ENVIRONMENTAL QUALITY OF WILMINGTON AND NEW HANOVER COUNTY WATERSHEDS, 2010

by

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Executive Summary

This report represents combined results of Year 12 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 2010.

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 12,200. There was one station sampled in this watershed during 2010, lower Barnard's Creek at River Road. Based on 3 samples collected between January and June 2010, there was one minor algal bloom and no major turbidity problems. Dissolved oxygen was below the state standard on 33% of occasions sampled. Fecal coliform bacteria exceeded the NC standard of 200 CFU / 100 mL on one of the sampling trips and equaled it on another; in general water quality in this creek was poor in 2010.

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, with a population of about 16,470. Three sites were sampled, all from shore. In 2010 there were no problems with turbidity or algal blooms exceeding the state standard. Average dissolved oxygen was good to fair at the three sites. However, all 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 2010. This creek has very poor water quality, with 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 > 60% of occasions sampled. These levels of pollution have characterized the system for the past several years. Dissolved oxygen concentrations were fair in 2010. Sediment sampling showed that significant pollution by toxic compounds called polycyclic aromatic hydrocarbons (PAHs) occurred throughout the creek, and the lower creek sediments were also polluted by high lead, zinc and mercury concentrations.

The effectiveness of Ann McCrary wet detention pond on Randall Parkway as a pollution control device for upper Burnt Mill Creek was not strong for 2010. Comparing inflows to outflows, there was 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 2010. 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 with a population of about 10,630. 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 2010 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 2010 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.

Algal blooms are periodically problematic in Greenfield Lake, and have occurred during all seasons, but are primarily a problem in spring and summer. In 2010 algal blooms did occur in the lake, but we note that chlorophyll *a*, as well as average total nitrogen and total phosphorus were lower than they had been in the past three years.

In the period 2007-2010 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 periodically impact the lake, although average fecal coliform counts in 2010 were lower than in the previous two years. 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 with a population of about 20,210. In recent years this system has been plagued by a number of sewage spills. In 2010 the creek was sampled at four tidal sites and one non-tidal freshwater site. There was only one month where incidents of low dissolved oxygen were seen in our sampling (September) although none were severe (below 3.6 mg/L). Turbidity was low and no major algal blooms were seen at these stations in 2010. Fecal coliform bacterial pollution continued to impact Hewletts Creek in 2010, with three of the five sites (one at NB-GLR, the north branch at Greenville Loop Rd., one at MB-GLR, the middle branch at Pine Grove Rd., and one at PVGC-9, draining Pine Valley Golf Course); exceeding the North Carolina standard of 200 CFU/100 mL 80% of the time or more. Fecal coliforms at the south branch site, SB-PGR, did not exceed the State standard. Sediment sampling in Hewletts Creek found no sites with concentrations of metals, PCBs or PAHs that are considered dangerous to aquatic life.

During 2007 the 7.6 acre JEL Wade wetland was constructed to treat stormwater runoff from a 589 acre watershed within the Hewletts Creek drainage. Drainage for this wetland enters the south branch of the creek, upstream of the SB-PGR sampling site. A rain event sampling program was carried out in 2009-2010 to evaluate the efficacy of the wetland in reducing pollutant loads (fecal bacteria, nutrients, suspended solids and metals) from the stormwater runoff passing through the wetland. During the eight storms sampled, the wetland served to retain and/or remove 50-75% of the inflowing stormwater volume within the wetland. High removal rates of fecal coliform bacteria were achieved (based on “first flush”), with an average load reduction of 99% and overall concentration reduction of > 90%. Particularly high (>90%) load reductions of ammonium and orthophosphate loads also occurred, and lesser but still substantial reductions of total phosphorus (89%) and TSS loads (88%) were achieved. Removal of nitrate was seasonally dependent, with lower removal occurring in cold weather and high percentage (90%+) nitrate load removal occurring in the growing season when water temperatures exceeded 15^{o}C. Most metals tested had concentrations too low to be measured in inflowing and outflowing waters, except for zinc, for which an average load reduction of 87% was achieved. Since the principal source of impairment in Hewletts Creek is fecal bacteria contamination, and a secondary source is algal blooms (limited by nitrogen in this system), this constructed wetland appears to be very successful in reducing both concentrations and loads of polluting substances to the receiving waters. Additionally, data for Station SB-PGR showed a statistically significant decline in both ammonium and nitrate after completion of the wetland.

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 and a population of about 6,460. Three stations were sampled in Howe Creek in 2010. 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 40% and 60% of the times sampled, respectively. The lower station HW-FP was rated good, not exceeding the standard in 2010. Dissolved oxygen concentrations were fair in Howe Creek in 2010. 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 with a population of about 9,530. This creek was sampled 3 times at one station at River Road in 2010 as a result of funding from the private sector. Dissolved oxygen concentrations were above the state standard of 5.0 mg/L on all three of the sampling occasions in 2010. Neither turbidity nor suspended solids were problematic in 2010, and there was only one major algal bloom encountered in the sampling and a consequent pulse of 10 mg/L of BOD5. However, fecal coliform bacteria contamination was a problem in Motts Creek, with the State standard of 200 CFU/100 mL exceeded on 67% of the occasions sampled and the geometric mean above the NC standard. 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 2010 this creek showed poor water quality based on periodic algal blooms and fecal coliform problems.

Pages Creek – Pages Creek drains a 3,039 acre watershed into the ICW. UNC Wilmington was not funded to sample this creek from 2008-2010. The County employed a private firm to sample this creek and data are available on the County website.

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, SC-CH, was sampled by UNCW under the auspices of the Lower Cape Fear River Program (LCFRP) 2010. The water quality in 2010 was generally good, but having a few elevated fecal coliform counts.

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 8,000, and is covered by approximately 19% impervious surface area. One station, on Masonboro Loop Road, was sampled from shore along this creek in 2010. This site had low to moderate nutrient concentrations and no algal bloom problems. Dissolved oxygen was substandard (4.0 mg/L) only in September. Fecal coliform bacteria counts were generally good at this site in 2010.

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 than 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 2010 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 24% to be in good condition, 14% in fair condition, but **62%** in poor condition. Dissolved oxygen conditions system-wide (24 sites) showed 29% of the sites were in good condition, 50% were in fair condition, and 21% were in poor condition. For algal bloom presence, measured as chlorophyll *a*, 75% of the 20 stations sampled were rated as good, 10% as fair and 15% as poor (sites in Greenfield Lake, Burnt Mill Creek, and Motts Creek). In terms of turbidity all 100% of the 24 sites sampled were rated as good. 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 several combined Tidal Creeks – Wilmington City Watersheds reports (Mallin et al. 1998b; 1999; 2000b; 2002a; 2003; 2004; 2006a; 2007; 2008) In fall 2007 New Hanover County decided to stop funding UNCW sampling on the tidal creeks and UNCW has subsequently produced several reports largely focused on City watersheds (2009a; 2010). In the present report we present results of sampling conducting during 2010, 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 reinitiated sampling of Motts and Barnards Creeks along River Road. This sampling continued until July 2010, when plans for development of the site were delayed due to the economic slowdown and funding was suspended. As such, 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 (from January-June 2010) reflect present upstream development activities that impact the creeks.

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. In addition, a suite of metals, PAHs and PCBs were assessed in the sediments of Burnt Mill Creek and Hewletts Creeks.

In 2010 Wilmington Stormwater Services also began a collaboration with UNCW to investigate potential sewage spills and leaks and illicit sanitary connections potentially polluting city waterways. The results of samples collected under that effort are also presented.

1.1 Water Quality Methods

Samples were collected on five occasions at most locations within the Wilmington City watersheds from August through December 2010. 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 instrument measured water temperature, pH, dissolved oxygen, turbidity, salinity, and conductivity. YSI Model 85 and 55 dissolved oxygen meters were available as back-up meters. The YSI 6920 was 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). Samples were collected on-site for laboratory 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 0.7 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. UNCW Aquatic Ecology Laboratory is State-certified for laboratory chlorophyll *a* measurements.

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 1997).

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 12,200
Overall water quality: Poor
Problematic pollutants: Low dissolved oxygen; some elevated 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 planned for the area east of River Road and between Barnards and Motts Creeks, although no project construction has yet occurred near Barnards Creek. In 2010 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 on three occasions (January, April and June 2010); funding for sampling after June was stopped due to economic issues. We also have extensive data for 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.

BNC-RR had an average salinity of 3.1 ppt with a range of 0.4-5.4 ppt. This station had dissolved oxygen levels ranging from 4.0-8.6, with 33% of the samples yielding readings that fell below the 5.0 mg/L North Carolina standard for dissolved oxygen in brackish waters. We note that sampling did not occur in July and August, the warmest months when DO levels are expected to be lowest. Turbidity on average was moderate (16 NTU), and did not exceed the state standard for estuarine waters of 25. Average total suspended solids concentrations were likewise moderate during 2010 (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 did not find such concentrations during our limited sampling.

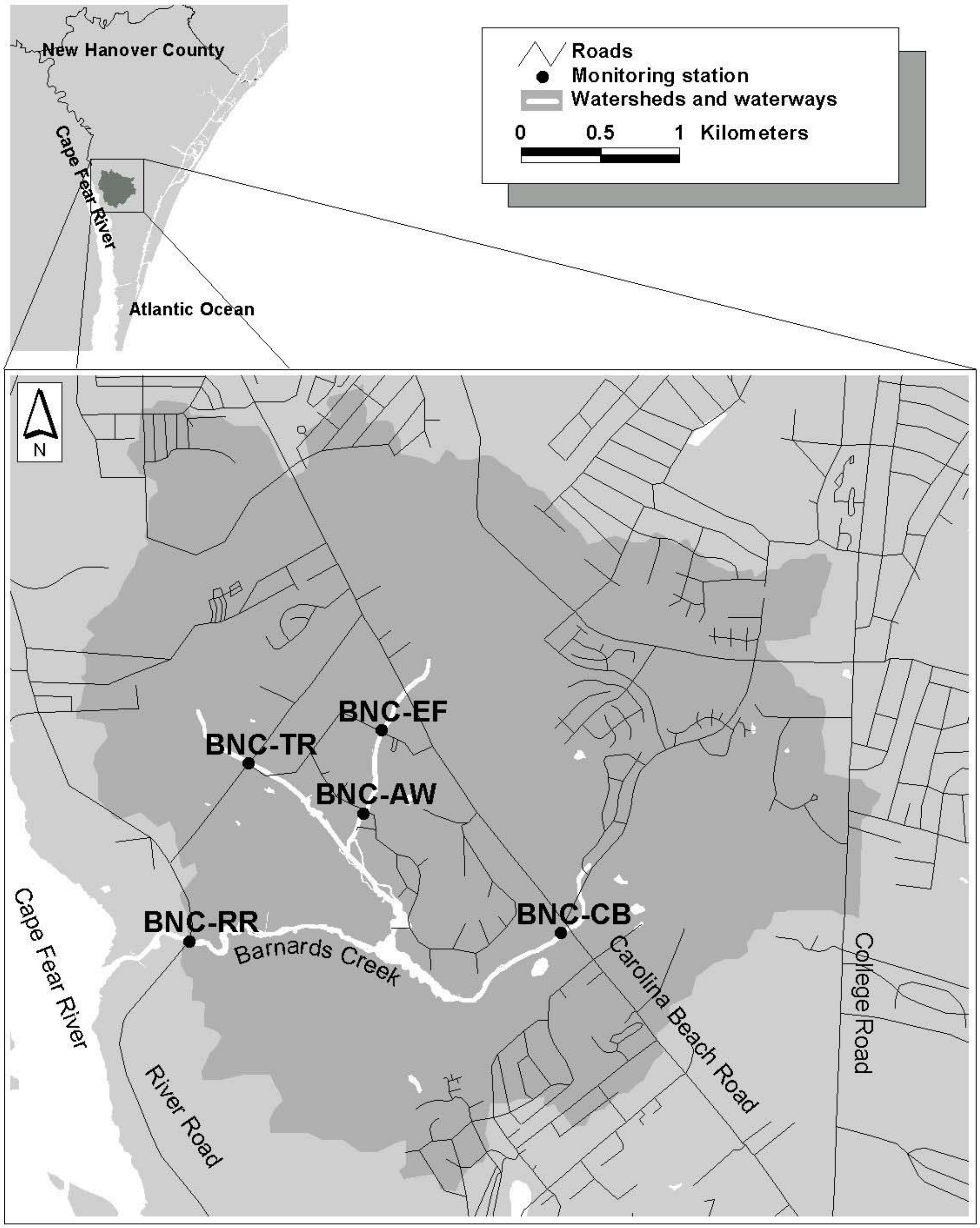
Concentrations of nitrate, ammonium and orthophosphate were among the highest in streams and tidal creeks of similar salinities in the Wilmington area (Table 2.1). There was only one algal bloom seen in our 2010 sampling, of 26 µg/L as chlorophyll *a* (Table 2.1).

Average BOD5 was low to moderate compared with urban streams with mean of 1.3 mg/L and a maximum value of 2.0 mg/L (Mallin et al. 2006a; 2006b; 2007; 2008). However, fecal coliform counts were somewhat elevated; on one occasion they exceeded the state standard (220) and on a second occasion they were at the standard of 200 CFU/100 mL. The geometric mean was well below the state standard (76 CFU/100 mL).

Table 2.1. Mean and standard deviation of water quality parameters in Barnards Creek watershed, January – June 2010. Fecal coliforms as geometric mean; N/P ratio as mean (n = 3 for all parameters).

Parameter BNC-RR	mean (st. deviation)	range
Salinity (ppt)	3.1 (2.5)	0.4-5.4
DO (mg/L)	6.4 (2.)	4.0-8.6
Turbidity (NTU)	16 (2)	14-18
TSS (mg/L)	11.5 (1.3)	11-13
Nitrate (mg/L)	0.31 (0.05)	0.25-0.35
Ammonium (mg/L)	0.12 (0.04)	0.08-0.16
TN (mg/L)	0.97 (0.04)	0.95-1.02
Phosphate (mg/L)	0.07 (0.02)	0.06-0.09
TP (mg/L)	0.12 (0.01)	0.11-0.13
N/P molar ratio	13.6	
Chlorophyll *a* (μg/L)	12.0 (12.3)	3.0-26.0
BOD5	1.3 (0.6)	1.0-2.0
Fecal coliform bacteria (CFU/100 mL)	76	10-220

Figure 2.1 Barnards Creek watershed



3.0 Bradley Creek

Snapshot
Watershed area: 4,631 acres (1,874 ha)
Impervious surface coverage: 23%
Watershed population: Approximately 16,470
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 has been 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 problem during 2010; 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 August when it was 24.7 mg/L at BC-NB (there are no NC ambient standards for TSS). There were minor issues with low dissolved oxygen (hypoxia) upstream, with two stations (BC-NB and BC-SB) each having DO < 5.0 mg/L on one occasion each during the five sampling occasions (Appendix B).

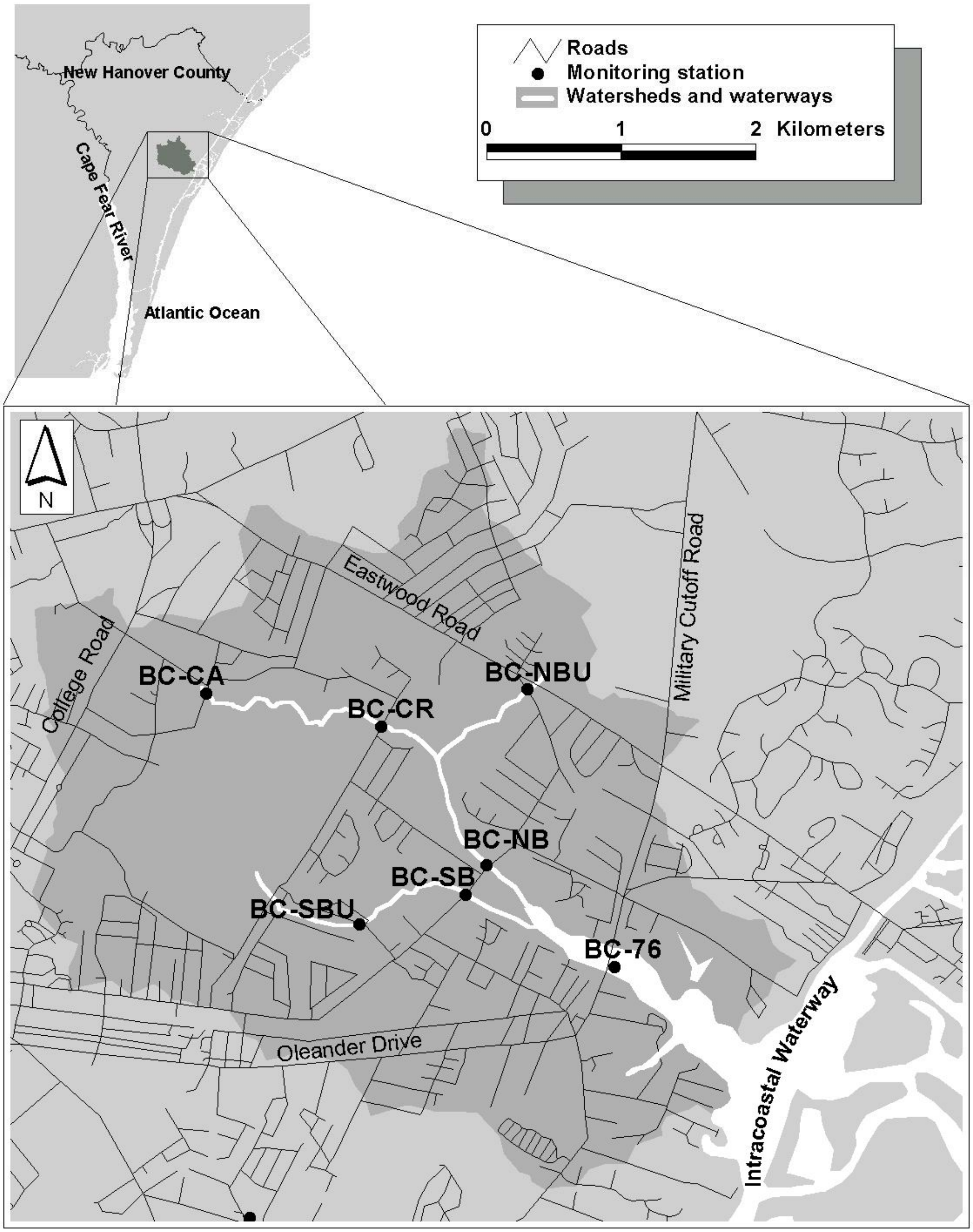
Ammonium concentrations were low on all sampling occasions. Nitrate concentrations were highest at station BC-CA, and slightly decreased from the previous year at all sites (Table 3.1). Total nitrogen concentrations were low to moderate at all times sampled. Orthophosphate concentrations were low in all samples in 2010, while total phosphorus was low at BC-CA and moderate at BC-NB and BC-SB. Bradley Creek station BC-SB hosted one minor algal bloom of 37 μg/L chlorophyll *a* in August 2010. Nitrogen to phosphorus ratios at BC-NB and BC-SB were low (3-4) indicating that inputs of inorganic nitrogen are likely to stimulate the algal blooms.

Fecal coliform bacteria counts were excessive at all three upstream stations during all seasons, with the NC standard being exceeded on at least 40% of occasions sampled at all sites. The geometric means of the fecal coliform counts ranged from under the standard (141 CFU/100 mL) at BC-NB to >3X the standard (631 CFU/100 mL) at BC-SB (Table 3.1). Fecal coliform contamination in 2010 was worse than the previous year.

Table 3.1 Water quality parameter concentrations at Bradley Creek sampling stations, 2010. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 5 months.

Station	BC-CA	BC-NB	BC-SB
Salinity (ppt)	0.1 (0.0) 0.1-0.1	23.4 (5.0) 16.3-30.2	9.2 (6.1) 3.3-19.5
Dissolved Oxygen (mg/L)	7.6 (0.3) 7.2-7.9	6.2 (1.9) 3.7-8.5	7.1 (1.6) 4.8-8.4
Turbidity (NTU)	3 (2) 1-7	8 (4) 2-11	9 (4) 3-12
TSS (mg/L)	3.5 (3.0) 1.4-8.1	19.0 (3.7) 14.5-24.7	12.2 (5.2) 6.2-18.7
Nitrate (mg/L)	0.244 (0.014) 0.220-0.250	0.012 (0.004) 0.010-0.020	0.026 (0.015) 0.010-0.040
Ammonium (mg/L)	0.026 (0.015) 0.010-0.050	0.010 (0.006) 0.005-0.020	0.008 (0.007) 0.005-0.020
TN (mg/L)	0.344 (0.013) 0.320-0.350	0.240 (0.152) 0.100-0.400	0.282 (0.133) 0.100-0.440
Orthophosphate (mg/L)	0.012 (0.004) 0.010-0.020	0.018 (0.011) 0.010-0.030	0.022 (0.011) 0.010-0.030
TP (mg/L)	0.026 (0.011) 0.010-0.040	0.042 (0.025) 0.020-0.080	0.056 (0.023) 0.030-0.090
N/P	53.1 59.8	3.1 3.3	4.0 3.3
Chlorophyll *a* (μg/L)	1 (2) 1-5	8 (7) 1-18	17 (18) 1-37
Fecal coliforms (CFU/100 mL)	507 136-1,637	141 55-364	631 100-11,000

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 23,700
Overall water quality: poor
Problematic pollutants: Fecal bacteria, algal blooms, some low dissolved oxygen, high sediment PAH, lead, zinc and mercury concentrations

Introduction

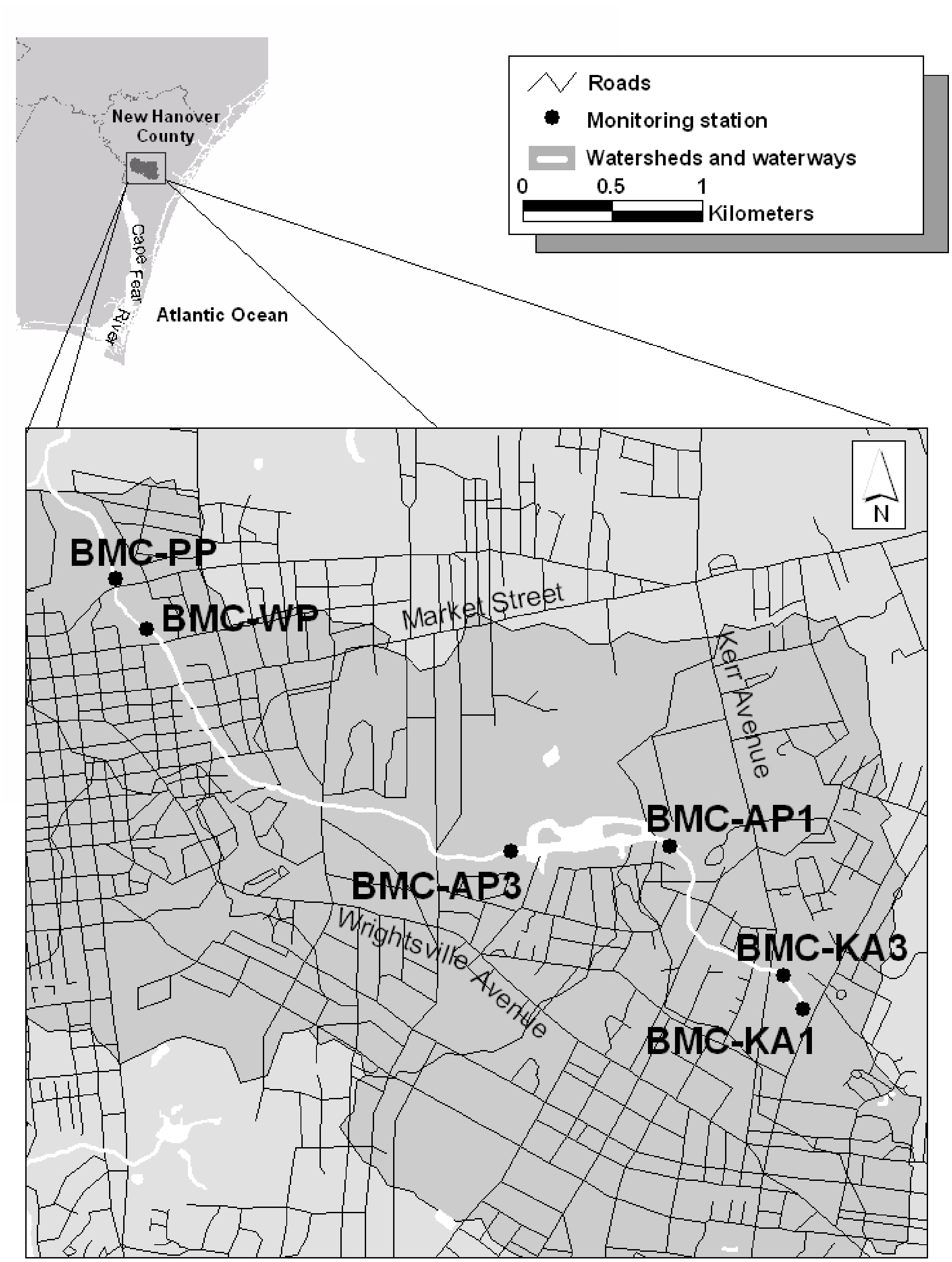
In 1997 the City of Wilmington contracted with the Aquatic Ecology Laboratory at the UNC Wilmington Center for Marine Sciences to begin citywide water quality sampling. A prominent feature in the Burnt Mill Creek watershed (Fig. 4.1) is the Ann McCrary Pond, which is a large (28.8 acres) regional wet detention pond draining 1,785 acres, with a large apartment complex (Mill Creek Apts.) at the upper end. 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. Burnt Mill Creek has been studied by a number of researchers, and 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; Perrin et al. 2008; Mallin et al. 2009a; Mallin et al. 2009b).

Methods

<u>Sampling Sites</u>: During 2010 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.

An additional set of sediment samples was taken at six locations in 2010, including BMC-KA1 (entering Kerr Avenue constructed wetland), BMC-AP3, BMC-PP, BMC-GS (tributary creek entering Burnt Mill Creek near Gibson Avenue upstream of Wallace Park), BMC-ODC (in the creek within Oakdale Cemetery, and BMC-WP in Wade Park.

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 five occasions in 2010. Dissolved oxygen concentrations fell below the State standard of 5.0 mg/L on only one occasion at BMC-AP1. The State standard for turbidity in freshwater is 50 NTU; there were no exceedences of this value in our 2010 samples. Suspended solids concentrations were not unusually high on any sampling occasion at either BMC-AP1 or at BMC-AP3 leaving this large regional pond; there was 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 (very visible to the observer) runoff from the Mill Creek apartment complex and runoff from urban upstream areas (including the Kerr Avenue wetland). Over the sampling period three of the five regular samples collected at BMC-AP1 had counts exceeding 200 CFU/100 mL, whereas none of the samples from BMC-AP3 exceeded the standard. This did not result in a statistically significant decrease, though, due to the high variability (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 one lesser bloom. 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 34% 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.

Lower Burnt Mill Creek: The Princess Place location (BMC-PP) was the only lower creek station sampled in 2010. One parameter that is key to aquatic life health is dissolved oxygen. Dissolved oxygen at BMC-PP in 2010 was substandard on only one sampling occasion in 2010. Turbidity concentrations at BMC-PP did not exceed the State standard on any of our sampling occasions. 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. All samples collected in 2010 were well below this benchmark level.

In 2010 BMC-PP showed no major algal blooms exceeding the North Carolina water quality standard for chlorophyll *a* of 40 µg/L. However, this site did host two minor summer algal blooms of 25 and 23 µg/L (Table 4.1). 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? Nitrate concentrations were somewhat elevated at BMC-PP, while phosphorus concentrations were low. Examination of inorganic nitrogen to phosphorus ratios (Table 4.1) shows that median N/P ratios were 13.0 and mean ratios were 15.2. 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, as at BMC-PP, 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, 2010, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as mean/median.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	6.7 (1.7) 4.9-8.7	11.1 (2.0)** 9.5-14.1	6.3 (2.2) 4.2-10.0
Cond. (μS/cm)	294 (16) 272-317	249 (25) 228-285	1,148 (1,678) 371-4,150
pH	7.2 (0.2) 7.0-7.5	8.0 (0.4)* 7.6-8.4	7.3 (0.1) 7.2-7.4
Turbidity (NTU)	6 (5) 3-14	13(7) 7-22	5 (3) 3-9
TSS (mg/L)	2.8 (2.9) 1.4-7.9	11.3 (8.3) 4.5-22.4	2.7 (3.0) 1.2-8.1
Nitrate (mg/L)	0.102 (0.065) 0.030-0.170	0.043 (0.047) 0.010-0.110	0.260 (0.051) 0.180-0.320
Ammonium (mg/L)	0.039 (0.029) 0.005-0.080	0.019 (0.015) 0.005-0.040	0.054 (0.029) 0.010-0.090
TN (mg/L)	0.202 (0.140) 0.100-0.370	0.413 (0.158) 0.300-0.640	0.404 (0.283) 0.100-0.820
OrthoPhos. (mg/L)	0.010 (0.000) 0.010-0.010	0.023 (0.015) 0.010-0.040	0.048 (0.016) 0.030-0.070
TP (mg/L)	0.048 (0.055) 0.010-0.140	0.075 (0.044) 0.040-0.140	0.078 (0.036) 0.050-0.130
N/P molar ratio	31.2 35.4	9.7 5.5	15.2 13.0
Chlor. *a* (μg/L)	5 (6) 1-14	60 (51) 18-129	14 (12) 1-27
FC (CFU/100 mL)	1,419 73-60,000	65 19-145	353 62-637

* 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 80% of occasions sampled at Princess Place. It is notable that fecal coliform bacteria counts increased along the passage from BMC-AP3 (geometric mean 85 CFU/100 mL) to the Princess Place location (geometric mean 353 CFU/100 mL; Fig. 4.2), as in previous years. It is likewise notable that nutrient concentrations increased from the outflow from Ann McCrary Pond downstream to the lower main stem station (Table 4.1; Fig. 4.3).

Figure 4.2. Fecal coliform bacteria geometric means for Burnt Mill Creek, 2010

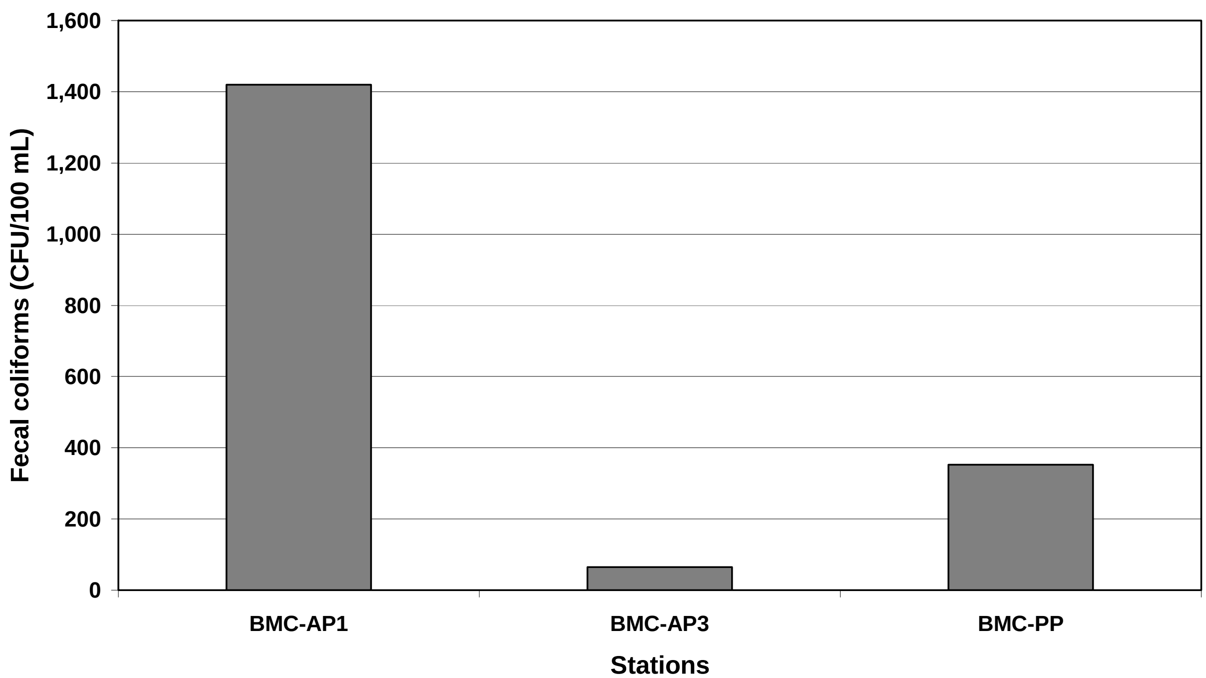
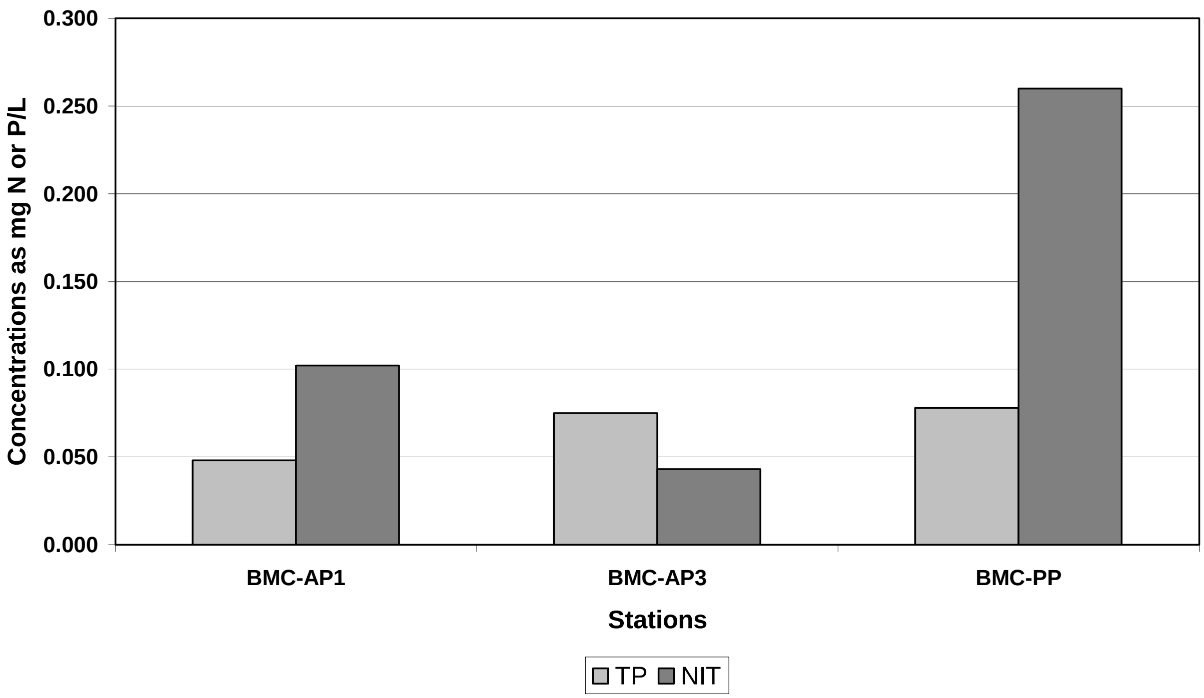


Figure 4.3. Average total phosphorus and nitrate concentrations by station for Burnt Mill Creek, 2010



To summarize, in some years Burnt Mill Creek has had severe problems with low dissolved oxygen (hypoxia) at some of the stations, but in 2010 dissolved oxygen (DO) were fair rather than poor. Algal blooms remained a problem in the creek during 2010. 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 Ann McCrary 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. We note that strong statistical correlations between fecal coliform counts, TSS, BOD and rainfall have been demonstrated for this creek (Mallin et al. 2009b). As this is one of the most heavily-developed creeks in the Wilmington area, it also remains one of the most polluted.

Sediment Metals and Chemical Toxins

Wilmington Stormwater Services and UNCW are interested in potential toxicants buried in or adhering to the creek sediments in City watersheds. Thus, we collected sediment samples on one occasion throughout Burnt Mill Creek for analysis of sediment metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) as well some basic chemical parameters including total nitrogen, total phosphorus and total organic carbon. The State of North Carolina has no official guidelines for sediment concentrations of metals and organic pollutants in reference to protection of invertebrates, fish and wildlife. However, academic researchers (Long et al. 1995) have produced guidelines (Table 4.2) based on extensive field and laboratory testing that are used by the US Environmental Protection Agency in their National Coastal Condition Report II (US EPA 2004).

Table 4.2. Guideline values for sediment metals and organic pollutant concentrations (ppm, or μg/g, dry wt.) potentially harmful to aquatic life (Long et al. 1995; U.S. EPA 2004). ERL = (Effects range low). Concentrations below the ERL are those in which harmful effects on aquatic communities are rarely observed. ERM = (Effects range median). Concentrations above the ERM are those in which harmful effects would frequently occur. Concentrations between the ERL and ERM are those in which harmful effects occasionally occur.

Metal	ERL	ERM
Arsenic (As)	8.2	70.0
Cadmium (Cd)	1.2	9.6
Chromium (Cr)	81.0	370.0
Copper (Cu)	34.0	270.0
Lead (Pb)	46.7	218.0
Mercury (Hg)	0.15	0.71
Nickel (Ni)	20.9	51.6
Silver (Ag)	1.0	3.7
Zinc (Zn)	150.0	410.0
Total PCBs	0.0227	0.1800
Total DDT	0.0016	0.0461
Total PAHs	4.02	44.80
Pyrene	0.665	2.600
Flouranthene	0.600	5.100

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds with a fused ring structure. PAHs with two to five rings are of considerable environmental concern. They are compounds of crude and refined petroleum products and coal and are also produced by incomplete combustion of organic materials (US EPA 2000). They are characteristic of urban runoff as they derive from tire wear, automobile oil and exhaust particles, and leaching of asphalt roads. Other sources include domestic and industrial waste discharge, atmospheric deposition, and spilled fossil fuels. They are carcinogenic to humans, and bioconcentrate in aquatic animals. In these organisms they form carcinogenic and mutagenic intermediaries and cause tumors in fish (US EPA 2000).

Polychlorinated biphenyls (PCBs) have been banned for use in the United States since 1979. They are closely related to many chlorinated hydrocarbon pesticides, and were used industrially as insulating fluids, heat transfer fluids, plasicizers, lubricants and hydraulic fluids (US EPA 2000). They are persistent in the environment and bioaccumulate in the food chain, and individual PCBs cause health problems including developmental impacts in children, hepatotoxicity, neurotoxicity and carcinogenicity (US EPA 2000).

Most metals in the creek sediments had concentrations that were well below levels considered potentially toxic to benthic organisms (see Table 4.2). A major exception was lead, which exceeded the ERL (Table 4.2) at the Wallace Park Station BMC-WP and the Princess Place Station BMC-PP and the cemetery Station BMC-ODC (Table 4.3). Copper did not exceed the ERL at any site but was close to the ERL at both BMC-PP and BMC-ODC (Table 4.3). Mercury exceeded the ERL only at Station BMC-PP. Additionally, zinc exceeded the ERL at BMC-PP and BMC-ODC. PCBs were below detection limit at all sites. Total PAH sediment concentrations exceeded the ERM at all sites sampled (Table 4.3). In terms of individual PAHs, Pyrene was high at all sites, while Fluoranthrene was high at BMC-OD and KA-1. These two PAHs are not individually known human carcinogens, but are known to produce toxicity to either the liver, kidney or gastrointestinal regions in animals. Where these two PAHs showed measurable concentrations they exceeded the ERM for sediment benthic invertebrate health (Tables 4.2 and 4.3). Other PAHs were generally below detection limit except for station KA-1, where many individual PAHs were high.

Compared with sediment data collected in 2007, lead concentrations increased at both BC-WP and BC-PP (Mallin et al. 2008). Zinc doubled at BMC-WP and tripled at BMC-PP from 2007-2010. Additionally, there were no excess mercury concentrations in 2007 but in 2010 mercury was considerably increased at BC-PP. As in previous years, total PAHs were high, and whereas in 2007 PAHs at BMC-AP3 were below detection limit, in 2010 they exceeded the ERM at that site. Samples at BMC-GS and BMC-ODC were not collected in previous years. Thus, the lower creek had sediment metals contamination while the upper creek did not; however, the entire creek suffered from PAH sediment contamination.

Table 4.3. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Burnt Mill Creek, 2010 (as mg/kg = ppm, except for the PCBs which are µg/kg). Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur, and italicized concentrations are near potentially harmful levels (see Table 4.2 for more detail).

Parameter	KA1	AP3	GS	WP	PP	ODC
Antimony	<4.23	<4.43	<4.50	<7.48	<12.40	<5.96
Arsenic	<1.06	2.29	<1.13	5.76	<3.09	3.95
Beryllium	<1.06	<1.11	<1.13	<1.87	<3.09	<1.48
Cadmium	<1.06	<1.11	<1.13	<1.87	<3.09	<1.48
Chromium	3.10	1.82	1.24	16.60	17.80	16.80
Copper	3.72	1.91	7.10	20.30	*32.40*	*32.40*
Lead	8.40	2.42	3.49	**102.00**	**143.00**	**124.00**
Mercury	0.0240	0.0218	0.0242	0.0740	**0.2950**	0.0481
Nickel	1.57	<1.11	<1.13	5.26	5.90	6.74
Selenium	<2.12	<2.22	<2.24	<3.74	<6.18	<2.98
Silver	<1.06	<1.11	<1.13	<1.87	<3.09	<1.48
Thallium	<1.06	<1.11	<1.13	<1.87	<3.09	<1.48
Zinc	35.60	8.10	19.00	111.00	**221.00**	**247.00**
Total PAH	**114,330**	**298**	**1,630**	**2,220**	**1,060**	**4,480**
Pyrene	**17,100**	**298**	**1,630**	**2,220**	**1,060**	**2,360**
Fluoranthene	**27,000**	BDL	BDL	BDL	BDL	**2,120**
Total PCBs	BDL	BDL	BDL	BDL	BDL	BDL
TN	37.2	37.2	9.0	747.0	4,800.0	450.0
TP	35.1	22.0	73.7	235.0	1,180.0	204.0
TOC	7.6	9.9	3.6	101.0	484.0	30.0

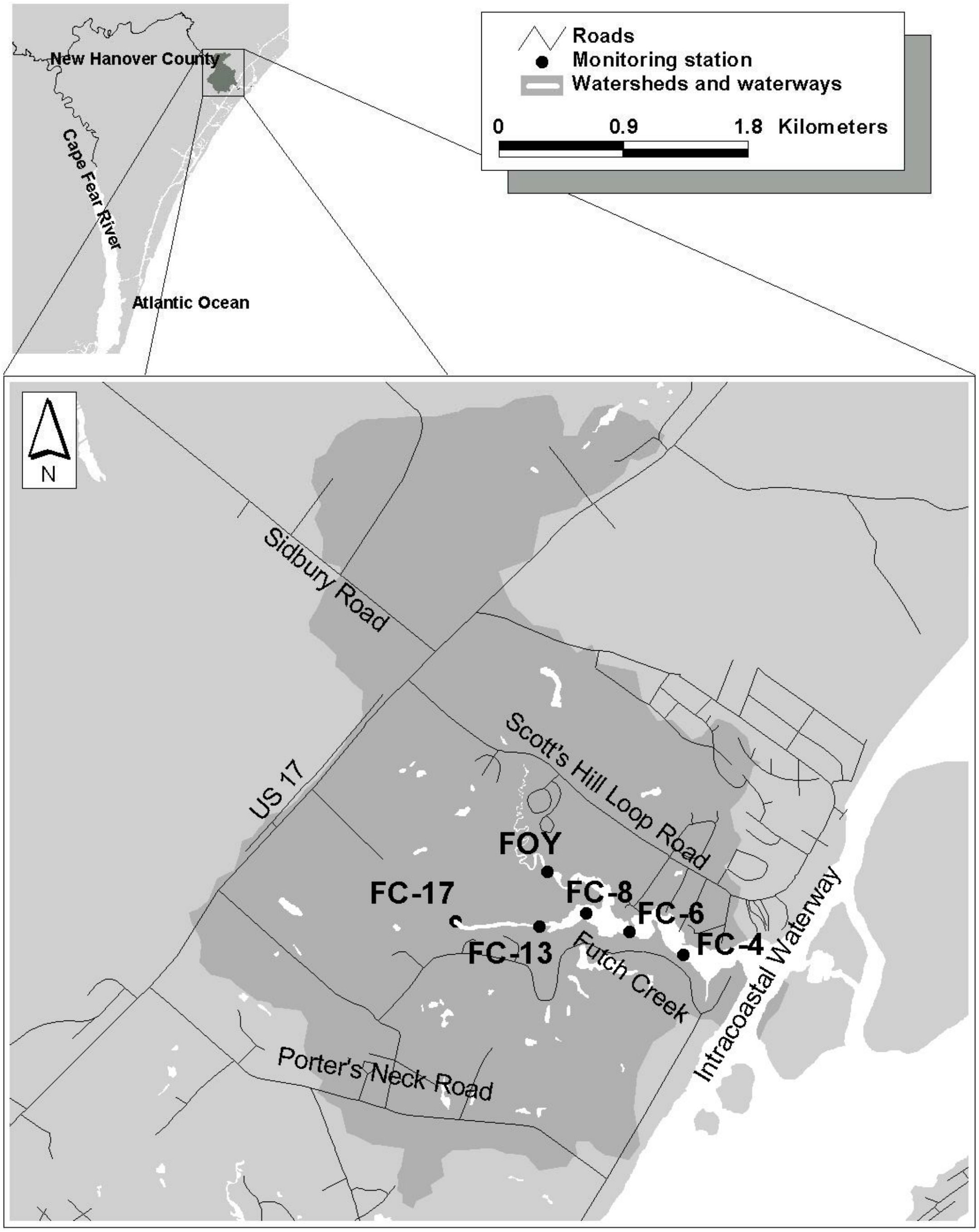
BDL = below detection limit

5.0 Futch Creek

Snapshot
Watershed area: 3,247 acres (1,314 ha)
Impervious surface coverage: >11%
Watershed population: 3,670

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 2008-2010 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: 10,630
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 2010 (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). Dissolved oxygen levels were below the state standard of 5.0 mg/L on four of five occasions at both GL-LB and GL-LC, and on two of five occasions at Jumping Run Branch GL-JRB (Table 6.1; Appendix B). Turbidity concentrations were generally low in the tributary stations, with no violations 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, 2010. n = 5.

Parameter	GL-JRB	GL-LB	GL-LC
DO (mg/L)	5.9 (3.3) 2.0-10.6	2.6 (1.6) 0.9-5.1	3.6 (2.5) 1.6-8.0
Turbidity (NTU)	4 (4) 2-4	4 (3) 1-8	6 (4) 2-11

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 five occasions, and DO was below standard on one occasion at GL-P (see also Section 6.1). Turbidity was below the state standard on all sampling occasions, and suspended solids were generally low. Fecal coliform concentrations were improved from 2009; only problematic at GL-2340 where they exceeded the State standard on three of five sampling occasions; there was only one violation each in 2010 at GL-P and GL-YD.

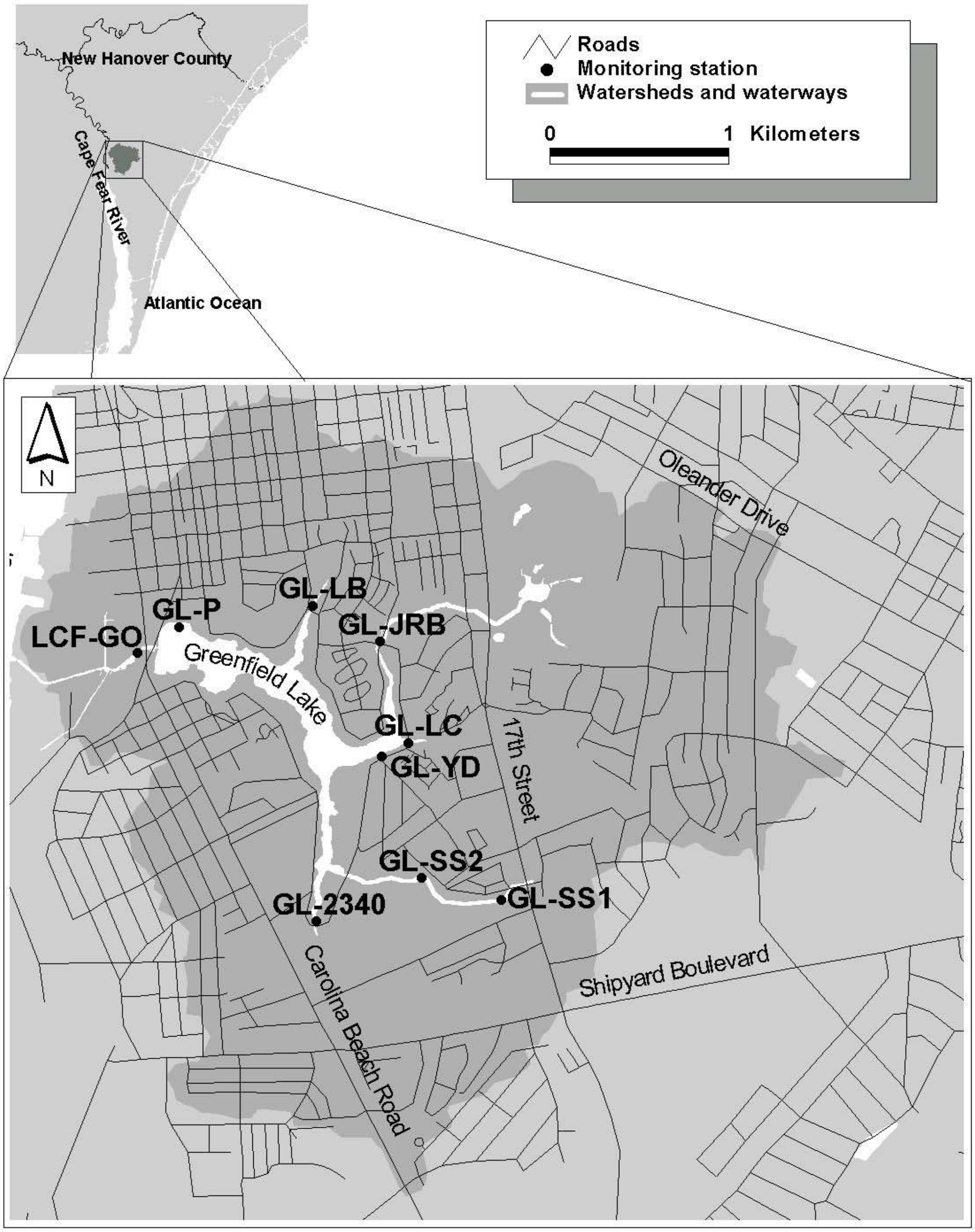
Total nitrogen (TN) concentrations were generally highest at GL-YD, but concentrations of inorganic nitrogen (nitrate and ammonium) were highest at the upstream station GL-2340, which receives input from tributaries. Ammonium levels in the lake were generally low. Total phosphorus (TP) concentrations were highest at GL-YD among stations, although none of the TP values were remarkable, and orthophosphate was generally low (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 low mean and median N/P ratios (Table 6.2), phytoplankton growth in Greenfield Lake was limited by nitrogen (i.e. inputs of nitrogen can cause algal blooms) 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 (three) and GL-2340 (one) in 2010, with no violations of standard at GL-P. Average biochemical oxygen demand (BOD5) for 2010 was high (2.6-5.5) among the three sites sampled (Table 6.1), which was similar to the elevated BOD concentrations found in previous years. As phytoplankton (floating algae) are easily-decomposed sources of BOD, the blooms in this lake continue to be a periodic source of low dissolved oxygen.

Table 6.2. Mean and (standard deviation) / range of water quality parameters in Greenfield Lake sampling stations, 2010. Fecal coliforms given as geometric mean, N/P ratio as mean / median; n = 5 samples collected.

Parameter	GL-2340	GL-YD	GL-P
DO (mg/L)	5.3 (1.4) 3.5-6.8	8.3 (2.3) 5.6-10.8	9.3 (3.5) 3.8-12.2
Turbidity (NTU)	5 (3) 2-8	4 (2) 3-7	5 (3) 3-9
TSS (mg/L)	2.0 (1.1) 1.4-4.0	3.4 (1.4) 1.4-5.1	2.5 (1.0) 1.4-3.4
Nitrate (mg/L)	0.25 (0.18) 0.01-0.45	0.07 (0.10) 0.01-0.24	0.05 (0.07) 0.01-0.16
Ammonium (mg/L)	0.08 (0.06) 0.03-0.18	0.05 (0.06) 0.01-0.15	0.06 (0.07) 0.01-0.15
TN (mg/L)	0.49 (0.13) 0.35-0.63	0.58 (0.37) 0.10-1.13	0.42 (0.22) 0.10-0.64
Orthophosphate (mg/L)	0.02 (0.01) 0.01-0.05	0.02 (0.02) 0.01-0.05	0.02 (0.01) 0.01-0.04
TP (mg/L)	0.06 (0.03) 0.03-0.10	0.09 (0.04) 0.05-0.14	0.07 (0.03) 0.04-0.12
N/P molar ratio	40.2 28.8	10.6 6.6	8.5 4.4
Fec. col. (CFU/100 mL)	283 37-1,819	57 5-546	35 5-240
Chlor. *a* (μg/L)	16 (25) 0-58	53 (35) 7-97	26 (6) 15-31
BOD5	2.6 (1.9) 1.0-5.7	5.5 (2.4) 2.6-9.2	4.4 (1.2) 3.1-6.1

Figure 6.1 Greenfield Lake watershed



6.1 A Continuing Assessment of the Efficacy of the 2005-2010 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 has considered the lake to have a problem with aquatic weeds (NCDENR 2005). Periodic phytoplankton blooms have occurred in spring, summer and fall. Some of the 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, and the herbicide sonar was added in June 2010.

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 assessments 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 2010 (after restoration efforts have been underway).

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 2010.

<u>Dissolved oxygen (DO)</u>: 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 substandard dissolved oxygen problems and the other two in-lake stations had generally good dissolved oxygen (Table 6.2). In 2010 average DO conditions were below standard in August (the warmest month) but well above standard the rest of the year (Fig. 6.2).

<u>Turbidity</u>: Turbidity was not excessive in the lake during the two years prior to restoration efforts (Mallin et al. 2006a). It has remained low (well below the North Carolina standard) following these efforts throughout 2010 (Table 6.2).

<u>Ammonium</u>: 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. In 2010 average ammonium concentrations were low, with a minor increase in December (Fig. 6.3).

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 and 2010 were elevated at GL-2340 but low at the other two sites (Table 6.2). Pulses of nitrate within stormwater runoff likely cause the elevated concentrations at GL-2340.

Total nitrogen: Total nitrogen (TN) is a combination of all inorganic and organic forms of nitrogen. Average lake concentrations and concentrations at individual stations appeared to show no overall trend over time, although there was an unusually large peak in May of 2009 (Table 6.2; Fig. 6.4). In 2010 TN concentrations were among the lowest seen in the past seven years (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. In 2010 TP concentrations were lower than both 2008 and 2009 (Fig. 6.5).

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). The overall reduction in macrophyte coverage may also encourage phytoplankton growth because there is less competition for nutrients, and less shading of the water column by the macrophytes cover. 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). There were some blooms in 2010 but on average the chlorophyll *a* abundance was low relative to the previous two years (Fig. 6.6).

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 and 2009 chlorophyll *a* and BOD data. The results showed significant positive correlations between the two parameters, although regression analysis indicated that only 26% and 31% of the variability in dissolved oxygen was accounted for by chlorophyll *a* in 2008 and 2009, respectively. However, in 2010 there was an extremely strong regression ($p<0.0001$) with chlorophyll *a* explaining 77% of the variability in BOD5 (Fig. 6.7). 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. In 2010 average fecal coliform counts were low in comparison to 2008 and 2009 (Fig. 6.8). However, fecal coliform counts were not targeted by the type of restoration efforts currently ongoing in the lake. Efforts to reduce runoff into tributary streams would likely have a positive benefit in reducing fecal bacteria counts.

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 has continued from 2007-2010. We note that DO in the lake overall remains considerably better than the period before restoration efforts began (Fig. 6.2).

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 growth 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 heterocytes (formerly called heterocysts). These species have the added ability to utilize these structures to fix atmospheric nitrogen into a useable form 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 in the two years after the largest treatments. On a positive note, average TN, TP and chlorophyll *a* concentrations in 2010 were among the lowest seen since restoration began.

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. We do re-emphasize that fecal coliform counts in 2010 were the lowest in several years. Overall, Greenfield Lake in 2010 showed some improvement over conditions in recent years.

Figure 6.2. Average dissolved oxygen concentrations in Greenfield Lake, 2003-2010.

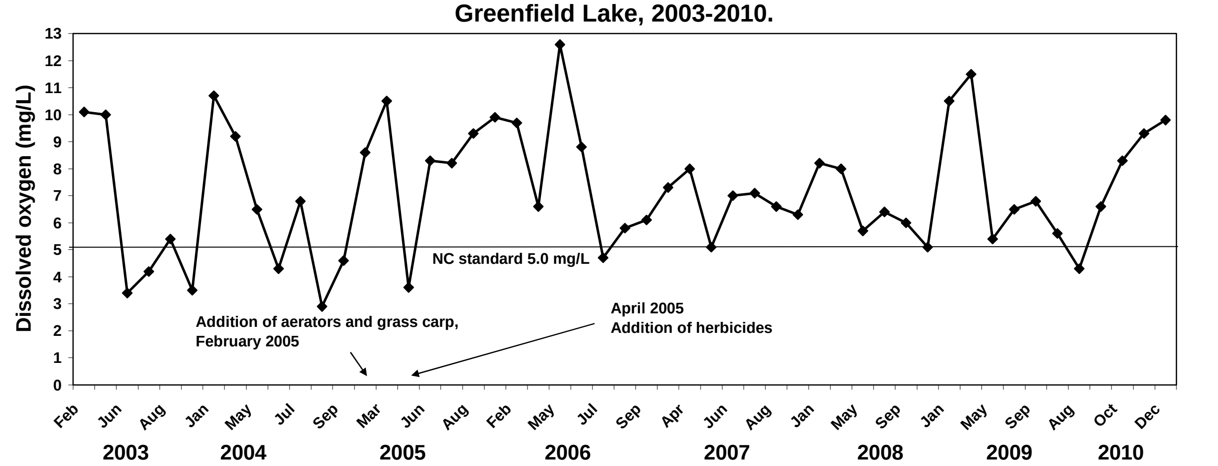


Figure 6.3. Average ammonium concentrations for Greenfield Lake, 2003-2010

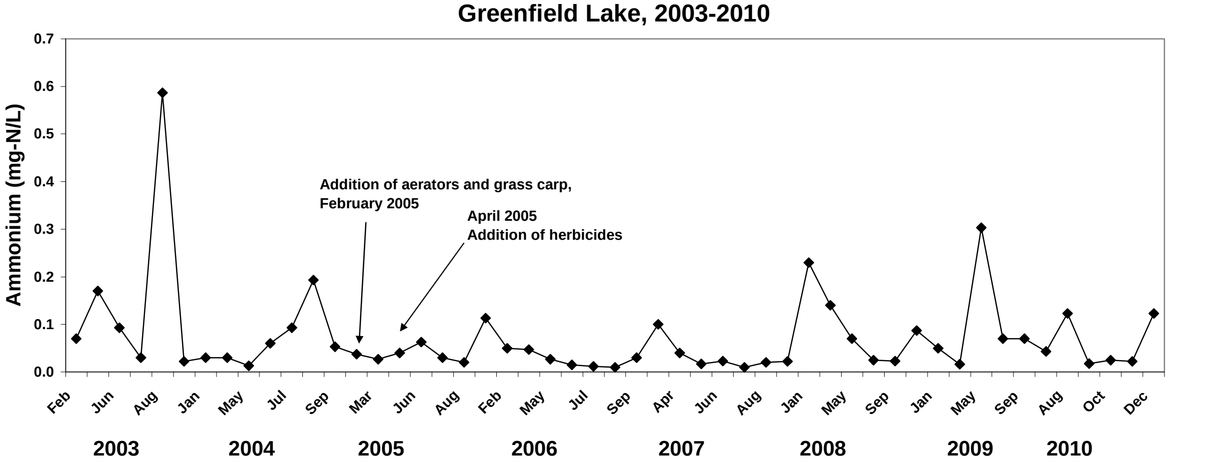


Figure 6.4. Average total nitrogen (TN) concentrations in Greenfield Lake, 2003-2010

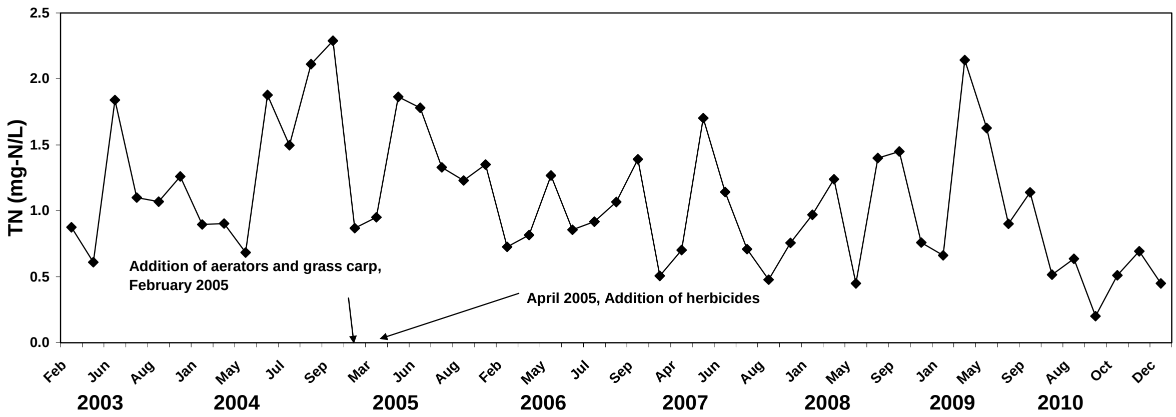
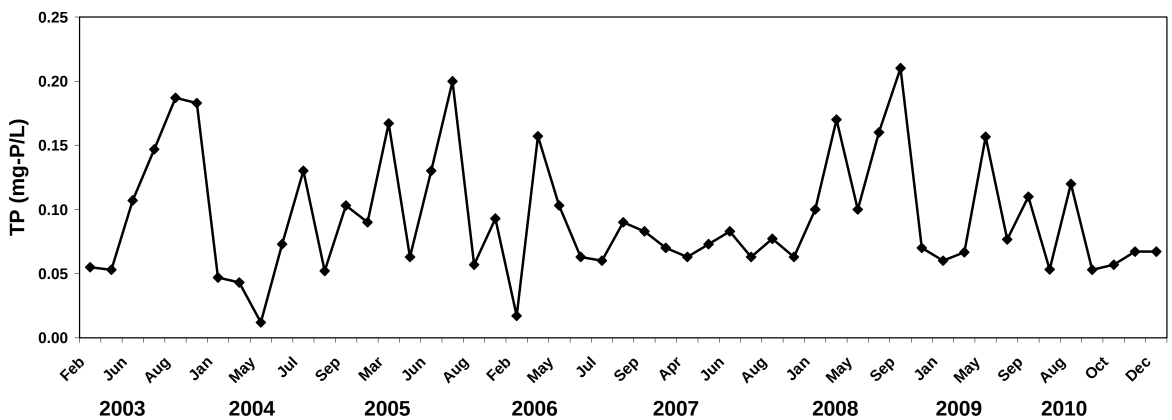


Figure 6.5. Average total phosphorus (TP) concentrations for Greenfield Lake, 2003-2010



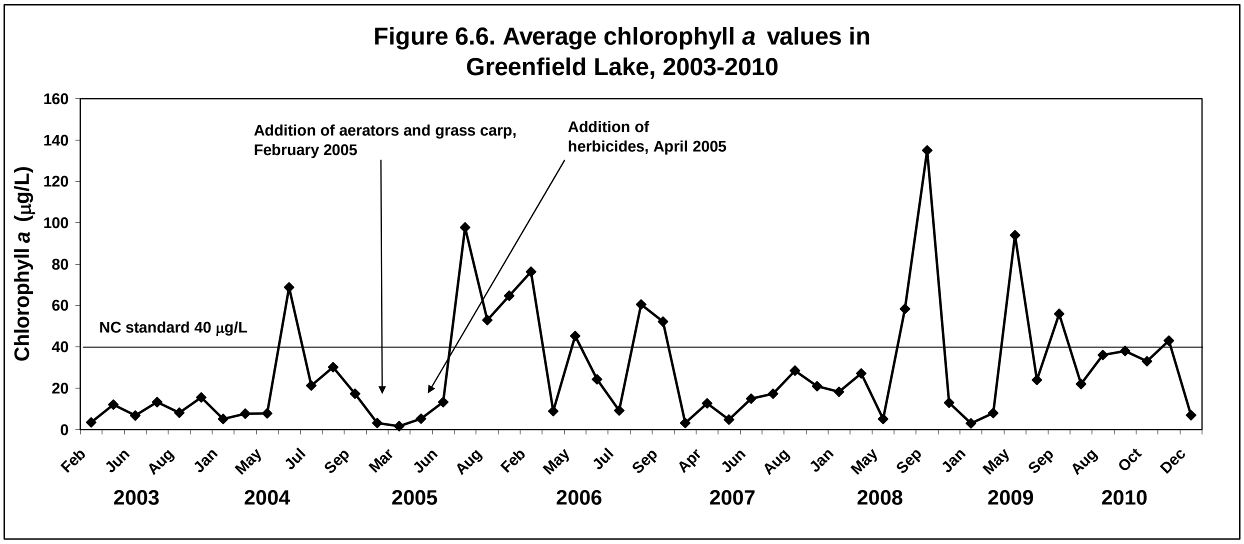


Figure 6.6. Average chlorophyll *a* values in Greenfield Lake, 2003-2010
Chlorophyll a (µg/L)
160
140
120
100
80
60
40
20
0
Addition of aerators and grass carp, February 2005
Addition of herbicides, April 2005
NC standard 40 µg/L
Feb Jun Aug Jan May Jul Sep Mar Jun Aug Feb May Jul Sep Apr Jun Aug Jan May Sep Jan May Sep Aug Oct Dec
2003 2004 2005 2006 2007 2008 2009 2010

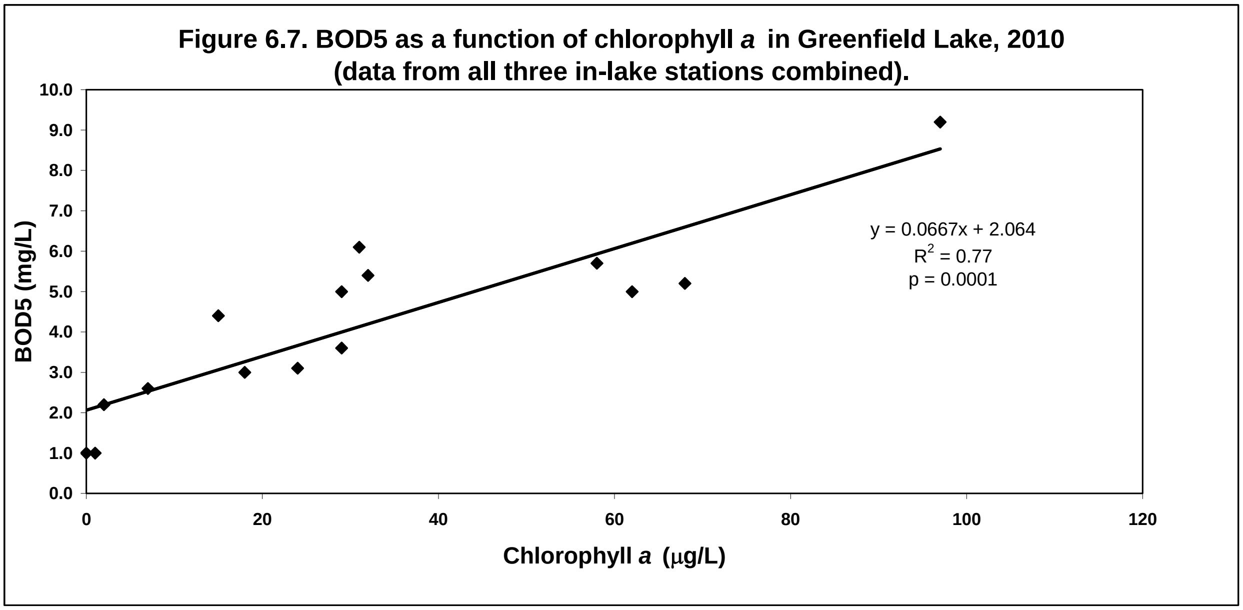
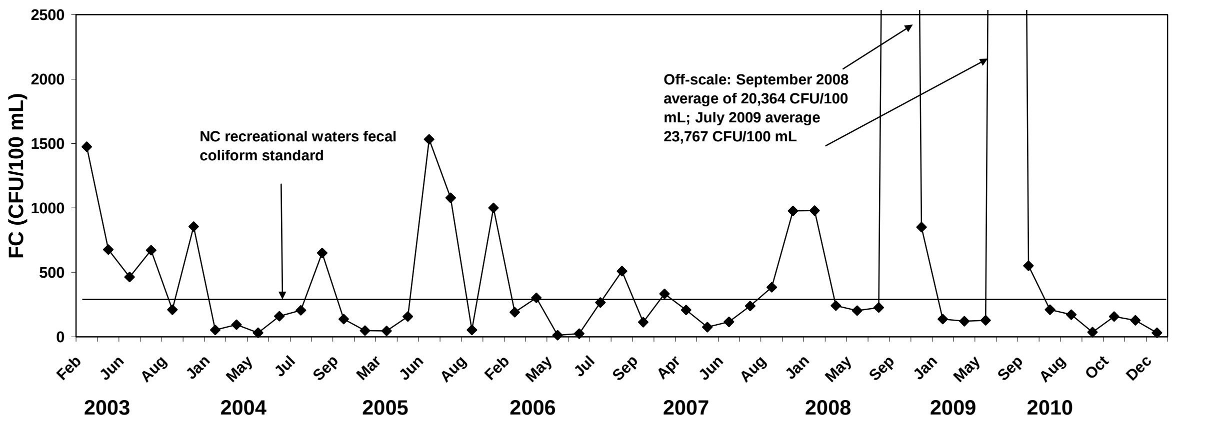


Figure 6.7. BOD5 as a function of chlorophyll *a* in Greenfield Lake, 2010 (data from all three in-lake stations combined).
BOD5 (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
y = 0.0667x + 2.064
R^2 = 0.77
p = 0.0001
0 20 40 60 80 100 120
Chlorophyll *a* (µg/L)

Figure 6.8. Average fecal coliform bacteria counts (FC) for Greenfield Lake, 2003-2010



7.0 Hewletts Creek

Snapshot
Watershed area: 7,435 acres (3,009 ha)
Impervious surface coverage: 19%
Watershed population: Approximately 20,200
Overall water quality: Fair
Problematic pollutants: high fecal bacteria, minor dissolved oxygen issues, minor algal blooms

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 all sites the physical data indicated that turbidity was well within State standards during this sampling period during all sampling events, and TSS levels were below 25 mg/L at all times sampled (Table 7.2). Hypoxia occurred at four of the five sites in September 2010; there were no other violations of the dissolved oxygen standard. 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-PGR, which also receives inputs from the Wilmington Municipal Golf Courses (Fig. 7.1; Mallin and Wheeler 2000). Nitrate was still elevated at MB-PGR; however, none of the other stations had elevated nitrate concentrations. In general nitrate concentrations creek-wide were less than in 2009. Ammonium concentrations were low at all sites. Orthophosphate concentrations were low, as were total phosphorus concentrations. The N/P ratios were low at the lower creek sites indicating that inputs of inorganic nitrogen could cause algal blooms; however, as mentioned nitrate and ammonium were low in the lower creek areas in 2010. The chlorophyll *a* data (Tables 7.1 and 7.2) showed that the Hewletts Creek samples were free of major algal blooms in 2010, with only one minor bloom in August at NB-GLR. 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 three areas of the creek. Counts exceeded State standards 80% of the time sampled at MB-PGR and PVGC-9, and 100% of the time at NB-GLR (Tables 7.1 and 7.2). We note that there were no samples taken at SB-PGR that exceeded 130 CFU/100 mL; possibly this was a result of the JEL Wade wetland upstream of this station significantly reducing pollutant loads to the south branch of Hewletts Creek (Mallin et al. 2010).

Figure 7.1 Hewletts Creek watershed

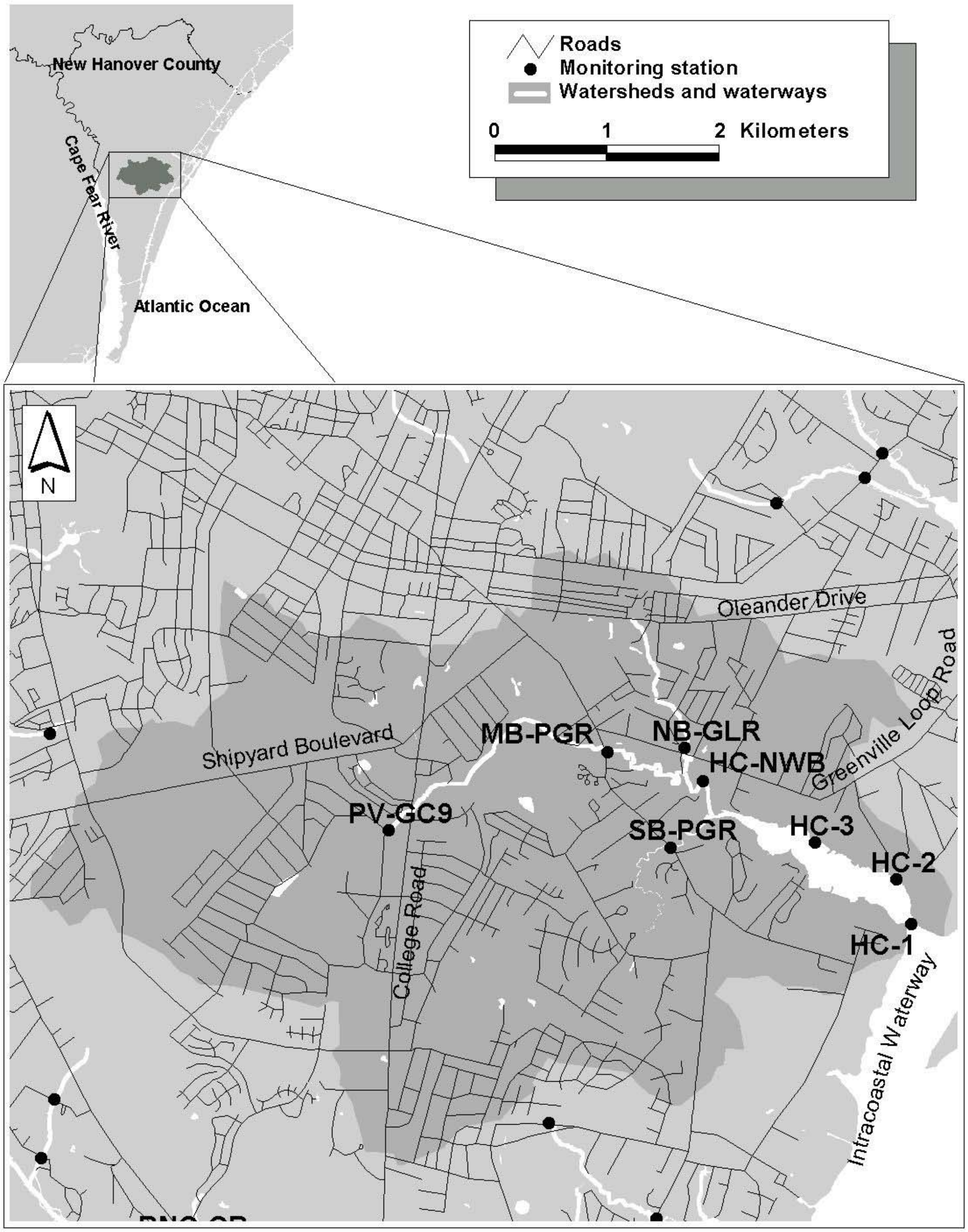


Table 7.1. Selected water quality parameters at upper and middle creek stations in Hewletts Creek watershed 2010 as mean (standard deviation) / range, N/P ratios as mean / median, fecal coliform bacteria presented as geometric mean / range.

Parameter	PVGC-9	MB-PGR
Salinity (ppt)	0.1 (0) 0.1-0.1	0.2 (0.1) 0.1-0.3
Turbidity (NTU)	2 (1) 1-3	1 (1) 1-2
TSS (mg/L)	3.3 (2.0) 1.4-6.2	1.4 (0.0) 1.4-1.4
DO (mg/L)	6.2 (0.9) 4.9-7.2	7.2 (0.9) 6.5-8.6
Nitrate (mg/L)	0.918 (0.217) 0.760-1.300	0.268 (0.070) 0.190-0.350
Ammonium (mg/L)	0.023 (0.018) 0.005-0.050	0.011 (0.005) 0.005-0.020
TN (mg/L)	1.078 (0.265) 0.760-1.340	0.330 (0.164) 0.100-0.550
Orthophosphate (mg/L)	0.010 (0.000) 0.010-0.010	0.016 (0.009) 0.010-0.030
TP (mg/L)	0.044 (0.042) 0.010-0.110	0.030 (0.012) 0.010-0.040
N/P	208.4 190.4	49.3 46.5
Chlorophyll *a* (µg/L)	2 (0) 2-2	1 (1) 0-2
Fecal col. (CFU/100 mL)	461 91-1,546	464 82-1,637

Table 7.2. Selected water quality parameters at stations in Hewletts Creek watershed, 2010, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 5 months.

Parameter	NB-GLR	SB-PGR	HC-3
Salinity (ppt)	16.9 (6.9) 8.6-24.1	27.0 (4.1) 22.6-31.6	34.2 (1.4) 32.6-35.8
Turbidity (NTU)	7 (2) 3-8	7 (4) 2-11	6 (2) 2-8
TSS (mg/L)	9.7(3.3) 6.1-14.6	17.2 (4.2) 13.2-23.4	12.6(2.2) 10.5-16.0
DO (mg/L)	6.5 (1.6) 4.4-8.6	6.1 (1.7) 3.8-8.4	6.6 (1.3) 4.7-8.1
Nitrate (mg/L)	0.066 (0.030) 0.030-0.110	0.022 (0.016) 0.010-0.040	0.010 (0.000) 0.010-0.010
Ammonium (mg/L)	0.012 (0.010) 0.005-0.030	0.011 (0.005) 0.005-0.020	0.006 (0.002) 0.005-0.010
TN (mg/L)	0.214 (0.165) 0.100-0.460	0.276 (0.152) 0.100-0.500	0.240 (0.152) 0.100-0.500
Orthophosphate (mg/L)	0.024 (0.009) 0.010-0.030	0.020 (0.007) 0.010-0.030	0.010 (0.000) 0.010-0.010
TP (mg/L)	0.054 (0.021) 0.040-0.090	0.062 (0.045) 0.030-0.140	0.040 (0.012) 0.030-0.060
Mean N/P ratio Median	8.0 8.5	3.8 3.3	3.5 3.3
Chlor *a* (µg/L)	9 (6) 1-21	6 (6) 1-16	4 (2) 2-8
Fecal coliforms (CFU/100 mL)	477 210-1,091	60 28-127	36 10-73

Sediment Metals and Chemical Toxins

Wilmington Stormwater Services and UNCW are interested in potential toxicants buried in or adhering to the creek sediments in City watersheds. Thus, we collected sediment samples on one occasion at a selection of upper Hewletts Creek sites for analysis of sediment metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) as well some basic chemical parameters including total nitrogen, total phosphorus and total organic carbon. The State of North Carolina has no official guidelines for sediment concentrations of metals and organic pollutants in reference to protection of invertebrates, fish and wildlife. However, academic researchers (Long et al. 1995) have produced guidelines (Table 7.3) based on extensive field and laboratory testing that are used by the US Environmental Protection Agency in their National Coastal Condition Report II (US EPA 2004).

Table 7.3. Guideline values for sediment metals and organic pollutant concentrations (ppm, or µg/g, dry wt.) potentially harmful to aquatic life (Long et al. 1995; U.S. EPA 2004). ERL = (Effects range low). Concentrations below the ERL are those in which harmful effects on aquatic communities are rarely observed. ERM = (Effects range median). Concentrations above the ERM are those in which harmful effects would frequently occur. Concentrations between the ERL and ERM are those in which harmful effects occasionally occur.

Metal	ERL	ERM
Arsenic (As)	8.2	70.0
Cadmium (Cd)	1.2	9.6
Chromium (Cr)	81.0	370.0
Copper (Cu)	34.0	270.0
Lead (Pb)	46.7	218.0
Mercury (Hg)	0.15	0.71
Nickel (Ni)	20.9	51.6
Silver (Ag)	1.0	3.7
Zinc (Zn)	150.0	410.0
Total PCBs	0.0227	0.1800
Total PAHs	4.02	44.80
Total DDT	0.0016	0.0461

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds with a fused ring structure. PAHs with two to five rings are of considerable environmental concern. They are compounds of crude and refined petroleum products and coal and are also produced by incomplete combustion of organic materials (US EPA 2000). They are characteristic of urban runoff as they derive from tire wear, automobile oil and exhaust particles, and leaching of asphalt roads. Other sources include domestic and industrial waste discharge, atmospheric deposition, and spilled fossil fuels. They are carcinogenic to humans, and bioconcentrate in aquatic animals. In these organisms they form carcinogenic and mutagenic intermediaries and cause tumors in fish (US EPA 2000).

Polychlorinated biphenyls (PCBs) have been banned for use in the United States since 1979. They are closely related to many chlorinated hydrocarbon pesticides, and were used industrially as insulating fluids, heat transfer fluids plasicizers, lubricants and hydraulic fluids (US EPA 2000). They are persistent in the environment and bioaccumulate in the food chain, and individual PCBs cause health problems including developmental impacts in children, hepatotoxicity, neurotoxicity and carcinogenicity (US EPA 2000).

All four stations in Hewletts Creek had sediment metals concentrations that were well below levels considered potentially toxic to benthic organisms. Total PAH sediment concentrations were below the detection limit at all sites sampled, as were total PCBs (Table 7.4). We note that this is first set of comprehensive sediment samples taken in Hewletts Creek.

Table 7.4. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Hewletts Creek, 2010 (as mg/kg = ppm, except for the PCBs which are μg/kg). Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur, and italicized concentrations are near potentially harmful levels (see Table 7.3 for more detail).

Parameter	PVGC-9	MB-PGR	NB-GLR	SB-PGR
Antimony	<4.85	<5.48	<5.26	<6.73
Arsenic	<1.22	<1.37	<1.31	3.34
Beryllium	<1.22	<1.37	<1.31	<1.68
Cadmium	<1.22	<1.37	<1.31	<1.58
Chromium	1.26	<1.37	2.18	7.79
Copper	<1.22	<1.37	1.41	3.72
Lead	4.62	2.57	3.32	9.71
Mercury	<0.0230	<0.0269	0.0304	0.0342
Nickel	<1.22	<1.37	<1.31	<1.68
Selenium	<2.43	<2.74	<2.63	<3.36
Silver	<1.22	<1.37	<1.31	<1.68
Thallium	<1.22	<1.36	<1.31	<1.68
Zinc	6.92	9.00	9.41	23.00
Total PAH	BDL	BDL	BDL	BDL
Total PCBs	BDL	BDL	BDL	BDL
TN	77.2	286.0	299.0	724.0
TOC	88.2	59.2	34.9	81.5

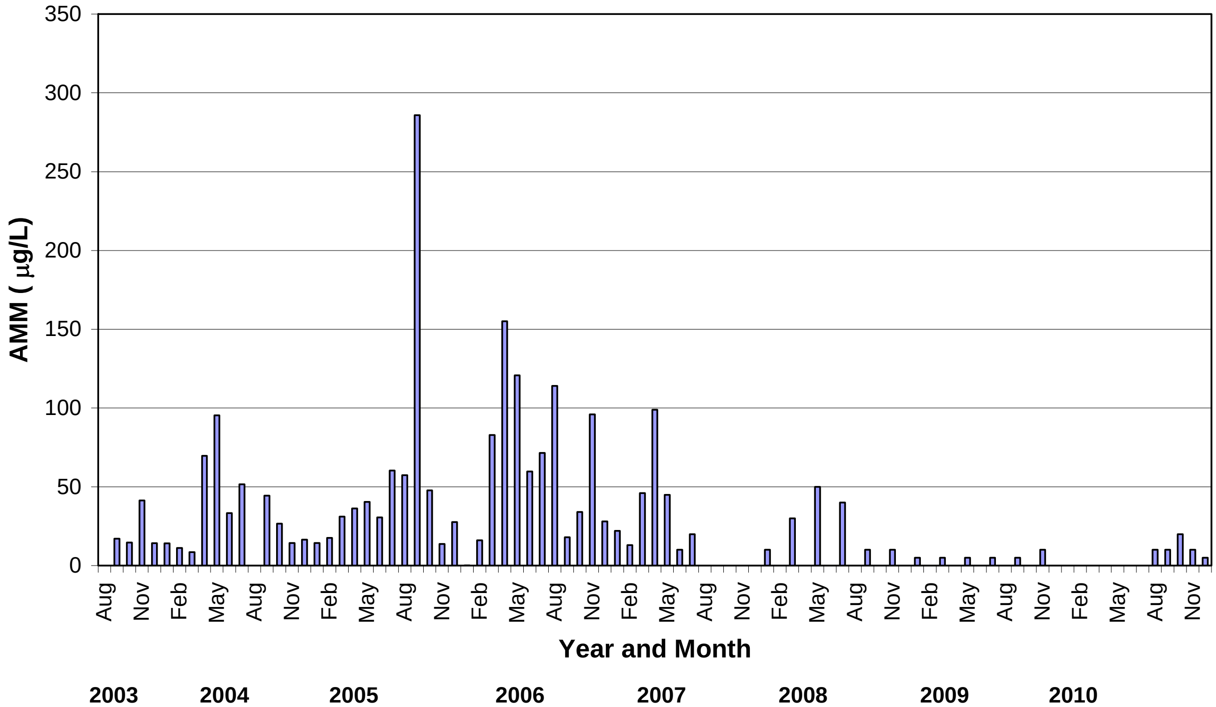
BDL = below detection limit

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. Thus, during 2007 the 7.6 acre JEL Wade wetland was constructed to treat stormwater runoff from a 589 acre watershed within the Hewletts Creek drainage; we note that due to droughts the vegetation did not reach near-full coverage until spring 2010. A rain event sampling program was carried out in 2009-2010 by UNCW to evaluate the efficacy of the wetland in reducing pollutant loads (fecal bacteria, nutrients, suspended solids and metals) from the stormwater runoff passing through the wetland. During the eight storms sampled, the wetland served to greatly moderate the stream hydrograph, retaining and/or removing 50-75% of the inflowing stormwater volume within the wetland. High removal rates of fecal coliform bacteria were achieved (based on "first flush"), with an average load reduction of 99% and overall concentration reduction of > 90%. Particularly high (>90%) load reductions of ammonium and orthophosphate loads also occurred, and lesser but still substantial reductions of total phosphorus (89%) and TSS loads (88%) were achieved. Removal of nitrate was seasonally dependent, with lower removal occurring in cold weather and high percentage (90%+) nitrate load removal occurring in the growing season when water temperatures exceeded 15^{o}C. Most metals tested had concentrations too low to be measured in inflowing and outflowing waters, except for zinc, for which an average load reduction of 87% was achieved. Since the principal source of impairment in Hewletts Creek is fecal bacteria contamination, and a secondary source of impairment is algal blooms (caused by nitrogen loading in this system), this constructed wetland appears to be very successful in reducing both concentrations and loads of polluting substances to the receiving waters. Details on the wetland and on the sampling results are presented in a technical report (Mallin et al. 2010).

Early observations indicate that the wetland may already be having a positive influence on the main creek. The outflow from JEL Wade wetland enters Hewletts Creek upstream of our Station SB-PGR, so we examined some water quality parameters there for which there are available before-and-after data (Figure 7.2-7.6). Data were log-transformed and t-tests were performed to test for differences between pre-and-post July 2007 data (i.e. 2003-July 2007 vs. August 2007-2010) with a probability (p) value of < 0.05 used for significance. Ammonium showed a significant ($p < 0.001$) decrease following the wetland completion (Figure 7.2). The high peaks seen in earlier years have not been present in our samples since 2007.

Figure 7.2 Ammonium concentrations over time at south branch Station SB-PGR in Hewletts Creek



From early spring 2009 on, creek nitrate concentrations appear to have decreased overall and the peak concentrations are also generally lower than previous to wetland construction (Figure 7.3). There was a statistically-significant ($p = 0.02$) decrease between pre-and-post July 2007 nitrate concentrations. Orthophosphate concentrations were generally low before wetland construction, with no significant change in creek orthophosphate concentrations after wetland construction (Figure 7.4).

Figure 7.3 Nitrate concentration changes over time at south branch Station SB-PGR in Hewletts Creek

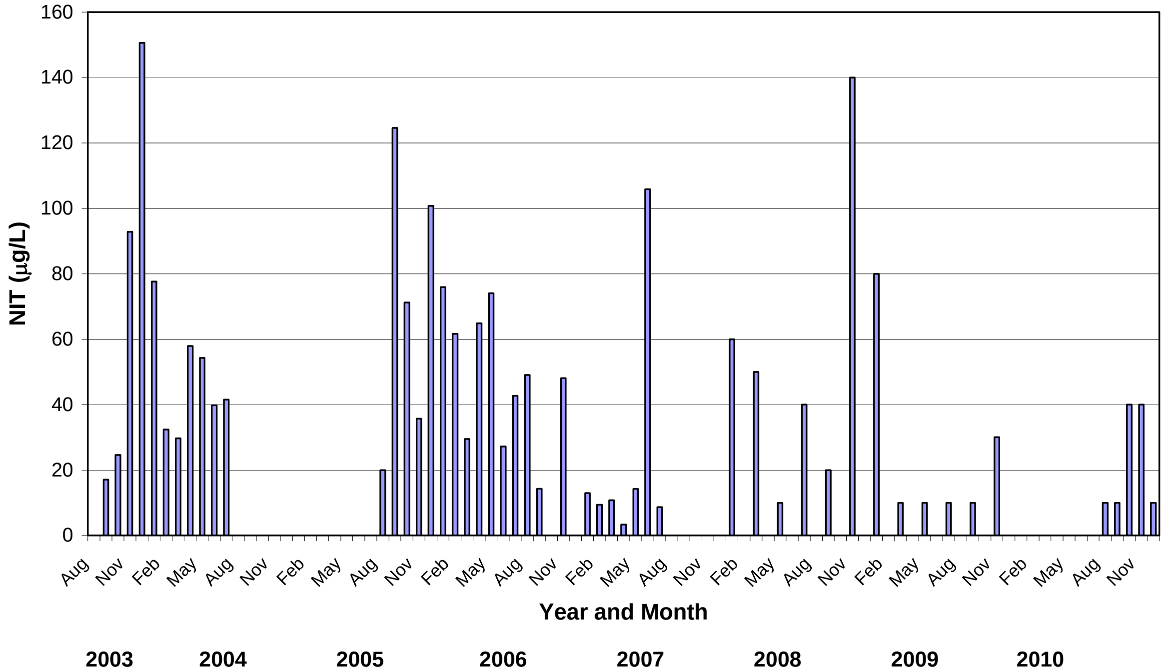
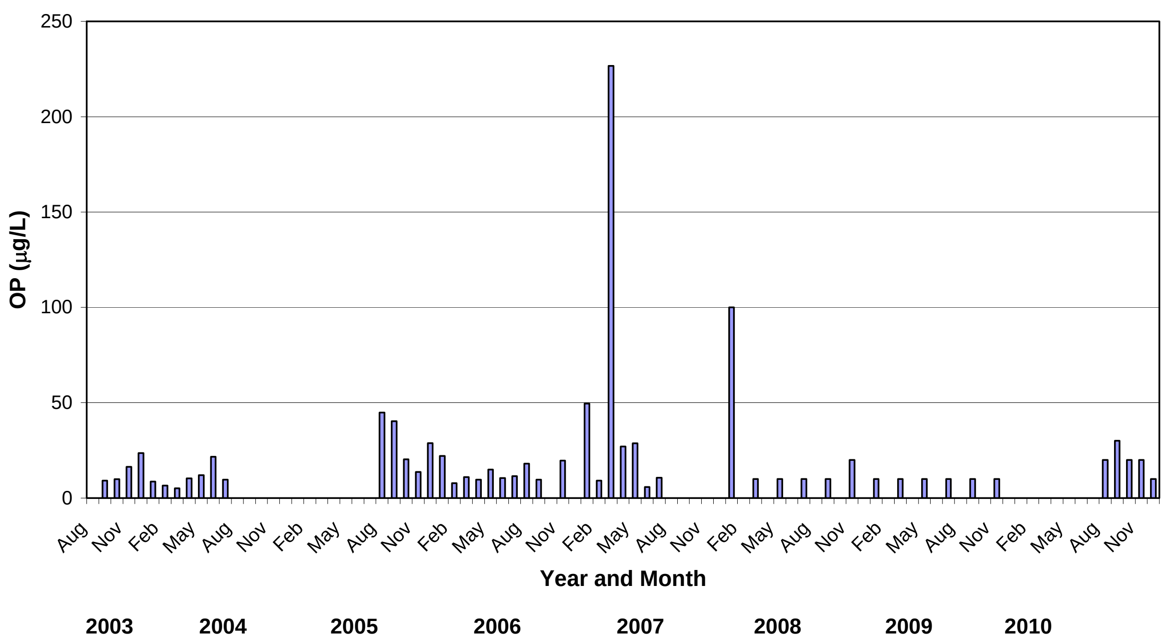
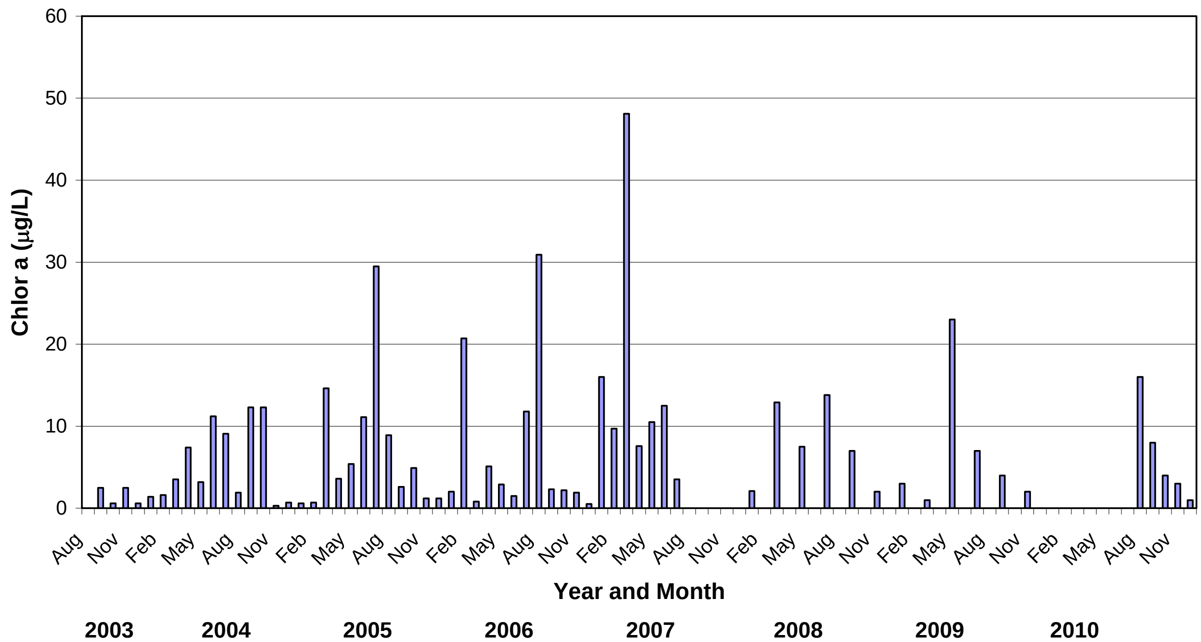


Figure 7.4 Orthophosphate concentration changes over time at south branch Station SB-PGR in Hewletts Creek



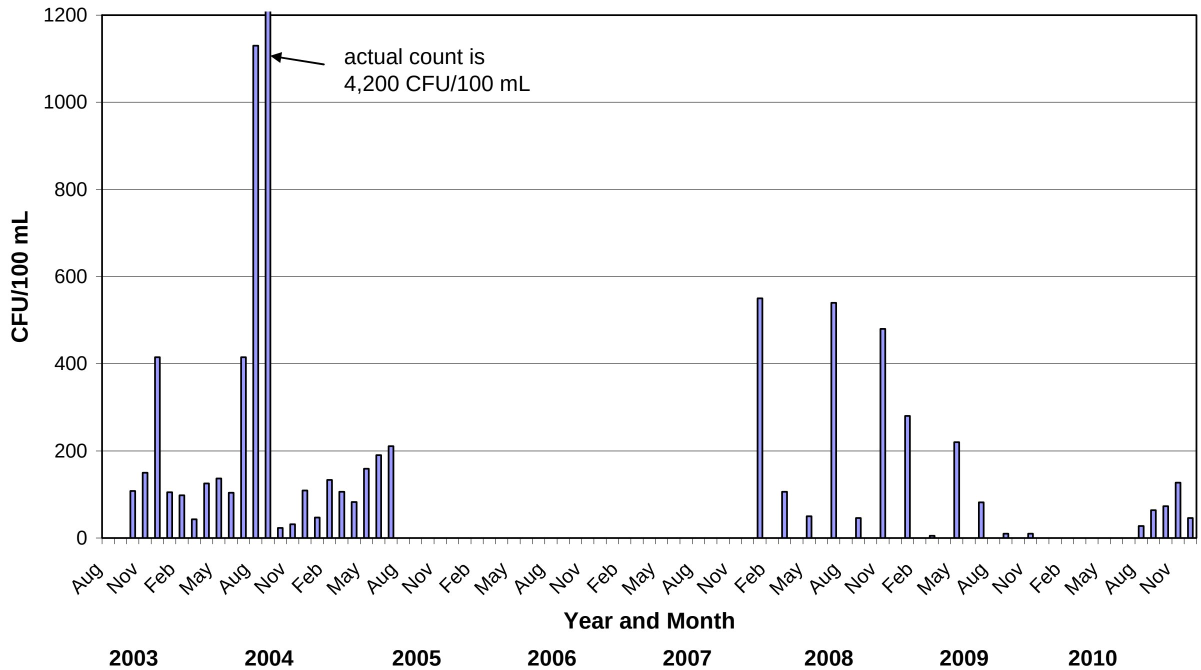
Algal blooms, represented by chlorophyll *a* concentrations, show fewer and smaller peaks in the south branch of Hewletts Creek than prior to wetland construction, but the reductions were not statistically significantly, $p = 0.33$ (Figure 7.5).

Figure 7.5 Chlorophyll *a* concentration changes over time at south branch Station SB-PGR in Hewletts Creek



Fecal coliform bacteria concentrations showed some moderately high peaks in the south branch of Hewletts Creek during early wetland operation (2008) but appear to have stabilized at much lower concentrations since summer 2009 (Figure 7.6). The difference between the pre-and-post wetland closure periods was not statistically significant, although the probability (p value) was close to 0.05 ($p = 0.06$). We re-emphasize that the wetland vegetation was not at a high coverage level until spring 2010, so that is when the effectiveness of wetland pollutant treatment would be realized most. Thus, we are cautiously optimistic that the JEL Wade wetland is both effective in treatment of pollutants entering the wetland, and also having a measurable positive effect on tidal creek water quality downstream as well.

Figure 7.6 Fecal coliform bacteria concentrations over time at south branch Station SB-PGR in Hewletts Creek



According to City of Wilmington Stormwater Services, the watershed draining into the south branch of Hewletts Creek (upstream of SB-PGR) is approximately 504 acres. The area draining into the JEL Wade wetland is approximately 238 acres. Therefore, the wetland drains about 47% of the south branch watershed. During rain events exceeding 0.5 inches, the JEL Wade wetland receives about 430,000 L/hour (Mallin et al. 2010). Thus, if one computes the flow that entered the entire south branch (prior to wetland construction) during an hour rain it was approximately 915,000 L. The south branch of Hewletts Creek contains approximately 6,000,000 liters at low tide and 22,151,000 L at high tide (Duernberger 2009). Thus, previous to wetland construction in one hour of rain the south branch could get 15% added to its volume as runoff if the storm occurs at low tide. At high tide stormwater inputs to the south branch in an hour would be about 4% of volume. For a rain lasting three hours, at low tide the creek was likely receiving up to 45% of its volume from stormwater runoff alone, prior to wetland construction. However, the wetland, on average, retains (over a six-hour period) 63% of the stormwater entering it, greatly reducing the peak hydrograph of the stream entering Hewletts Creek (Mallin et al. 2010). Water retention and treatment by the wetland reduce loads of ammonium, orthophosphate and fecal coliform bacteria by >90%, and nitrate, TN, TP and TSS loads by > 80%, thus positive impacts on Hewletts Creek water quality should not be surprising.

8.0 Howe Creek Water Quality

Snapshot
Watershed area: 3,518 acres (1,424 ha)
Impervious surface coverage: 19%
Watershed population: Approximately 6,460
Overall water quality: Fair
Problematic pollutants: Fecal coliform bacteria, some algal blooms, some low DO

Howe Creek was sampled for physical parameters, nutrients, chlorophyll *a*, and fecal coliform bacteria at three locations on five occasions during 2010 (HW-FP, HW-GP and HW-DT- Fig. 8.1). Turbidity was generally low and did not exceed the North Carolina water quality standard of 25 NTU (Table 8.1; Appendix B). Dissolved oxygen concentrations were fair, with 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 in 2010 (Table 8.2). Orthophosphate was also low at the three sites.

Mean and 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 substantial algal bloom of 83 μg/L as chlorophyll *a* at HW-DT, but the lower two stations did not experience algal bloom problems in 2010 (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 no exceedences of the water contact standard of 200 CFU/100 mL at the lower station HW-FP to 40% exceedence at HW-GP, to 60% exceedences at the upper station HW-DT, where the geometric mean of 233 CFU/100 mL was greater than the NC standard (Table 8.1). The fecal coliform counts were an improvement from the two previous years (Fig. 8.3); we note also that salinities were higher during our sample collections in 2011 as well, which may account for some of the improvement.

Table 8.1. Water quality summary statistics for Howe Creek, 2010, as mean (st. dev.) / range. Fecal coliform bacteria as geometric mean / range.

Parameter	HW-FP	HW-GP	HW-DT
Salinity (ppt)	34.9(0.9) 33.8-35.8	31.3(2.8) 27.4-34.9	12.3(4.3) 7.1-17.7
Dissolved oxygen (mg/L)	7.0(1.5) 5.1-9.1	6.6(1.8) 4.5-9.4	7.1(2.1) 4.2-10.1
Turbidity (NTU)	8(7) 2-20	6(2) 3-7	8(3) 4-10
TSS (mg/L)	13.5(5.7) 4.4-19.9	13.0(5.1) 9.3-21.6	8.8(1.7) 6.7-10.5
Chlor *a* (µg/L)	3(2) 1-6	5(2) 3-7	33(35) 1-83
Fecal coliforms (CFU/100 mL)	7 5-10	72 5-260	233 82-590

Figure 8.1. Howe Creek watershed and sampling sites used in various years.

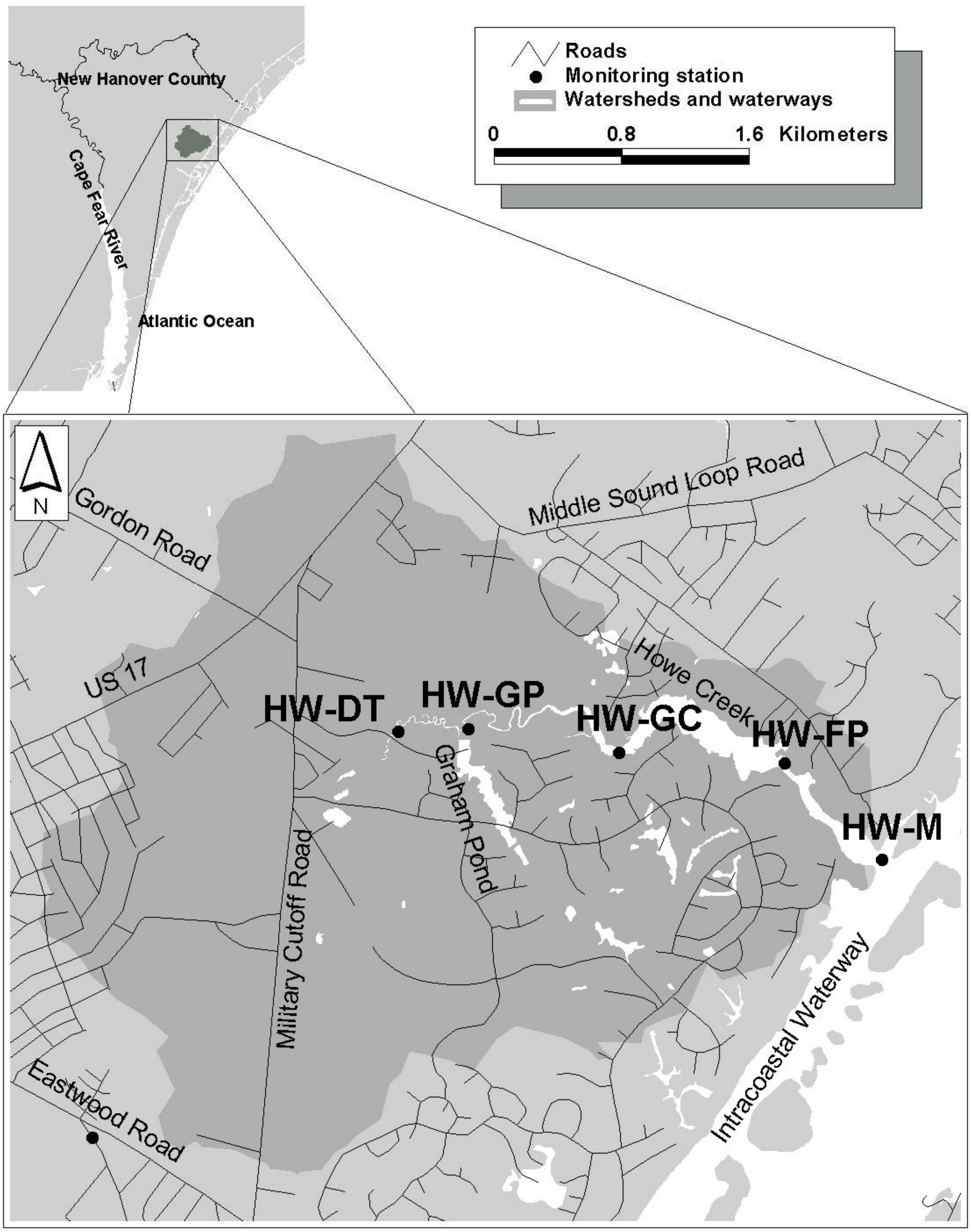


Figure 8.3. Chlorophyll *a* concentrations (algal blooms) in Howe Creek below Graham Pond before and after 1998 wetland enhancement in upper Graham Pond, 1993-2010.

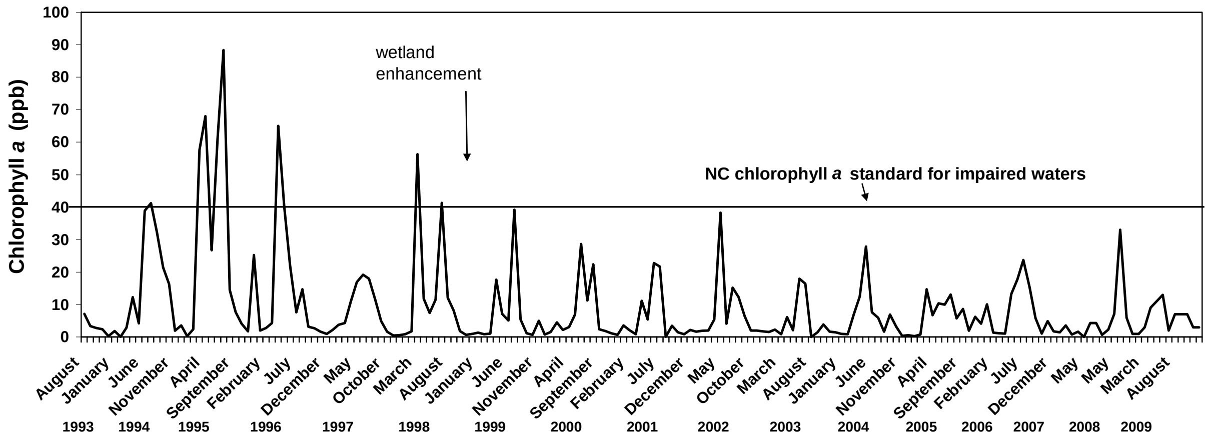
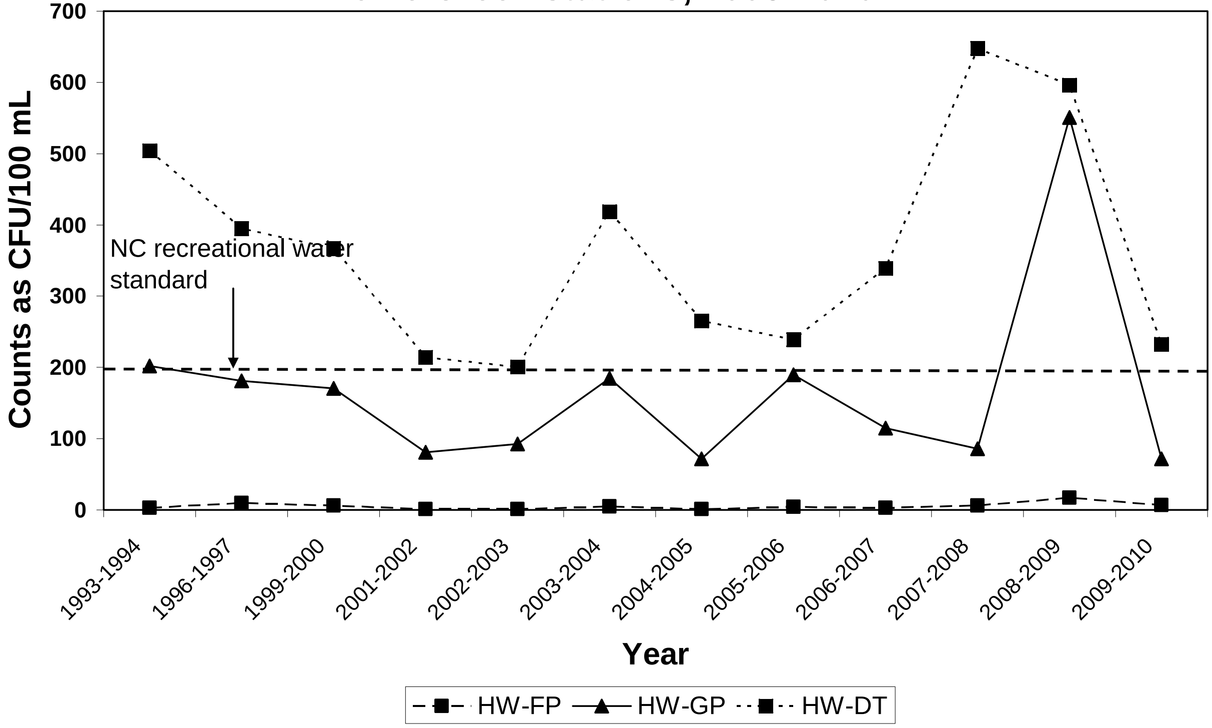


Table 8.2. Inorganic nutrient concentration summary statistics for Howe Creek, 2010, as mean (standard deviation) / range, N/P ratio as mean / median.

Parameter	HW-FP	HW-GP	HW-DT
Nitrate (mg/L)	0.022(0.018) 0.010-0.050	0.010(0.000) 0.010-0.010	0.014(0.009) 0.010-0.030
Ammonium (mg/L)	0.005(0.000) 0.005-0.005	0.006(0.002) 0.005-0.010	0.011(0.011) 0.005-0.030
Orthophosphate (mg/L)	0.010(0.000) 0.010-0.010	0.012(0.004) 0.010-0.020	0.020(0.010) 0.010-0.030
Molar N/P ratio	6.0 3.3	3.1 3.3	3.2 3.3

Figure 8.3. Fecal coliform counts over time for three Howe Creek stations, 1993-2010.



9.0 Motts Creek

Snapshot
Watershed area: 3,328 acres (1,347 ha)
Impervious surface coverage: 14%
Watershed population: 9,530
Overall water quality: poor
Problematic pollutants: Periodic algal blooms; 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 3 occasions during 2010 (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. This development was put on pause due to economic conditions and samples were not funded after June 2010.

Dissolved oxygen concentrations were above the North Carolina brackish water standard of 5.0 mg/L on all three occasions sampled. Neither turbidity nor suspended solids were problematic in this period in 2010.

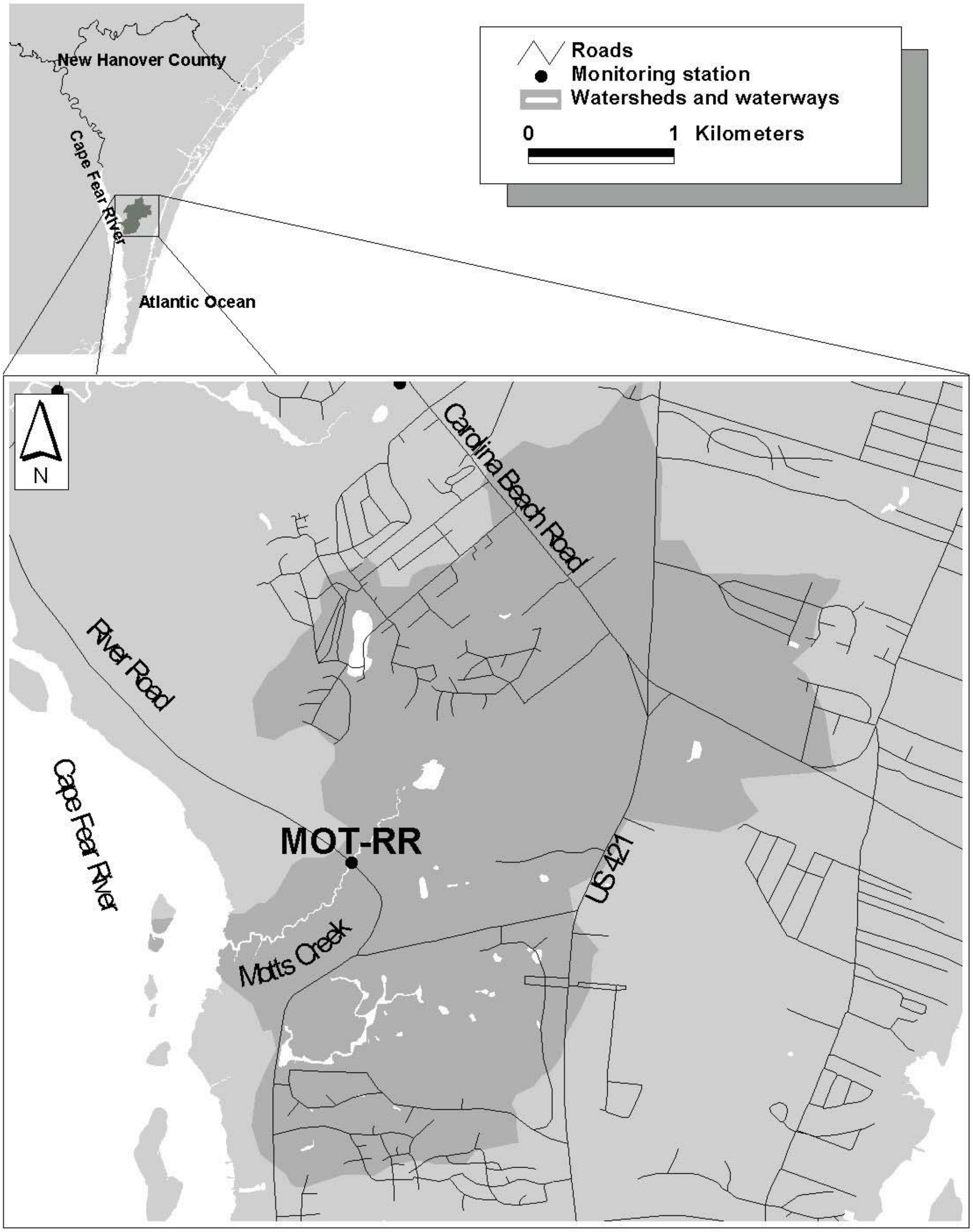
Total nitrogen, ammonium, nitrate, total phosphorus and orthophosphate levels were low to moderate, and the inorganic N/P ratio was 75, well above the Redfield ratio, indicating that phosphorus loading would be the nutrient most likely to stimulate algal blooms, at during the period sampled. There was one major algal bloom, of 139 µg/L of chlorophyll *a*, occurring in June (Table 9.1).

BOD5 was rather high for urban streams, yielding a mean value of 4.3 mg/L, which was skewed to the high range by a maximum value of 10.0 mg/L (Table 9.1). This high level was caused by the algal bloom in June, which created a large amount of labile organic material that raised the BOD. Fecal coliform contamination was a problem in Motts Creek, with the geometric mean of 218 CFU/100 mL above the State standard of 200 CFU/100 mL; the standard was exceeded on two of the three sampling occasions in 2010. 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 periodic 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 – June 2010. Fecal coliforms as geometric mean / range, n = 3.

Parameter	MOT-RR	
	Mean (SD)	Range
Salinity (ppt)	0.8 (0.9)	0.1-11.9
DO (mg/L)	6.3 (1.1)	5.1-7.3
Turbidity (NTU)	12 (3)	10-15
TSS (mg/L)	8.0 (1.8)	6.0-9.1
Nitrate (mg/L)	0.09 (0.07)	0.01-0.15
Ammonium (mg/L)	0.06 (0.05)	0.01-0.11
Total nitrogen (mg/L)	0.72 (0.18)	0.55-0.91
Orthophosphate (mg/L)	0.02 (0.01)	0.01-0.03
Total phosphorus (mg/L)	0.06 (0.02)	0.04-0.07
Mean N/P ratio	75.0	
Chlor *a* (μg/L)	54.0 (74.1)	3.0-139.0
BOD5 (mg/L)	4.3 (4.9)	1.0-10.0
Fecal coliforms (CFU/100 mL)	218	136-300

Figure 9.1 Motts Creeks watershed

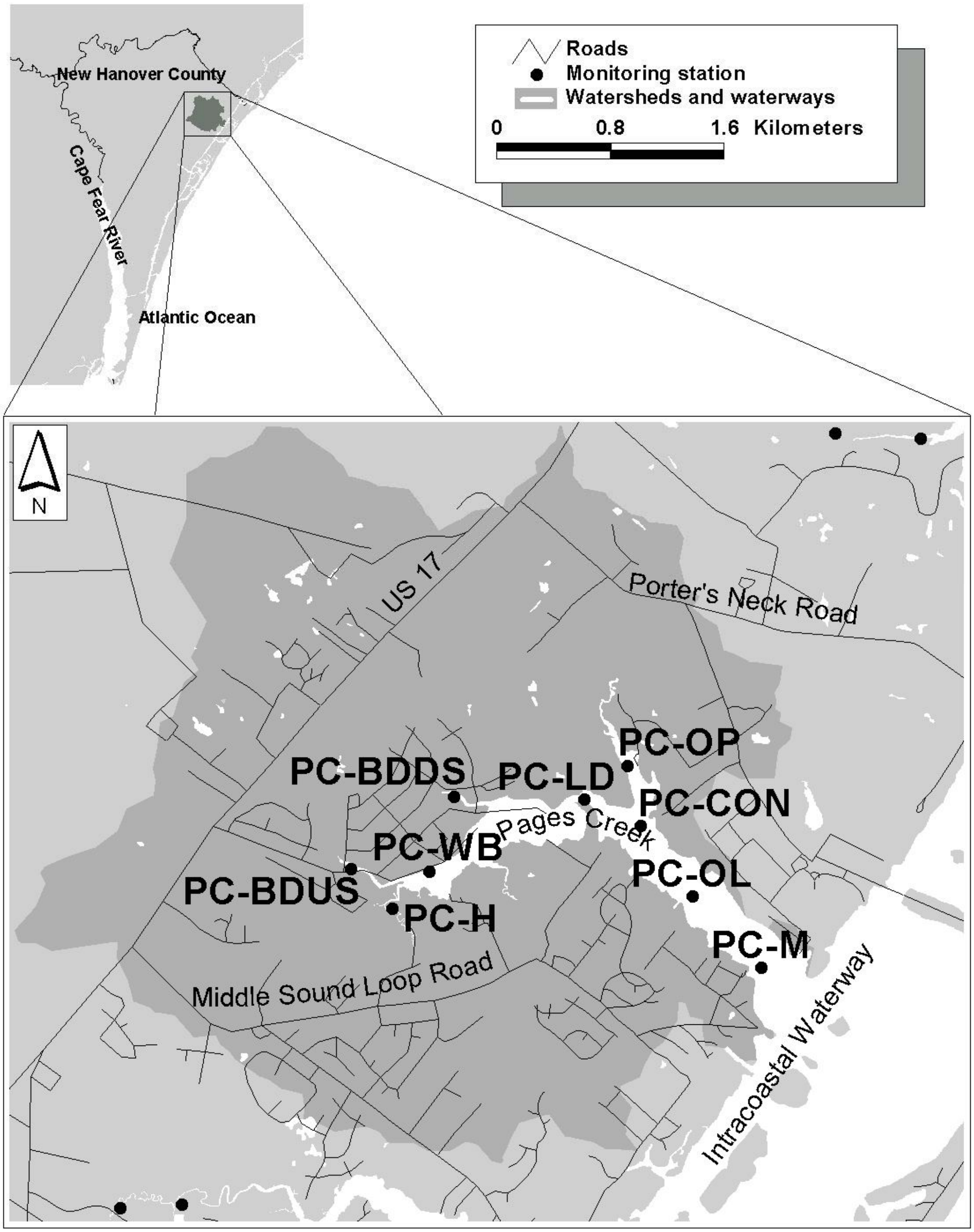


10.0 Pages Creek

Snapshot
Watershed area: 4,100 acres (1,659 ha)
Impervious surface coverage: >13%
Watershed population: Approximately 8,390

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.

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: 31,780
Overall water quality: Fair
Problematic pollutants: moderate turbidity, some fecal coliform pollution

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 2010. However, one location on Smith Creek, SC-CH at Castle Hayne road (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).

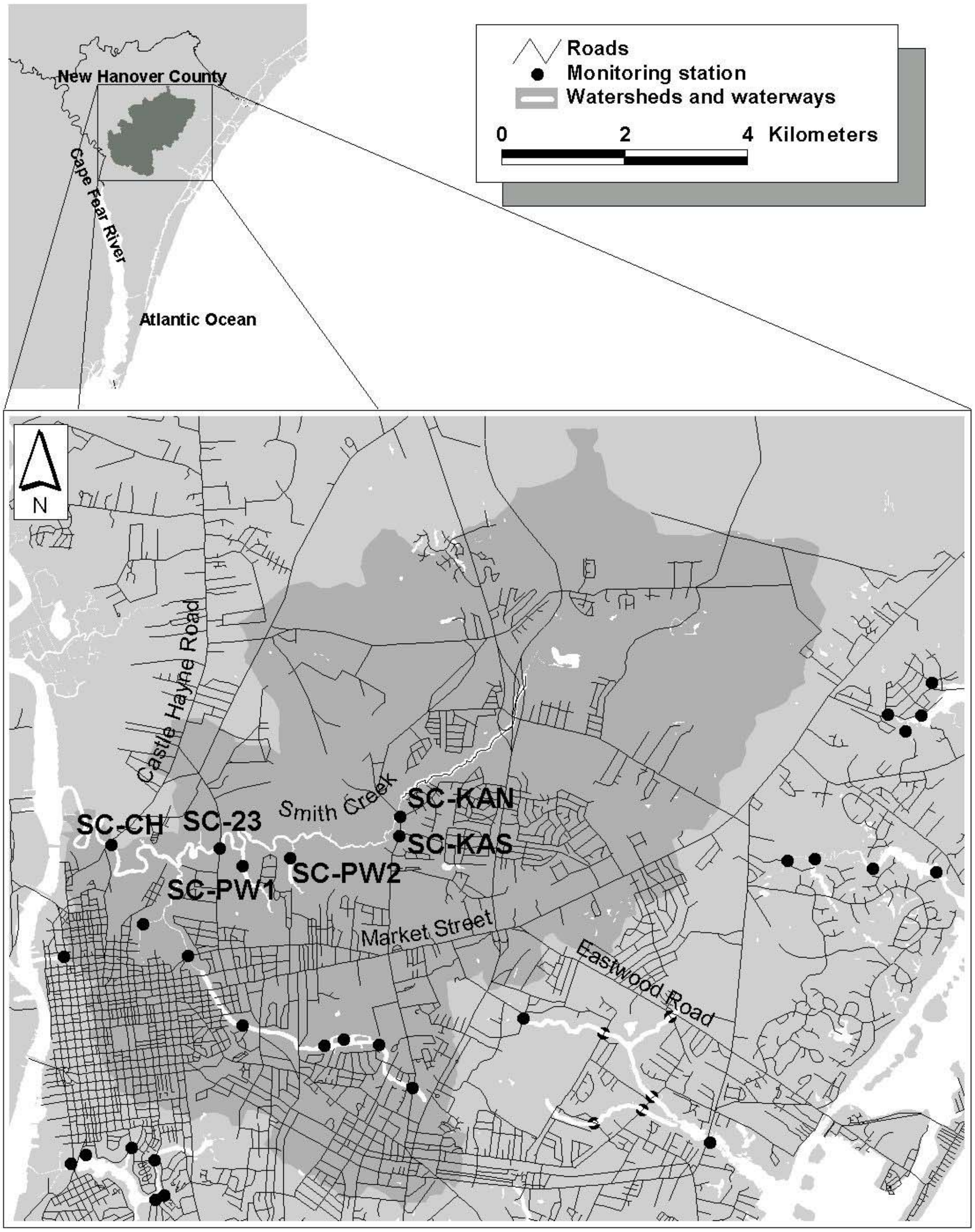
The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters is 4.0 mg/L, which was not violated in our 2010 samples. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded, although it registered 25 NTU on two occasions.

Fecal coliform bacteria concentrations exceeded 200 CFU/100 mL on two sampling occasions at SC-CH in 2010, for a Fair rating; one exceedence was high at 3,400 CFU/100 mL (Table 11.1).

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range, 2010, n = 12 months.

Parameter	SC-CH	
	Mean (SD)	Range
Salinity (ppt)	3.9 (3.9)	0.1-12.0
Dissolved oxygen (mg/L)	7.0 (2.3)	4.4-11.3
Turbidity (NTU)	15 (8)	4-25
Fecal col. /100 mL (geomean / range)	88	28-3,400

Figure 11.1 Smith Creek watershed



12.0 Whiskey Creek

Snapshot
Watershed area: 2,095 acres (848 ha)
Impervious surface coverage: 19%
Watershed population: 7,980
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). In 2010 salinity at this station was relatively high, what scientists consider euhaline, ranging from 26 – 34 ppt and averaging about 30 ppt (Table 12.1).

Dissolved oxygen concentrations were below the State standard on only one of five 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 major blooms detected in our 2010 sampling (Table 12.1); one minor bloom of 18 µg/L of chlorophyll *a* was seen in August 2010. Nutrient concentrations were generally low at this station, particularly inorganic nitrogen (ammonium and nitrate).

Fecal coliform bacteria were acceptable for human contact at this site and below the North Carolina standard of 200 CFU/100 mL for all five samples taken. 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.

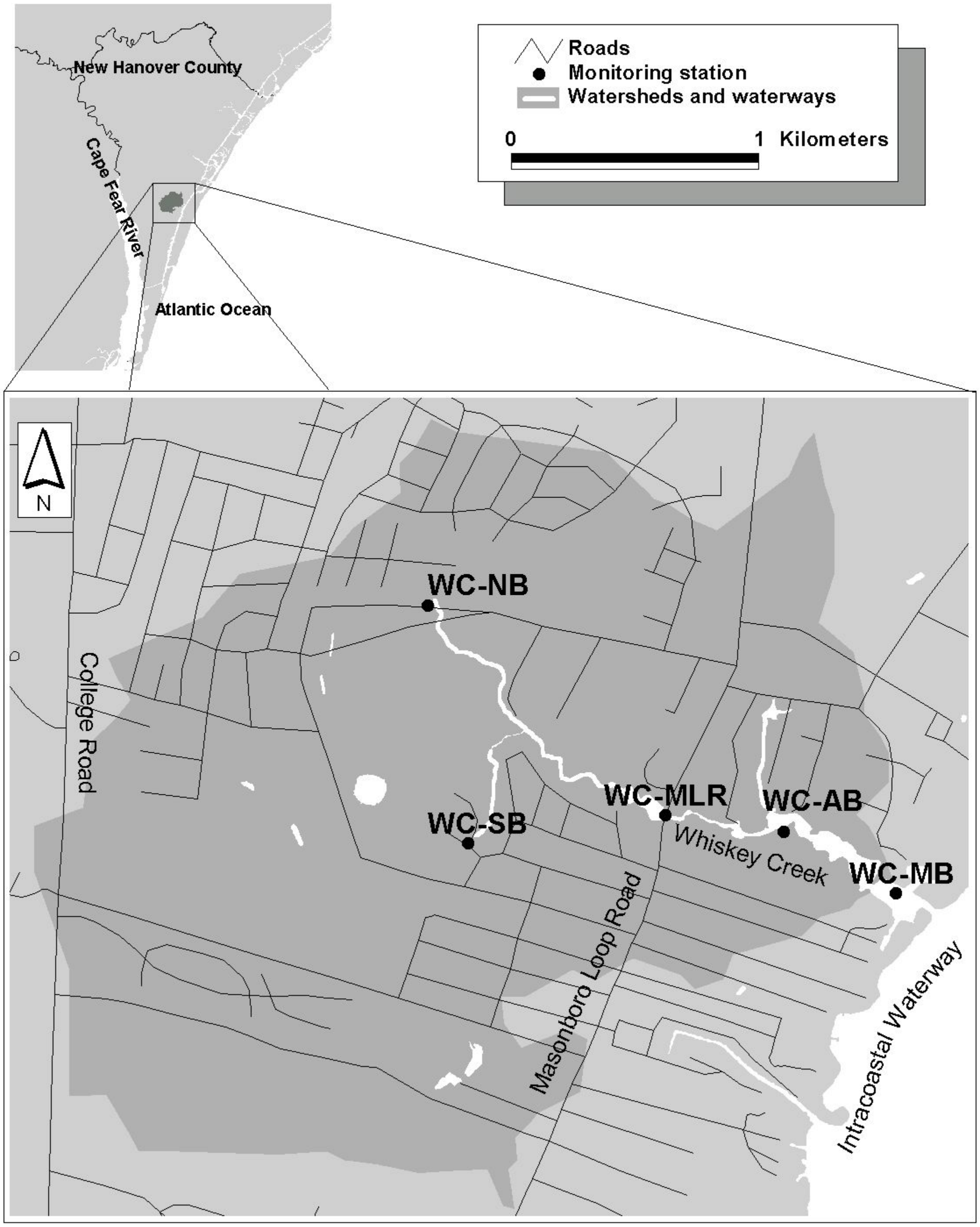
Table 12.1. Water quality summary statistics for Whiskey Creek, 2010, presented as mean (standard deviation) / range, fecal coliforms as geometric mean / range.

	Salinity (ppt)	DO (mg/L)	Turbidity (NTU)	TSS (mg/L)	Chlor *a* (μg/L)	FC CFU/100 mL
WC-MLR	30.9 (3.1)	6.1 (1.7)	8 (4)	17.2 (7.4)	7 (7)	18
	26.4-34.1	4.0-8.3	2-11	6.7-25.5	1-18	5-46

Table 12.2. Nutrient concentration summary statistics for Whiskey Creek, 2010, 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)	0.02 (0.02)	0.31 (0.19)	0.02 (0.01)	0.06 (0.03)	3.8
	0.01-0.03	0.01-0.06	0.10-0.60	0.01-0.03	0.03-0.10	4.4

Figure 12.1. Whiskey Creek. Watershed and sampling sites.



13.0 Special Pollution Investigations

City Stormwater Services and UNCW collaborate on special investigations to further assess deliberate or accidental sewage discharges, stormwater problems, or other pollution incidents. On October 13, 2010, Aquatic Ecology Laboratory personnel accompanied Stormwater Services staff to Mill Creek apartments along upper Burnt Mill creek to investigate potential high fecal bacteria counts. Samples were taken for fecal coliform bacteria and optical brighteners. Sampling was concentrated in an area near a vehicle bridge over Burnt Mill Creek, with a footbridge upstream of that vehicle bridge, a pipe entering the stream just below the vehicle bridge (*see report cover photo*), the water downstream of the bridge area, and BMC-AP1 farther downstream. Fecal coliform data showed the following (Table 13.1):

Table 1. Results of October 13 special sampling in Burnt Mill Creek at Mill Creek Apartments.

Site	fecal coliforms (CFU/100 mL)	optical brighteners
Footbridge upstream	21,000	27
Stream below vehicle bridge	637	29
Pipe entering water at v. bridge	24,000	56
BMC-AP1 downstream	31,000	26

Fecal coliforms - clearly the pipe showed a problem, with 24,000 CFU/100 mL in its discharge. High concentrations of fecal bacteria were also in the creek upstream of the pipe outfall and near the footbridge. Station BMC-AP1 downstream entering the detention pond was polluted (31,000) that day; we note that very high counts were also seen at BMC-AP1 in August (60,000 CFU/100 mL).

Optical brighteners - the reading of 56 from the pipe indicated sewage input, according to our previous work on local streams (Tavares et al. 2008).

Thus, we recommended a second sampling, carried out October 28, yielding the following data (Table 13.2).

Table 13.2. Results of October 28 special sampling in Burnt Mill Creek at Mill Creek Apartments.

Site	fecal coliforms (CFU/100 mL)
BMC-KA3 – exiting Kerr Avenue wetland	6,819
Footbridge upstream	11,000
Stream below vehicle bridge	17,000
Pipe entering water at v. bridge	819
BMC-AP1 downstream	31,000

Stormwater Services staff indicated they would recommend smoke tests for the pipe outfall. In addition, City staffers have made further investigations on foot to branches entering the stream, and our laboratory will continue to investigate these sites.

We do note that within Mill Creek Apartments a considerable number of dog manure piles were seen and photographed by our laboratory personnel along the street with storm drainages directly entering the creek. Thus, enforcement of dog manure cleanup is recommended.

On October 13 Stormwater Services staff and UNCW Aquatic Ecology laboratory researchers visited a site along Princess Place Dr. near Burnt Mill Creek (*see cover photo*) to investigate potential pollutant leakage/runoff from a series of storm drains and pipes that drain into the creek.

At this site the fecal coliforms were low, 10 CFU/100 ml, as were optical brighteners (22). Metals and petroleum-based chemical pollutants were all below the detection limit, and nutrient concentrations were low (Table 13.3). Thus, further sampling at this location was not planned.

Table 13.3. Results of storm drain sampling along Princess Place, October 13, 2010.

Parameter (all as mg/L)	Concentrations
Arsenic	<0.01
Cadmium	<0.10
Chromium	<0.10
Copper	<0.10
Lead	<0.10
Nickel	<0.10
Selenium	<0.10
Zinc	<0.10
Mercury	<0.0002
TKN	<0.20
Nitrate-N	0.15
Total phosphorus	0.04
Total organic carbon	4.70
TPH diesel	<0.11
Gasoline Range Organics	<0.10

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15.0 Acknowledgments

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16.0 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

17.0 Appendix B. UNCW ratings of sampling stations in Wilmington watersheds based on 2010, 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	G	P
Bradley Creek	BC-CA	G	G	G	P
	BC-SB	G	F	G	P
	BC-NB	G	F	G	P
Burnt Mill Creek	BMC-AP1	G	F	G	P
	BMC-AP3	P	G	G	G
	BMC-PP	G	F	G	P
Greenfield Lake	GL-LC	-	P	G	-
	GL-JRB	-	P	G	-
	GL-LB	-	P	G	-
	GL-2340	F	P	G	P
	GL-YD	P	G	G	F
	GL-P	G	F	G	F
Hewletts Creek	HC-3	G	F	G	G
	NB-GLR	G	F	G	P
	MB-PGR	G	G	G	P
	SB-PGR	G	F	G	G
	PVGC-9	G	F	G	P
Howe Creek	HW-FP	G	G	G	G
	HW-GP	G	F	G	P
	HW-DT	F	F	G	P
Motts Creek	MOT-RR	P	G	G	P
Smith Creek	SC-CH	-	G	G	F
Whiskey Creek	WC-MLR	G	F	G	G

18.0 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.

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