ENVIRONMENTAL QUALITY OF WILMINGTON AND NEW HANOVER COUNTY WATERSHEDS, 2014

by

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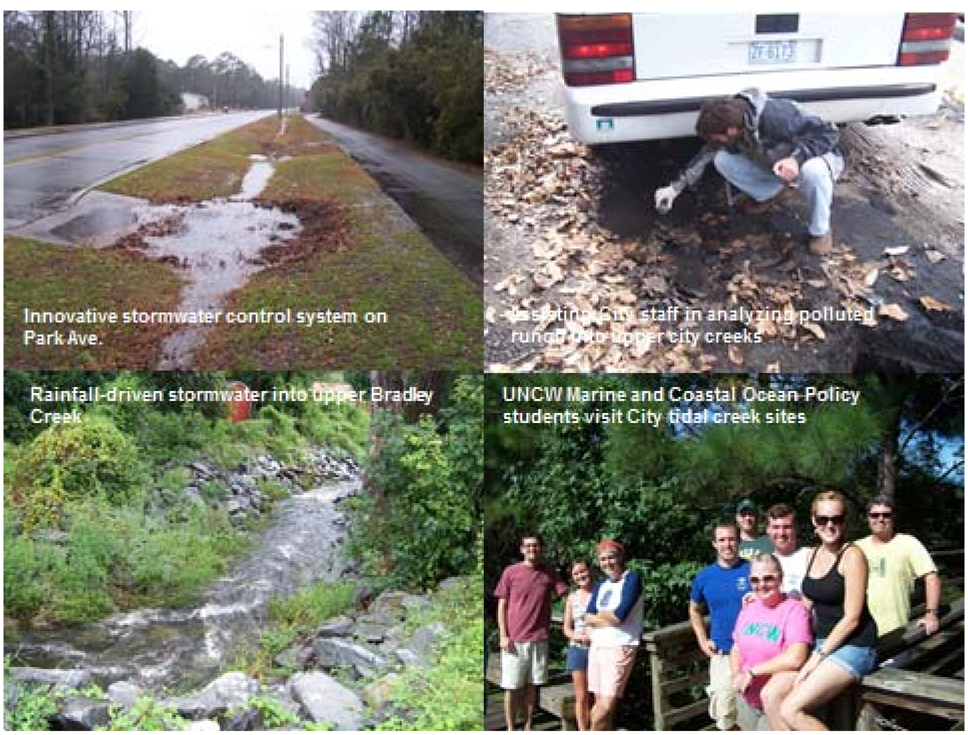

Executive Summary

This report represents combined results of Year 17 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The 2014 program involved 7 watersheds and 22 sampling stations. In this summary we first present brief water quality overviews for each watershed from data collected between January and December 2014.

Barnards Creek – Barnards Creek drains into the Cape Fear River Estuary. It drains a 4,173 acre watershed that consists of 22.3% impervious surface coverage, and a population of approximately 12,200. Water column sampling was not funded during 2014.

Bradley Creek – Bradley Creek drains a watershed of 4,583 acres, including much of the UNCW campus, into the Atlantic Intracoastal Waterway (ICW). The watershed contains about 27.8% impervious surface coverage, with a population of about 16,470. Three sites were sampled, all from shore. In 2014 there were no significant algal blooms recorded, and average dissolved oxygen was good to fair at the three sites. All three sites sampled were rated poor due to high fecal coliform bacteria, with the south branch site BC-SB and the College Acres station BC-CA both having especially high counts.

Burnt Mill Creek – Burnt Mill Creek drains a 4,207 acre watershed with a population of about 23,700. Its watershed is extensively urbanized (39.8% impervious surface coverage) and drains into Smith Creek. Three locations were sampled during 2014. This creek had very poor water quality, with high fecal coliform counts occurring at two of the three sites exceeding the human contact standard > 80% of occasions sampled. One major and one minor algal bloom occurred in 2014. Dissolved oxygen concentrations were good in the upper creek and poor in the lower creek in 2014.

The effectiveness of Ann McCrary wet detention pond on Randall Parkway as a pollution control device for upper Burnt Mill Creek was mixed for 2014. Comparing inflows to outflows, there were significant increases in dissolved oxygen and pH, but also significant increases in total phosphorus, turbidity and total suspended solids. However, there were significant decreases in conductivity, fecal coliform counts, ammonium and nitrate. Several water quality parameters showed an increase in pollutant levels along the creek from the exit from the detention pond to the downstream Princess Place sampling station, including fecal coliform bacteria and nitrate.

Futch Creek – Futch Creek is situated on the New Hanover-Pender County line and drains a 3,813 acre watershed (12.3% impervious coverage) into the ICW. UNC Wilmington was not funded to regularly sample this creek in 2014. New Hanover 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 2,465 acres, covered by about 37% impervious surface area with a population of about 10,630. This urban lake has

suffered from low dissolved oxygen, algal blooms, periodic fish kills and high fecal bacteria counts over the years. The lake was sampled at four tributary sites and three in-lake sites. The four tributaries of Greenfield Lake (near Lake Branch Drive, 17th Street, Jumping Run Branch, and Lakeshore Commons Apartments) all suffered from low dissolved oxygen problems, as did one of the three in-lake stations.

Algal blooms are periodically problematic in Greenfield Lake, and have occurred during all seasons, but are primarily a problem in spring and summer. In 2014 algal blooms continued to occur in the lake. The continuing presence of the blooms has led NCDENR to propose (February 2014) that this lake be added to the NC 303(d) list for excessive chlorophyll *a.* In the period 2007-2013 there was a statistically significant relationship within the lake between chlorophyll *a* and BOD5, meaning that the algal blooms are an important cause of low dissolved oxygen in this lake. Stormwater runoff into the streams also contributes BOD materials into the lake. In 2014 all tributary stations and two in-lake stations exceeded the fecal coliform State standard on 50% or more of occasions sampled.

Beginning in 2005 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, and improved in-lake dissolved oxygen content. However, the times that chlorophyll *a* concentrations exceeded the state standard have tripled since the installation of the mixers, addition of herbicides, and grass carp introductions.

<u>Hewletts Creek</u> – Hewletts Creek drains a large (7,478 acre) watershed into the Intracoastal Waterway. This watershed has about 25.1% impervious surface coverage with a population of about 20,210. In 2014 the creek was sampled at four tidal sites and one non-tidal freshwater site.

Incidents of low dissolved oxygen were rare in 2014. Turbidity was low, and only one large algal bloom was documented in 2014. Fecal coliform bacteria counts exceeded State standards on 100% of the time at MB-PGR and 83% of the time at NB-GLR, 67% of the time at PVGC-9, and 33% of the time at SB-PGR. The geometric means at PVGC-9, MB-PGR and NB-GLR all well exceeded 200 CFU/100 mL for a poor rating for this pollutant parameter, but the geometric mean of fecal bacteria counts at SB-PGR was well under the standard at 130 CFU/100 mL.

During 2007 the 7.6 acre JEL Wade wetland (located at the end of Bethel Road) 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. This constructed wetland has continued to function extremely well in reduction of nutrients and fecal bacteria from stormwater inputs. Additionally, sampling data collected downstream of the wetland at Station SB-PGR shows a statistically significant decline in ammonium and nitrate and near-significant decrease in fecal coliform bacteria after completion of the wetland, demonstrating the wetland's benefits to the creek system as a whole.

Howe Creek – Howe Creek drains a 3,516 acre watershed into the ICW. This watershed hosts a population of approximately 6,460 with about 21.4% impervious surface coverage. Two stations were sampled in Howe Creek in 2014. Several minor algal blooms occurred, but none exceeded the NC standard. The uppermost station HW-DT was rated poor for high fecal coliform bacteria counts, exceeding the state standard on 83% of the times sampled, while HW-GP was also rated poor, exceeding the standard on 67% of occasions sampled. Dissolved oxygen concentrations were rated fair at both sample sites in 2014.

Motts Creek – Motts Creek drains a watershed of 3,342 acres into the Cape Fear River Estuary with a population of about 9,530; impervious surface coverage 23.4%. This creek was not sampled for water quality by UNCW in 2014.

Pages Creek – Pages Creek drains a 5,025 acre watershed with 17.8% impervious surface coverage into the ICW. UNC Wilmington was not funded to sample this creek from 2008-2014. New Hanover 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 16,650 acres that has about 21.3% impervious surface coverage, with a population of about 31,780. One estuarine site on Smith Creek, SC-CH, was sampled by UNCW under the auspices of the Lower Cape Fear River Program (LCFRP).

The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters is 4.0 mg/L, which was violated one time in our 2014 samples. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded. There were no algal blooms present upon any of our 2014 sampling occasions. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on 17% of samples in 2014, for a Fair rating, although no samples were unusually high.

Whiskey Creek – Whiskey Creek is the southernmost large tidal creek in New Hanover County that drains into the ICW. It has a watershed of 2,078 acres, a population of about 8,000, and is covered by approximately 25.1% impervious surface area. One station, on Masonboro Loop Road, was sampled from shore along this creek in 2014. This site had low to moderate nutrient concentrations and no algal bloom problems. Dissolved oxygen was substandard (below 5.0 mg/L) on one of six occasions sampled, whereas fecal coliform bacteria counts were above standard on 33% of occasions sampled.

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 (see Appendix A) 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 2014 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 (22 sites sampled for fecal coliforms) showed 0% (i.e. none) to be in good condition, 18% in fair condition, but **82%** in poor condition, same as in 2013. Dissolved oxygen conditions system-wide (22 sites) showed 41% of the sites were in good condition, 36% were in fair condition, and 23% were in poor condition, a deterioration from 2013. For algal bloom presence, measured as chlorophyll *a*, 73% of the 22 stations sampled were rated as good, 14% as fair and 14% as poor. For turbidity, all 22 of the 22 sites sampled were rated as good. It is important to note that the 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 – 39% impervious coverage; Greenfield Lake – 37% impervious coverage; Bradley Creek – 28% impervious coverage.

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Plate 1. Wilmington and New Hanover County watersheds (map by M. Hayes, Wilmington Stormwater Services). Station coordinates are in Appendix C.

1.0 Introduction

In 1993 scientists from the Aquatic Ecology Laboratory 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 2006-2009 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 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 16 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; 2010a; 2011; 2012; 2013). In the present report we present results of sampling conducted during 2014, with funding by the City of Wilmington through the N.C. Water Resources Research Institute. 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 a large residential project called River Lights along River Road between Barnards and Motts Creeks. Through this funding we sampled of Motts and Barnards Creeks along River Road until July 2010, when plans for development were delayed due to the economic slowdown and funding was suspended. There has been no construction near either creek as of yet, although a lake has been dug in mid-site.

Water quality parameters analyzed in the 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 2010, a suite of metals, PAHs and PCBs were assessed in the sediments of Burnt Mill Creek and Hewletts Creeks. In 2011 the sediments of Barnards and Bradley Creeks were sampled, in 2012 the sediments of Smith Creek and Greenfield Lake were sampled, and in 2013 sediments of Motts Creek, Whiskey Creek and Howe Creek were sampled for those parameters. This report presents summary material regarding that study.

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 six occasions at 21 locations within the Wilmington City watersheds between January and December 2014. In addition, one station on Smith Creek was also sampled during 12 months as part of the Lower Cape Fear River Program and reported here as well. 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 State-certified 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* is based on Welschmeyer (1994) and Method 445.0 from 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, orthophosphate, total phosphorus) and total suspended solids (TSS) were analyzed by a state-certified 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).

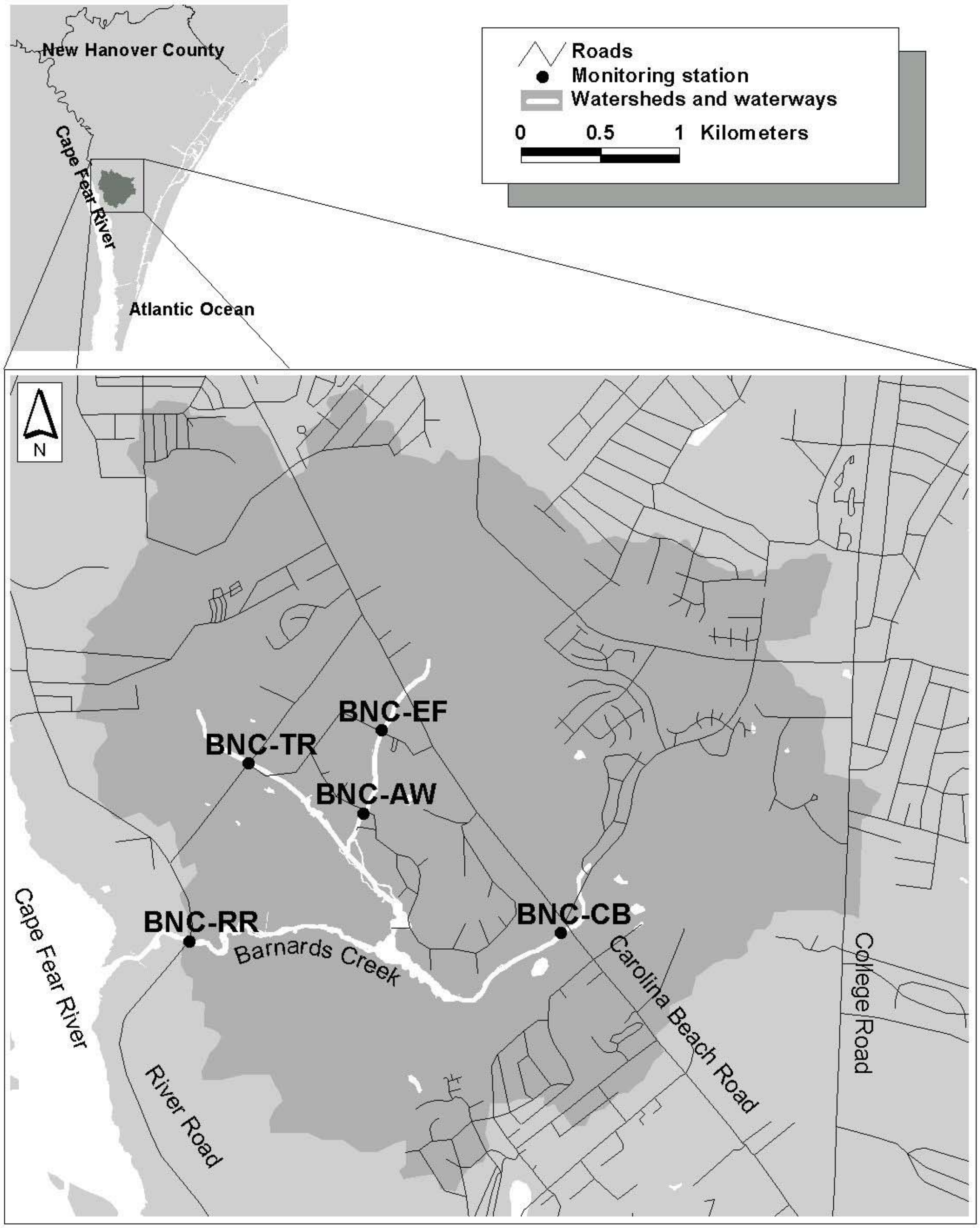
For a large wet detention pond (Ann McCrary Pond on Burnt Mill Creek) we collected data from input and outfall stations. We used these data to test for statistically significant differences in pollutant concentrations between pond input and output stations. The data were first tested for normality using 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).

2.0 Barnards Creek

Snapshot
Watershed area: 4,161 acres (1,690 ha)
Impervious surface coverage: 22.3%
Watershed population: Approximately 12,200
Overall water quality: not measured in 2014

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 2014 UNCW was not funded for water quality studies on lower Barnards Creek. We do have extensive data for this site under a previous funding arrangement from 1999 – 2007 (see the following website for reports on-line: http://www.uncw.edu/cms/aelab/.

Figure 2.1 Barnards Creek watershed



3.0 Bradley Creek

Snapshot
Watershed area: 4,583 acres (1,856 ha)
Impervious surface coverage: 27.8% (2014 data)
Watershed population: Approximately 16,470
Overall water quality: fair-poor
Problematic pollutants: high 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. There is currently ongoing redevelopment of the former Duck Haven property bordering Eastwood Road, which is of 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) and has suffered from sewage leaks (Tavares et al. 2008) and stormwater runoff. 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 2014; the standard of 25 NTU was not exceeded (Table 3.1). Total suspended solids (TSS) were elevated (>25 mg/L) on two occasions at BC-NB, and was 24.4 mg/L in June at BC-SB. There are no NC ambient standards for TSS, but UNCW considers 25 mg/L high for the Coastal Plain. Dissolved oxygen (hypoxia) was slightly below the 5.0 mg/L standard once each at BC-CA and BC-NB in June 2014 (Appendix B).

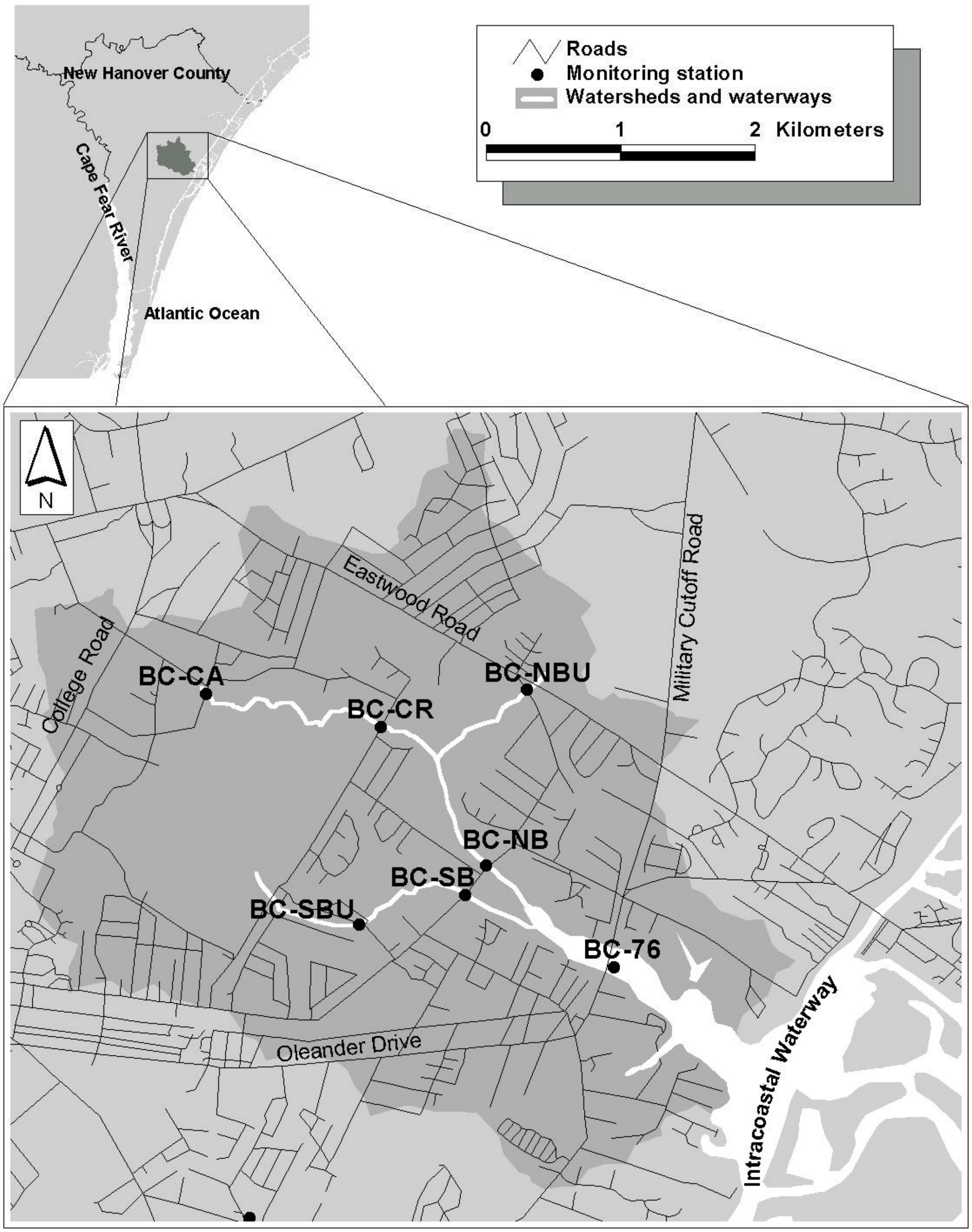
Ammonium concentrations were generally low, with highest levels at BC-CA. Nitrate concentrations were highest at station BC-CA, but low in general (Table 3.1). Total nitrogen concentrations were low to moderate at all times sampled (< 1.0 mg/l). Orthophosphate concentrations were low with highest levels at BC-CA; TP followed a similar spatial pattern as orthophosphate. Our Bradley Creek stations did not host significant algal blooms in 2014. Median nitrogen to phosphorus ratios at BC-NB and BC-SB were low (8-12) indicating that inputs of inorganic nitrogen are likely to stimulate algal blooms in this creek.

Fecal coliform bacteria counts were excessive at all three stations sampled during 2014. The NC contact standard was exceeded on 100% of occasions sampled at BC-CA, 50% of occasions at BC-SB and 33% of occasions sampled at BC-NB. The geometric means of the fecal coliform counts ranged from under the standard (130 CFU/100 mL at BC-NB) to >20X the standard (4,404 CFU/100 mL at BC-CA, Table 3.1).

Table 3.1 Water quality parameter concentrations at Bradley Creek sampling stations, 2014. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 6 samples collected.

Station	BC-CA	BC-NB	BC-SB
Salinity (ppt)	0.1 (0.0) 0.1-0.1	26.1 (8.6) 8.6-30.2	16.1 (7.2) 1.9-20.8
Dissolved Oxygen (mg/L)	6.9 (1.2) 4.8-8.0	6.5 (1.8) 4.4-8.9	7.0 (1.4) 5.3-9.1
Turbidity (NTU)	4 (6) 0-14	4 (4) 0-8	3 (3) 0-8
TSS (mg/L)	6.5 (4.3) 1.5-13.7	18.8 (6.7) 12.6-28.2	13.8 (6.1) 6.7-24.4
Nitrate (mg/L)	0.158 (0.085) 0.050-0.260	0.015 (0.012) 0.010-0.040	0.020 (0.013) 0.010-0.040
Ammonium (mg/L)	0.182 (0.241) 0.010-0.640	0.012 (0.004) 0.010-0.020	0.010 (0.000) 0.010-0.010
TN (mg/L)	0.808 (0.239) 0.560-1,140	0.465 (0.253) 0.050-0.800	0.498 (0.217) 0.100-0.700
Orthophosphate (mg/L)	0.043 (0.041) 0.010-0.120	0.015 (0.008) 0.010-0.030	0.020 (0.015) 0.010-0.040
TP (mg/L)	0.082 (0.035) 0.050-0.130	0.040 (0.024) 0.010-0.070	0.047 (0.027) 0.010-0.070
N/P	29.4 29.5	4.3 4.4	4.2 4.4
Chlorophyll *a* (μg/L)	7 (5) 1-15	6 (5) 1-11	8 (7) 1-17
Fecal coliforms (CFU/100 mL)	4,404 240-60,000	130 10-7,000	621 154-17,000

Figure 3.1. Bradley Creek watershed and sampling sites.



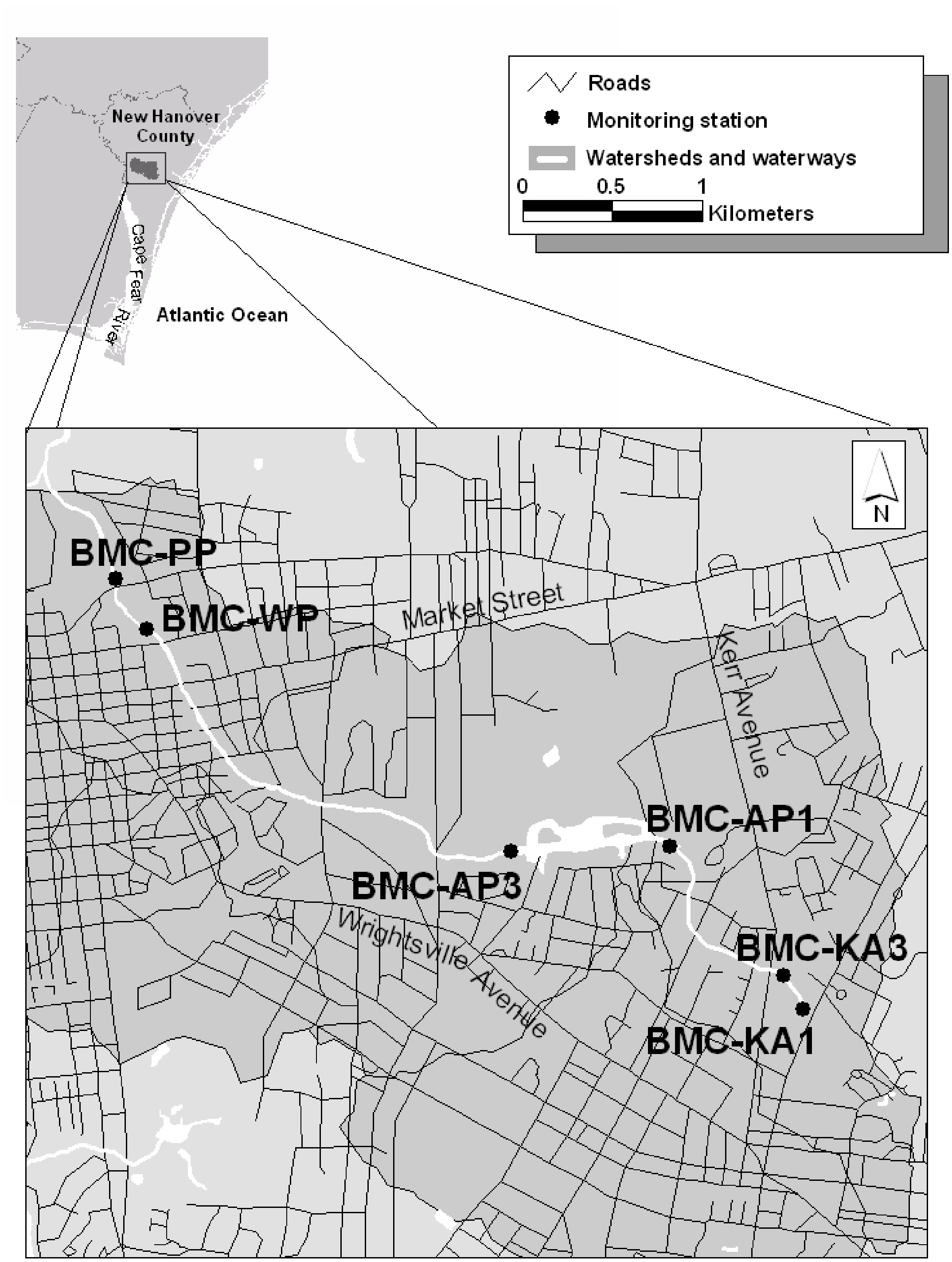
4.0 Burnt Mill Creek

Snapshot
Watershed area: 4,207 acres (1,703 ha)
Impervious surface coverage: 39.3%
Watershed population: Approximately 23,700
Overall water quality: poor
Problematic pollutants: Fecal bacteria, periodic algal blooms, some low dissolved oxygen issues, contaminated sediments (PAHs, Hg, Pb, Zn, TN, and TP)

Burnt Mill Creek is an urban creek flowing entirely through the City of Wilmington. Its high impervious surface coverage (about 39%) puts it at risk for excessive pollutant loads. 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 has periodically hosted 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 (Perrin et al. 2008; Mallin et al. 2009a; Mallin et al. 2009b; Mallin et al. 2010a; 2011). This creek is currently on the NC 303(d) list for impaired waters, for an impaired benthic community.

<u>Sampling Sites</u>: During 2014 samples were collected from three stations on the creek (Fig. 4.1). In the upper creek Ann McCrary Pond, a large regional wet detention pond on Randall Parkway was sampled just upstream (BMC-AP1) and about 40 m downstream (BMC-AP3) of the pond (Fig. 4.1). Several km downstream of Ann McCrary Pond is Station BMC-PP, located at the Princess Place bridge over the creek, respectively (Fig. 4.1). This is a main stem station in what is considered to be the mid-to-lower portion of Burnt Mill Creek, in a mixed residential and retail area.

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



The Upper Creek

About one km downstream from Kerr Avenue along Randall Parkway is the large regional wet detention pond known as Ann McCrary Pond. Data were collected at the input (BMC-AP1) and outflow (BMC-AP3) stations on six occasions in 2014. Dissolved oxygen concentrations were within standard on all sampling occasions at these two sites in 2014, and there was a statistically-significant increase in DO through the pond, likely a result of aquatic plant photosynthesis and mixing at the outfall. The State standard for turbidity in freshwater is 50 NTU; there were no exceedences of this value in our 2014 samples; there was a significant increase through the pond but averages only went from 1 to 6 NTU. Likewise, total suspended solids concentrations were relatively low on all sampling occasions in 2014, but there was a significant increase through the pond, likely due to phytoplankton (Table 4.1). Fecal coliform concentrations entering Ann McCrary Pond at BMC-AP1 were very high, exceeding the state standard 100% of the time sampled (Table 4.1). These high counts were 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). Notably only one of the samples from BMC-AP3 exceeded the standard. This resulted in a statistically significant decrease in fecal coliform counts from passage through the regional detention pond (Table 4.1). The Wilmington Stormwater Services Department is aware of the problem in upper Burnt Mill Creek and UNCW continues to work with them to determine sources of fecal contamination to the upper creek.

There was one major algal bloom at BMC-AP3 that exceeded the North Carolina water quality standard in 2014, as well as a lesser bloom of 32 µg/L. Statistically, there was no significant increase in chlorophyll *a* concentrations exiting the pond compared with entering the pond (Table 4.1). Concentrations of ammonium and nitrate showed a significant decease between entering and exiting the pond, but TP significantly increased. 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 2014. One parameter that is key to aquatic life health is dissolved oxygen. Dissolved oxygen at BMC-PP in 2014 was substandard on two of six occasions, ranking this site in poor condition for 2014. 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 area, for the lower Coastal Plain a reasonable TSS “interest concentration” is 25 mg/L; in 2014 this level was not approached at BC-PP.

In 2014 there were no documented algal blooms at BMC-PP that exceeded the North Carolina water quality standard for chlorophyll *a* of 40 µg/L. Algal blooms can cause disruptions in the food web, depending upon the species present (Burkholder 2001), and decomposing blooms can contribute to low dissolved oxygen (Mallin et al. 2006b).

It is important to determine 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 35 and mean ratios were 28. 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.

Important from a public health perspective are the excessive fecal coliform bacteria counts, which maintained geometric means at BMC-PP 7X the State standard for human contact waters (200 CFU/100 mL). Fecal coliform counts were greater than the State standard on 83% of occasions sampled at Princess Place. As mentioned, fecal coliform bacteria counts dropped significantly after passage through the regional detention pond, but then increased along the passage from BMC-AP3 (geometric mean 127 CFU/100 mL) to the Princess Place location (geometric mean 1,463 CFU/100 mL; Fig. 4.2), as in previous years. It is likewise notable that nitrate concentrations increased from the outflow from Ann McCrary Pond downstream to the lower main stem station (Table 4.1; Fig. 4.3).

Table 4.1. Water quality data in Burnt Mill Creek, 2014, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as mean/median, n = 6 samples collected.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	6.7 (0.7) 5.5-7.6	10.1 (1.5)** 7.6-11.5	5.4 (1.9) 2.5-7.0
Cond. (µS/cm)	243 (56) 135-287	161 (95)* 2-242	300 (87) 128-355
pH	6.9 (0.0) 6.8-6.9	7.7 (0.3)** 7.3-8.3	7.2 (0.1) 7.1-7.3
Turbidity (NTU)	1 (1) 0-3	6 (5)* 0-12	2 (3) 0-8
TSS (mg/L)	2.3 (1.3) 1.4-4.5	9.2 (3.7)** 5.7-14.4	3.4 (3.7) 1.4-10.9
Nitrate (mg/L)	0.162 (0.038) 0.100-0.210	0.045 (0.034)* 0.010-0.090	0.200 (0.082) 0.080-0.310
Ammonium (mg/L)	0.093 (0.064) 0.020-0.200	0.030 (0.026)* 0.010-0.080	0.092 (0.026) 0.050-0.130
TN (mg/L)	0.912 (1,080) 0.210-3,070	0.542 (0.246) 0.250-0.830	0.750 (0.613) 0.310-1,980
OrthoPhos. (mg/L)	0.013 (0.008) 0.010-0.030	0.013 (0.005) 0.010-0.020	0.028 (0.018) 0.010-0.050
TP (mg/L)	0.032 (0.020) 0.010-0.070	0.055 (0.021)** 0.030-0.080	0.055 (0.024) 0.030-0.090
N/P molar ratio	52 52	13 12	35 28
Chlor. *a* (µg/L)	5 (7) 1-19	25 (23) 5-68	9 (7) 1-21
FC (CFU/100 mL)	1,026 360-14,000	127* 5-11,000	1,463 172-26,000

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

Figure 4.2. Fecal coliform bacteria geometric means for Burnt Mill Creek, 2014

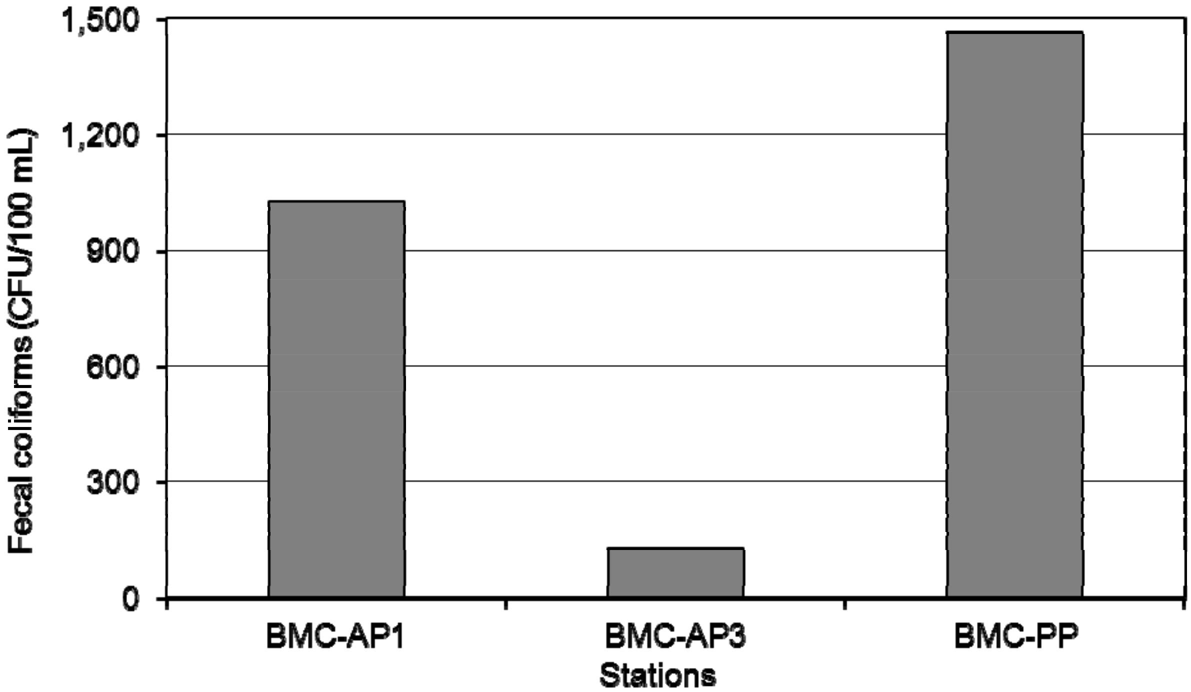
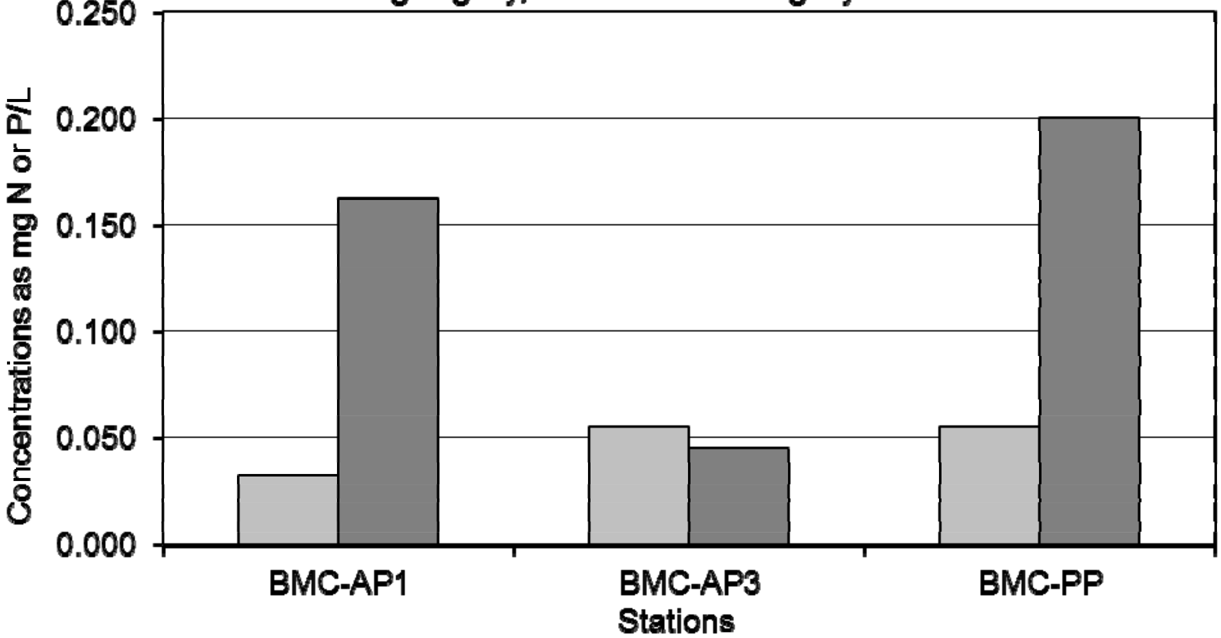


Figure 4.3. Average total phosphorus and nitrate concentrations by station for Burnt Mill Creek, 2014; TP as light grey, nitrate as dark grey.



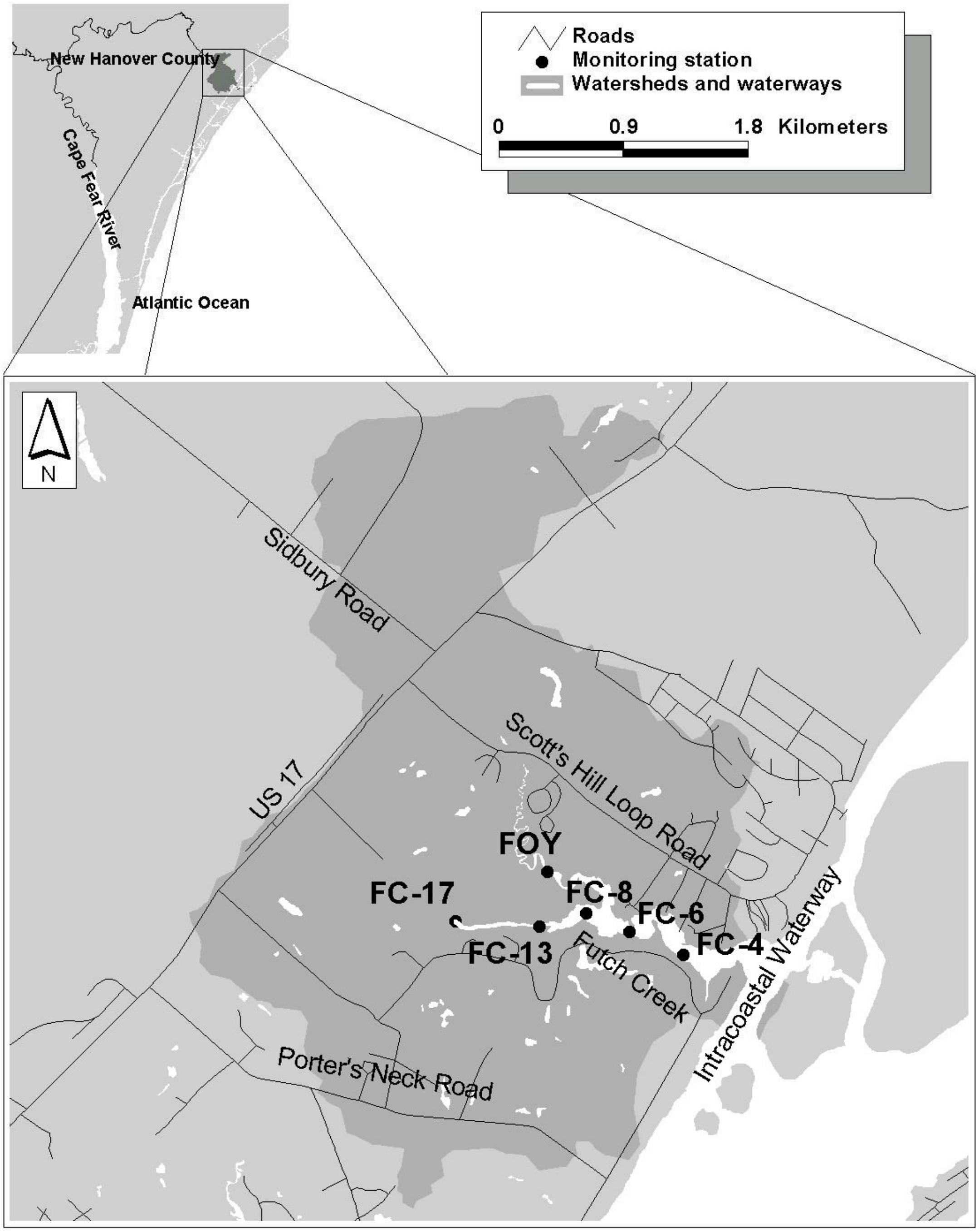
To summarize, in most years Burnt Mill Creek has problems with low dissolved oxygen (hypoxia) chronically at the Princess Place station BMC-PP. Algal blooms were less of a problem in 2014 than in previous years. The N/P ratios in the lower creek indicate that inputs of either nitrogen or phosphorus are likely to stimulate algal bloom formation, depending upon location, season and inputs of nitrogen. It is notable that nutrient concentrations increased by a factor of 4X from the outfall 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.

5.0 Futch Creek

Snapshot
Watershed area: 3,813 acres (1,544 ha)
Impervious surface coverage: 12.3%
Watershed population: 4,620

Six stations were sampled by the University of North Carolina Wilmington’s Aquatic Ecology Laboratory in Futch Creek from 1993 through 2007. UNCW was not funded by the County to sample Futch Creek in 2014. We present the above information and map below purely for informational purposes. Water quality information for 2008-2014 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 (1,033 ha)
Impervious surface coverage: 37% (2013 data)
Watershed population: 10,630
Overall water quality: Poor
Problematic pollutants: High fecal bacteria and low dissolved oxygen in tributaries, high BOD and algal blooms in main lake.

Four tributary stations to Greenfield Lake were sampled for a full suite of physical, chemical and biological parameters in 2014 (Table 6.1, Fig. 6.1). Three tributary sites suffered from severe hypoxia, as GL-LB (creek at Lake Branch Drive), GL-LC (creek beside Lakeshore Commons) and GL-JRB (Jumping Run Branch) showed dissolved oxygen concentrations below the state standard (DO < 5.0 mg/L) on 50% of sampling occasions or more (Table 6.1; Appendix B). The newest station, JRB-17, located in upper Jumping Run Branch at 17th Street, had substandard dissolved oxygen on only one sampling occasion. Turbidity concentrations were generally low in the tributary stations, with no violations of the freshwater standard of 50 NTU (Table 6.1). Suspended solids were in low concentrations in 2014 in the tributary stations (Table 6.1).

Nitrate, ammonium and TN concentrations were highest at GL-LB (Table 6.1). There were no differences in orthophosphate or TP concentrations among the stream stations. Chlorophyll *a* concentrations were low at most tributary stream sites except for GL-LC, at Lakeshore Commons, which had two significant algal blooms in summer 2014. The geometric fecal coliform bacteria counts exceeded the state standard at all four tributary stations (Table 6.1). The standard was exceeded on all six sampling dates at JRB-17, GL-JRB and GLB-LB, and on four of six dates at GL-LC.

Table 6.1. Mean and (standard deviation) / range of selected field water quality parameters in tributary stations of Greenfield Lake, 2014. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 6 samples collected.

Parameter	JBR-17	GL-JRB	GL-LB	GL-LC
DO (mg/L)	7.2 (1.6) 4.8-9.1	4.9 (2.0) 2.3-7.4	3.3 (2.0) 1.0-6.6	5.4 (3.5) 1.5-9.5
Turbidity (NTU)	1 (2) 0-5	1 (1) 0-2	1 (2) 0-4	1 (2) 0-4
TSS (mg/L)	4.6 (3.3) 1.4-10.9	3.8 (2.9) 1.4-8.0	2.6 (1.3) 1.4-4.0	6.1 (3.1) 1.4-10.2
Nitrate (mg/L)	0.17 (0.13) 0.03-0.41	0.21 (0.12) 0.06-0.41	0.26 (0.16) 0.10-0.46	0.17 (0.17) 0.01-0.39
Ammon. (mg/L)	0.12 (0.03) 0.07-0.15	0.09 (0.03) 0.05-0.14	0.20 (0.10) 0.06-0.33	0.04 (0.02) 0.02-0.07
TN (mg/L)	0.70 (0.60) 0.05-1.76	0.62 (0.24) 0.22-0.84	1.11 (0.81) 0.50-2.73	0.91 (0.78) 0.25-2.20
Ortho-P. (mg/L)	0.03 (0.01) 0.02-0.04	0.04 (0.02) 0.02-0.07	0.04 (0.02) 0.02-0.06	0.04 (0.03) 0.01-0.08
TP (mg/L)	0.06 (0.03) 0.03-0.11	0.06 (0.02) 0.04-0.10	0.06 (0.03) 0.04-0.11	0.07 (0.02) 0.05-0.11
FC (CFU/100 mL)	2,039 460-9,000	1,154 250-19,000	2,009 470-60,000	210 5-5,800
Chlor. *a* (μg/L)	5 (6) 2-17	6 (4) 2-14	3 (2) 1-5	25 (30) 4-76

Three in-lake stations were sampled (Figure 6.1). 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 not a problem in-lake in 2014 at two sites, but was slightly below standard on 33% of sampling occasions at GL-2340 (see also Section 6.1). Turbidity was below the state standard on all sampling occasions, and suspended solids were low in general. Fecal coliform concentrations deteriorated from 2013. In 2014 coliforms exceeded the State standard on 83% of sampling occasions at GL-2340, 50% of occasions at GL-YD, and once of six occasions at GL-P.

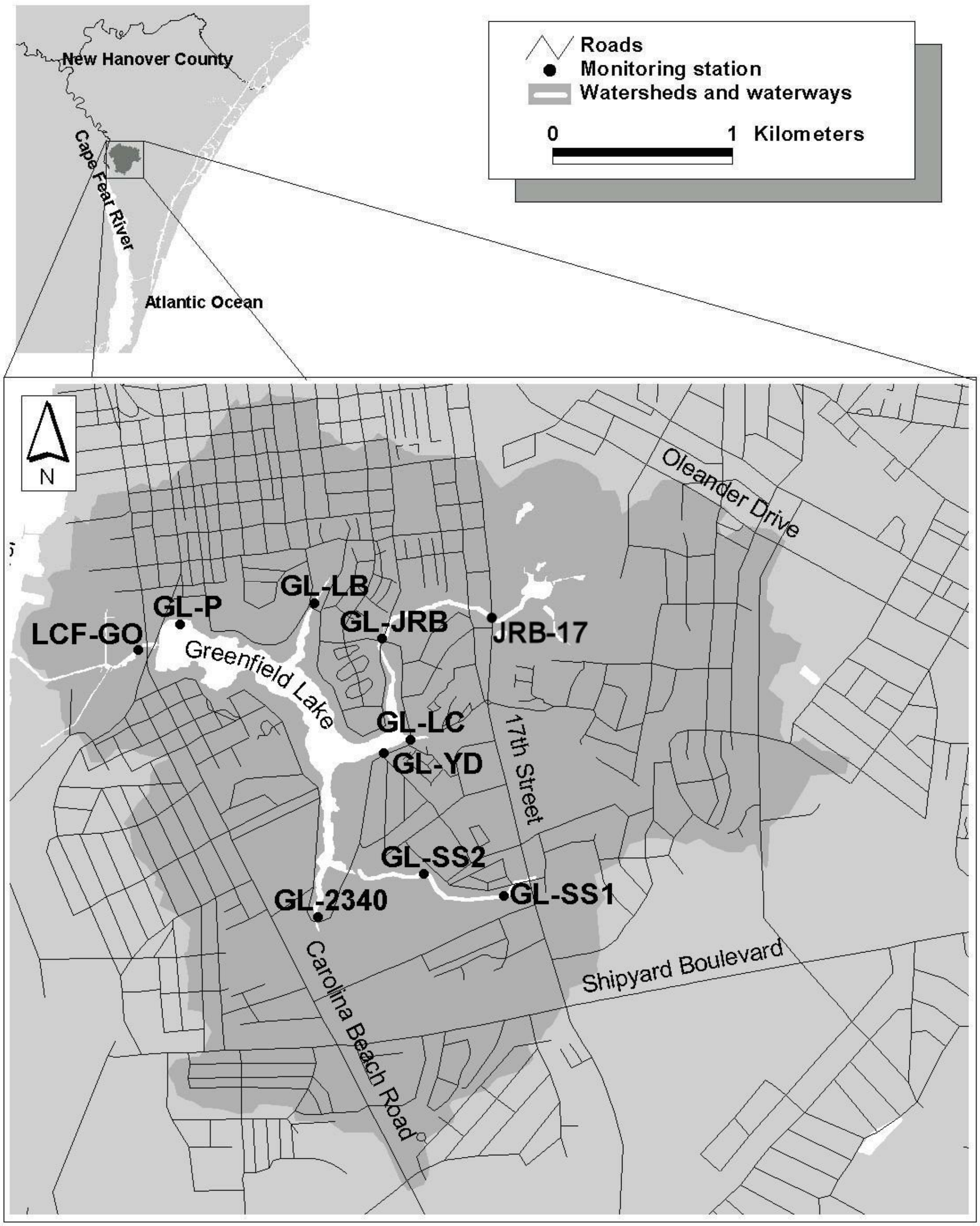
Concentrations of nitrate were highest at the upstream station GL-2340, where concentrations were similar to those of the tributary streams (Table 6.2). Ammonium levels in the lake were generally low. Total nitrogen was highest at GL-2340 as well. Total phosphorus (TP) and orthophosphate concentrations were highest at GL-P, although none of the concentrations were remarkable (Table 6.2). Inorganic N/P molar ratios can be computed from ammonium, nitrate, and orthophosphate data and can help determine what the potential limiting nutrient can be in a water body. Ratios well below 16 (the Redfield ratio) can indicate potential nitrogen limitation, and ratios well above 16 can indicate potential phosphorus limitation (Hecky and Kilham 1988). Based on the low mean and median N/P ratios at GL-P and GL-YD (Table 6.2), phytoplankton growth in much of Greenfield Lake was limited by nitrogen (i.e. inputs of nitrogen can cause algal blooms). However, in the uppermost station GL-2340 the high N/P ratios indicated that P inputs could cause algal blooms at that site. Our previous bioassay experiments indicated that nitrogen was usually the limiting nutrient in this lake (Mallin et al. 1999).

Phytoplankton blooms are problematic in Greenfield Lake (Table 6.2), 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. Two blooms exceeding the North Carolina water quality standard of 40 μg/L of chlorophyll *a* occurred at GL-P and three occurred at GL-YD, with one large bloom (206 μg/L) occurring at GL-2340. For the past several years chlorophyll *a* has exceeded the state standard approximately 33% of occasions sampled. Based on these data, the North Carolina Division of Water Resources has placed this lake on a preliminary 303(d) list for 2014, pending comments from the public. Average biochemical oxygen demand (BOD5) for 2014 was higher (3.5-4.2) among the three sites sampled (Table 6.1), compared to the BOD concentrations found in 2013. As phytoplankton (floating algae) are easily-decomposed sources of BOD, the blooms in this lake are a periodic driver of low dissolved oxygen. We note a major blue-green algal bloom consisting of *Anabaena* sp. was investigated by NC DWR during July 2014.

Table 6.2. Mean and (standard deviation) / range of selected field water quality parameters in lacustrine stations of Greenfield Lake, 2014. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 6 samples collected.

Parameter	GL-2340	GL-YD	GL-P
DO (mg/L)	5.9 (1.7) 4.4-9.1	9.0 (1.4) 7.0-10.5	9.2 (2.5) 7.4-13.9
Turbidity (NTU)	1 (2) 0-4	1 (1) 0-2	0 (1) 0-2
TSS (mg/L)	4.8 (3.8) 1.4-10.8	5.5 (3.0) 1.4-10.0	4.5 (2.9) 1.4-8.6
Nitrate (mg/L)	0.24 (0.16) 0.01-0.39	0.03 (0.05) 0.01-0.14	0.03 (0.05) 0.01-0.13
Ammonium (mg/L)	0.05 (0.04) 0.01-0.10	0.02 (0.02) 0.01-0.07	0.10 (0.14) 0.01-0.34
TN (mg/L)	0.85 (0.57) 0.39-1.89	0.72 (0.40) 0.34-1.30	0.62 (0.29) 0.30-0.93
Orthophosphate (mg/L)	0.02 (0.01) 0.01-0.03	0.04 (0.03) 0.01-0.10	0.06 (0.05) 0.01-0.13
TP (mg/L)	0.07 (0.04) 0.03-0.14	0.08 (0.03) 0.04-0.11	0.10 (0.04) 0.06-0.17
N/P molar ratio	61 70	8 3	8 6
Fec. col. (CFU/100 mL)	636 73-11,000	216 5-60,000	116 37-1,515
Chlor. *a* (μg/L)	36 (83) 1-206	37 (27) 7-69	26 (16) 6-45
BOD5	4.2 (5.2) 1.0-13.0	3.5 (1.9) 1.0-6.0	3.5 (1.0) 2.0-5.0

Figure 6.1. Greenfield Lake watershed.



6.1 Assessing the Efficacy of the 2005-2013 Greenfield Lake Restoration Measures

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 five 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 approximately 37%.

This urban lake that receives drainage from a largely commercial and residential watershed. Prior to 2005 a number of water quality problems became chronic within the lake, including low dissolved oxygen, nuisance aquatic macrophyte growths, algal blooms, fish kills and high fecal coliform bacterial counts. Some of these problems are typically related to eutrophication, a process driven by loading of excessive nutrients to a body of water. Periodic phytoplankton blooms occurred in spring, summer and fall. Some of the bloom-forming taxa were the cyanobacteria species *Anabaena cylindrica* and *Microcystis aeruginosa*, and the filamentous chlorophytes *Spirogyra* and *Mougeotia* spp. Frequently observed free-floating macrophytes have included duckweed *Lemna minor* and watermeal *Wolffia columbiana*. Below a massive duckweed bloom in the summer of 2004 dissolved oxygen concentrations were nearly anoxic. Submersed macrophytes that have occurred in substantial amounts have included alligatorweed *Althernanthera philoxeroides*, coontail *Ceratophyllum demersum*, pennywort *Hydrocotyle umbellate* and water primrose *Ludwigia hexapetala*.

Beginning in 2005 several steps were taken by the City of Wilmington to restore viability to the lake. 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 (SB10000v12 units) were installed in the lake with the general objectives of providing algae control, improving water quality and the fishery, reducing and/or compacting soft organics in the littoral zone and enhance nuisance macrophyte control. Such solar-driven circulators have been found to reduce cyanobacterial abundance in some nutrient-rich reservoirs, but in other situations they have failed to control harmful algal blooms (Hudnell 2010). From April through June 2005 and in March and July 2006 herbicides and algicides were added by city crews and contractors, and in April 2006 500 additional grass carp were added. In March 2007 200 more grass carp were added to the lake. City crews and contract firms have spot treated areas of the lake to control macrophyte and nuisance filamentous growths with herbicide annually since 2007. Herbicide application and grass carp addition are both commonly used methods for lake nuisance vegetation control (Leslie et al. 1987; Ross and Lembi 1998). However, regeneration of inorganic nutrients and increases in phytoplankton productivity has resulted from such vegetation removal practices in some systems (Richard et al. 1984; Leslie et al. 1987; O’Dell et al. 1995).

Since the various treatments (artificial circulation, grass carp additions, herbicide use) the lake's water quality has changed, in some ways improving and in some ways deteriorating. This report describes the current status of the lake, provides experimental evidence of the nutrients limiting algal growth, discusses sources of nutrients to the lake, examines the impacts of the lake rehabilitation treatments by comparing before-and-after water quality, and suggests future strategies for lake improvement.

Statistical analysis

Water quality data were subjected to summary statistics using Excel. Data were tested for normality using the Shapiro-Wilk Test, with most data (except water temperature, DO and BOD5) requiring log-transformation to achieve a normal distribution. Correlation analyses were performed among water quality parameters and meteorological data including temperature and rainfall. Pre-rehabilitation data (considered to be January 2000 through January 2005) were tested (t-tests) against post-rehabilitation data (March 2005 through December 2013) to determine difference between means. Statistical tests were performed using SAS (Schlotzhauer and Littell 1997) using a significance level of $p<0.05$.

Impact of rehabilitation measures

What were the impacts to water quality of the set of lake rehabilitation measures performed? Visually, based on decreased public complaints and City maintenance staff observations, excessive surface macrophyte and algal growth has declined. Between the pre-and-post rehabilitation periods there were no significant differences in turbidity, TSS, or fecal coliform bacteria (Table 6.3). Likewise, there was no significant difference in dissolved oxygen (DO) (Table 6.3). From a regulatory standpoint the incidences of DO violations < 5.0 mg/L were decreased from 27% of total samples to 20% of total samples (Table 6.4). Thus, aeration improvement from the solar mixers had a positive regulatory impact and aided in preventing the occasional near-anoxic conditions seen pre-rehabilitation (see DO ranges in Table 6.3).

There were no statistically significant changes in nutrient concentrations between periods with the exception of a 50% decrease in ammonium (Table 6.3). This was interesting in that we originally assumed there would be notable inorganic nutrient release from macrophyte decomposition (Dierberg et al. 1994) including following herbicide treatments (O'Dell et al. 1995) and excretion of nutrients via grass carp feeding (see review in Leslie et al. 1987). The ammonium decrease was also likely responsible for a decrease in the DIN/DIP ratio (Table 6.3) as nitrate concentrations did not change between periods. Whereas aeration due to the artificial mixing might be expected to enhance microbial nitrification, again nitrate did not change between periods. Orthophosphate and TP concentrations showed an apparent downward trend but the between-period difference was not significant ($p > 0.05$). Evidently TP inputs to the water column will vary year-to-year according to waterfowl community composition and abundance (and their subsequent defecation of phosphorus-rich guano), a factor largely out of control of the lake management. What was statistically significant (p <

0.0001) and striking was the 74% increase in average chlorophyll *a* concentrations following the rehabilitation measures (Table 6.3).

Average concentrations of the response variable chlorophyll *a* were representative of eutrophic conditions compared with large numbers of lakes and reservoirs (Wetzel 2001, Dodds et al. 1998). As a further metric, North Carolina has a chlorophyll *a* standard for eutrophic conditions of 40 µg/L (NCDENR 2003). The percent of chlorophyll *a* water quality standard violations tripled following installation of mixers, introduction of grass carp, and herbicide treatments (Table 6.4). From 2006-2013 lakewide chlorophyll *a* was highly correlated with BOD5 ($r = 0.678$, $p < 0.0001$). Average BOD5 showed a 20% increase following rehabilitation measures, but this change was not statistically significant. Chlorophyll *a* was also strongly correlated with TSS ($r = 0.584$, $p < 0.0001$) and more weakly correlated with turbidity ($r = 0.214$, $p = 0.013$). Average BOD5 was 3.6 mg/L and ranged up to 16.0 mg/L (Table 6.3). The BOD5 concentrations in this lake were generally high compared to a wide selection of lakes and streams in the US southeast (Mallin et al. 2006b).

The increase in chlorophyll violations led the NCDENR (in February 2014) to propose adding Greenfield Lake to the NC 303(d) list for chlorophyll violations. Regarding cyanobacteria, surface scums of *Microcystis aeruginosa* have not been noted following rehabilitation measures, but water column blooms of N-fixing *Anabaena* sp. continue to occur, with lake-wide blooms recorded by our laboratory and NCDENR in 2005, 2006, 2011 and 2014. Evidently the ammonium, and possibly bioavailable P (Dierberg 1993) remineralized from the various restoration measures lead to increased algal blooms, as have occurred elsewhere following herbicide and grass carp treatments (Richard et al. 1984; O'Dell et al. 1995). The nitrate entering from the tributaries continues to supply the principal limiting nutrient, N (as "new" N) to the phytoplankton. In other blackwater systems nitrate, ammonium and urea have all be shown to stimulate phytoplankton growth (Mallin et al. 2004). Also, in other southeastern coastal ecosystems, ammonium has been demonstrated to preferentially enhance cyanobacterial production in summer (Siegel et al. 2011).

Why have the rehabilitation measures caused a significant increase in algal bloom frequency and chlorophyll *a* biomass? None of the measures get at the root of the eutrophication problem, which is inputs of nutrients, especially N. The mixers do nothing to reduce nutrient inputs; instead they may make nutrients in bottom water more available to epilimnetic algae. Grass carp consume macrophyte vegetation, but in turn excrete dissolved nutrients (such as ammonium) into the water column. Herbicides kill macrophytes and filamentous algae, but upon decomposition they release N and P into the water column to be available to phytoplankton. also, removal of surface macrophyte masses allows more sunlight to reach the phytoplankton within the water column.

Conclusions

Rehabilitation measures performed on Greenfield Lake have improved the appearance of the lake to the public, and have improved dissolved oxygen concentrations by eliminating near-anoxia incidents and reducing water quality standard violations by 26%. However, they have led to a tripling of chlorophyll *a* violations that have made this lake a candidate for the NC 303(d) list. Chlorophyll *a* is strongly correlated with BOD5 in this lake; thus, the algal blooms work to reduce DO. At present, the solar-powered mixers bring hypolimnetic water to the surface for aeration; should they be removed, DO standard violations would likely considerably increase.

Greenfield Lake will continue to express symptoms of eutrophication (algal blooms and elevated BOD) until nutrient inputs, especially N, are decreased. Nutrient reduction is considered the key to eutrophication control. Little can likely be done to decrease P deposition from resident and seasonal waterfowl defecation. However, the lake drains a large, heavily developed watershed of 37% impervious surface coverage, much of which is residential and commercial. We suggest a nutrient reduction program focused on best management practices centered on the tributaries as an appropriate measure. Also, this lake continues to be polluted by fecal bacteria (Tables 6.3 and 6.4), so hopefully efforts to reduce N inputs from the watershed may also decrease fecal microbial inputs, improving human health aspects of the lake environs.

Table 6.3. Water quality conditions in Greenfield Lake before and after lake rehabilitation measures in 2005, averages of three sites. Presented as mean ± standard deviation / range. * indicates significant difference ($p < 0.05$) between periods.

Parameter	Jan 2000- Jan 2005 (n=147)	Mar 2005- Dec 2013 (n=168)
Dissolved oxygen (mg/L)	7.1±3.5 (0.2-18.9)	7.5±3.1 (1.0-17.0)
Turbidity (NTU)	6.1±9.8 (1.0-54.0)	4.4±5.0 (0-35.0)
TSS (mg/L)	7.0±11.6 (1.0-113.0)	8.4±16.2 (1.0-151.0)
Ammonium (µg/L)	105.7±212.3 (5.0-1,680.0)	53.0±69.8 (5.0-410.0)*
Nitrate + nitrite (µg/L)	82.1±113.4 (5.0-620.0)	78.3±107.4 (5.0-470.0)
Total nitrogen (µg/L)	1,047.2±1,194.9 (70.0-9-810.0)	921.1±783.7 (50.0-5,100)
Orthophosphate (µg/L)	55.6±232.1 (5.0-213.0)	27.1±26.0 (5.0-180.0)
Total phosphorus (µg/L)	145.3±425.4 (10.0-3,760.0)	96.1±69.7 (10.0-420.0)
DIN/DIP	30.1±48.2 (0.1-385.3)	16.9±22.9 (0.5-119.6)*
Chlorophyll *a* (µg/L)	19.4±28.7 (1.0-169.1)	33.8±39.3 (1.0-303.0)*
BOD5 (mg/L)	3.0±2.1 (1.0-9.0)	3.6±2.4 (1.0-16.0)
Fecal coliform bacteria (CFU/100 mL)	914±5,009 (1-60,000)	1,090±6,270 (3-60,000)

Table 6.4. Number and percent of occasions when water samples exceeded NC water quality standards before (January 2000-January 2005) and after (March 2005 – December 2013) lake aeration, grass carp additions, and herbicide treatments were performed.

Parameter	NC standard	Pre-rehabilitation	Post-rehabilitation
Dissolved oxygen	5.0 mg/L	39/147 (27%)	33/168 (20%)
Turbidity	50 NTU	3/147 (2%)	0/168 (0%)
Chlorophyll *a*	40 µg/L	16/147 (11%)	52/168 (31%)
Fecal coliform bacteria	200 CFU/100 mL*	60/147 (40%)	59/168 (35%)

*Violation of the freshwater fecal coliform standard actually requires the geometric mean of 5 samples collected within 30 days to exceed 200 CFU/100 mL; thus the standard as shown here is for general guideline purposes only.

7.0 Hewletts Creek

Snapshot
Watershed area: 7,478 acres (3,028 ha)
Impervious surface coverage: 25.1% (2013 data)
Watershed population: Approximately 20,200
Overall water quality: Fair
Problematic pollutants: high fecal bacteria, minor algal bloom issues

Hewletts Creek was sampled at four tidally-influenced areas (HC-3, NB-GLR, MB-PGR and SB-PGR) and a freshwater stream station draining Pine Valley Country Club (PVGC-9 - Fig. 7.1). At 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 was detected in our samples on two instances, where DO was between 4 and 5 mg/L. 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 elevated at MB-PGR; however, none of the other stations had elevated nitrate concentrations. In general nitrate concentrations creek-wide were slightly lower than in 2013. Ammonium concentrations were generally low in lower creek areas. Total nitrogen was low except for the middle branch station. Orthophosphate concentrations were low, as were total phosphorus concentrations. The N/P ratios were elevated in the middle branch coming from the golf course, but 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 creek in 2014. The chlorophyll *a* data (Tables 7.1 and 7.2) showed that the Hewletts Creek samples were free of major algal blooms in 2014, except for a bloom of 63 µg/L as chlorophyll *a* at PVGC-9. Fewer blooms have occurred in the past few years than had previously occurred in upper Hewletts Creek (Mallin et al. 1998a; 1999; 2002a; 2004; 2006a; 2008; Duernberger 2009).

Fecal coliform bacteria counts exceeded State standards 100% of the time at MB-PGR and 83% of the time at NB-GLR, 67% of the time at PVGC-9, and 33% of the time at SB-PGR. The geometric means at PVGC-9, MB-PGR and NB-GLR all well exceeded 200 CFU/100 mL for a poor rating for this pollutant parameter, but the geometric mean of fecal bacteria counts at SB-PGR was well under the standard at 130 CFU/100 mL.

Figure 7.1. Hewletts Creek watershed.

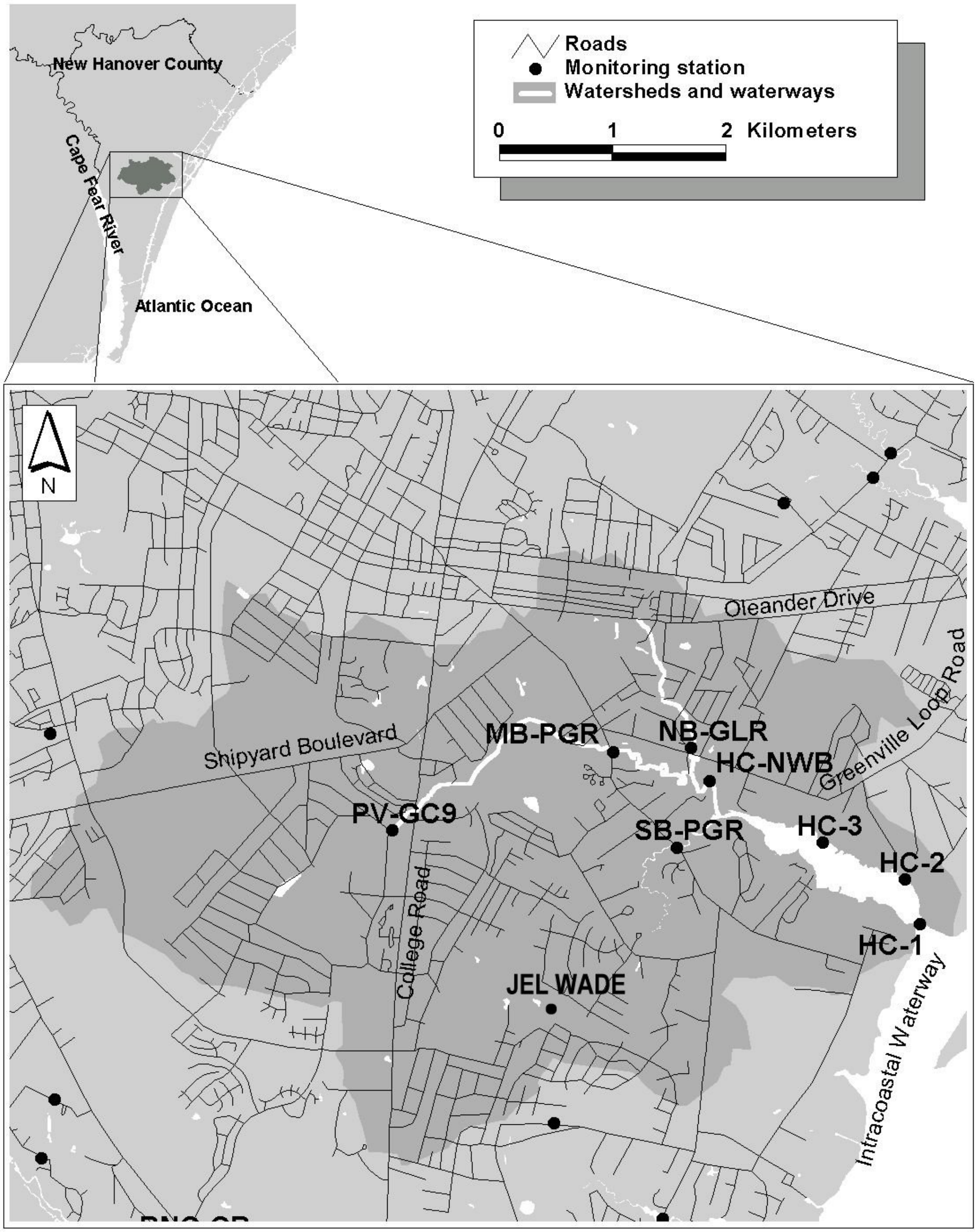


Table 7.1. Selected water quality parameters at upper and middle creek stations in Hewletts Creek watershed 2014 as mean (standard deviation) / range, N/P ratios as mean / median, fecal coliform bacteria presented as geometric mean / range, n = 6 samples collected.

Parameter	PVGC-9	MB-PGR
Salinity (ppt)	0.1 (0) 0.1-0.1	0.3 (0.3) 0.1- 0.8
Turbidity (NTU)	1 (1) 0-3	0 (1) 0-1
TSS (mg/L)	2.8 (2.1) 1.3-6.8	2.1 (1.1) 1.4-3.8
DO (mg/L)	7.6 (1.3) 5.9-8.8	7.3 (1.4) 6.3-9.5
Nitrate (mg/L)	0.397 (0.127) 0.170-0.540	0.255 (0.055) 0.180-0.330
Ammonium (mg/L)	0.052 (0.045) 0.010-0.130	0.040 (0.033) 0.010-0.090
TN (mg/L)	1.213 (0.809) 0.640-2.670	0.622 (0.163) 0.420-0.830
Orthophosphate (mg/L)	0.015 (0.005) 0.010-0.020	0.018 (0.013) 0.010-0.040
TP (mg/L)	0.043 (0.015) 0.030-0.070	0.045 (0.014) 0.020-0.060
N/P	88 85	58 75
Chlorophyll *a* (µg/L)	14 (24) 1-63	3 (2) 1-6
Fecal col. (CFU/100 mL)	755 82-19,000	1,162 230-13,000

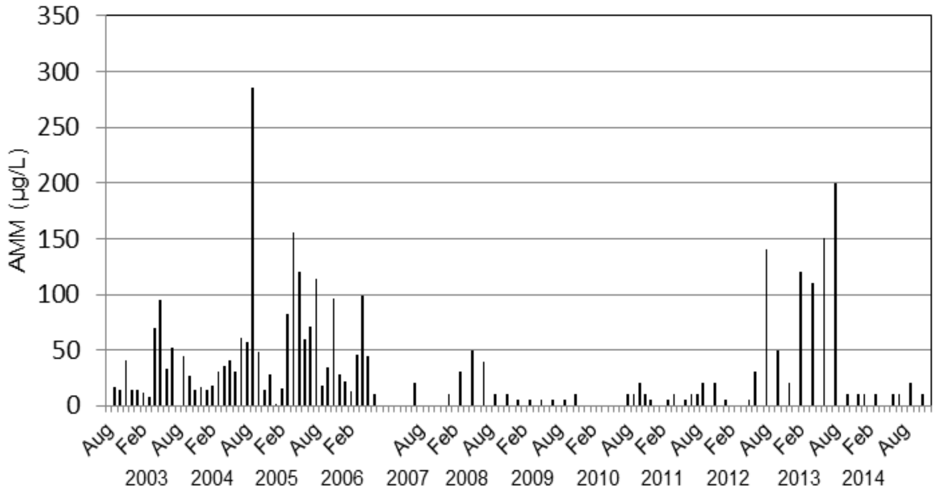
Table 7.2. Selected water quality parameters at stations in Hewletts Creek watershed, 2014, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 6 samples collected.

Parameter	NB-GLR	SB-PGR	HC-3
Salinity (ppt)	16.9 (7.7) 4.4-26.0	27.4 (4.4) 20.1-32.0	32.2 (2.2) 29.2-34.9
Turbidity (NTU)	2 (1) 0-4	2 (2) 0-6	2 (2) 0-6
TSS (mg/L)	11.3 (3.7) 5.4-15.4	15.8 (3.9) 11.2-20.0	17.6 (3.3) 13.9-21.7
DO (mg/L)	6.9 (1.7) 5.0-9.3	6.7 (2.0) 4.0-9.1	7.1 (1.8) 4.2-9.1
Nitrate (mg/L)	0.032 (0.040) 0.010-0.110	0.018 (0.013) 0.010-0.040	0.010 (0.000) 0.010-0.010
Ammonium (mg/L)	0.012 (0.004) 0.010-0.020	0.012 (0.004) 0.010-0.020	0.010 (0.010) 0.010-0.010
TN (mg/L)	0.492 (0.193) 0.240-0.800	0.370 (0.306) 0.030-0.700	0.408 (0.269) 0.050-0.700
Orthophosphate (mg/L)	0.025 (0.025) 0.010-0.070	0.018 (0.013) 0.010-0.040	0.013 (0.005) 0.010-0.020
TP (mg/L)	0.042 (0.017) 0.020-0.060	0.032 (0.018) 0.010-0.050	0.027 (0.014) 0.010-0.040
Mean N/P ratio Median	5 4	5 4	4 4
Chlor *a* (µg/L)	8 (6) 2-16	5 (4) 1-10	3 (2) 1-6
Fecal coliforms (CFU/100 mL)	967 127-60,000	133 10-18,000	46 5-10,000

Dobo Property/Bethel Rd./JEL Wade Park constructed 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. 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 is 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 peer-reviewed article in a technical journal (Mallin et al. 2012).

Continued monitoring of Hewletts Creek indicates that the wetland is 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- December 2014) with a probability (p) value of < 0.05 used for significance. Ammonium concentrations have demonstrated a statistically-significant 39% decrease between pre-wetland and post-wetland concentrations (Figure 7.2).

Figure 7.2 Ammonium concentrations over time at south branch Station SB-PGR in Hewletts Creek 2003-2014.



From spring 2009 on, creek nitrate concentrations showed peak concentrations that were generally lower than previous to wetland construction (Figure 7.3). There was a statistically-significant ($p < 0.01$) mean decrease in nitrate concentrations of 51% between pre-and-post wetland construction (July 2007). 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 2003-2014.

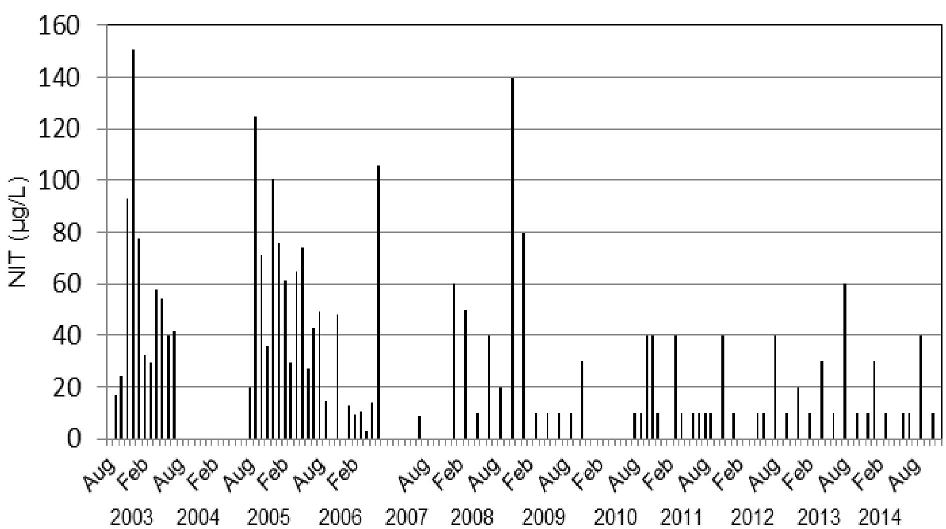
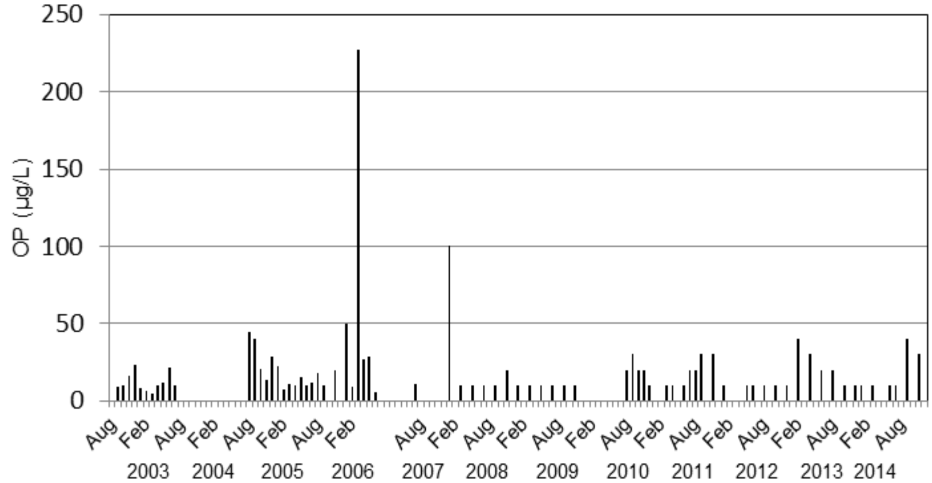
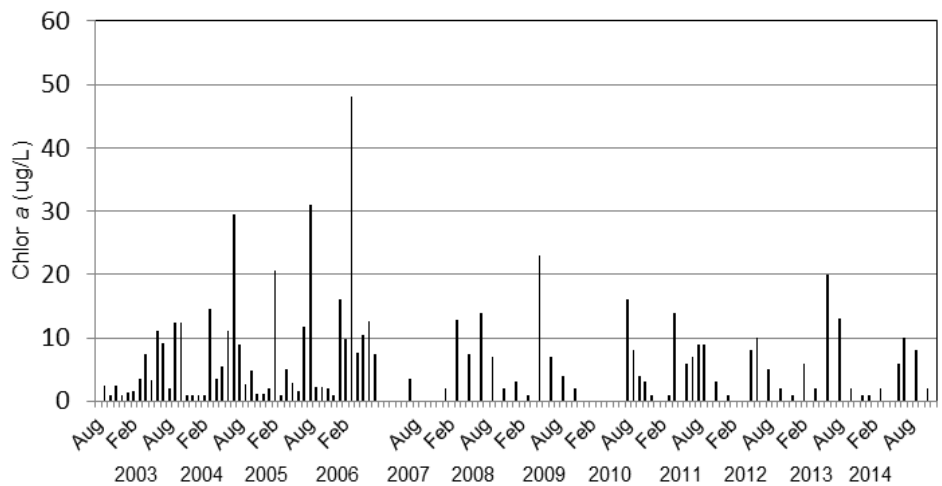


Figure 7.4 Orthophosphate concentration changes over time at south branch Station SB-PGR in Hewletts Creek 2003-2014.



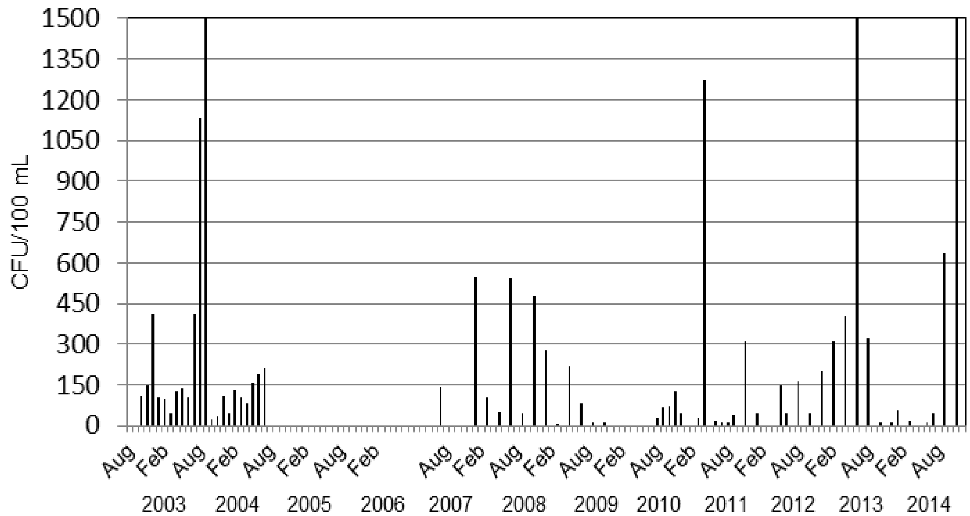
Algal blooms, represented by chlorophyll *a* concentrations, show fewer and smaller peaks in the south branch of Hewletts Creek than prior to wetland construction, but the reductions were not statistically significantly, ($p > 0.05$) (Figure 7.5).

Figure 7.5 Chlorophyll *a* concentration changes over time at south branch Station SB-PGR in Hewletts Creek 2003-2014.



Fecal coliform bacteria concentrations showed some moderately high peaks in the south branch of Hewletts Creek during early wetland operation (2008) then stabilized at much lower concentrations since summer 2009 (Figure 7.6). However, extreme rains led to occasional high fecal coliform counts in 2013 and 2014 (Figure 7.6). Overall geometric counts at SB-PGR in Hewletts Creek are still considerably reduced (from 144 CFU/100 mL pre-wetland) to 81 CFU/100 mL (post-wetland); this difference is not quite statistically significant ($p = 0.06$). However, 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 2003-2014.



8.0 Howe Creek Water Quality

Snapshot
Watershed area: 3,516 acres (1,424 ha)
Impervious surface coverage: 21.4%
Watershed population: Approximately 6,460
Overall water quality: Poor
Problematic pollutants: Fecal coliform bacteria, algal blooms, occasional low DO

Howe Creek was sampled for physical parameters, nutrients, chlorophyll *a*, and fecal coliform bacteria at two locations on six occasions during 2014 (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). Suspended solids were generally moderate (< 20 mg/L) except for one occasion, May 19 at HW-DT when they reached 30.6 mg/L. Dissolved oxygen concentrations were slightly below the NC standard of 5 mg/L on two occasions in 2014 (Appendix B).

Nitrate and ammonium concentrations were both low at both sites in 2014 (Table 8.1). Orthophosphate was also low at the two sites. Mean and median inorganic molar N/P ratios were low (below 8.0), indicating that nitrogen was probably the principal nutrient limiting phytoplankton growth at both stations. Previously Mallin et al. (2004) demonstrated that nitrogen was the primary limiting nutrient in Howe Creek. Chlorophyll *a* did not exceed the NC standard during 2014 on our sampling trips, but algal blooms exceeding 30 μg/L occurred on three dates at HW-DT and once at HW-GP in 2014 Since wetland enhancement was performed in 1998 above Graham Pond on Landfall Property, 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 four exceedences of the water contact standard of 200 CFU/100 mL (67%) at the mid-creek station HW-GP, to 83% exceedence of the standard at the upper station HW-DT, where the geometric mean of 533 CFU/100 mL was more than double the NC standard (Table 8.1).

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

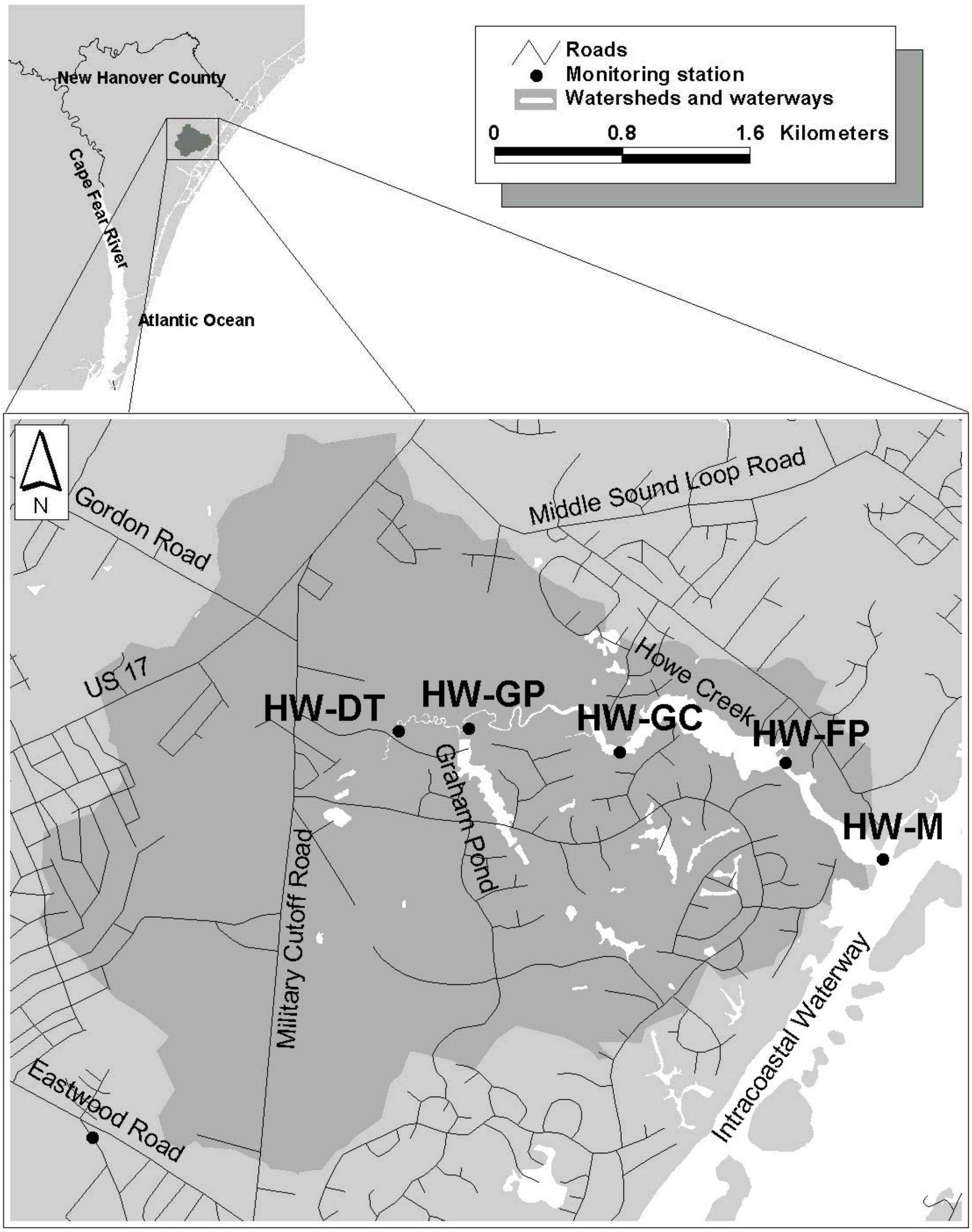


Table 8.1. Water quality summary statistics for Howe Creek, 2014, as mean (st. dev.) / range. Fecal coliform bacteria as geometric mean / range, n = 6 samples collected.

Parameter	HW-DT	HW-GP
Salinity (ppt)	8.6(10.4) 0.4-25.2	17.3(11.8) 1.9-31.5
Dissolved oxygen (mg/L)	8.1(2.0) 4.7-2.0	7.8(2.1) 4.7-10.0
Turbidity (NTU)	5(4) 1-11	4(4) 0-10
TSS (mg/L)	13.1(9.6) 1.5-30.6	11.0(3.7) 4.2-15.2
Chlor *a* (µg/L)	19(17) 1-39	9(11) 1-31
Fecal coliforms (CFU/100 mL)	533 190-1,360	237 46-1,550
Nitrate (mg/L)	0.030(0.023) 0.010-0.060	0.010(0.000) 0.010-0.010
Ammonium (mg/L)	0.017(0.012) 0.010-0.040	0.022(0.018) 0.010-0.050
Orthophosphate (mg/L)	0.018(0.008) 0.010-0.030	0.017(0.008) 0.010-0.030
Molar N/P ratio	7.0 6.0	4.2 4.4

Figure 8.2. Chlorophyll *a* concentrations (algal blooms) in Howe Creek below Graham Pond before and after 1998 wetland enhancement in Pond, 1993-2014.

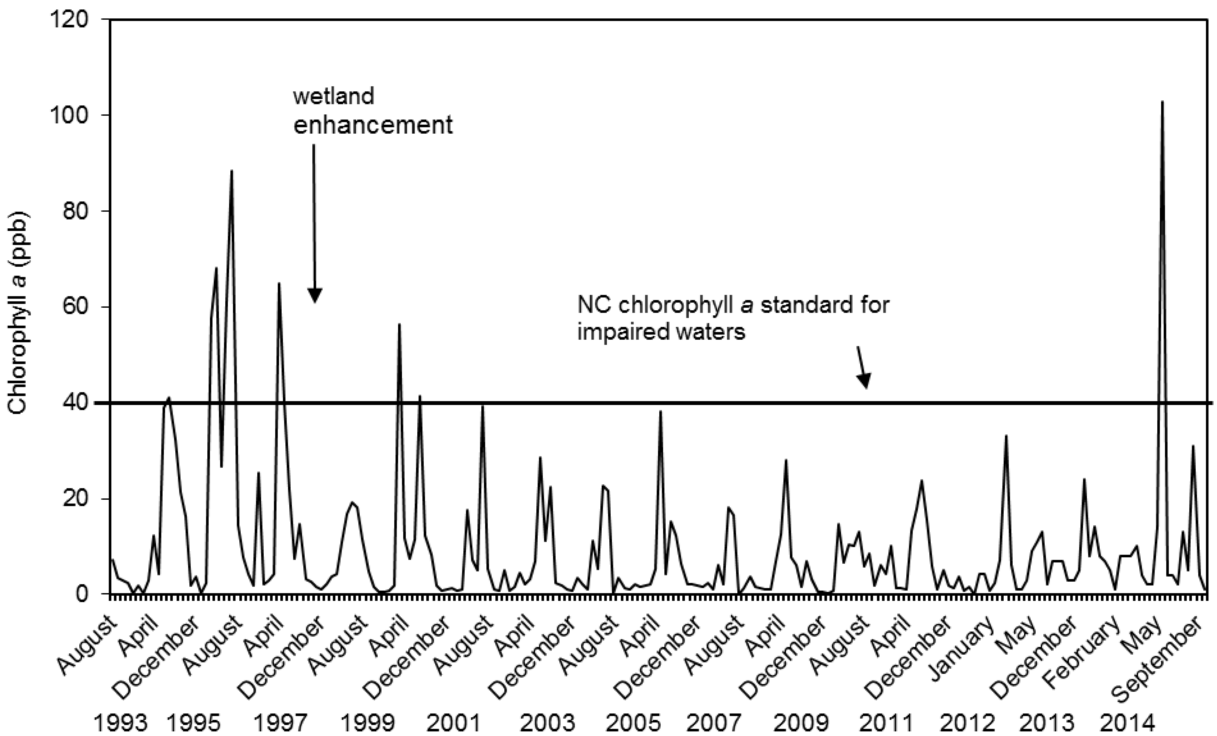
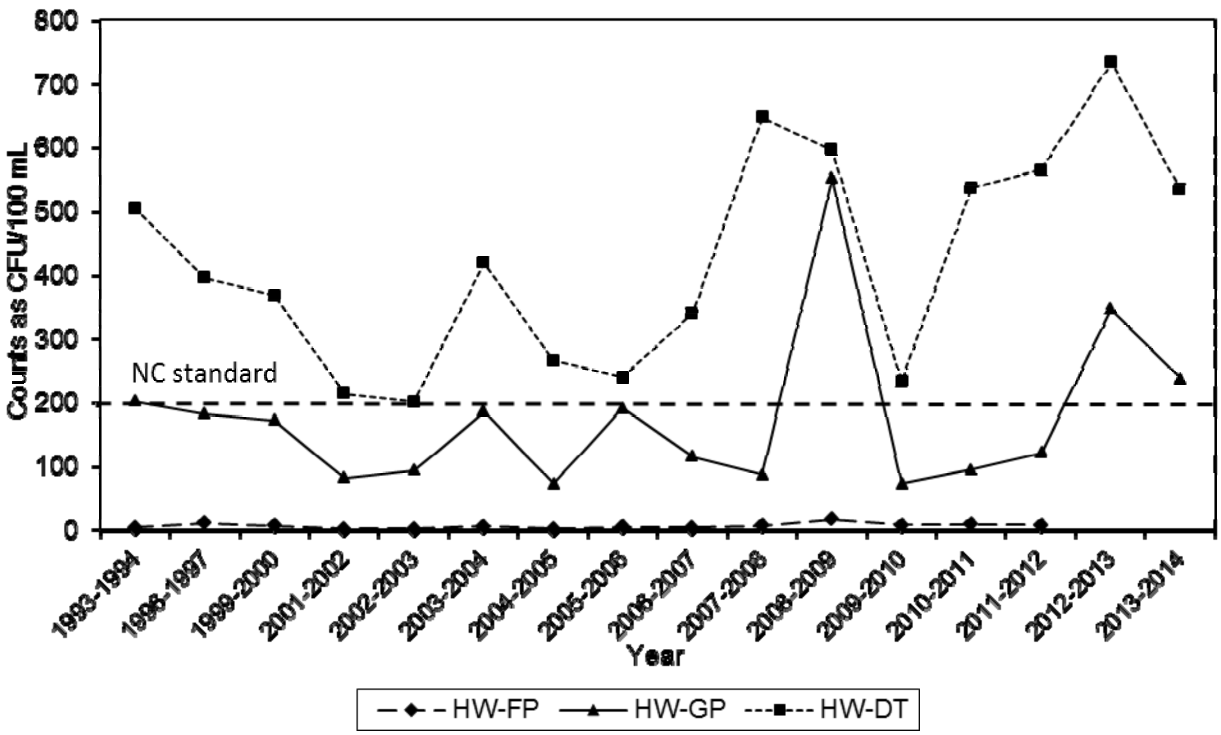


Figure 8.3. Fecal coliform counts over time for Howe Creek stations, 1993-2014.

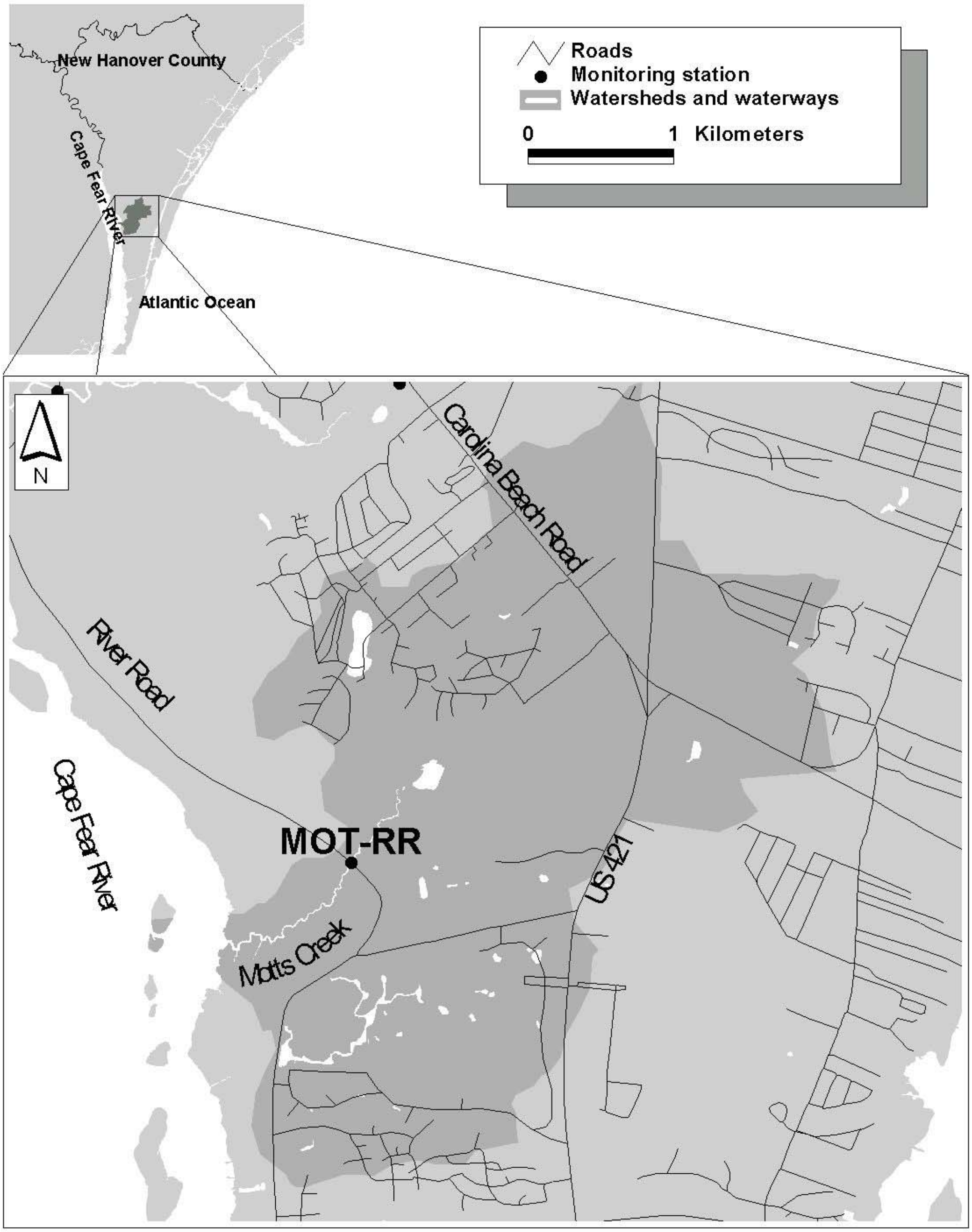


9.0 Motts Creek

Snapshot
Watershed area: 3,328 acres (1,354 ha)
Impervious surface coverage: 23.4%
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. During 2014 UNCW was not funded to sample water quality in lower Motts Creek. New Hanover County sponsors some water quality sampling in areas of upper Motts Creek, collected by Coastal Planning & Engineering of North Carolina, Inc.

Figure 9.1 Motts Creeks watershed

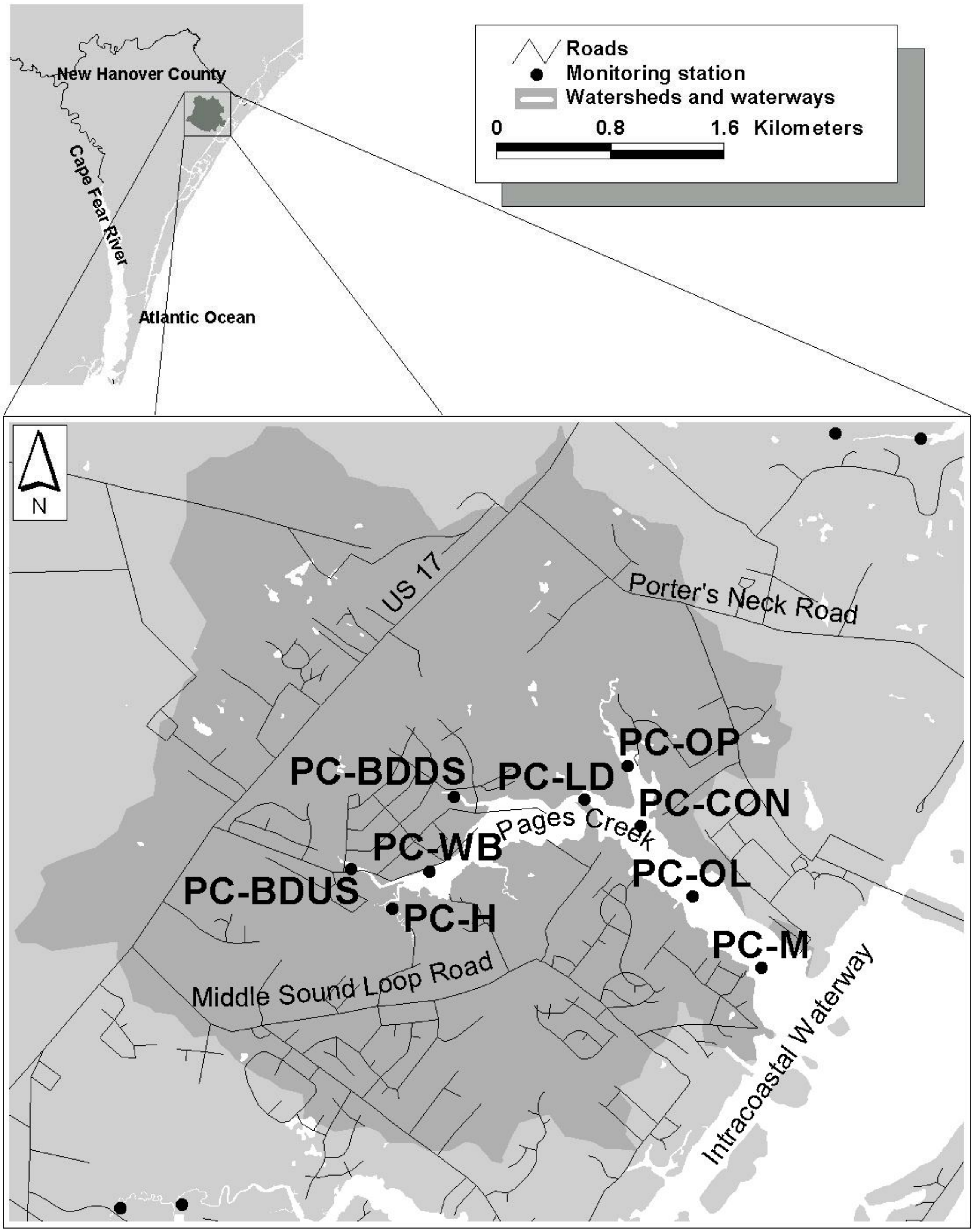


10.0 Pages Creek

Snapshot
Watershed area: 5,025 acres (2,035 ha)
Impervious surface coverage: 17.8 % (2014 data)
Watershed population: Approximately 8,390

The University of North Carolina Wilmington was not funded by the County in 2014 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: 16,650 acres (6,743 ha)
Impervious surface coverage: 21.3% (2014 data)
Watershed population: 31,780
Overall water quality: Fair
Problematic pollutants: occasional turbidity and low dissolved oxygen, primarily problems with 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). 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 summarized below (Table 11.1).

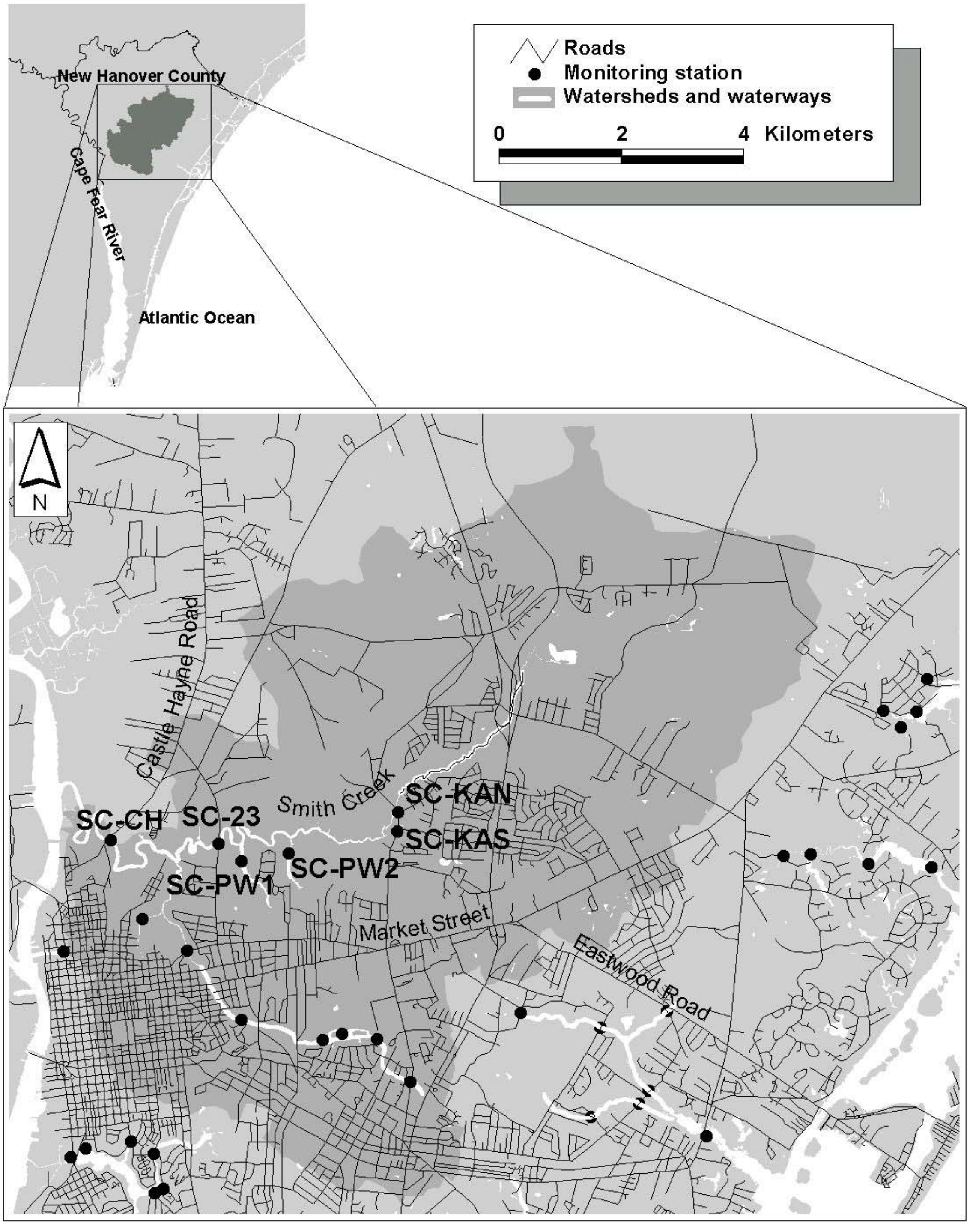
The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters, is 4.0 mg/L, violated one time in our 2014 samples. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded in our 2014 samples.

Nutrient concentrations were low to moderate in 2014 (Table 11.1). There were no algal blooms present upon any of our 2014 sampling occasions. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on two sampling occasions at SC-CH in 2014, for a Fair rating (Table 11.1).

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range, 2014, n = 12 samples collected.

Parameter	SC-CH	
	Mean (SD)	Range
Salinity (ppt)	2.9 (3.6)	0.1-9.8
Dissolved oxygen (mg/L)	7.0 (2.8)	3.8-11.7
Turbidity (NTU)	8 (4)	1-14
TSS (mg/L)	13.8 (5.6)	3.8-23.7
Ammonium (mg/L)	0.064 (0.044)	0.010-0.170
Nitrate (mg/l)	0.298 (0.157)	0.050-0.640
Orthophosphate (mg/L)	0.028 (0.017)	0.000-0.050
Chlorophyll a (µg/L)	3.0 (2.0)	1-9
Fecal col. /100 mL (geomean / range)	108	37-819

Figure 11.1 Smith Creek watershed



12.0 Whiskey Creek

Snapshot
Watershed area: 2,078 acres (842 ha)
Impervious surface coverage: 25.1% (2014)
Watershed population: 7,980
Overall Water Quality: Fair
Problematic pollutants: High fecal coliform counts; minor low dissolved oxygen issue

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 2014 salinity at this station was relatively high, what scientists consider euhaline, ranging from 26 – 32 ppt and averaging about 28 ppt (Table 12.1).

Dissolved oxygen concentrations were below the State standard on one of six sampling occasions at WC-MLR (Table 12.1). Turbidity was within state standards for tidal waters on all sampling occasions (Table 12.1; Appendix B). Suspended solids were low to moderate in 2014. Algal blooms are relatively rare in this creek and there were no blooms detected in our 2014 sampling (Table 12.1). Nitrate, ammonium and orthophosphate concentrations were generally low at this station. Total nitrogen and total phosphorus were low, similar to previous years.

Whereas in 2013 fecal coliform bacteria slightly exceeded the state standard on three of six occasions, in 2014 the standard was exceeded on two of six occasions, with a very high count of 19,000 CFU/100 mL in November 2014 (Table 12.1). 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.

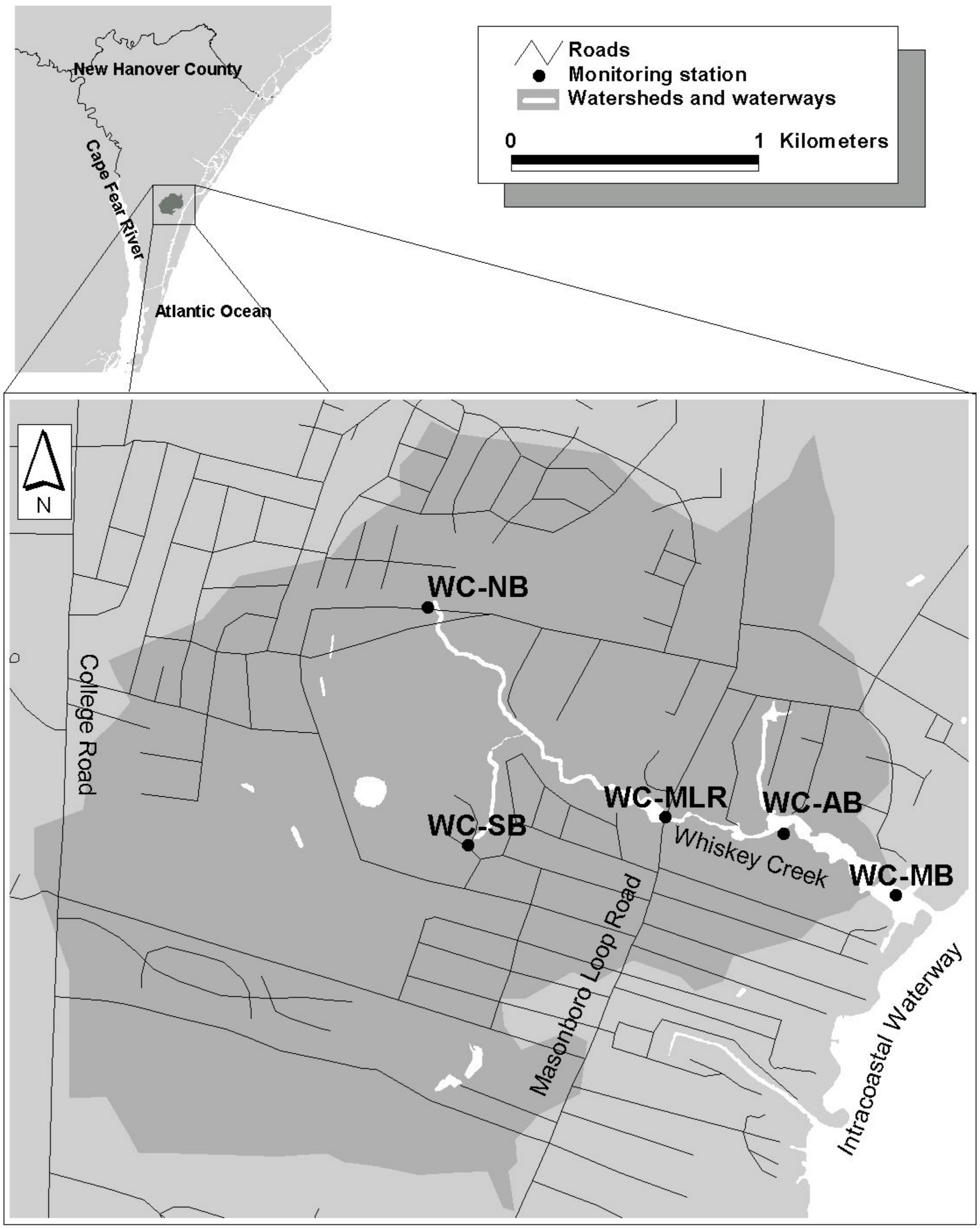
Table 12.1. Water quality summary statistics for Whiskey Creek, 2014, presented as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 6 samples collected.

	Salinity (ppt)	DO (mg/L)	Turbidity (NTU)	TSS (mg/L)	Chlor *a* (μg/L)	FC CFU/100 mL
WC-MLR	28.4 (2.5)	6.7 (2.0)	3 (2)	16.0 (5.0)	6 (5)	170
	25.8-31.8	3.8-9.0	0-5	9.9-22.4	2-15	5-19,000

Table 12.2. Nutrient concentration summary statistics for Whiskey Creek, 2014, as mean (standard deviation) / range, N/P ratio as mean / median, n = 6 samples collected.

	Nitrate (mg/L)	Ammonium (mg/L)	TN (mg/L)	Phosphate (mg/L)	TP (mg/L)	N/P ratio
WC-MLR	0.02 (0.02)	0.06 (0.12)	0.36 (0.25)	0.02 (0.02)	0.04 (0.02)	9.4
	0.01-0.07	0.01-0.31	0.05-0.70	0.01-0.05	0.01-0.06	6.6

Figure 12.1. Whiskey Creek. Watershed and sampling sites.



13.0 Sediment Metals and Chemical Toxins: Results of a 4-Year Summary

Abstract

Between 2010 and 2014 we collected 37 sediment samples among 8 tidal creeks and urban Greenfield Lake in Wilmington, North Carolina. Samples were analyzed using standard methods for EPA priority pollutant metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), total nitrogen (TN) and total phosphorus (TP). Watersheds draining into each site were assessed using GIS techniques for size and percent impervious surface coverage, and correlation analyses were used to compare pollutant concentrations with demographic attributes. Excessively high PAH concentrations, as well as high levels of arsenic, copper, mercury, lead and zinc were found in Greenfield Lake (37% impervious coverage), Burnt Mill Creek (34% impervious coverage) and Bradley Creek (28% impervious coverage). Highest TN concentrations occurred in Burnt Mill Creek sediments, and highest TP levels occurred in Greenfield Lake sediments. PCBs were not at problematic concentrations in the sample set. The most common polluting individual PAHs were pyrene, fluoranthene, phenanthrene, chrysene, anthracene, benzo(a)anthracene and benzo(a)pyrene. Watersheds draining residential neighborhoods rarely had elevated metals or PAHs, although TN was rather high in some of these. Watersheds draining commercial areas yielded highest sediment PAH concentrations, while the two marina sites sampled had elevated copper and zinc in the sediments. Correlation analyses found that concentrations of total PAHs, as well as several individual PAHs were strongly correlated with percent watershed impervious surface coverage. Sediment phosphorus levels were correlated with impervious coverage, but sediment TN was not. Watershed area was not a significant predictor of pollution concentrations in this urban area.

Introduction

Metals and other toxic compounds tend to accumulate in the sediments of water bodies. If accumulations are high enough, they can be toxic to or impact the reproduction of benthic organisms, i.e. the invertebrates that dwell on the bottom. 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 13.1) 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).

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, plasticizers, 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).

Table 13.1. Guideline values for sediment metals and organic pollutant concentrations 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
	Dry wt., ppm = µg/g = mg/kg	
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
	Dry wt., ppb = ng/g = µg/kg	
Total PCBs	22.7	180.0
Total DDT	1.6	46.1
Total PAHs	4,020	44,800
Anthracene	85.3	1,100
Phenanthrene	240	1,500
Pyrene	665	2,600
Flouranthene	600	5,100
Benzo(a)pyrene	430	1,600
B(a)anthracene	261	1,600
Chrysene	384	2,800

Methods

- In consultation with Dave Mayes, Wilmington Stormwater Services Manager, we chose 37 locations throughout 8 Wilmington watersheds for sediment analyses.

- Between 2010 and 2013 samples were collected once at each site between for analyses of metals, PCBs, PAHs, total nitrogen, total phosphorus and organic carbon, which were analyzed by a state-certified laboratory.
- Samples were collected by combining several subsamples at each site into a stainless steel bowl, mixing the material, and placing the samples into a sealed glass jar. Samples were kept frozen until analysis.
- GIS techniques were used to determine subwatershed size and impervious surface coverage. ESRI Spatial Analyst tools were used in a series of literature-based hydrology techniques to determine contributing area for each sampling site. City, county and state data bases were used in a user-based assessment of catchment impervious cover – see Appendix D for these sub-watershed data.
- Academically-derived levels of concern were used to place sediment pollutant concentrations into meaningful biological perspectives following Long et al. (1995).
- Correlation analyses using SAS (Schlotzhauer and Littell 1997) were used to compare pollutant concentrations with the demographic attributes watershed area and watershed percent impervious surface coverage

Results

PCBs were not found to be at problematic concentrations in the Wilmington area. However, PAHs were at known toxic levels in several locations, especially the most highly developed drainages sampled. As such, elevated PAHs were found in Burnt Mill Creek, Greenfield Lake, Bradley Creek and Whiskey Creek (Table 13.2). PAHs are often associated with automobile use, and these locations are likely to see runoff from heavily-traveled roads as well as well-used parking lots. The most frequently problematic individual PAHs found in excessive concentrations are listed in Table 13.3.

<u>PAHs</u>: The individual site with the highest PAH pollution was Station KA-1 on Burnt Mill Creek. This headwaters site receives runoff from College Rd., businesses on that road, and some parking lots on UNCW campus, areas totaling 63% impervious surface coverage. Next highest was GL SS-1, the upper area of Silver Stream, a lengthy wet detention pond draining into Greenfield Lake. This site has 67% impervious coverage and collects runoff from 17th St. and businesses along that roadway. Third was GL-2340, an upper Greenfield Lake site draining a 53% impervious surface coverage sub-watershed. Other locations with elevated PAHs were stations GL-LB, GL-P and GL-YD in Greenfield Lake drainage, BC-CA in upper Bradley Creek, and BMC-OD in lower Burnt Mill Creek. Impervious surface coverage of these sites ranged from 63-82%. Total PAH concentrations were strongly correlated with watershed impervious surface coverage ($r = 0.50$, $p = 0.002$). The individual PAH compounds listed in Table 13.3 were also positively correlated with impervious surface coverage (Fig. 13.1).

<u>Metals</u>: Metals concentrations were not correlated with watershed size or watershed impervious surface area. Lead was the most metal most frequently found in excess concentrations (Table 13.2). it was particularly abundant in Burnt Mill Creek and Greenfield Lake. As there are no industrial sources nearby, is possibly a legacy pollutant left over from the period when lead was a common gasoline additive.

Table 13.2. The most polluted sediment sites in Wilmington watersheds system and principal associated pollutants.

Upper and Lower Burnt Mill Creek	PAHs, Hg, Pb, Zn, TN, TP
Greenfield Lake	PAHs, Pb, Zn, TP
Upper and Lower Bradley Creek	PAHs, As, Cu
Upper Smith Creek	As
Whiskey Creek	PAHs, Cu

Table 13.3. The most common and abundant polycyclic aromatic hydrocarbons (PAHs) in urban sediments of New Hanover county, N.C.

PAH	Polluted watersheds
Anthracene	Greenfield Lake
Benzo(a)anthracene	Greenfield Lake, Barnards Creek, Bradley Creek
Chrysene	Bradley Creek, Smith Creek
Fluoranthene	Greenfield Lake, Bradley Creek, Burnt Mill Creek, Smith Creek
Phenanthrene	Greenfield Lake, Bradley Creek
Pyrene	Greenfield Lake, Bradley Creek, Burnt Mill Creek
Benzo(a)pyrene	Bradley Creek

Copper was found in excess at two marina locations. At the Whiskey Creek Marina (WC-MB) the only metal found in excessive sediment concentrations was copper. Likewise this metal, along with arsenic, was found in samples from the Bradley Creek marina site BC-76 (Table 13.2). It is likely that leachate of copper from boat paints accounted for the excessive concentrations in these two locations. Other sites with high sediment copper included stations in Greenfield Lake and Burnt Mill Creek.

Zinc (Zn) was particularly concentrated in lower Burnt Mill Creek sites, as well as Greenfield Lake. As mentioned, excessive arsenic (As) was found in sediments of Bradley Creek Marina (BC-76), as well as the south branch of Smith Creek at Kerr Avenue (SC-KAS). Other locations in Bradley Creek and Burnt Mill Creek had somewhat elevated levels. Mercury was generally not problematic except for lower Burnt Mill Creek at Princess Place (BMC-PP) and Jumping Run Branch (GL-JRB) a tributary of Greenfield Lake.

<u>Nutrients</u>: the highest concentrations of total nitrogen (TN) were found in the sediments of lower Burnt Mill Creek, followed by Greenfield Lake. The south branch of Hewletts Creek, SB-PGR, draining mostly suburban areas, also showed high TN concentrations. TN was not significantly correlated with watershed size or impervious surface coverage. Sources of TN are likely runoff of fertilizers from suburban areas and ornamental vegetation in commercial areas.

Greenfield Lake also had the highest levels of sediment total phosphorus (TP), followed by lower Burnt Mill Creek (BMC-PP). TP was significantly correlated with percent watershed impervious surface coverage ($r = 0.43$, $p = 0.012$). An important source of phosphorus in Greenfield Lake is waterfowl guano, especially in winter. Other likely sources are runoff of fertilizers along with suspended sediments during rain events.

<u>Organic carbon</u>: Total organic carbon (TOC) within the sediments was inversely related to impervious coverage ($R = -0.399$, $p = 0.014$). A similar result occurred with surface tidal creek waters in this region previously (Mallin et al. 2009). As organic carbon is related to decomposition of plant material, natural areas would be expected to have higher TOC levels.

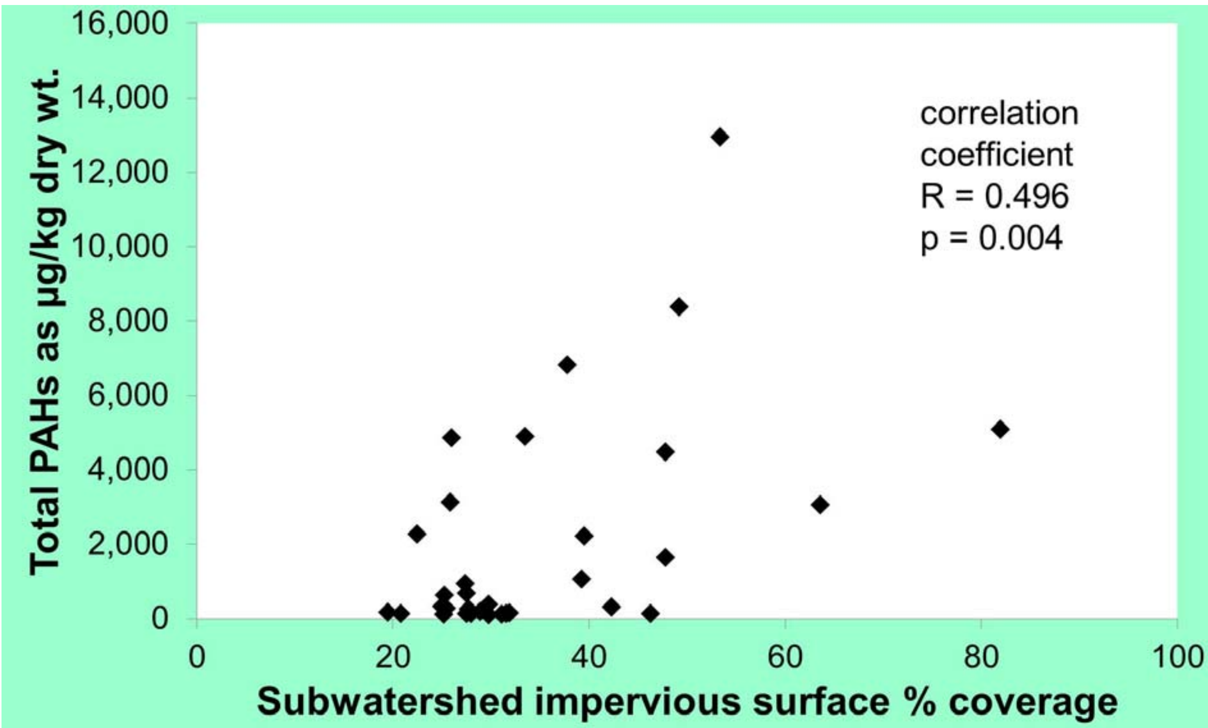


Figure 13.1.. Relationship between sub-watershed percent impervious surface coverage and total polycyclic aromatic hydrocarbons. When PAH concentrations are log transformed regression analyses shows a relatively strong positive r^2 value of 0.48 for % impervious cover as a PAH predictor. The two sites with highest PAH concentrations (114,330 at BMC-KA1 and 51,480 µg/kg at GL-SS1) were removed for better presentation.

Conclusions

- Of the sites chosen (biased toward subwatersheds of considerable usage) the average impervious surface coverage was 36.5%, median was 29.5% and maximum percent coverage was 82%.
- As there is little heavy industry within the city the subwatersheds with highest impervious cover were largely commercial.
- Total PAHs as well as six individual PAH compounds were significantly correlated with subwatershed percent impervious coverage.
- While several metals were found at high concentrations in the more highly-developed subwatersheds, impervious coverage was not a significant predictor of metals in this largely residential and commercial city.
- Polychlorinated biphenyls (PCBs) were in low concentrations in these sediment samples.
- Whereas TP was significantly correlated with impervious coverage, TN was not.
- Total organic carbon within the sediments was inversely related to impervious coverage ($R = -0.399$, $p = 0.014$). A similar result occurred with surface tidal creek waters in this region previously (Mallin et al. 2009).

14.0. Analysis of Fecal Coliform Bacteria and Optical Brighteners in the Bradley Creek Watershed

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Abstract
The purpose of this project was to assess the concentrations of fecal coliform bacteria and optical brighteners in the Bradley Creek watershed, which is centrally located in the New Hanover County. Monitoring efforts have persisted over the years and are essential for assessing the health of the watershed. Sampling for fecal coliform bacteria and optical brighteners are effective techniques for assessing water quality in watersheds that might be affected by sewage and septic breaches. Finding high concentrations of fecal coliform bacteria and possible sewage breaches in the watershed is very likely as the watershed is susceptible to human waste due to the infrastructure and activities surrounding the location. This project collected data from five stations along the Bradley Creek watershed. All five stations were sampled during rainy and dry periods to analyze the fluctuations in concentrations of optical brighteners and fecal coliform bacteria during these types of events. Two locations, Stations BC-SD and BC-SBU had strongly correlated fecal coliform and optical brightener concentrations, indicating probable sewage spills or leaks.

Introduction
The southeastern portion of the United States has been affected by some of the nation's most rapid growth and urbanization. This rapid development influences the hydrological processes of many regions and their watersheds, altering their natural progression (O'Driscoll et al., 2010). Among New Hanover County tidal creeks, urban development has been heavy around the Bradley Creek watershed. It is the largest watershed in New Hanover County, covering 4,631 acres with a reported 28% surface area that is considered impervious that empties into the Atlantic Intracoastal Waterway (Tavares et al., 2008; Mallin et al., 2013). Urban development increases the amount of impervious surface area and introduces waste water systems such as septic systems and sewage lines to the region (O'Driscoll et al., 2010). Sewage leaks and runoff from rainfall events are ways in which pollutants, such as fecal pollution, can be introduced into an estuarine system from urbanized areas (Tavares et al., 2008). Urban development around Bradley Creek encroaches onto the area surrounding the watershed, increasing the likelihood of introducing pollutants into the estuarine system. Due to this increased development, Bradley Creek has the highest levels of pollution throughout the county (Mallin et al., 2013).

According to USEPA (2012), sampling for fecal and coliform bacteria is a common method in assessing the water quality within a watershed searching for potential sources of fecal pollution. The two groups of bacteria, fecal streptococci and coliforms, are collectively known as fecal coliform bacteria that are found in the intestinal tracts of warm-blooded animals, including humans, which are introduced into the environment through fecal matter (USEPA, 2012). Sampling for fecal coliform bacteria in estuarine waters can help to establish the potential for organisms that may be pathogenic to be present (Murphy, 2007). Fecal coliform bacteria are considered to be largely benign; however, they are good indicators of possible pathogens when found in dense concentrations that can be a potential health hazard (USEPA, 2012). The maximum acceptable concentration standard for fecal coliform bacteria is 200 organisms per 100mL in freshwater and 14 organisms per 100mL in saltwater (NCDENR, 2013). Prior research has shown that fecal coliform bacteria are a major pollutant in the Bradley Creek watershed (Mallin et al. 2013).

Another water quality assessment method is sampling for optical brighteners. Optical brighteners are utilized in several different manufacturing processes, including the many brands of laundry detergent on the market today. They are utilized in laundry detergent to enhance the ability of the detergent to allow clothing to appear brighter in their respective colors after washing (Tavares et al., 2008). The presences of optical brighteners, which are introduced into sewage systems after household and commercial use, in local watersheds are indicators of human wastewater influx. They can help to indicate sources of sewage leaks and septic leachate in urbanized areas. Optical brighteners respond to light within the range of 360-365nm and emit wavelengths that are in the range of 400-440nm. The emitted wavelengths of light given off due to the use of optical brighteners are capable of being analyzed by a fluorometer in order to measure their concentrations.

Methods

Water samples from five stations located along the upper portions of the Bradley Creek watershed were collected and analyzed for fecal coliform bacteria and optical brightener concentrations. The samples were primarily from freshwater sources that eventually flow downstream prior to reaching the saltwater interface of the watershed. Sampling from the upper portion of the watershed allowed for the water samples to be in closer proximity to sources of fecal coliform bacteria and optical brighteners entering the watershed. Six samples were taken from each station, consisting of 3 dry period samples and 3 wet period samples. The 3 samples collected during dry periods where there had been no recent rainfall help to identify possible sources of sewage leaks as populations of fecal coliform bacteria could potentially increase. The 3 wet period samples were collected after recent (within 5 days) rainfall events in order to account for the flux of fecal coliform bacteria into the watershed system influenced from sources on the surface such as animal waste carried in stormwater runoff.

The 5 stations that were sampled (see Fig. 14.1, also station coordinates in Table 14.1), include some previously sampled locations of past water quality monitoring projects conducted by the Center for Marine Science at the University of North Carolina Wilmington. Station BC-RAC is situated furthest upstream from the watershed than all other stations. BC-RAC is located near Racine Drive between two apartment complexes behind a shopping center adjacent to College Road. The second station sampled was BC-CA. This location had been sampled previously in other water quality assessment studies. Station BC-CA is located along College Acres Drive. BC-CA has been a site where an increase in fecal coliform bacteria averages over the past few years have been documented and was a location of where a sewage spill occurred in 2007 (Mallin et al. 2008). It is downstream from BC-RAC in a residential neighborhood. These two stations fed into the northern neck of the Bradley Creek. The other three stations feed into the southern neck of Bradley Creek. Station BC-CCT was located on Rose Avenue adjacent to the Cross City Trail and the woods behind the university, and collects campus drainage. Station BC-SBU was another station located within a residential neighborhood and was included in previous studies. BC-SBU is situated off of Andover Road. The final station is located closest to Bradley Creek. Station BC-SD was located along a public works right of way in the Surrey Downs neighborhood behind a horse farm adjacent to Wrightsville Avenue. The station was located in a wooded region along the southern neck of Bradley Creek. This station was situated in close proximity to a city drainage system that was present in the right of way access trail. There were two manhole entrances into the drainage system along the pathway.

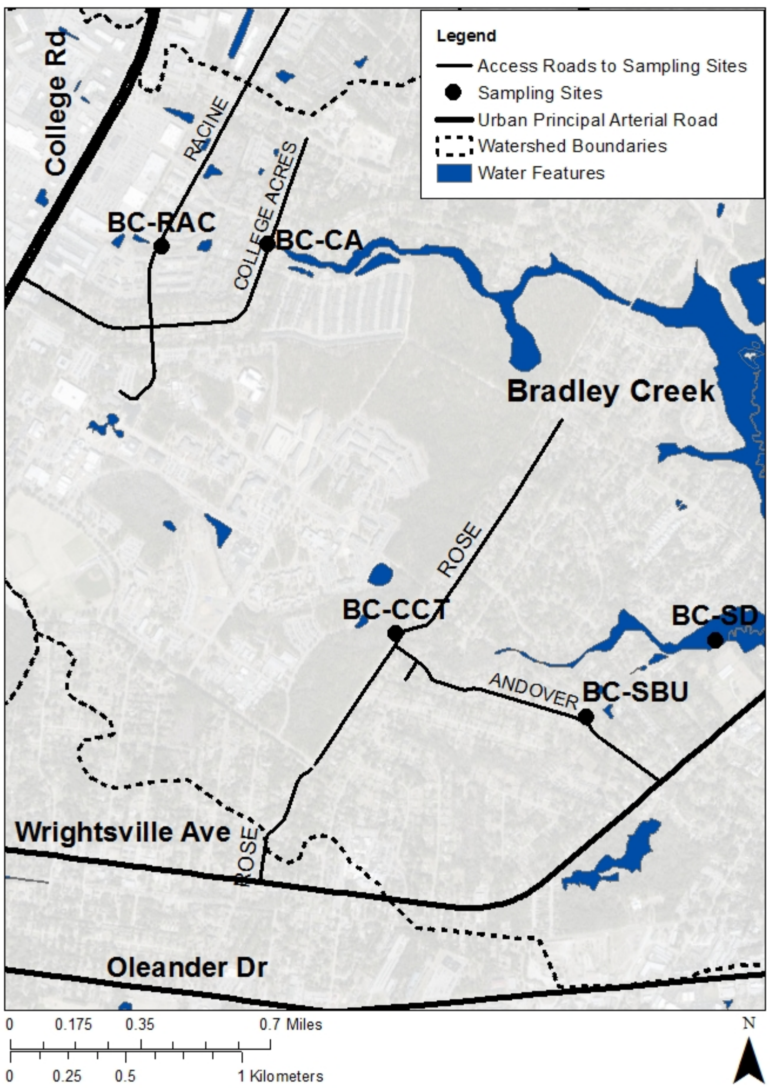

Figure 14.1. Bradley Creek watershed special study sampling station locations.

Table 14.1. Sampling station coordinates in the Bradley Creek watershed.

BC – RAC	34.23252˚N	77.87067˚W
BC – CA	34.23261˚N	77.86656˚W
BC – CCT	34.22008˚N	77.86155˚W
BC- SD	34.21988˚N	77.84915˚W
BC – SBU	34.21741˚N	77.85417˚W

Samples were collected in 500mL sterilized Pyrex glass bottles just beneath the surface to prevent influx of material that might have been present on the water surface. The bottle was placed directly on ice for storage and transported back to the laboratory for analysis within a 6-hr holding time.

Samples were filtered in duplicates of 1mL and 10mL increments onto a 0.45µm membrane filter, placed in petri dishes containing the mFC agar, and placed in Ziploc bags then incubated in a water bath for a period of 24 hours (±1 hour) at 44.5˚C . After the 24-hour period, the petri dishes were removed from the water bath and inspected for the presence of fecal coliform bacteria that appear as blue colonies on the petri dishes. Having redundant samples ensures an accurate count of the fecal coliform colonies as some samples may contain dense concentrations of colonies that are too difficult to count. High populations increase stress on many colonies within the sample due to high competition for nutrients. When populations were excessive, they were deemed to be too numerous to be accurately enumerated. State laboratory standards require that the optimal population counts per petri dish are deemed to be between 20-80 colonies per 10 mL sample. The laboratory standard at UNCW allows for counts to be from 150-200 colonies per petri dish if possible to decipher separate colonies and ensure an accurate census. The accepted results were multiplied for each petri dish sample, 100 for 1mL samples and 10 for 10mL samples.

Samples for optical brighteners were taken directly from the 500mL Pyrex bottles that were used to acquire the station sample and placed on ice while prohibiting exposure to light. Although there is some debate as to the decay rates of optical brighteners, it is accepted that exposure to UV light will degrade optical brighteners in water samples which is the reasoning for prohibiting exposure to light (Tavares et al. 2008). Each sample can be stored in a cool, dark environment place for up to 10 days. In the laboratory a portion of the sample was transferred to Nalgene 125mL bottles for analysis. The samples were analyzed with a Turner Designs handheld fluorometer. Calibration of the unit was conducted by utilizing 100 mg of Tide laundry detergent. The detergent is mixed with 1L of distilled water resulting in a fluorometeric value of 100. Prior to sampling, it was necessary to acquire blank value from a sample of distilled water. Water samples were then transferred to cuvettes that were analyzed for 10 seconds with the value being recorded. Each sample was analyzed in triplicate with the mean of each sample being reported.

Basic summary statistics were performed on all the data collected for optical brighteners and fecal coliform bacteria counts. Averages for each indicator were calculated and recorded to apply to graphical data in order to identify trends and possible sources of sewage leaks. Fecal coliform bacteria colony counts were computed in relation to a 100mL sample, and geometric means generated for station-to-station comparisons. Calculating geometric means for fecal coliform analysis was the preferred method of analysis as the data were highly variable due to the data ranges being quite excessive, which inhibits a normal distribution of the data set. In order to apply analysis of the counts to the same order of magnitude as the optical brighteners, it is necessary to calculate the geometric means of each stations data results. Correlation analyses were performed between fecal coliform counts and optical brightener concentrations. This was done to establish the possible relationships between both indicators and if there may be sewage leaks being introduced into the system.

Results

The raw data indicated that the fecal coliform bacteria counts ranged were from 0-6,300 CFU/100mL for all stations. It should be noted that a few samples at 10mL were considered to be too numerous to assess, which in these cases the 1mL sample counts were utilized as previously discussed. Geometric means were computed for the raw data that ranged from 60-5,800 CFU/100mL among all the stations (Table 14.2 and Figure 14.2). The lowest concentrations were recorded at station BC-CCT and the highest readings were recorded at station BC-CA. The data for the optical brightener analysis had an average fluorometric value range from 7.5 to 42.0 with the lowest value being recorded at BC-CA and the highest value being recorded at BC-SBU (Table 14.3).

Correlation analyses conducted for fecal coliform bacteria and optical brighteners concluded with mixed results for the watershed, according to station. Correlation analysis indicated a strong positive relationship between the two parameters at stations BC-SD (Figure 14.4) and BC-SBU (Figure 14.5). Stations BC-CA (Fig. 14.6), BC-RAC (Fig. 14.7) and BC-CCT (Fig. 14.8) had non-significant correlations that would suggest no relationship between the two variables.

Discussion

Bradley Creek, being the largest watershed in the New Hanover county area, has had many problems with pollution and sewage breaches before in the past. Concerns over the water quality date back as far as 1947 when the first shellfish bed closure occurred within the watershed (Tavares et al., 2008). In recent years sewage leaks (Tavares et al. 2008) and sewage spills (Mallin et al. 2007) have been documented from this urbanized creek. The results of this study are consistent with previous research that established the case for pollution issues with Bradley Creek, which exceeds the state’s maximum acceptable concentration standard for fecal coliform bacteria.

The data gathered from all five stations expressed inverse relationships for both indicators during dry periods and rain events. Higher fecal coliform counts tended to occur during rain events with lower optical brightener levels during the same events. Optical brightener concentrations tended to be higher during dry periods while fecal coliform counts were relatively lower. The rise in fecal bacteria counts during rain events can be attributed to fecal bacterial flux from stormwater runoff during rain events (Tavares et al., 2008). In regards to optical brighteners, the trend could be interpreted as the accumulation of optical brighteners during dry periods within the watershed. Once the area is exposed to a rain event, the watershed will begin to flush the reservoirs in a short period of time. Flushing of the system appears to inhibit the significant accumulation of optical brighteners within the watershed. The build-up of optical brighteners within the system during dry periods can be an indication of a possible sewage leak into the Bradley Creek watershed whether slight or significant. However, other sources of manmade substances could influence the levels of optical brighteners, which would include coolants from automobile radiators and paper products. There are types of organic matter that fluoresce that could influence the levels that were witnessed in this and previous water quality assessments (Tavares et al. 2008).

The correlation analyses between fecal coliform bacteria and optical brighteners resulted in strong positive relationships at both stations BC-SD and BC-SBU. This relationship between fecal coliform bacteria counts and the concentration of optical brighteners can be an indication of human waste entering into the watershed (Tavares et al. 2008). These stations are located furthest downstream on the south branch of the Bradley Creek watershed. The large concentration of suburban development that is adjacent to the watershed flowing along this path provides many sources that are likely influencing these results. Even with station BC-SD being located in an isolated area, the results of the positive correlation appears to result in the influence of possible human waste sources rather than stormwater runoff alone. The city sewage drainage system that is present near this station could be a potential source for this result. The remaining stations did not demonstrate a significant relationship between fecal coliform counts and optical brightener concentrations. The periodic high fecal coliform counts are thus likely to stormwater runoff at these sites.

Table 14.2. Geometric mean fecal coliform (FC) and mean optical brightener (OB) (+/-) standard deviation, for each sample collected.

Date	Station	FC	OB	Standard Deviation
3/7	BC-RAC	685	8.4	0.02
3/11	BC-RAC	463	22.6	0.09
3/16	BC-RAC	1006	15.4	0.06
3/24	BC-RAC	643	24.2	0.12
3/29	BC-RAC	681	8.9	0.04
4/5	BC-RAC	283	24.8	0.44
3/7	BC-CA	947	7.5	0.09
3/11	BC-CA	175	18.7	0.16
3/16	BC-CA	5778	21.5	0.15
3/24	BC-CA	905	25.2	0.16
3/29	BC-CA	808	9.6	0.04
4/5	BC-CA	410	25.4	0.05
3/7	BC-CCT	949	10.9	0.08
3/11	BC-CCT	52	15.6	0.03
3/16	BC-CCT	865	20.4	0.06
3/24	BC-CCT	100	17.5	0.12
3/29	BC-CCT	516	14.4	0.03
4/5	BC-CCT	160	19.2	0.07
3/7	BC-SD	1442	22.3	0.1
3/11	BC-SD	249	20.1	0.04
3/16	BC-SD	700	19.0	0.23
3/24	BC-SD	305	17.9	0.05
3/29	BC-SD	1208	24.6	0.14
4/5	BC-SD	253	18.7	0.1
3/7	BC-SBU	1707	42.0	0.11
3/11	BC-SBU	294	33.4	0.17
3/16	BC-SBU	429	29.2	0.09
3/24	BC-SBU	177	27.3	0.16
3/29	BC-SBU	1338	40.0	0.42
4/5	BC-SBU	330	31.3	0.08

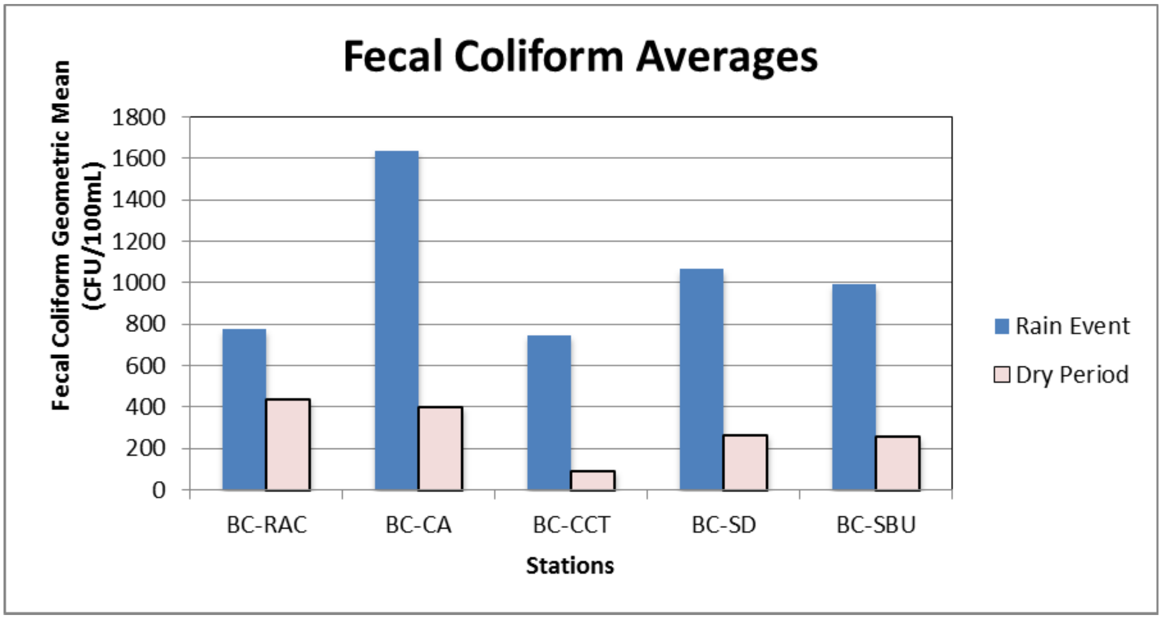

Figure 14.2. Geometric means of fecal coliform bacteria counts by station, demonstrating higher counts at all sites during wet periods as opposed to dry periods.

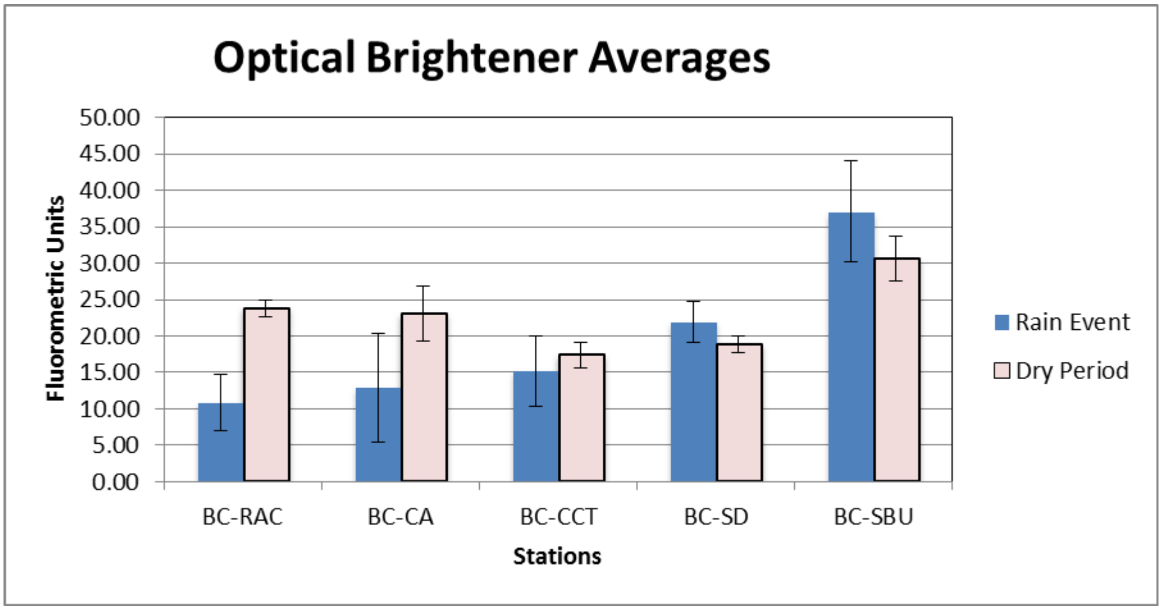

Figure 14.3. Average optical brightener concentrations (+/-) standard deviation by station, for dry and wet periods.

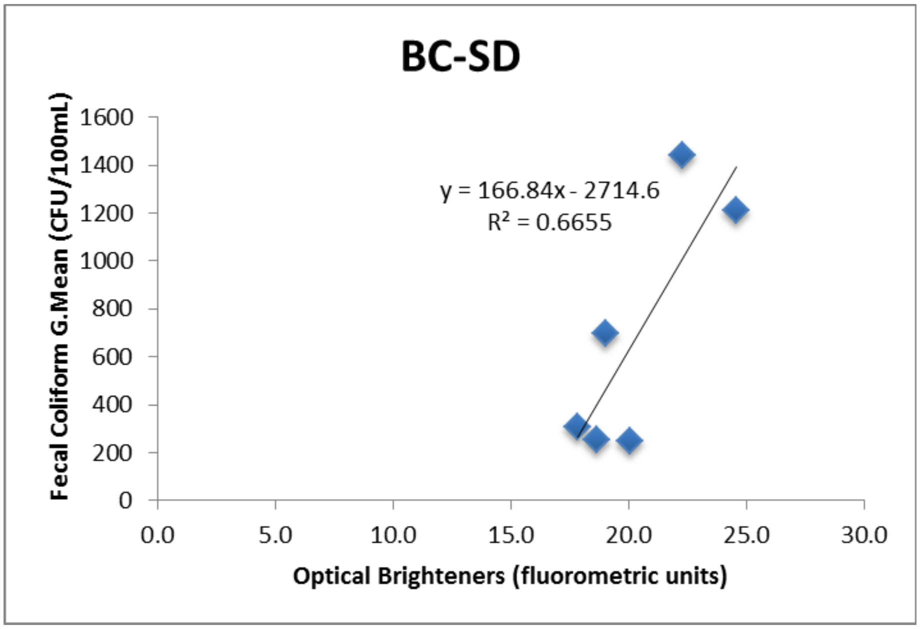

Figure 14.4. Strong positive correlation between fecal coliform counts and optical brightener concentrations at Station BC-SD, located near sewage infrastructure in south branch of Bradley Creek.

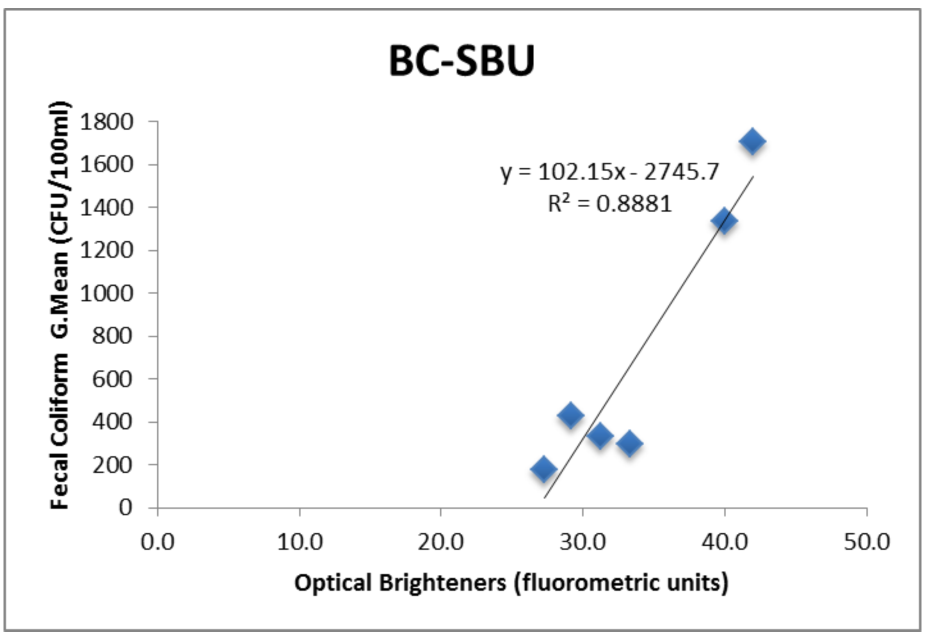

Figure 14.5. Strong positive correlation between fecal coliform counts and optical brightener concentrations at Station BC-SBU, located along Andover Rd. near the south branch of Bradley Creek.

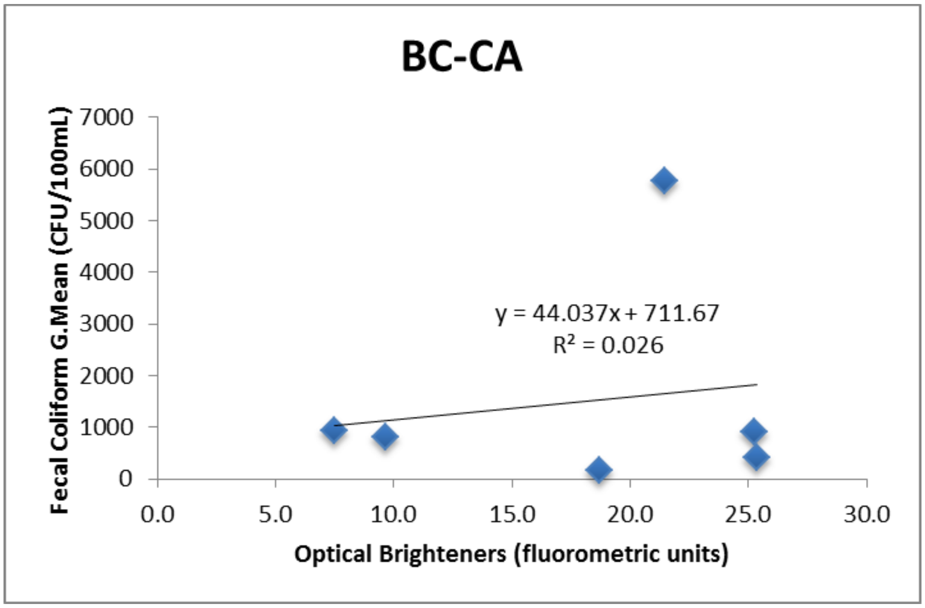

Figure 14.6. Lack of a significant positive relationship between fecal coliform counts and optical brightener concentrations at Station BC-CA along College Acres Dr.

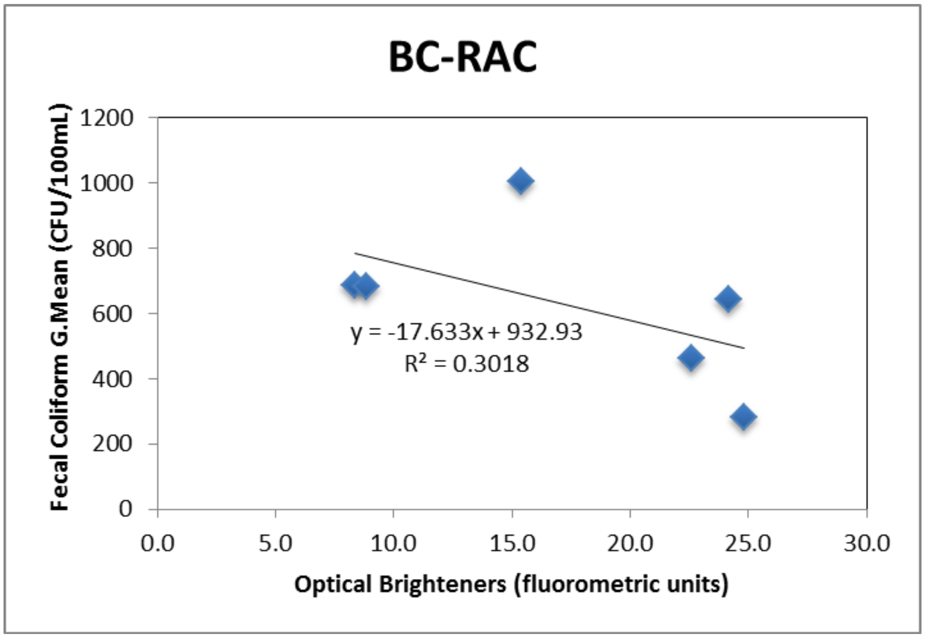

Figure 14.7. Lack of a significant positive relationship between fecal coliform counts and optical brightener concentrations at Station BC-RAC along Racine Dr.

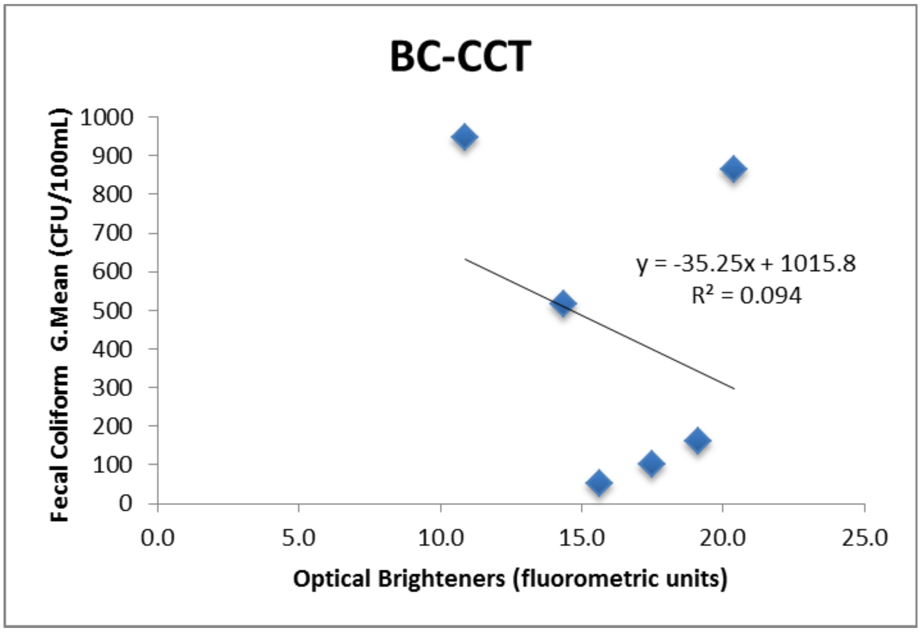

Figure 14.8. Lack of a significant positive relationship between fecal coliform counts and optical brightener concentrations at Station BC-CCT, along Rose Avenue draining UNCW campus.

Conclusions

Fecal coliform counts in the 5 upper Bradley Creek watershed stations sampled in 2014 showed highest counts at station BC-CA, along College Acres Dr., and generally lowest counts at Station BC-CCT, located along Rose Avenue and draining UNCW campus. At all sites wet period counts exceeded dry period counts, demonstrating the polluting impact of stormwater runoff in this urbanized watershed.

Two locations from the study, BC-SBU along Andover Road, and BC-SD among sewage infrastructure behind the horse farm on Wrightsville Avenue (Fig. 14.1), can be strongly argued as being influenced by sources of sewage leaking into the system that should be further investigated for mitigation purposes. In regards to the results of the remaining stations, a proactive approach to the problem of fecal pollution in the watershed will help to reduce the number of bacteria being introduced through stormwater runoff. During the study, it was noticed at station BC-RAC, there were proactive measures in place. Pet waste stations were placed on the property to encourage the residents to clean up after their pets. Simple methods such as this will help to reduce levels of fecal coliform bacteria being introduced into the watershed. With the sources of human influenced waste from sewage systems and other sources of pollution introduced through stormwater runoff, urbanization has negatively affected the water quality of the Bradley Creek watershed system.

15.0 Special Pollution Investigations

Periodically the City Stormwater Services and UNCW collaborate on special investigations to further assess deliberate or accidental sewage discharges, stormwater problems, or other pollution incidents.

Beth Nunnally of City Stormwater Services, along with Matthew McIver and Dr. Mike Mallin of UNC Wilmington did a site visit to a bus terminal on the corner of Evans St. and Market St. on October 3, 2014. We collected sediment samples from the storm drain on Evans St. that collects drainage from the bus terminal. Results showed that both copper and zinc were at elevated concentrations that are considered bad for invertebrate health.

Note we have no sediment ammonia baseline for natural areas. However, the ammonium in the sediments was at 266 ppm, which would be a factor of 123 times that of ammonia in the Burnt Mill Creek water column, i.e. that is very high for what one might expect in an ordinary street storm drain.

Oil and grease concentrations were at 15,300 ppm. That is 3,000 times the concentration of oil and grease in the Burnt Mill Creek water column, again very high. Photographic evidence was collected that shows the storm drain, the sampling, the oil splatter on the road, and the busses.

Matthew McIver, Dr. Mike Mallin, and Beth Nunnally, along with other members of City staff revisited the site on December 5, 2014. We sampled sediments on-site adjoining the only stormwater drain for the bus terminal, as well as standing water from under the nearest on-site bus.

Water sample: the water sample (see report cover photo) collected from under the bus had a fecal coliform count of 2,000 CFU/100 mL, 10X the standard for Class C waters. Lead concentrations in the standing water were 0.246 mg/L, which is 10X the Class C water standard for lead (0.025 mg/L). There is no NC or US standard for grease and oil due to the various compounds in it. However, the Association of Southeast Asian Nations has a proposed interim standard for marine waters of 0.14 mg/L. As a comparison, the water under the bus had 57.0 mg/L, or 400X the proposed Asian marine standard.

Sediments: The grease and oil concentration was extremely high, at 105,000 mg/kg. The interference from the oil prevented the contract lab from being able to accurately analyze PAHs in the sediments. The contract lab report states:
"the sediment sample contained an excessive amount of material that had the chromatographic profile of a hydrocarbon mixture such as motor oil". The lab diluted the material by 1,000, with the result that PAHs were "<146,000 µg/kg", which is orders of magnitude above toxic PAH concentrations. Further dilutions did not permit proper quality control so a more accurate measurement was not possible.

Thus, our interpretation is that the water pooled under the bus had polluting concentrations of fecal coliform bacteria, lead, and oil, and the sediments next to the storm drain had very high concentrations of oil. As these sample sites were within 1 meter of the only stormwater outfall on-site, in rain events the stormwater would be expected to carry high concentrations of fecal bacteria, ammonium, copper, zinc, lead, and motor oil into the stormwater system that discharges into nearby Burnt Mill Creek.

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17.0 Acknowledgments

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18.0 Appendix A. North Carolina Water Quality standards for selected parameters (NCDENR 2005). 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

19.0 Appendix B. UNCW ratings of sampling stations in Wilmington watersheds based on 2014, where available, for chlorophyll *a*, dissolved oxygen, turbidity, and fecal coliform bacteria (human contact standard) based in part on North Carolina state chemical standards for freshwater or tidal saltwater.

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
Bradley Creek	BC-CA	G	F	G	P
	BC-SB	G	F	G	P
	BC-NB	G	G	G	P
Burnt Mill Creek	BMC-AP1	G	G	G	P
	BMC-AP3	F	G	G	F
	BMC-PP	G	P	G	P
Greenfield Lake	JRB-17	G	F	G	P
	GL-JRB	G	P	G	P
	GL-LC	P	P	G	P
	GL-LB	G	P	G	P
	GL-2340	F	P	G	P
	GL-YD	P	G	G	P
	GL-P	P	G	G	F
Hewletts Creek	HC-3	G	F	G	F
	NB-GLR	G	G	G	P
	MB-PGR	G	G	G	P
	SB-PGR	G	F	G	P
	PVGC-9	F	G	G	P
Howe Creek	HW-GP	G	F	G	P
	HW-DT	G	F	G	P
Smith Creek	SC-CH	G	G	G	P
Whiskey Creek	WC-MLR	G	F	G	P

20.0 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 34.15867	W 77.93784
Bradley Creek	BC-CA	N 34.23260	W 77.86659
	BC-CR	N 34.23070	W 77.85251
	BC-SB	N 34.21963	W 77.84593
	BC-SBU	N 34.21724	W 77.85435
	BC-NB	N 34.22138	W 77.84424
	BC-NBU	N 34.23287	W 77.84036
	BC-76	N 34.21484	W 77.83368
Burnt Mill Creek	BMC-KA1	N 34.22215	W 77.88522
	BMC-KA3	N 34.22279	W 77.88592
	BMC-AP1	N 34.22917	W 77.89173
	BMC-AP2	N 34.23016	W 77.89805
	BMC-AP3	N 34.22901	W 77.90125
	BMC-WP	N 34.24083	W 77.92415
	BMC-PP	N 34.24252	W 77.92515
	BMC-ODC	N 34.24719	W 77.93304
Futch Creek	FC-4	N 34.30150	W 77.74660
	FC-6	N 34.30290	W 77.75050
	FC-8	N 34.30450	W 77.75414
	FC-13	N 34.30352	W 77.75760
	FC-17	N 34.30374	W 77.76370
	FOY	N 34.30704	W 77.75707
Greenfield Lake	GL-SS1	N 34.19963	W 77.92460
	GL-SS2	N 34.20051	W 77.92947
	GL-LC	N 34.20752	W 77.92976
	JRB-17	N 34.21300	W 77.92480
	GL-JRB	N 34.21266	W 77.93157
	GL-LB	N 34.21439	W 77.93559
	GL-2340	N 34.19853	W 77.93556
	GL-YD	N 34.20684	W 77.93193
	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 34.19011	W 77.85062
	HC-NWB	N 34.19512	W 77.86155
	NB-GLR	N 34.19783	W 77.86317

	MB-PGR	N 34.19800	W 77.87088
	SB-PGR	N 34.19019	W 77.86474
	PVGC-9	N 34.19161	W 77.89177
Howe Creek	HW-M	N 34.24765	W 77.78718
	HW-FP	N 34.25468	W 77.79510
	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 34.12924	W 77.91611
Pages Creek	PC-M	N 34.27020	W 77.77123
	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 34.28090	W 77.78485
	PC-BDDS	N 34.28143	W 77.79447
	PC-WB	N 34.27635	W 77.79582
	PC-BDUS	N 34.27702	W 77.80163
	PC-H	N 34.27440	W 77.79890
Smith Creek	SC-23	N 34.25794	W 77.91956
	SC-CH	N 34.25897	W 77.93872
	SC-KAN	N 34.26249	W 77.88759
	SC-KAS	N 34.25964	W 77.88778
Whiskey Creek	WC-NB	N 34.16803	W 77.87648
	WC-SB	N 34.15939	W 77.87481
	WC-MLR	N 34.16015	W 77.86629
	WC-AB	N 34.15967	W 77.86177
	WC-MB	N 34.15748	W 77.85640

21.0 Appendix D. Sampling station sub-watershed drainage area and percent impervious surface coverage, 2015 (compiled by Anna Robuck).

Sampling Station	**Catchment Polygon Area (acres)**	**Percent Impervious**
Hewletts Creek		
PVGC-9	1296.1	27.5%
MB-PGR	2044.5	27.5%
NB-GLR	876.4	29.8%
SB-PGR	1480.2	27.4%
HC-NWB	3185.1	27.4%
HC-3	5117.5	26.6%
HC-2	5557.1	25.3%
HC-M	5642.2	25.0%
Barnards Creek		
BNC-EF	154.6	20.8%
BNC-TR	277.4	25.5%
BNC-AW	196.0	22.2%
BNC-CB	1077.8	31.6%
BNC-RR	3437.3	25.3%
Burnt Mill Creek		
BMC-KA1	191.4	63.3%
BMC-KA3	195.1	62.3%
BMC-AP1	995.1	46.2%
BMC-AP2	1036.4	44.9%
BMC-AP3	1537.2	42.3%
BMC-GS	256.9	47.8%
BMC-WP	2981.9	39.5%
BMC-PP	3030.8	39.3%
BMC-ODC	772.0	47.8%
Bradley Creek		
BC-SBU	439.5	28.0%
BC-NBU	683.6	33.5%
BC-CA	372.1	82.0%
BC-CR	649.7	46.3%
BC-SB	1022.3	28.9%
BC-NB	2047.6	31.9%
BC-76	3589.0	29.8%
Whiskey Creek		
WC-NB	211.6	31.1%
WC-SB	734.7	25.2%

WC-MLR	1378.1	26.0%
WC-AB	1552.2	25.5%
WC-MB	1643.3	25.0%
Futch Creek		
FC-13	726.6	25.6%
FC-17	692.5	25.9%
FC-FOY	2261.0	6.6%
FC-8	1086.6	24.2%
FC-6	3447.4	12.0%
FC-4	3651.2	12.4%
Greenfield Lake		
GL-SS1	140.2	66.8%
GL-SS2	264.1	53.4%
GL-2340	422.2	73.6%
JRB-17	595.4	22.3%
GL-JRB	795.8	25.9%
GL-LC	94.2	63.6%
GL-YD	978.0	30.4%
GL-LB	130.8	49.2%
GL-P	2402.4	37.8%
Motts Creek		
MOT-RR	2350.1	27.7%
Howe Creek		
HW-DT	1255.2	29.4%
HW-GP	1794.3	25.5%
HW-GC	2368.2	25.0%
HW-FP	2737.1	23.8%
HW-M	3103.6	23.0%
Smith Creek		
SC-KAN	10605.4	19.5%
SC-KAS	2153.5	39.5%
SC-23	14803.3	22.6%
SC-CH	15837.8	22.5%
Pages Creek		
PC-BDUS	345.1	25.7%
PC-H	1019.7	22.8%
PC-WB	1444.6	22.9%
PC-BDDS	357.8	27.7%
PC-LD	2296.4	22.2%
PC-OP	1788.9	15.7%
PC-CON	1949.5	15.2%
PC-OL	4378.8	18.7%
PC-M	4615.9	18.3%

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

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