W 77.85410
	BC-NB	N 34.22150	W 77.84405
	BC-NBU	N 34.23265	W 77.92362
	BC-76	N 34.21473	W 77.83357
Burnt Mill Creek	BMC-KA1	N 34.22207	W 77.88506
	BMC-KA3	N 34.22280	W 77.88601
	BMC-AP1	N 34.22927	W 77.86658
	BMC-AP2	N 34.22927	W 77.89792
	BMC-AP3	N 34.22927	W 77.90143
	BMC-WP	N 34.24083	W 77.92419
	BMC-PP	N 34.24252	W 77.92510
Futch Creek	FC-4	N 34.30127	W 77.74635
	FC-6	N 34.30298	W 77.75070
	FC-8	N 34.30423	W 77.75415
	FC-13	N 34.30352	W 77.75790
	FC-17	N 34.30378	W 77.76422
	FOY	N 34.30705	W 77.75707
Greenfield Lake	GL-SS1	N 34.19963	W 77.92447
	GL-SS2	N 34.20038	W 77.92952
	GL-LC	N 34.20752	W 77.92980
	GL-JRB	N 34.21260	W 77.93140
	GL-LB	N 34.21445	W 77.93553
	GL-2340	N 34.19857	W 77.93560
	GL-YD	N 34.20702	W 77.93120
	GL-P	N 34.21370	W 77.94362
Hewletts Creek	HC-M	N 34.18230	W 77.83888
	HC-2	N 34.18723	W 77.84307
	HC-3	N 34.19023	W 77.85083
	HC-NWB	N 34.19512	W 77.86155
	NB-GLR	N 34.19783	W 77.86317
	MB-PGR	N 34.19807	W 77.87088
	SB-PGR	N 34.19025	W 77.86472
	PVGC-9	N 34.19165	W 77.89175

Howe Creek	HW-M	N 34.24765	W 77.78718
	HW-FP	N 34.25443	W 77.79488
	HW-GC	N 34.25448	W 77.80512
	HW-GP	N 34.25545	W 77.81530
	HW-DT	N 34.25562	W 77.81952
Motts Creek	MOT-RR	N 34.15867	W 77.91605
Pages Creek	PC-M	N 34.27008	W 77.77133
	PC-OL	N 34.27450	W 77.77567
	PC-CON	N 34.27743	W 77.77763
	PC-OP	N 34.28292	W 77.78032
	PC-LD	N 34.28067	W 77.78495
	PC-BDDS	N 34.28143	W 77.79417
	PC-WB	N 34.27635	W 77.79582
	PC-BDUS	N 34.27732	W 77.80153
	PC-H	N 34.27508	W 77.79813
Smith Creek	SC-23	N 34.25795	W 77.91967
	SC-CH	N 34.25897	W 77.93872
Whiskey Creek	WC-NB	N 34.16803	W 77.87648
	WC-SB	N 34.15935	W 77.87470
	WC-MLR	N 34.16013	W 77.86633
	WC-AB	N 34.15967	W 77.86177
	WC-MB	N 34.15748	W 77.85640

18.0 Appendix D. University of North Carolina at Wilmington reports and papers concerning water quality in New Hanover County's tidal creeks.

Reports

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