ENVIRONMENTAL QUALITY OF WILMINGTON AND NEW HANOVER COUNTY WATERSHEDS, 2013

by

Michael A. Mallin, Mary Grace Lemon, Matthew R. McIver

CMS Report 14-01
Center for Marine Science
University of North Carolina Wilmington
Wilmington, N.C. 28409

May 2014

http://www.uncw.edu/cms/aelab/

Funded by:

The City of Wilmington through the Water Resources Research Institute of the University of North Carolina, NCSU No. 2010-1651-01

Executive Summary

This report represents combined results of Year 16 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The 2013 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 2013.

Barnards Creek – Barnards Creek drains into the Cape Fear River Estuary. It drains a 4,161 acre watershed that consists of 22.3% impervious surface coverage, and a population of approximately 12,200. Water column sampling was not funded during 2013.

Bradley Creek – Bradley Creek drains a watershed of 4,631 acres, including much of the UNCW campus, into the Atlantic Intracoastal Waterway (ICW). The watershed contains about 27.6% impervious surface coverage, with a population of about 16,470. Three sites were sampled, all from shore. In 2013 there were no significant algal blooms recorded, and average dissolved oxygen was good 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 4,252 acre watershed with a population of about 23,700. Its watershed is extensively urbanized (33.8% impervious surface coverage) and drains into Smith Creek. Three locations were sampled during 2013. This creek had very poor water quality, with high fecal coliform counts occurring at two of the three sites exceeding the human contact standard > 50% of occasions sampled. One major and several minor algal blooms occurred in 2013. Dissolved oxygen concentrations were good in the upper creek and poor in the lower creek in 2013.

The effectiveness of Ann McCrary wet detention pond on Randall Parkway as a pollution control device for upper Burnt Mill Creek was mixed for 2013. Comparing inflows to outflows, there was a significant increase in dissolved oxygen and pH, but also increases in chlorophyll *a*, total phosphorus 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, nitrogen and phosphorus.

Futch Creek – Futch Creek is situated on the New Hanover-Pender County line and drains a 3,247 acre watershed (12.7% impervious coverage) into the ICW. UNC Wilmington was not funded to regularly sample this creek in 2013. 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 2,551 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. In 2013 there was good dissolved oxygen at the 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 2013 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 likely an important cause of low dissolved oxygen in this lake. Stormwater runoff into the streams also contributes BOD materials into the lake. In 2013 all tributary stations and one in-lake station exceeded the fecal coliform State standard on 33% or more of occasions sampled.

From 2005 to 2013 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 many 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.

Hewletts Creek – Hewletts Creek drains a large (7,435 acre) watershed into the Intracoastal Waterway. This watershed has about 25.1% impervious surface coverage with a population of about 20,210. In 2013 the creek was sampled at four tidal sites and one non-tidal freshwater site.

Incidents of hypoxia did not occur in 2013 as no concentrations sampled were below 5.0 mg/L. Turbidity was low, and algal blooms were not problematic in 2013. Fecal coliform bacteria counts exceeded State standards on 83% of the time at MB-PGR and NB-GLR, and 67% of the time at PVGC-9 and SB-PGR. The geometric means at PVGC-9, MB-PGR and NB-GLR all exceeded 200 CFU/100 mL for a poor rating for this pollutant parameter.

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, nitrate and 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 3,518 acre watershed into the ICW. This watershed hosts a population of approximately 6,460 with about 21.1% impervious surface coverage. Two stations were sampled in Howe Creek in 2013. Two major algal blooms were seen at the uppermost station HW-DT and one at HW-GP. The uppermost station HW-DT was rated poor for high fecal coliform bacteria counts, exceeding the state standard on 100% of the times sampled, while HW-GP was also rated poor, exceeding the standard on 33% of occasions sampled, and HW-FP were rated fair and good, respectively. Dissolved oxygen concentrations were rated fair at HW-DT and good at HW-GP.

Howe Creek sediments were sampled for metals and toxicants at two sites on October 7. None of the parameters sampled exceeded limits considered harmful to benthic organisms.

Motts Creek – Motts Creek drains a watershed of 3,328 acres into the Cape Fear River Estuary with a population of about 9,530; impervious surface coverage 23.1%. This creek was not sampled for water quality by UNCW in 2013.

However, UNCW sampled the Mott's Creek sediments at Station MOT-RR, the bridge where Mott's Creek passes under River Road. Based on the suggested guidelines for potential toxicity of metals, PCBs and PAHs, the creek sediments at that location were of good quality to support aquatic life.

Pages Creek – Pages Creek drains a 3,039 acre watershed with 15.8% impervious surface coverage into the ICW. UNC Wilmington was not funded to sample this creek from 2008-2013. 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 13,896 acres that has about 33% 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 2013 samples. The North Carolina turbidity standard for estuarine waters (25 NTU) was exceeded one of 12 sampling occasions. There were no algal blooms present upon any of our 2013 sampling occasions. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on 33% of samples in 2013, for a Poor 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 2,095 acres, a population of about 8,000, and is covered by approximately 26.3% impervious surface area. One station, on Masonboro Loop Road, was sampled from shore along this creek in 2013. 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 50% of occasions sampled.

Sediment metals and toxicants were collected on one occasion (5/31/13) from Whiskey Creek. The upper two tributary stations, WC-NB and WC-SB, had no levels of metals, PCBs, or PAHs that were in excess of concentrations known to be toxic to benthic organisms However, Station WB-MLR, at Masonboro Loop Road bridge, had excessive concentrations of total PAHs, as well as these individual PAHs: benzo(a)anthracene, benzo(a)pyrene, fluoranthene, phenanthrene and pyrene. Downstream at the Whiskey Creek Marina (WC-MR) the only parameter found in excessive sediment concentrations was copper. It is likely that leachate of copper from boat paints accounted for the excessive concentrations.

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 (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 2013 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 9% to be in good condition, 9% in fair condition, but **82%** in poor condition, worse than 2012. Dissolved oxygen conditions system-wide (22 sites) showed 73% of the sites were in good condition, 9% were in fair condition, and 18% were in poor condition, a notable improvement from 2012. For algal bloom presence, measured as chlorophyll *a*, 77% of the 22 stations sampled were rated as good, 9% as fair and 14% as poor (Greenfield Lake and upper Howe Creek) a slight improvement from 2012. For turbidity, 21 of the 22 sites sampled were rated as good, while one site, Smith Creek at Castle Hayne Rd. was rated fair. It is important to note that the two water bodies with the worst water quality in the system also have the most developed watersheds with the highest impervious surface coverage; Burnt Mill Creek – 34% impervious coverage; Greenfield Lake – 37% impervious coverage.

Table of Contents

Plate 1. Wilmington and New Hanover County watersheds (map by M. Hayes, Wilmington Stormwater Services).

1.0 Introduction

In 1993 scientists at the UNC Wilmington Center for Marine Science Research began studying five tidal creeks in New Hanover County. This project, funded by New Hanover County, the Northeast New Hanover Conservancy, and UNCW, yielded a comprehensive report detailing important findings from 1993-1997, and produced a set of management recommendations for improving creek water quality (Mallin et al. 1998a). Data from that report were later published in the peer-reviewed literature (Mallin et al. 2000a; Mallin et al. 2001) and were used 2006-2009 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 matrix of tidal creek watersheds analyzed in our program.

In October 1997 the Center for Marine Science began a project (funded by the City of Wilmington Engineering Department) with the goal of assessing water quality in Wilmington City watersheds under base flow conditions. Also, certain sites were analyzed for sediment heavy metals concentrations (EPA Priority Pollutants). In the past 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 2013, 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 and building 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 of the site were delayed due to the economic slowdown and funding was suspended. As such, there has been no construction near either creek as of yet related to this project.

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.

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 22 locations within the Wilmington City watersheds between January and December 2013. In addition, 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* (EPA Method 445.0) is based on Welschmeyer (1994) and US EPA (1997). Chlorophyll *a* concentrations were determined from the 0.7 micrometer glass fiber filters used for filtering samples for nitrate+nitrite and orthophosphate analyses. All filters were wrapped individually in aluminum foil, placed in an airtight container and stored in a freezer. During the analytical process, the glass filters were separately immersed in 10 ml of a 90% acetone solution and allowed to extract the chlorophyll from the material for three hours; filters were ground using a Teflon grinder prior to extraction. The solution containing the extracted chlorophyll was then analyzed for chlorophyll *a* concentration using a Turner AU-10 fluorometer. This method uses an optimal combination of excitation and emission bandwidths that reduces errors in the acidification technique. UNCW Aquatic Ecology Laboratory is State-certified for laboratory chlorophyll *a* measurements.

Nutrients (nitrate, ammonium, total Kjeldahl nitrogen, 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).

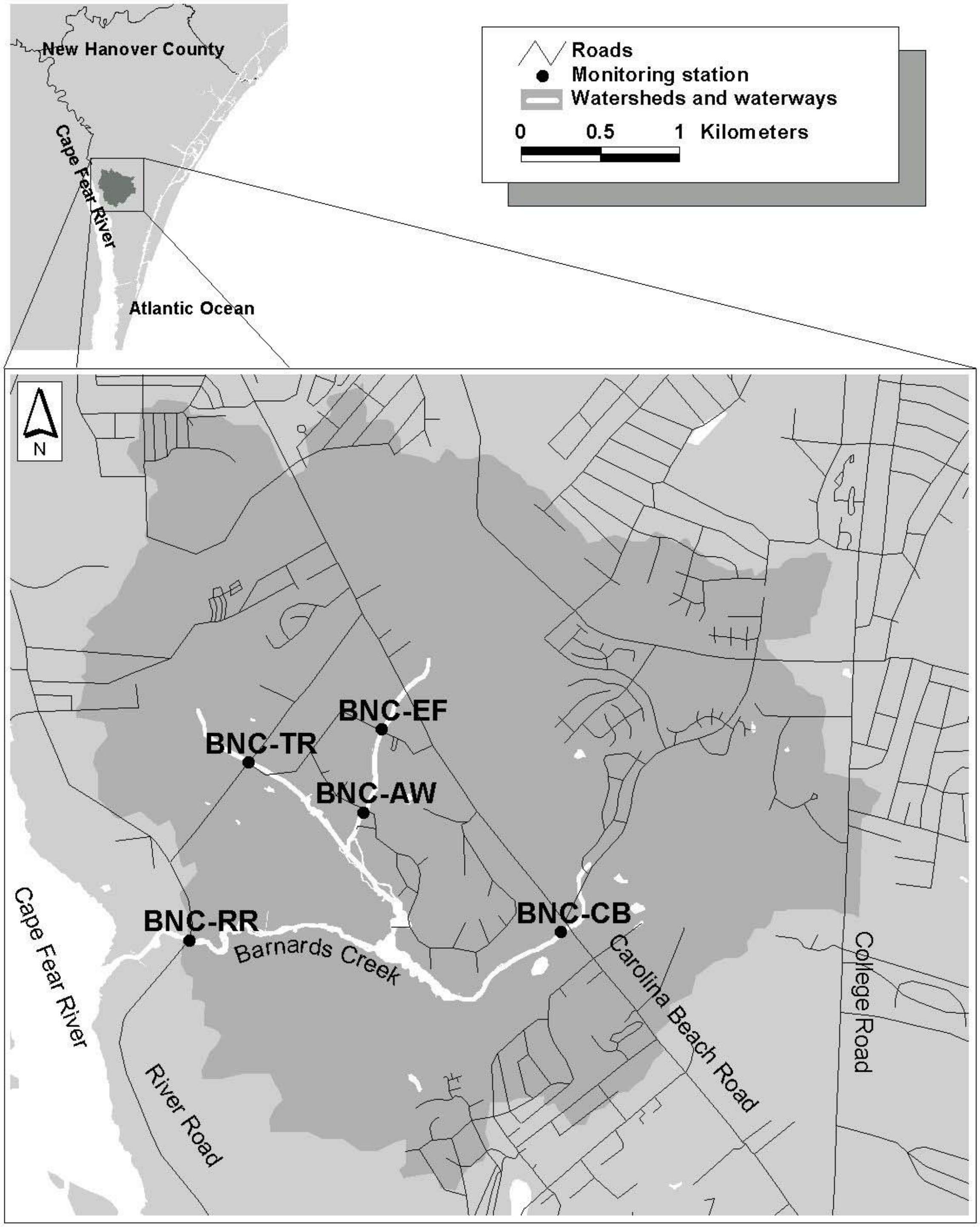
For comparative purposes, North Carolina water quality standards are listed in Appendix A.

2.0 Barnards Creek

Snapshot
Watershed area: 4,161 acres (1,684 ha)
Impervious surface coverage: 22.3%
Watershed population: Approximately 12,200
Overall water quality: not measured in 2013

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 2013 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: 4,631 acres (1,874 ha)
Impervious surface coverage: 27.6% (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 2013; the standard of 25 NTU was only exceeded on one sampling occasion (Table 3.1). Total suspended solids (TSS) were elevated on one occasion at BC-NB and BC-SB; in June when it was 66.2 and 40.8 mg/L, respectively. There are no NC ambient standards for TSS, but UNCW considers 25 mg/L high for the Coastal Plain. There were no issues with low dissolved oxygen (hypoxia) in 2013 (Appendix B).

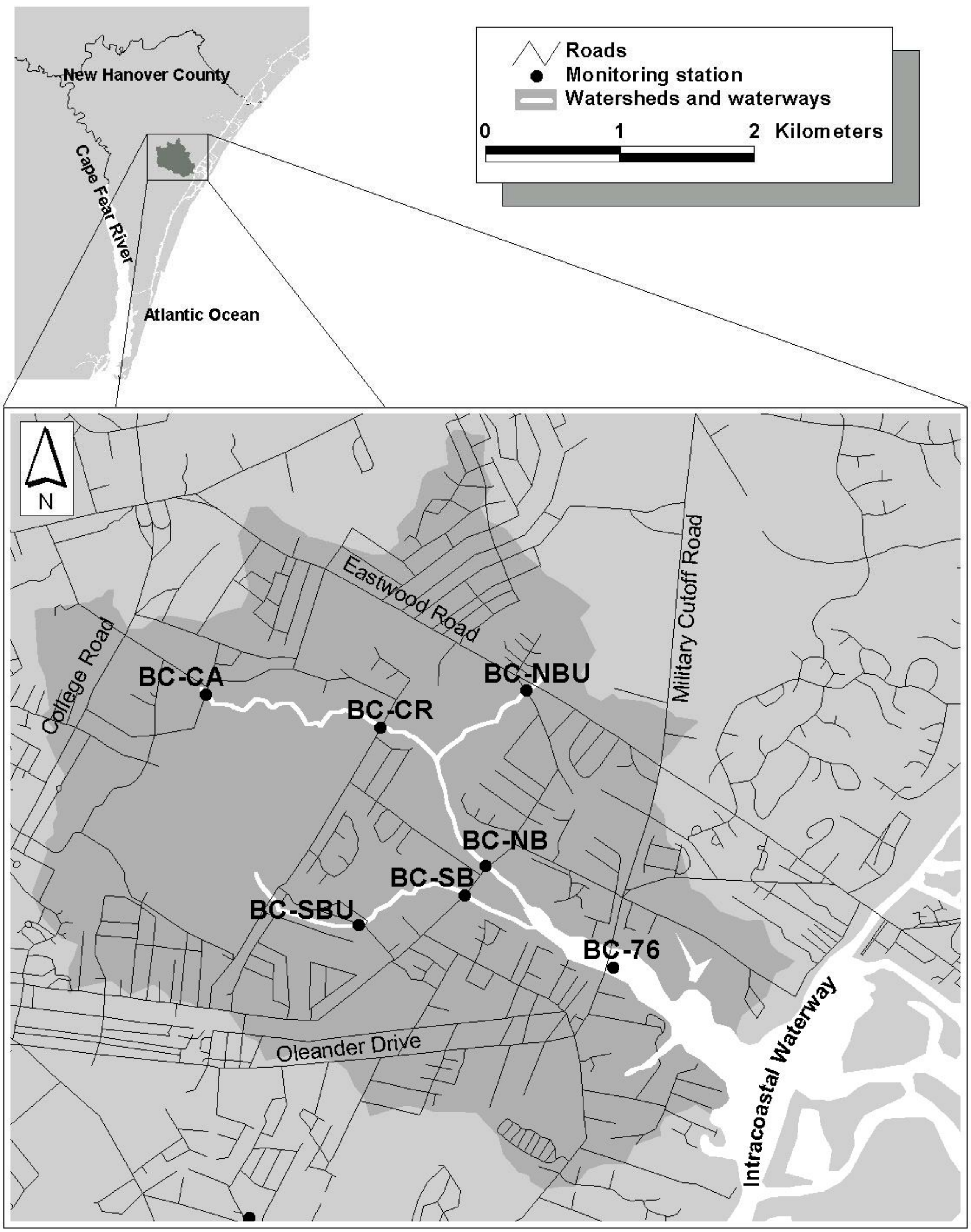
Ammonium concentrations were generally low, and similar to 2012. Nitrate concentrations were highest at station BC-CA, but low in general (Table 3.1). Total nitrogen concentrations were low to moderate at all times sampled, and lower than in 2012. Orthophosphate concentrations were low and similar to 2012; TP followed a similar spatial pattern as orthophosphate but increased from 2012. Our Bradley Creek stations did not host significant algal blooms in 2013. 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 2013. The NC contact standard was exceeded on 67% of occasions sampled at BC-SB and BC-CA, and 33% of occasions sampled at BC-NB. The geometric means of the fecal coliform counts ranged from under the standard (179 CFU/100 mL at BC-NB) to >6X the standard (1,397 CFU/100 mL at BC-CA, Table 3.1).

Table 3.1 Water quality parameter concentrations at Bradley Creek sampling stations, 2013. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 6 months.

Station	BC-CA	BC-NB	BC-SB
Salinity (ppt)	0.1 (0.0) 0.1-0.1	19.0 (12.7) 1.4-33.7	11.3 (14.2) 0.5-31.3
Dissolved Oxygen (mg/L)	6.8 (1.4) 5.3-8.6	8.1 (3.1) 4.9-13.8	7.6 (2.5) 5.1-12.0
Turbidity (NTU)	3 (4) 0-9	9 (13) 0-35	7 (8) 0-22
TSS (mg/L)	7.3 (7.2) 1.4-21.2	24.3 (21.0) 8.6-66.2	17.0 (11.9) 8.2-40.8
Nitrate (mg/L)	0.117 (0.098) 0.010-0.260	0.020 (0.020) 0.010-0.060	0.025 (0.037) 0.010-0.100
Ammonium (mg/L)	0.103 (0.050) 0.050-0.170	0.087 (0.093) 0.010-0.260	0.087 (0.056) 0.010-0.160
TN (mg/L)	0.292 (0.253) 0.050-0.760	0.362 (0.245) 0.050-0.700	0.350 (0.251) 0.100-0.700
Orthophosphate (mg/L)	0.060 (0.093) 0.010-0.250	0.015 (0.012) 0.010-0.040	0.042 (0.050) 0.010-0.140
TP (mg/L)	0.227 (0.276) 0.050-0.750	0.068 (0.046) 0.020-0.150	0.137 (0.133) 0.030-0.360
N/P	15.1 13.7	14.4 12.2	8.6 7.7
Chlorophyll *a* (µg/L)	9 (7) 3-19	8 (7) 2-20	7 (6) 1-17
Fecal coliforms (CFU/100 mL)	1,397 154-13,000	179 28-3,100	471 145-9,000

Figure 3.1. Bradley Creek watershed and sampling sites.



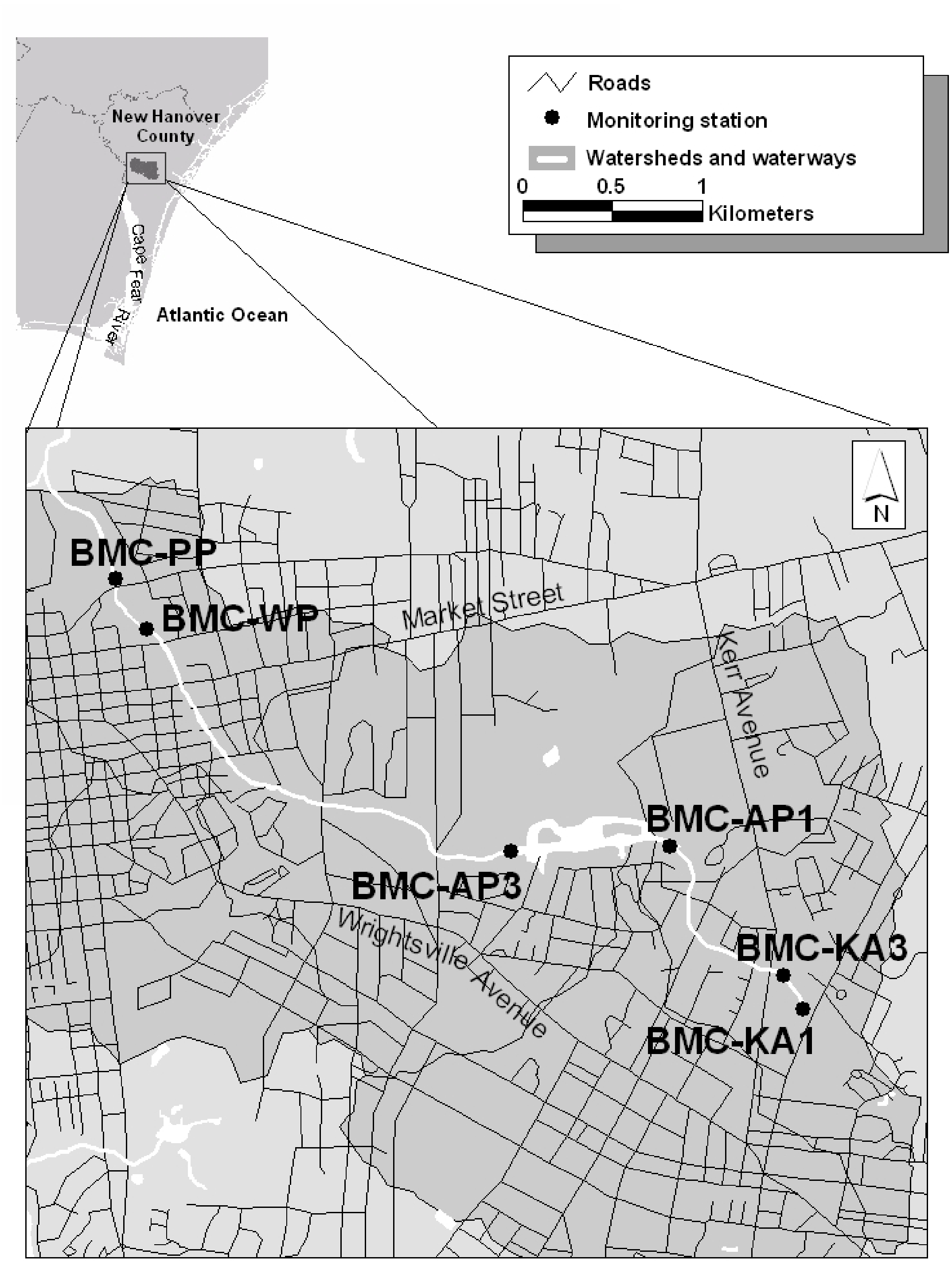
4.0 Burnt Mill Creek

Snapshot
Watershed area: 4,252 acres (1,721 ha)
Impervious surface coverage: 33.8%
Watershed population: Approximately 23,700
Overall water quality: poor
Problematic pollutants: Fecal bacteria, algal blooms, some low dissolved oxygen, high sediment PAH, lead, zinc and mercury concentrations

Burnt Mill Creek is an urban creek flowing entirely through the City of Wilmington. Its high impervious surface coverage (about 34%) 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 2013 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 2013. Dissolved oxygen concentrations were within standard on all sampling occasions at these two sites in 2013, 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 2013 samples; there was a significant increase through the pond but averages only went from 2 to 4 NTU. Suspended solids concentrations were relatively low on all sampling occasions in 2013, 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 high (Table 4.1), possibly a result of pet waste (very visible to the observer) runoff from the Mill Creek apartment complex and runoff from urban upstream areas (including the Kerr Avenue wetland). Over the sampling period five of the six samples collected at BMC-AP1 had counts exceeding 200 CFU/100 mL, whereas none 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 were no major algal blooms at BMC-AP1 or BMC-AP3 that exceeded the North Carolina water quality standard in 2013, although at the latter stations there were several lesser blooms between 25-36 µg/L. Statistically, there was a 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 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 2013. One parameter that is key to aquatic life health is dissolved oxygen. Dissolved oxygen at BMC-PP in 2013 was substandard on three of six occasions, ranking this site in poor condition for 2013. 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 2013 this level was not approached at BC-PP.

In 2013 BMC-PP showed one major algal bloom that exceeded the North Carolina water quality standard for chlorophyll *a* of 40 µg/L. In January chlorophyll *a* was 58 µg/L (Table 4.1); otherwise this station showed low algal biomass except for a lesser blooms of 26 µg/L in December. 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 17.6 and mean ratios were 21.1. In waters where the N/P ratio is well below 16 (the Redfield Ratio for algal nutrient composition) it is generally considered that algal production is limited by the availability of nitrogen (i.e. phosphorus levels are sufficient); where N/P ratios are well above 16, additions of phosphate should encourage algal blooms. If such values are near the Redfield Ratio, as at BMC-PP, inputs of either N or P could drive an algal bloom. Thus, control of inputs of both N and P would help reduce algal blooms in lower Burnt Mill Creek.

Important from a public health perspective are the excessive fecal coliform bacteria counts, which maintained geometric means at BMC-PP well in excess of the State standard for human contact waters (200 CFU/100 mL). Fecal coliform counts were greater than the State standard on 50% 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 22 CFU/100 mL) to the Princess Place location (geometric mean 280 CFU/100 mL; Fig. 4.2), as in previous years. It is likewise notable that nutrient concentrations increased from the outflow from Ann McCrary Pond downstream to the lower main stem station (Table 4.1; Fig. 4.3).

Table 4.1. Water quality data in Burnt Mill Creek, 2013, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as mean/median.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	6.8 (1.3) 5.8-9.2	10.2 (1.7)* 8.2-120	5.5 (3.0) 2.8-10.7
Cond. (μS/cm)	265 (13) 247-287	191 (49)** 115-263	326 (25) 289-354
pH	7.1 (0.1) 7.0-7.3	7.8 (0.3)* 7.4-8.3	7.3 (0.2) 7.0-7.7
Turbidity (NTU)	2 (3) 0-5	4 (3)* 1-8	2 (2) 0-5
TSS (mg/L)	1.8 (0.9) 1.4-3.7	6.9 (2.6)* 4.2-11.3	3.5 (1.8) 1.4-5.5
Nitrate (mg/L)	0.157 (0.029) 0.110-0.190	0.023 (0.024)** 0.010-0.070	0.192 (0.054) 0.140-0.270
Ammonium (mg/L)	0.148 (0.068) 0.080-0.240	0.043 (0.029)** 0.010-0.090	0.122 (0.075) 0.030-0.240
TN (mg/L)	0.223 (0.110) 0.110-0.370	0.153 (0.138) 0.050-0.400	0.258 (0.151) 0.140-0.550
OrthoPhos. (mg/L)	0.012 (0.004) 0.010-0.020	0.010 (0.000) 0.010-0.010	0.042 (0.021) 0.010-0.060
TP (mg/L)	0.033 (0.008) 0.020-0.040	0.055 (0.018)* 0.040-0.080	0.113 (0.091) 0.030-0.290
N/P molar ratio	60.3 60.9	14.8 16.6	21.1 17.6
Chlor. *a* (μg/L)	3 (3) 1-7	27 (9)** 11-36	16 (23) 2-58
FC (CFU/100 mL)	610 172-1,360	22* 5-73	280 118-1,270

* 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, 2013

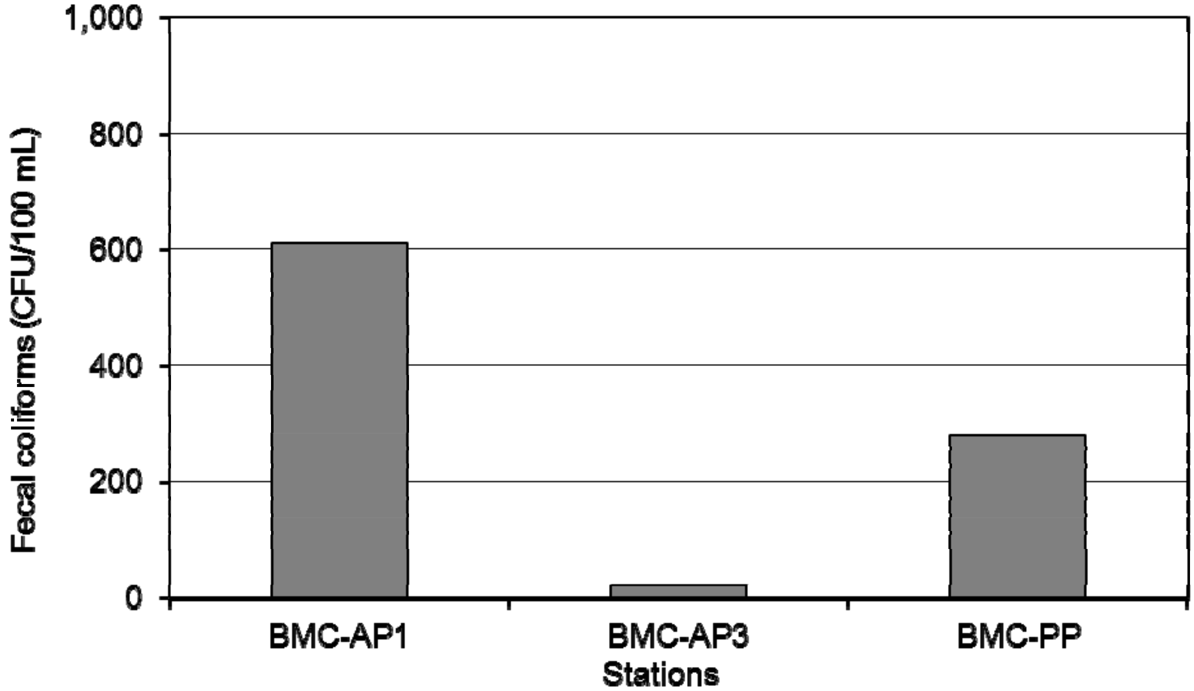
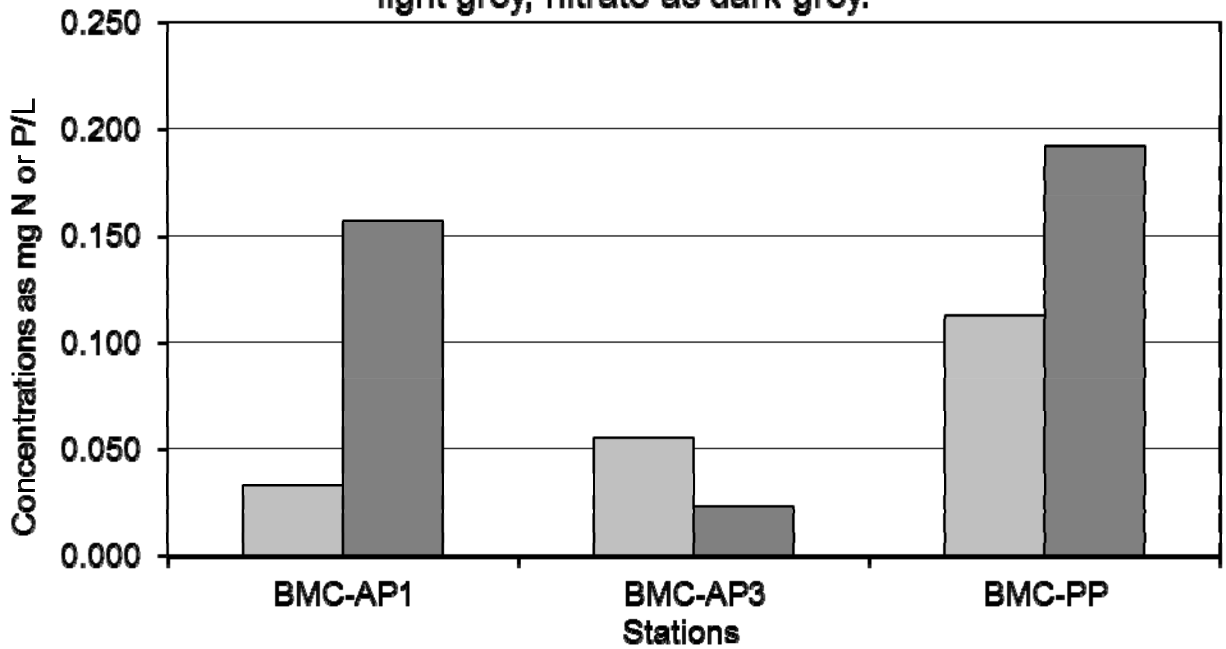


Figure 4.3. Average total phosphorus and nitrate concentrations by station for Burnt Mill Creek, 2013; TP as light grey, nitrate as dark grey.



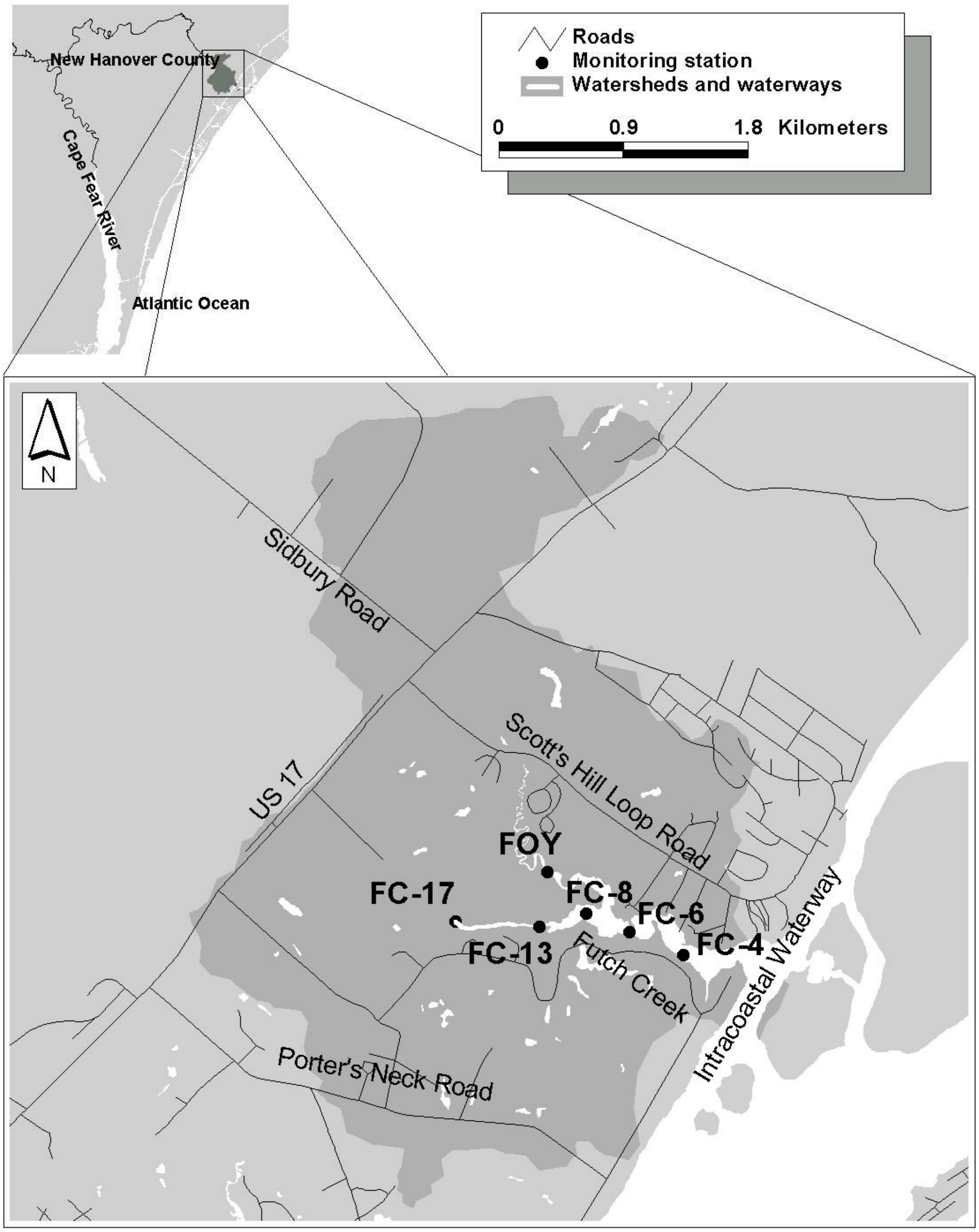
To summarize, in most years Burnt Mill Creek has problems with low dissolved oxygen (hypoxia) chronically at the Princess Place station BMC-PP. Algal blooms remained a problem in the creek during 2013, and algal bloom decomposition creates BOD that contributes to low DO. The N/P ratios in the lower creek indicate that inputs of either nitrogen or phosphorus are likely to stimulate algal bloom formation, depending upon season and inputs of nitrogen. It is notable that nutrient concentrations increase from the lower portion of the regional Ann McCrary wet detention pond as one moves downstream toward the lower creek. An important human health issue is the high fecal bacteria counts found at most sampling stations, with the exception of BMC-AP3 below the detention pond. As NPDES point source discharges are not directed into this creek, the fecal bacteria (and nutrient) loading appears to be caused either by non-point source stormwater runoff, illegal discharges, or leakage from sanitary sewer lines. We note that strong statistical correlations between fecal coliform counts, TSS, BOD and rainfall have been demonstrated for this creek (Mallin et al. 2009b). As this is one of the most heavily-developed creeks in the Wilmington area, it also remains one of the most polluted.

5.0 Futch Creek

Snapshot
Watershed area: 3,247 acres (1,314 ha)
Impervious surface coverage: 12.7%
Watershed population: 4,620

Six stations were sampled by the University of North Carolina Wilmington in Futch Creek from 1993 through 2007. UNCW was not funded by the County to sample Futch Creek in 2013. We present the above information and map below purely for informational purposes. Water quality information for 2008-2013 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 tributaries of Greenfield Lake were sampled for a full suite of physical, chemical and biological parameters in 2013 (Table 6.1, Fig. 6.1). Three tributaries suffered from hypoxia, as GL-LB (creek at Lake Branch Drive), GL-LC (creek beside Lakeshore Commons) and GL-JRB (Jumping Run Branch) showed average dissolved oxygen concentrations below the state standard (DO < 5.0 mg/L). Dissolved oxygen levels were below the state standard of 5.0 mg/L on four of six occasions at GL-LB, five of six occasions at GL-LC, and on four of six occasions at Jumping Run Branch GL-JRB (Table 6.1; Appendix B). The newest station, JRB-17, located in upper Jumping Run Branch at 17th Street, had adequate dissolved oxygen on all sampling occasions. 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 2013 in the tributary stations (Table 6.1).

Mean and median nitrate concentrations were highest at GL-LB and GL-LC and lowest at JRB-17 (Table 6.1). Mean and median ammonium levels at GL-LB were approximately double the concentrations at the other sites. Orthophosphate concentrations were highest at GL-LB. Chlorophyll *a* concentrations were low at all four tributary stream sites. However, 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 and GLB-LC, on five of six dates at GL-LB, and on four of six dates at GL-JRB.

Table 6.1. Mean and (standard deviation) / range of selected field water quality parameters in tributary stations of Greenfield Lake, 2013. 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)	7.8 (1.4) 6.1-9.1	4.0 (2.1) 1.5-7.3	2.8 (2.2) 0.4-5.4	2.9 (2.2) 0.4-6.1
Turbidity (NTU)	2 (1) 0-4	0 (1) 0-2	1 (1) 1-2	0 (0) 0-0
TSS (mg/L)	4.0 (2.5) 1.5-8.2	3.5 (3.3) 1.4-7.9	1.9 (0.8) 1.4-3.0	2.7 (3.1) 1.4-9.0
Nitrate (mg/L)	0.19 (0.05) 0.13-0.27	0.23 (0.04) 0.18-0.30	0.26 (0.10) 0.08-0.39	0.25 (0.12) 0.09-0.42
Ammon. (mg/L)	0.14 (0.04) 0.09-0.18	0.13 (0.08) 0.04-0.27	0.27 (0.12) 0.12-0.44	0.11 (0.05) 0.04-0.19
TN (mg/L)	0.34 (0.19) 0.13-0.67	0.40 (0.19) 0.18-0.62	0.39 (0.23) 0.05-0.68	0.33 (0.21) 0.05-0.52
Ortho-P. (mg/L)	0.03 (0.01) 0.02-0.04	0.04 (0.02) 0.02-0.06	0.05 (0.03) 0.02-0.08	0.03 (0.03) 0.01-0.07
TP (mg/L)	0.08 (0.04) 0.04-0.16	0.11 (0.07) 0.04-0.23	0.08 (0.03) 0.04-0.12	0.11 (0.10) 0.03-0.29
FC (CFU/100 mL)	772 210-2,400	213 118-330	489 190-1,730	717 310-2,700
Chlor. *a* (μg/L)	6 (4) 2-12	2 (1) 1-4	3 (1) 1-5	2 (2) 0-6

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 2013, an improvement over previous years (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 improved from 2012. In 2013 coliforms exceeded the State standard on two of six sampling occasions at GL-2340, and once of six occasions at GL-P.

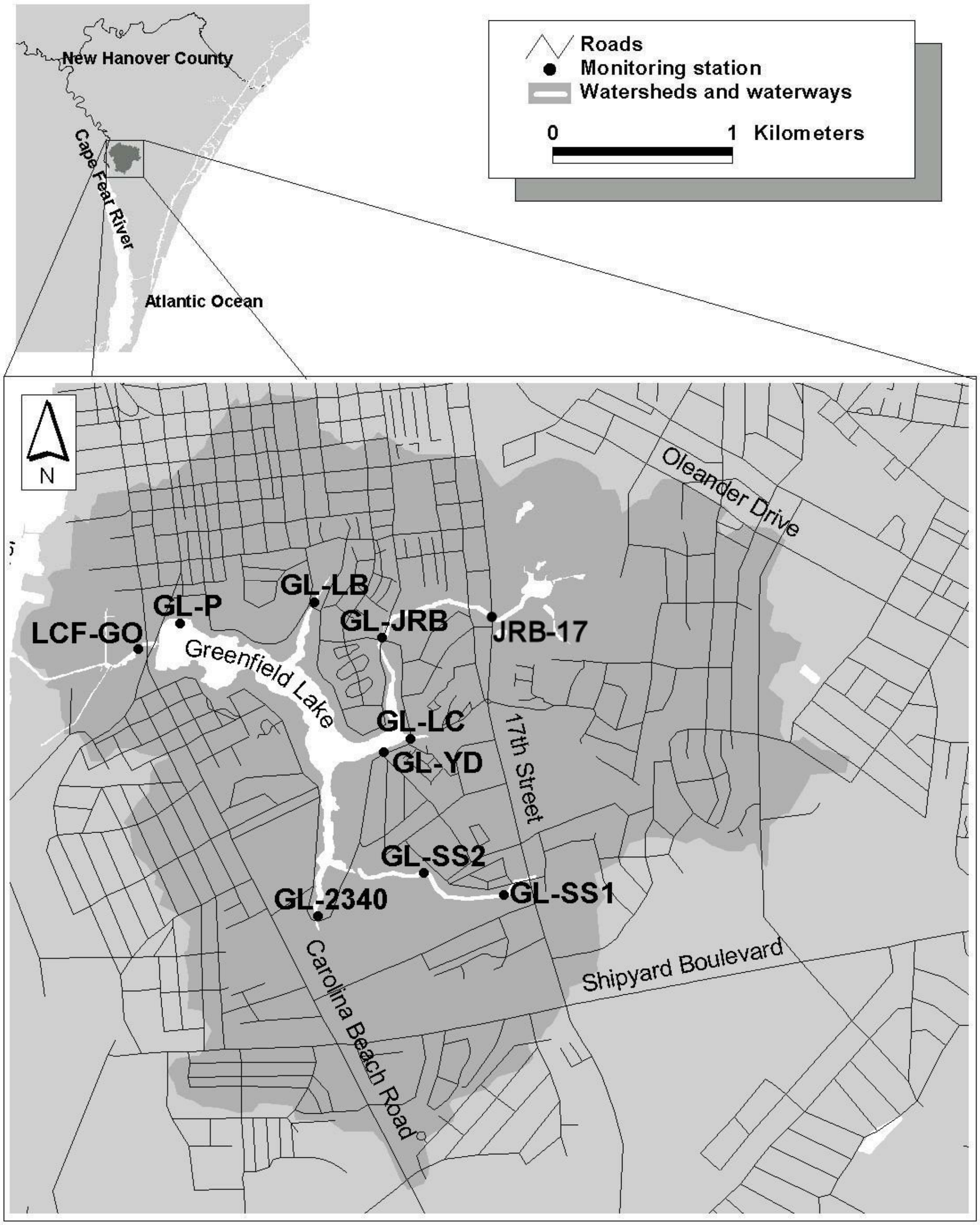
Concentrations of nitrate were highest at the upstream station GL-2340, where concentrations were similar to those of the tributary streams (Table 6.2). Ammonium levels in the lake were generally low, and highest at GL-2340. Total nitrogen was highest at GL-2340 as well. Total phosphorus (TP) concentrations were highest at GL-YD among stations, although none of the TP values were remarkable, and orthophosphate was generally low (Table 6.2). Inorganic N/P molar ratios can be computed from ammonium, nitrate, and orthophosphate data and can help determine what the potential limiting nutrient can be in a water body. Ratios well below 16 (the Redfield ratio) can indicate potential nitrogen limitation, and ratios well above 16 can indicate potential phosphorus limitation (Hecky and Kilham 1988). Based on the low mean and median N/P ratios 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 would 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 periodically 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. Three blooms exceeding the North Carolina water quality standard of 40 µg/L of chlorophyll *a* occurred at GL-P and two occurred at GL-YD, an increase from 2012. 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 2013 was higher (2.9-4.0) among the three sites sampled (Table 6.1), compared to the BOD concentrations found in 2012. As phytoplankton (floating algae) are easily-decomposed sources of BOD, the blooms in this lake are a periodic driver of low dissolved oxygen.

Table 6.2. Mean and (standard deviation) / range of selected field water quality parameters in lacustrine stations of Greenfield Lake, 2013. 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)	7.2 (1.5) 5.4-9.5	8.6 (1.5) 6.9-11.0	8.8 (2.4) 6.4-11.7
Turbidity (NTU)	0 (0) 0-1	1 (1) 0-2	1 (1) 0-3
TSS (mg/L)	3.4 (3.6) 1.4-10.4	4.8 (2.9) 1.4-7.9	3.8 (2.2) 1.4-7.0
Nitrate (mg/L)	0.24 (0.17) 0.01-0.47	0.03 (0.02) 0.01-0.06	0.02 (0.02) 0.01-0.06
Ammonium (mg/L)	0.09 (0.07) 0.02-0.18	0.04 (0.03) 0.01-0.10	0.03 (0.03) 0.01-0.07
TN (mg/L)	0.37 (0.22) 0.05-0.67	0.23 (0.23) 0.05-0.55	0.19 (0.20) 0.05-0.50
Orthophosphate (mg/L)	0.02 (0.01) 0.01-0.03	0.02 (0.01) 0.01-0.04	0.03 (0.03) 0.01-0.09
TP (mg/L)	0.08 (0.06) 0.03-0.16	0.19 (0.05) 0.04-0.20	0.10 (0.02) 0.06-0.13
N/P molar ratio	56.8 48.3	10.8 5.5	5.5 3.5
Fec. col. (CFU/100 mL)	133 19-819	56 19-190	66 28-210
Chlor. *a* (μg/L)	14 (15) 1-37	34 (28) 1-70	36 (18) 17-58
BOD5	2.9 (3.0) 0.8-8.0	4.0 (1.6) 2.0-6.0	3.3 (1.1) 2.0-4.8

Figure 6.1. Greenfield Lake watershed.



6.1 A Continuing Assessment of 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 six perennial inflowing streams (as well as intermittent ditches). The lake is surrounded by a watershed that is comprised mainly of residential, office, institutional and commercial areas, with an overall watershed impervious surface coverage of approximately 36%.

In recent decades a number of water quality problems have become chronic within the lake, including high fecal coliform bacterial counts, low dissolved oxygen problems, nuisance aquatic macrophyte growths, algal blooms and fish kills. Some of these problems are typically related to eutrophication, a process driven by loading of excessive nutrients to a body of water. The State of North Carolina Division of Water Quality previously considered the lake to have a problem with aquatic weeds (NCDENR 2005); however, the lake was subsequently removed from the 303(d) list. Periodic phytoplankton blooms have occurred in spring, summer and fall. Some of the bloom forming taxa are the cyanobacterium *Anabaena cylindrica* and the chlorophytes *Spirogyra* and *Mougeotia* spp. The free-floating macrophyte *Lemna* sp. (duckweed) is periodically observed on the surface. Below a massive *Lemna* bloom in the summer of 2004 dissolved oxygen concentrations at the park station were nearly anoxic. In-situ monitoring instruments have demonstrated that dissolved oxygen concentrations can decrease by as much as 45% at night compared with daytime DO measurements.

Beginning in 2005 several steps were taken by the City of Wilmington to restore viability to the lake (David Mayes, City of Wilmington Stormwater Services, personal communication). During February one thousand sterile grass carp were introduced to the lake to control (by grazing) the overabundant aquatic macrophytes. During that same month four SolarBee water circulation systems were installed in the lake to improve circulation and force dissolved oxygen from the surface downward toward the bottom. Additionally, 200 more grass carp were added March 28, 2007. City crews and contract firms have spot treated areas of the lake with herbicide annually since 2007.

Since 1998 the University of North Carolina Wilmington's Aquatic Ecology Laboratory, located at the Center for Marine Science, has been performing water quality sampling and associated experiments on Greenfield Lake. The City of Wilmington Stormwater Services has funded this effort. Monitoring of various physical, chemical, and biological parameters has occurred monthly. These data allow us to perform assessments of the effectiveness of the City's lake restoration efforts by comparing summer data from 2003 and 2004 (before restoration efforts) with data from the summers of 2005 through 2013 (after restoration efforts have been underway).

Results

To assess the results so far we have chosen several parameters to examine over time. One parameter that is only estimated visually is surface coverage by nuisance macrophyte vegetation. In the summers of 2003 and 2004 extensive mats of duckweed (*Lemna* sp.), mixed with algae and other vegetation covered large areas of the lake's surface, with visible estimates for some coves exceeding 95% coverage. In summer of 2005 surface coverage was minimal; with most lake areas 95% clear of surface mats. Some coverage returned in 2006 and some coverage, particularly in backwater areas has been seen in 2007 through 2012. Coverage is currently being monitored by Cape Fear River Watch; excessive coverage leads to spot herbicide treatments as stated above.

Dissolved oxygen (DO): During 2003 and 2004 hypoxia (DO < 4.0 mg/L) was common in surface waters. Areas beneath thick *Lemna* mats were anoxic (DO of zero) or nearly so, especially at GL-P, the main Park area (Fig. 6.1). Following the onset of herbicide addition in April 2005, the May DO (mean of the three in-lake stations) showed a distinct decrease; however, it subsequently rose in June and remained at or above the State standard of 5 mg/L through the rest of the summer of 2005 (Fig. 6.2). In summer of 2006 the average lake DO levels decreased compared with 2005, but were still higher than in 2003 and 2004 (Fig. 6.2). This was because Station GL-2340 experienced low DO levels from 1.2 to 3.8 mg/L from July through September, although the other two in-lake stations (GL-P and GL-YD) maintained good DO levels. Since that period the two lower lake stations have consistently maintained acceptable DO concentrations, while at times the upper lake station can dip to hypoxic levels. In 2013 all three lake stations had good DO levels (Table 6.2; Fig. 6.2).

Turbidity: Turbidity was not excessive in the lake during the two years prior to restoration efforts (Mallin et al. 2006a). It has remained low (below the North Carolina freshwater standard) following these efforts throughout 2013 (Table 6.2).

Ammonium: Ammonia, or ammonium is a common degradation product of organic material, and is an excretory product of fish and other organisms. The addition of grass carp and the herbicide usage did not raise ammonium concentrations in the lake for several years (Fig. 6.3). However, in early 2008 there was a large increase in average ammonium lake-wide, which decreased in late spring (Fig. 6.3). There were no herbicide sprayings immediately before this pulse, and no fish kills, so the reason for this remains unknown. In 2009 there were generally low ammonium levels except for an unusually large peak in July, which subsequently decreased (Fig. 6.3). There was no herbicide application within three months prior to this 2009 ammonium peak. In 2010 average ammonium concentrations were low, with a minor increase in December, whereas from 2011 to 2013 ammonium concentrations were low all year (Fig. 6.3).

Nitrate: Nitrate is an inorganic form of nitrogen that is known to enter the lake during rainfall and runoff periods (Mallin et al. 2002). The concentration of nitrate in the lake does not appear to have been influenced by the restoration efforts (Table 6.2). Nitrate concentrations are generally impacted by stormwater runoff, and the low rainfall in 2007 likely provided minimal nutrient inputs to the lake. During 2008 there was a sharp increase in nitrate concentrations, especially in the upper and middle lake stations, which we suspect was largely stormwater runoff-driven. Concentrations in 2009 through 2013 were elevated at GL-2340 but low at the other two sites (Table 6.2). Pulses of nitrate within stormwater runoff likely cause the elevated concentrations at GL-2340.

Total nitrogen: Total nitrogen (TN) is a combination of all inorganic and organic forms of nitrogen. Average lake concentrations and concentrations at individual stations appeared to show no overall trend over time, although there was an unusually large peak in May of 2009 (Table 6.2; Fig. 6.4). In 2010 TN concentrations were among the lowest seen in the past seven years. Concentrations of TN jumped considerably in summer 2011; since inorganic N was low this was likely organic nitrogen in the form of phytoplankton during the large summer algal bloom (Fig. 6.4). In 2012 (Fig. 6.4) there were high concentrations of TN in July (coincident with algal blooms and the fish kill) and high concentrations in November (with no apparent source). Low levels occurred in 2013.

Orthophosphate: Orthophosphate is the most common inorganic form of phosphorus, and is utilized as a key nutrient by aquatic macrophytes and phytoplankton. Orthophosphate concentrations have not experienced any major changes in the water column either before (Mallin et al. 2006a) or after the restoration effort (Table 6.2). Earlier research found that a significant quantity of phosphorus in the lake is contributed by waterfowl through excretion (Mallin et al. 2002).

Total phosphorus: Total phosphorus (TP) is a combination of all organic and inorganic forms of phosphorus in the water. Although pulses of TP occurred in summer 2005 and spring 2006, they were similar in magnitude to pulses of TP seen in 2003 and 2004 (Fig. 6.5). Pulses in 2007 were smaller than the previous years (Figure 6.5). In 2008 there was a jump in TP, which may in part by caused by high phytoplankton biomass and the phosphorus locked up as cell tissue (see next section). Another reason may include increased runoff of phosphorus into the lake with increased rainfall. In 2009 there was decreased TP compared with 2008, although it was not as low as in 2007. In 2010 TP concentrations were lower than both 2008 and 2009. In 2011 there was a large peak in TP that consisted of organic phosphorus tied up in phytoplankton biomass during the summer algal bloom in the lake, but in 2012 and 2013 low to moderate TP concentrations prevailed (Fig. 6.5).

Chlorophyll *a*: Chlorophyll *a* is the principal measure used to estimate phytoplankton biomass (algal bloom strength) in water bodies. As mentioned above, algal blooms have been a common occurrence in this lake. They are generally patchy in space, usually occurring at one or two stations at a time. However, in summer 2005 extensive phytoplankton blooms occurred at all three in-lake stations, with levels well exceeding the State standard of 40 μg/L (Fig. 6.6). Blooms continued throughout 2006 as well (Fig. 6.6). The overall reduction in macrophyte coverage may also encourage phytoplankton growth because there is less competition for nutrients, and less shading of the water column by the macrophytes cover. The magnitude of the blooms varies year-to-year, but normally about 30-35% of the samples yield chlorophyll *a* concentrations higher than the State standard of 40 µg/L (Fig. 6.6).

Algal blooms are the result of nutrient inputs, either from outside the lake or from the release of nutrients from decaying material. Algal blooms, when they die, cause a BOD (biochemical oxygen demand) load (Mallin et al. 2006b). Natural lake bacteria feed on this organic material and multiply, using up dissolved oxygen in the lake as they do so. We performed annual regression analysis on our chlorophyll *a* concentrations with the corresponding BOD concentrations for the three in-lake stations, and found that on any given year 22-77% of the variability in Greenfield Lake BOD can be caused by algal blooms (Fig. 6.7). Thus, the algal blooms can lead to low dissolved oxygen in the lake, but there are other factors that contribute as well. Research conducted on Burnt Mill Creek, Smith Creek, and Prince Georges Creek (Mallin et al. 2009b) showed that BOD was also strongly correlated with watershed rainfall and TSS concentrations, indicating that runoff of oxygen-demanding materials (organic waste, debris, various chemicals) can make a significant contribution to reducing dissolved oxygen in aquatic systems.

<u>Fecal coliform bacteria</u>: Fecal coliform bacteria are commonly used to provide an estimate of the human or animal derived microbial pollution in a water body. Greenfield Lake is chronically polluted by high fecal coliform counts, well exceeding the state standard of 200 CFU/100 mL during many months (Table 6.2; Fig. 6.8). In summer 2005 there were particularly large fecal coliform counts at each in-lake station, though the individual stations did not have pulses during the same months. Excessive fecal coliform counts occurred to a lesser degree in 2006 in the lake, mainly at GL-2340 (fig. 6.8). In 2007 high fecal coliform counts occurred within the lake on about 43% of the occasions sampled (Fig. 6.8). In 2008 the lake was highly polluted by fecal coliforms (Fig. 6.8), with stormwater runoff likely the principal source. In September 2008 at the upper station, GL-2340, there was a high concentration (60,000 CFU/100 mL) of fecal coliform bacteria. City staff was unaware of any sewage spills in that area, so the source remains unknown. In 2009 there were again high counts (Table 6.2) especially for July (Fig. 6.8) with other months not unusually high. In 2010 average fecal coliform counts were low in comparison to 2008 and 2009; whereas in 2011 counts were not high with the exception of a large lakewide pulse in August, and in 2012 and 2013 counts were only somewhat elevated (Fig. 6.8). We note that fecal coliform counts were not targeted by the type of restoration efforts currently ongoing in the lake. Efforts to reduce runoff into tributary streams would likely have a positive benefit in reducing fecal bacteria counts.

Discussion

A risk that is taken when applying herbicides to lakes is the creation of biochemical oxygen demand (BOD) from decomposing organic matter that is a product of dead or dying plant material. As mentioned above, this would serve to drive the lake DO concentrations downward. DO levels in summer 2005 were nearly twice what they were during summers of 2003 and 2004, and DO levels in 2006 were also higher than 2003 and 2004. It is very likely that the use of the SolarBee circulation systems has maintained elevated DO even when there was an obvious BOD source. The in-lake station with lowest DO levels in 2006 was GL-2340, which is located quite a distance from the SolarBees. This pattern has continued from 2007-2012. We note that DO in the lake overall remains considerably better than the period before restoration efforts began (Fig. 6.2).

Water column nutrient concentrations did not change notably after the introduction of grass carp or use of herbicide. Certainly ammonium, an excretory and decomposition product would be expected to rise following the consumption and death of large quantities of plant material. Likewise phosphorus did not increase, although it is a common excretory product. However, ammonium (like orthophosphate) is readily used as a primary nutrient by phytoplankton. Nutrient addition bioassay experiments have demonstrated that phytoplankton growth in this lake is limited by nitrogen (Mallin et al. 1999). It is likely that ammonium produced by fish excretion or dying plant material was utilized by phytoplankton to produce the excessive algal blooms that have continued to characterized the lake since 2005. Some of these phytoplankton blooms were dominated by blue green algae (cyanobacteria) including species containing heterocytes (formerly called heterocysts). These species have the added ability to utilize these structures to fix atmospheric nitrogen into a useable form when phosphorus is replete.

Unfortunately the installation of Solarbees in Greenfield Lake in early 2005 did not improve the algal bloom problem. Before SolarBee installation (2000-2004) chlorophyll *a* exceeded the State standard of 40 µg/L on 7 of 89 occasions sampled, an 8% exceedence rate. However, from 2009-2012 chlorophyll *a* exceeded 40 µg/L on 24 or 72 occasions, for a 33% exceedence rate, far higher that the frequency before installation (please note that NCDWQ considers waters impaired if chlorophyll *a* exceeds the standard > 25% of the time). The continual bloom presence has led the NCDENR to propose placing Greenfield Lake on the 2014 303(d) list of impaired waters for excessive chlorophyll violations.

The continuing problems with high fecal coliform bacteria do not appear to be related to any of the restoration activities. Fecal coliform bacteria enter the environment from the feces of warm blooded animals, so it is possible that increases in waterfowl, or dogs brought to the lake by their owners, or feral cats could lead to increased fecal coliform bacteria counts, but we have no data to support this speculation either way. Likewise on rare occasions large pulses of fecal bacteria have appeared in the lake or tributaries, potentially related to either sewage leaks or spills, or illicit connections. We do note that fecal coliform counts in 2010 were the lowest in several years. From 2011 to 2013 Greenfield Lake had generally low fecal coliform counts except for a large peak in August 2011(Fig. 6.8). However, the tributary streams continue to host large pulses of fecal bacteria.

Figure 6.2. Average dissolved oxygen concentrations in Greenfield Lake, 2003-2013.

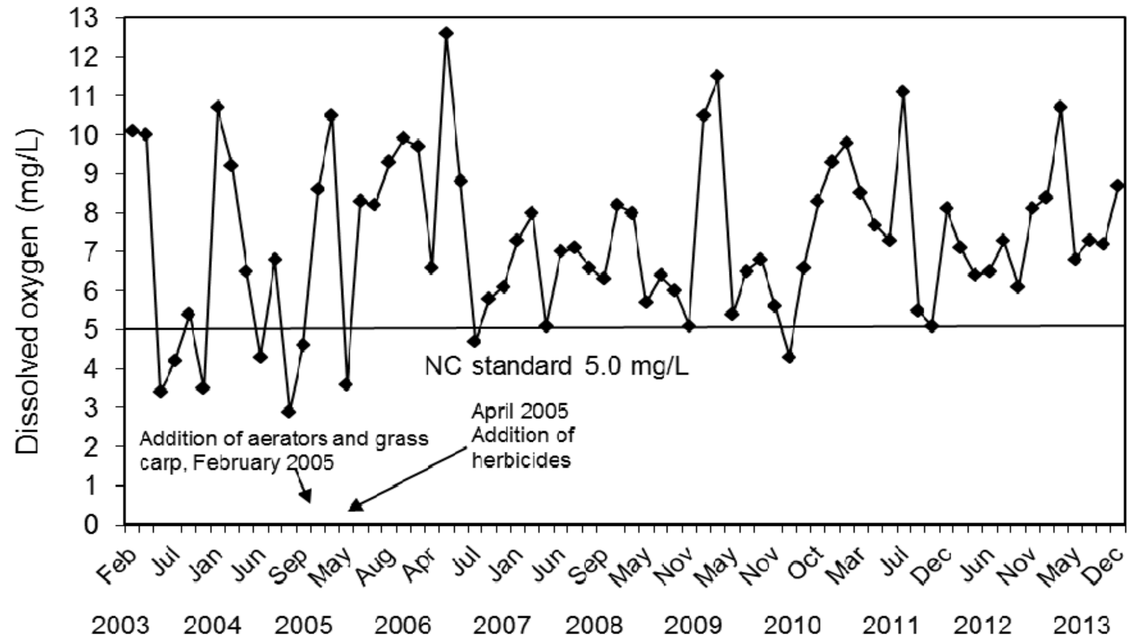


Figure 6.3. Average ammonium concentrations in Greenfield Lake 2003 - 2013.

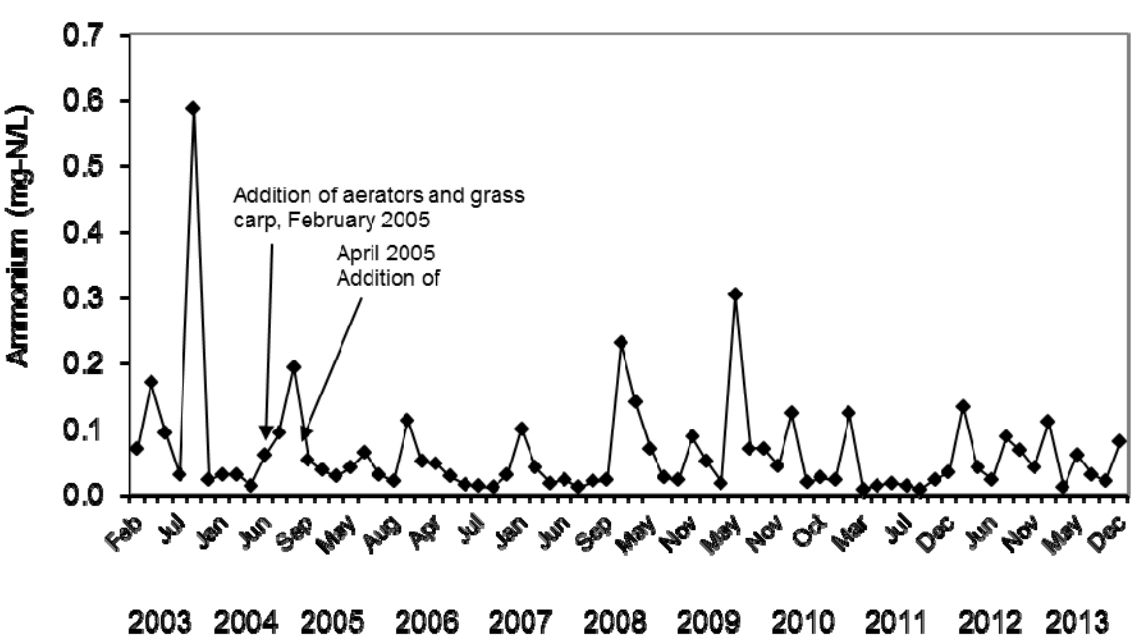


Figure 6.4. Average TN concentrations in Greenfield Lake, 2003-2013.

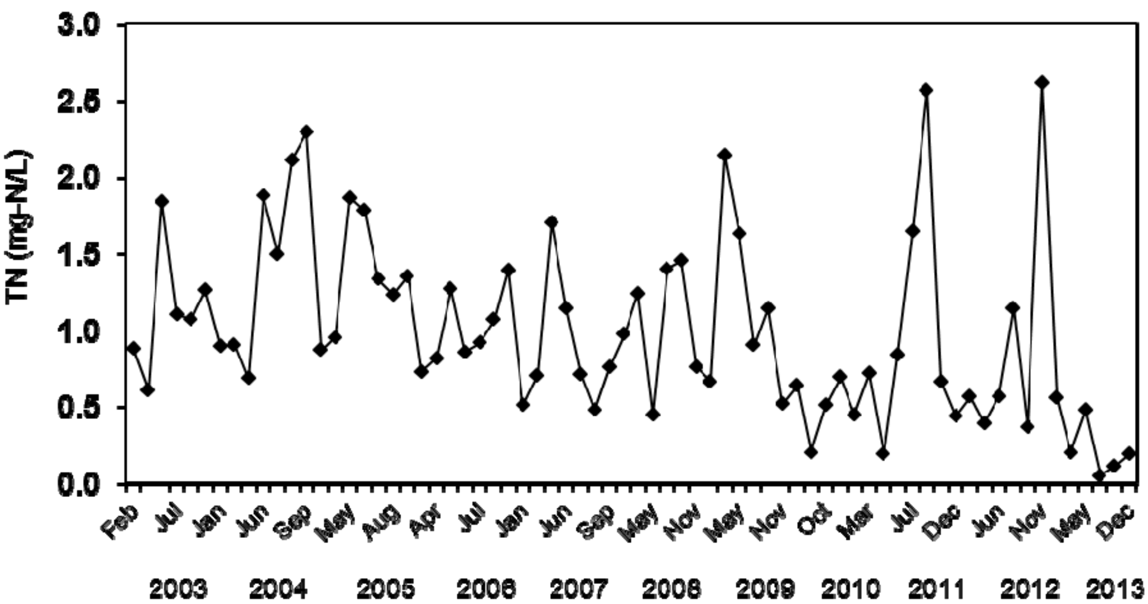


Figure 6.5. Average TP concentrations in Greenfield Lake, 2003-2013.

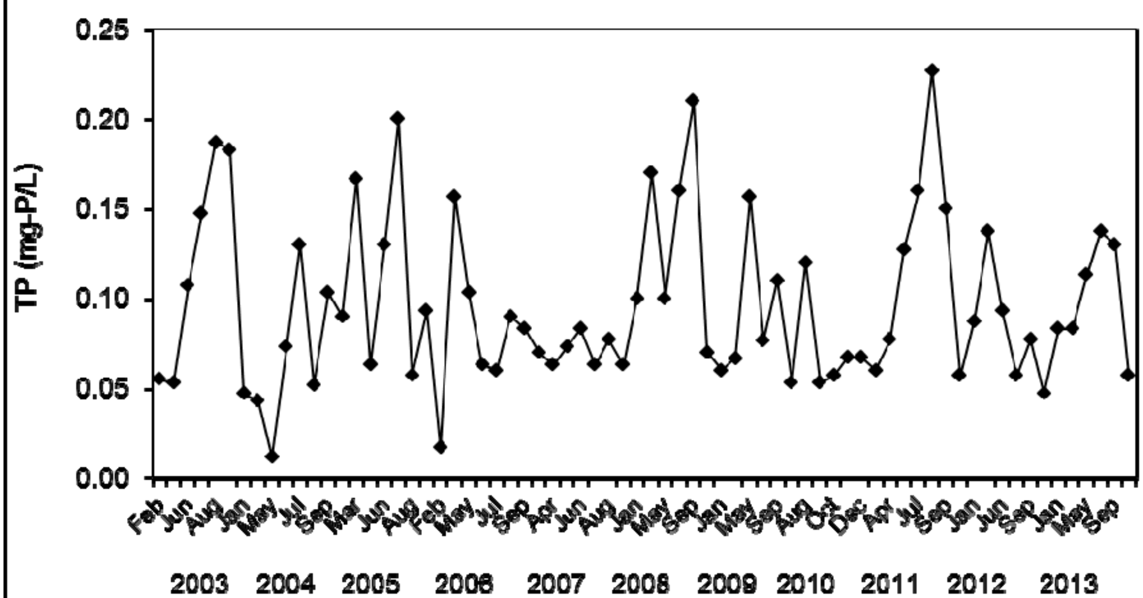


Figure 6.6. Average chlorophyll *a* concentrations in Greenfield Lake, 2003-2013.

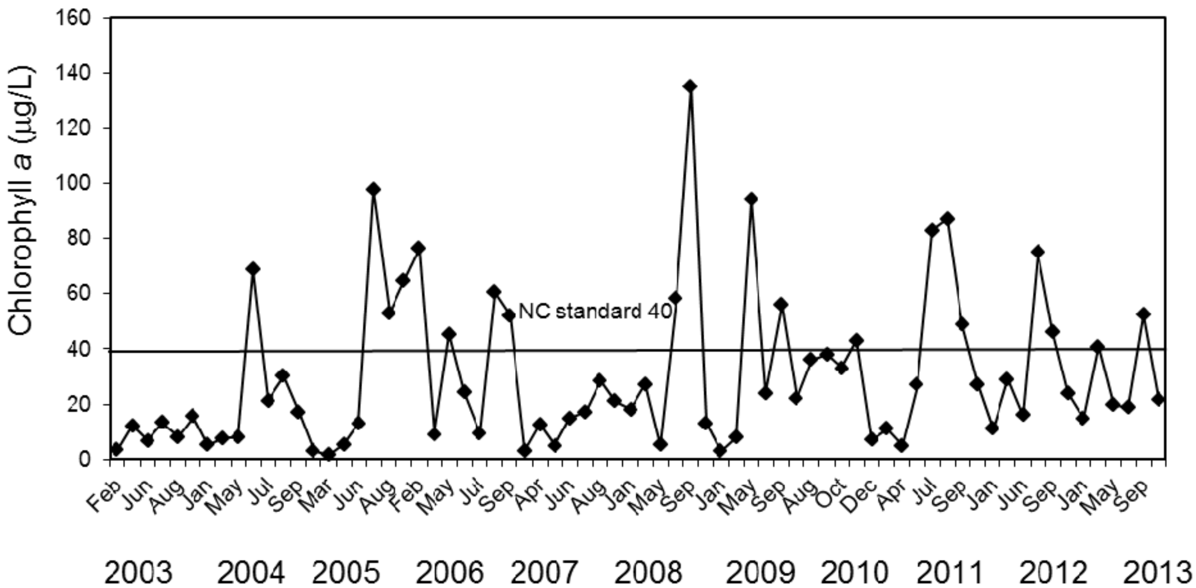


Figure 6.7. BOD5 as a Function of Chlorophyll *a* in Greenfield Lake

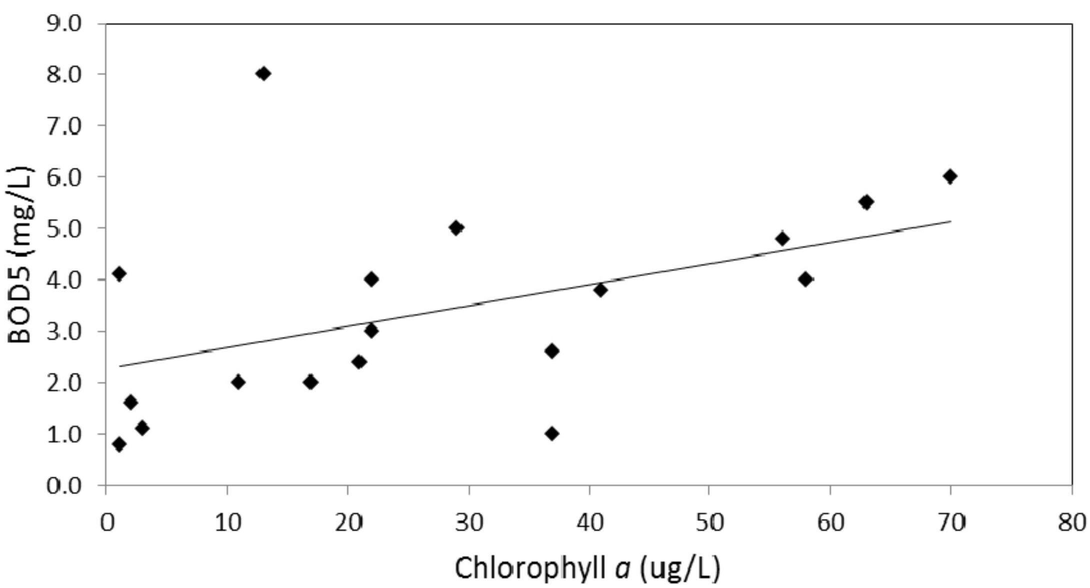
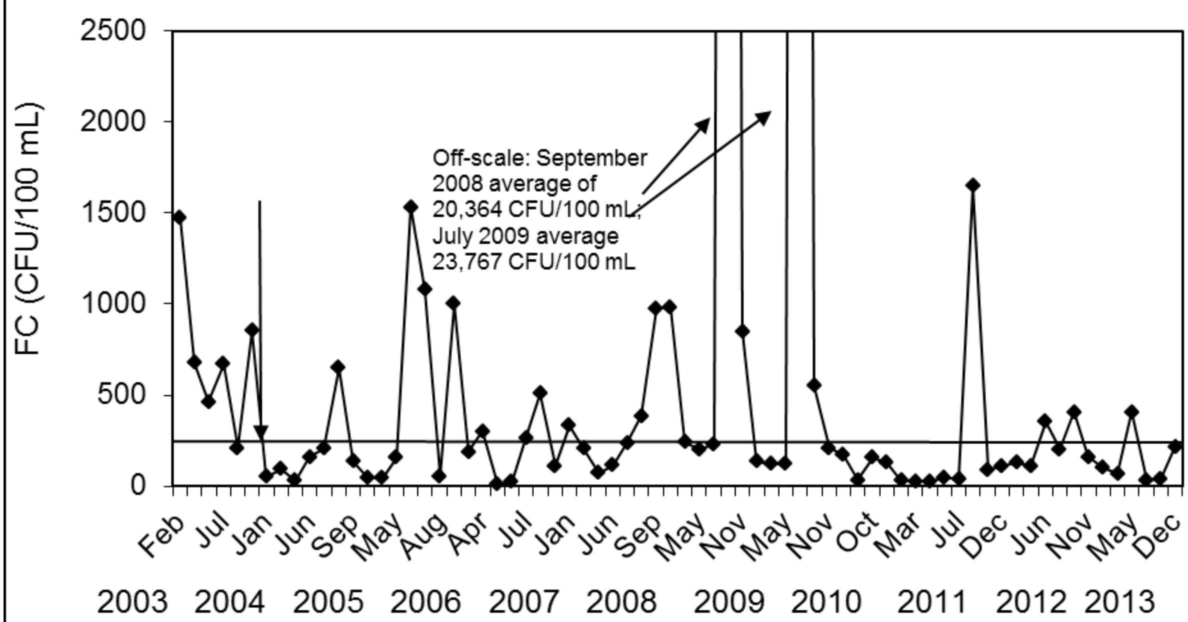


Figure 6.8. Average fecal coliform concentrations in Greenfield Lake, 2003-2013,



7.0 Hewletts Creek

Snapshot
Watershed area: 7,435 acres (3,009 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 not detected in our samples in 2013, in contrast to previous years. Nitrate concentrations were elevated leaving the golf course at PVGC-9 relative to the other stations, although lower than in previous years (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 somewhat 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 2012. Ammonium concentrations were generally low except downstream at Station HC-3 in the main creek, where they were higher than previous years. This is where the oyster reefs are concentrated and these organisms excrete ammonium as a waste product. Total nitrogen was lower than in 2012. Orthophosphate concentrations were low, as were total phosphorus concentrations. The N/P ratios were somewhat 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 2013 and elevated ammonium at HC-3 showed a tendency for phosphorus limitation. The chlorophyll *a* data (Tables 7.1 and 7.2) showed that the Hewletts Creek samples were free of major algal blooms in 2013, although lesser blooms exceeding 20 ug/L as chlorophyll a occurred twice at PVGC-9 and once at SB-PGR. However, fewer blooms have occurred in the past two years than had previously occurred in upper Hewletts Creek in the past (Mallin et al. 1998a; 1999; 2002a; 2004; 2006a; 2008; Duernberger 2009).

Fecal coliform bacteria counts were high in four stations sampled in the creek. Counts exceeded State standards on 83% of the time at MB-PGR and NB-GLR, and 67% of the time at PVGC-9 and SB-PGR (Tables 7.1 and 7.2). The geometric means at PVGC-9, MB-PGR and NB-GLR all exceeded 200 CFU/100 mL.

We note there was a raw sewage spill of 442,000 gallons into the creek from a pump station near the intersection of Pine Grove Drive and Greenville Loop Road on July 29, 2013. UNCW was not involved in the assessment.

Figure 7.1. Hewletts Creek watershed.

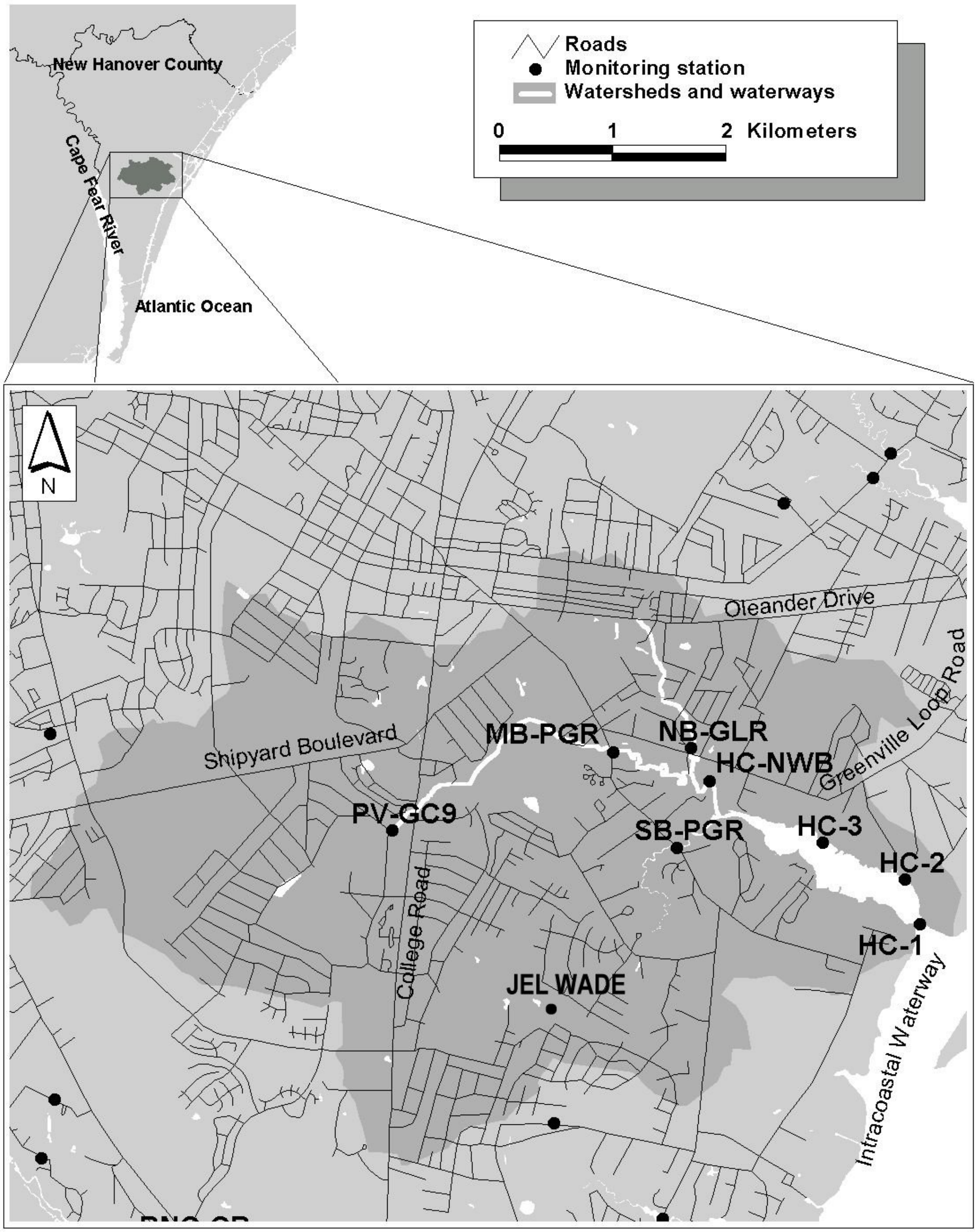


Table 7.1. Selected water quality parameters at upper and middle creek stations in Hewletts Creek watershed 2013 as mean (standard deviation) / range, N/P ratios as mean / median, fecal coliform bacteria presented as geometric mean / range, n = 6.

Parameter	PVGC-9	MB-PGR
Salinity (ppt)	0.1 (0) 0.1-0.1	4.2 (6.4) 0.1-13.6
Turbidity (NTU)	1 (1) 0-2	2 (3) 0-7
TSS (mg/L)	2.2 (1.1) 1.4-3.8	8.2 (5.7) 1.4-17.4
DO (mg/L)	7.0 (1.1) 5.7-9.0	7.5 (1.1) 5.8-8.9
Nitrate (mg/L)	0.202 (0.206) 0.010-0.460	0.113 (0.103) 0.010-0.240
Ammonium (mg/L)	0.082 (0.027) 0.050-0.130	0.042 (0.027) 0.010-0.080
TN (mg/L)	0.402 (0.267) 0.050-0.700	0.238 (0.146) 0.100-0.440
Orthophosphate (mg/L)	0.022 (0.013) 0.010-0.040	0.022 (0.008) 0.010-0.030
TP (mg/L)	0.057 (0.038) 0.030-0.130	0.047 (0.028) 0.020-0.100
N/P	3.4 18.8	13.8 9.4
Chlorophyll *a* (µg/L)	10 (12) 1-26	4 (4) 1-11
Fecal col. (CFU/100 mL)	533 118-7,000	632 163-5,200

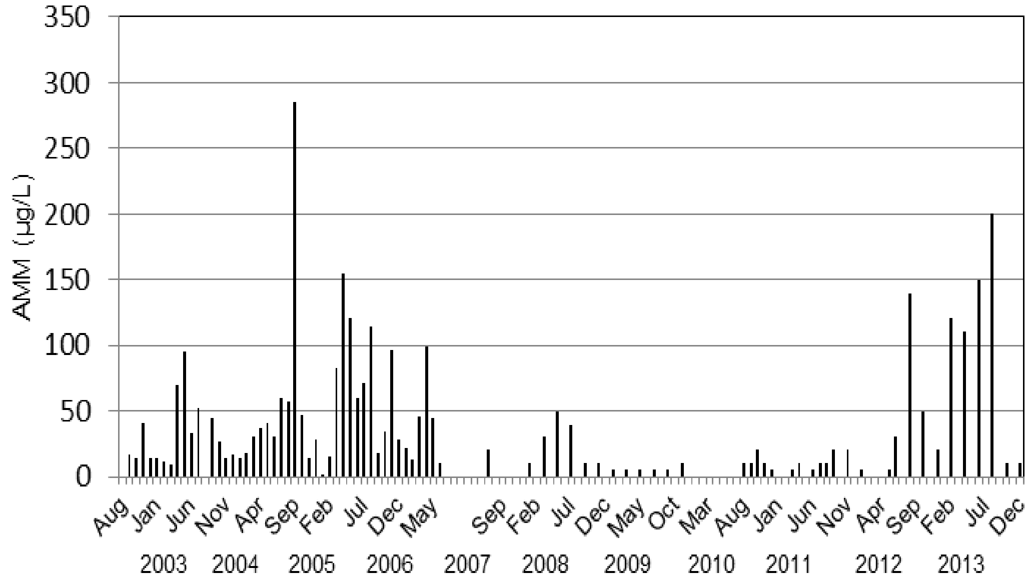
Table 7.2. Selected water quality parameters at stations in Hewletts Creek watershed, 2013, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 6 months.

Parameter	NB-GLR	SB-PGR	HC-3
Salinity (ppt)	12.0 (14.3) 3.8-34.6	21.8 (11.3) 3.8-34.6	30.0 (4.5) 22.5-35.5
Turbidity (NTU)	2 (2) 0-5	4 (3) 0-7	1 (1) 0-3
TSS (mg/L)	11.1 (4.3) 6.0-15.7	15.1 (3.4) 11.1-18.7	13.6 (4.6) 6.4-20.2
DO (mg/L)	8.6 (2.4) 5.9-12.0	7.4 (2.3) 5.1-11.1	8.1 (2.1) 5.8-11.5
Nitrate (mg/L)	0.040 (0.056) 0.010-0.150	0.022 (0.020) 0.010-0.060	0.013 (0.008) 0.010-0.030
Ammonium (mg/L)	0.058 (0.045) 0.010-0.110	0.100 (0.076) 0.010-0.200	0.178 (0.141) 0.010-0.340
TN (mg/L)	0.292 (0.150) 0.100-0.500	0.310 (0.144) 0.100-0.500	0.205 (0.238) 0.030-0.600
Orthophosphate (mg/L)	0.023 (0.012) 0.010-0.040	0.022 (0.012) 0.010-0.040	0.015 (0.008) 0.010-0.030
TP (mg/L)	0.067 (0.051) 0.020-0.160	0.040 (0.025) 0.010-0.070	0.035 (0.023) 0.010-0.070
Mean N/P ratio Median	7.5 7.0	10.3 8.8	32.7 30.6
Chlor *a* (µg/L)	8 (6) 2-16	7 (8) 1-20	3 (3) 1-8
Fecal coliforms (CFU/100 mL)	357 82-2,200	142 10-2,100	75 10-2,600

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 2013) with a probability (p) value of < 0.05 used for significance. For several years ammonium showed a significant decrease following the wetland completion (Figure 7.2). However, in 2013 unusually high ammonium concentrations occurred downstream. This may have been a result of the heavy rainfall in 2013 flushing sedimented decomposing materials from the wetland and watershed in general. However, there is still a statistically-significant 33% decrease in ammonium between the pre-and-post wetland concentrations.

Figure 7.2 Ammonium concentrations over time at south branch Station SB-PGR in Hewletts Creek 2003-2013.



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 49% 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 2003-2013.

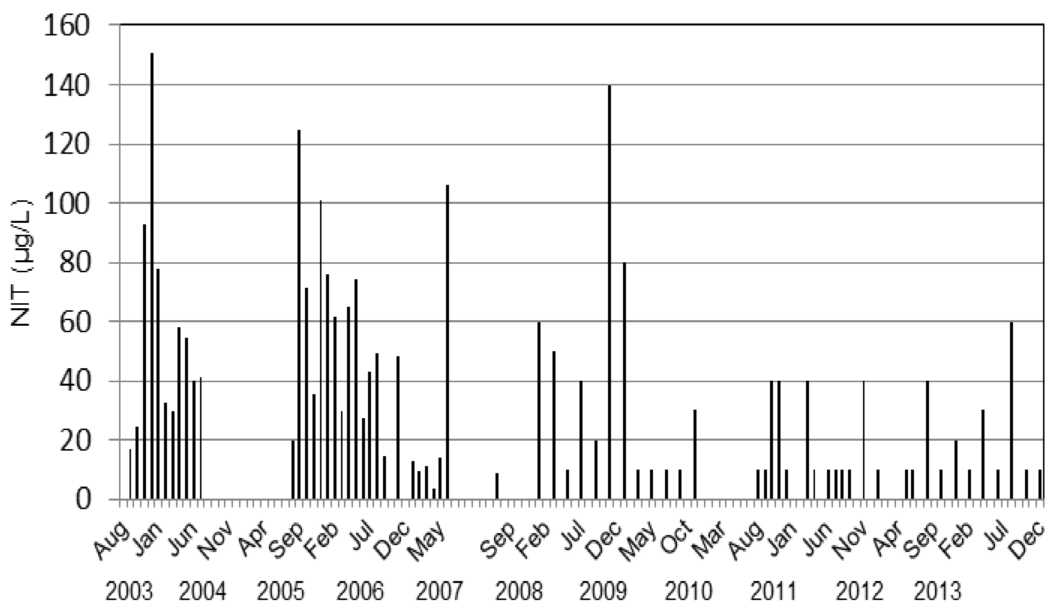
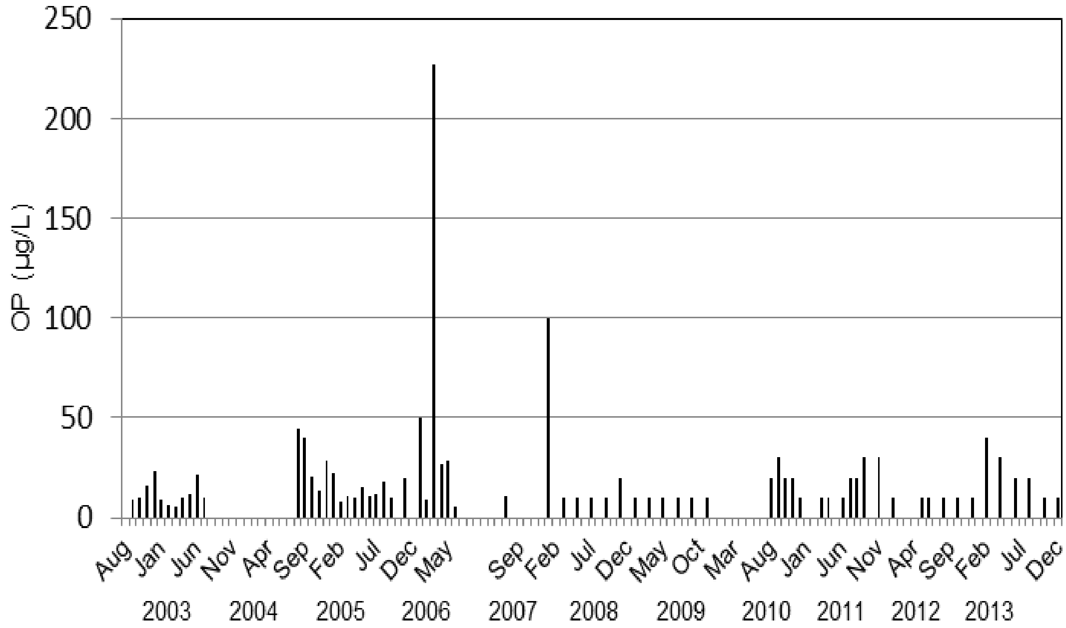
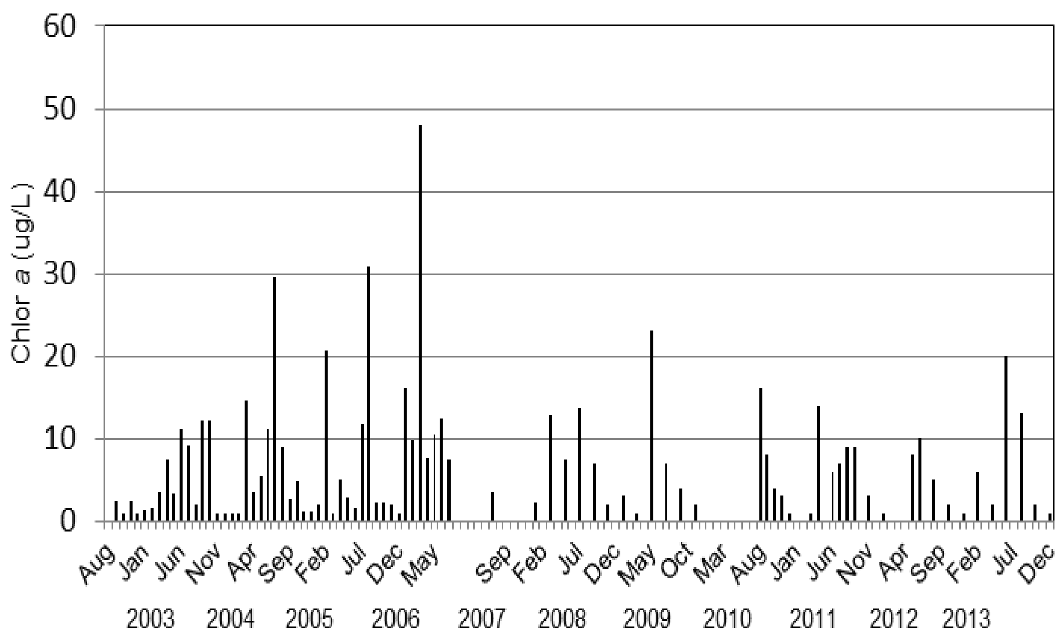


Figure 7.4 Orthophosphate concentration changes over time at south branch Station SB-PGR in Hewletts Creek 2003-2013.



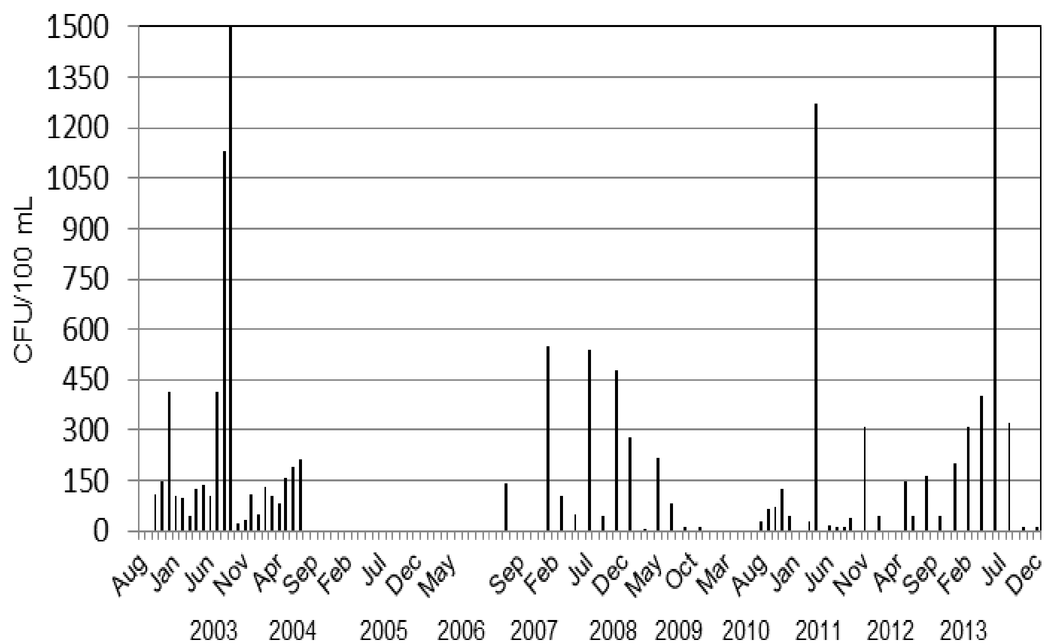
Algal blooms, represented by chlorophyll *a* concentrations, show fewer and smaller peaks in the south branch of Hewletts Creek than prior to wetland construction, but the reductions were not statistically significantly, ($p > 0.05$) (Figure 7.5).

Figure 7.5 Chlorophyll *a* concentration changes over time at south branch Station SB-PGR in Hewletts Creek 2003-2013.



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 with the exception of a sharp peak of 1,273 during an extreme weather event in spring 2011 (Figure 7.6). However, heavy rains increased fecal coliform counts in 2013 (Figure 7.6). Overall counts at SB-PGR in Hewletts Creek are still considerably reduced (from 144 CFU/100 mL pre-wetland) to 75 CFU/100 mL (post-wetland), but the difference is just outside of being statistically significant (p = 0.06). Regardless, 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 2003-2013.



8.0 Howe Creek Water Quality

Snapshot
Watershed area: 3,518 acres (1,424 ha)
Impervious surface coverage: 21.1%
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 2013 (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, July 9 at HW-GP when they reached 25.1 mg/L. Dissolved oxygen concentrations were fair at HW-DT, but good at HW-GP, an improvement from 2012 (Appendix B).

Nitrate and ammonium concentrations were both low at both sites in 2013 (Table 8.1). Orthophosphate was also low at the two sites. Mean and median inorganic molar N/P ratios were relatively low, 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. There were two major algal blooms of 65 and 58 µg/L of chlorophyll *a* at HW-DT, and one of 103 µg/L at HW-GP in 2013 (Table 8.1). Since wetland enhancement was performed in 1998 above Graham Pond the creek below the pond at HW-GP has had fewer and smaller algal blooms than before the enhancement, with the exception of the July bloom in 2013 (Fig. 8.2). For fecal coliform bacteria, the creek ranged from two exceedences of the water contact standard of 200 CFU/100 mL (33%) at the mid-creek station HW-GP, to 100% exceedence of the standard at the upper station HW-DT, where the geometric mean of 734 CFU/100 mL was more than triple the NC standard (Table 8.1). The fecal coliform counts were worse (i.e. higher) in 2013 than the previous year (Fig. 8.3).

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

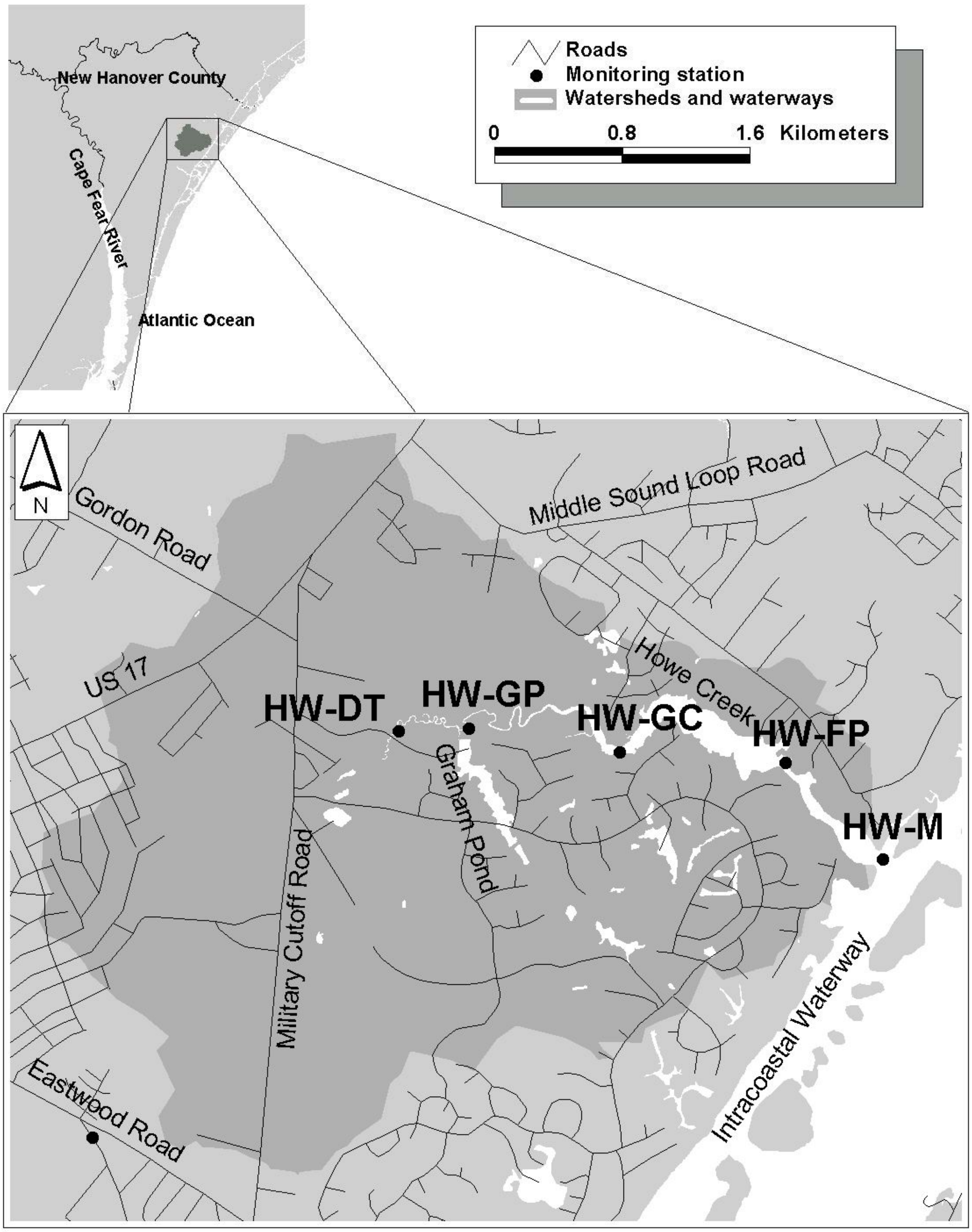


Table 8.1. Water quality summary statistics for Howe Creek, 2013, as mean (st. dev.) / range. Fecal coliform bacteria as geometric mean / range.

Parameter	HW-GP	HW-DT
Salinity (ppt)	21.8(13.8) 1.8-35.0	14.3(14.8) 0.2-32.4
Dissolved oxygen (mg/L)	7.4(1.6) 5.3-9.4	7.7(1.6) 4.9-9.6
Turbidity (NTU)	2(3) 0-8	4(3) 0-8
TSS (mg/L)	14.8(6.0) 6.7-25.1	12.8(6.3) 4.3-19.4
Chlor *a* (μg/L)	22(40) 2-103	24(30) 2-65
Fecal coliforms (CFU/100 mL)	346 118-7,000	734 300-4,000
Nitrate (mg/L)	0.017(0.016) 0.010-0.050	0.020(0.015) 0.010-0.040
Ammonium (mg/L)	0.087(0.095) 0.010-0.240	0.032(0.019) 0.010-0.060
Orthophosphate (mg/L)	0.018(0.016) 0.010-0.050	0.015(0.008) 0.010-0.030
Molar N/P ratio	18.1 8.9	8.5 5.7

Figure 8.2. Chlorophyll *a* concentrations (algal blooms) in Howe Creek below Graham Pond before and after 1998 wetland enhancement in Pond, 1993-2013.

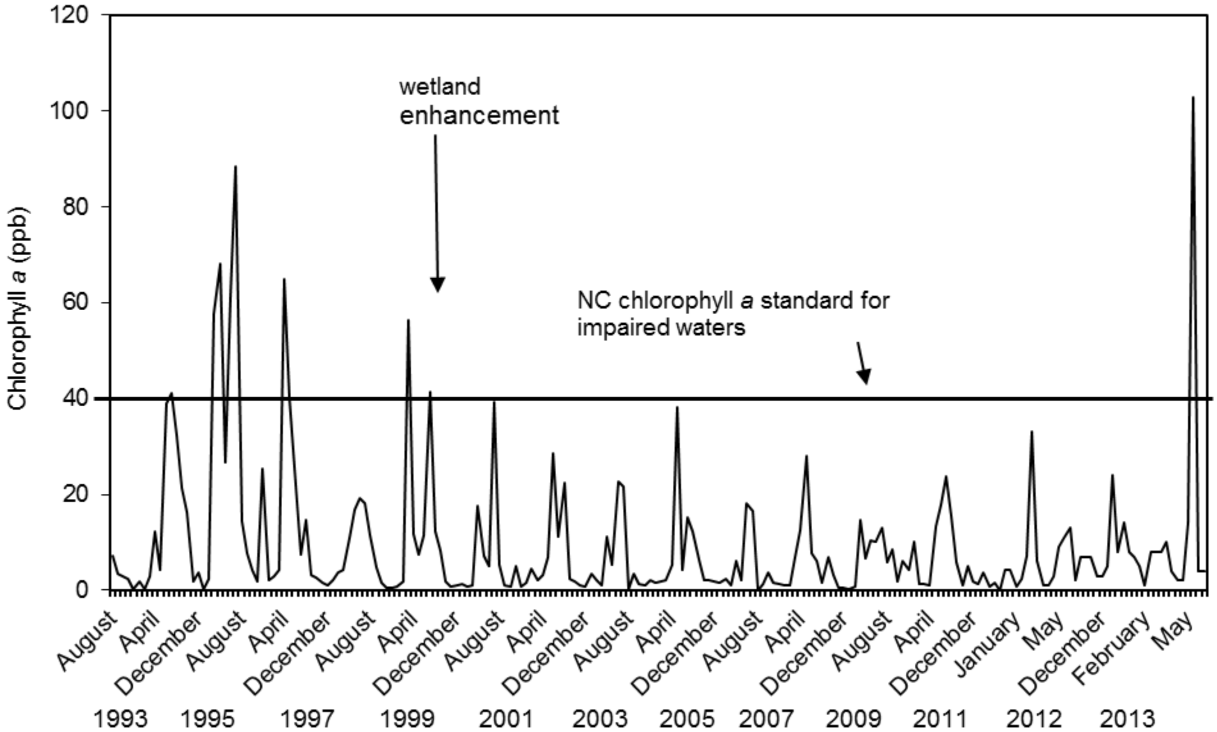
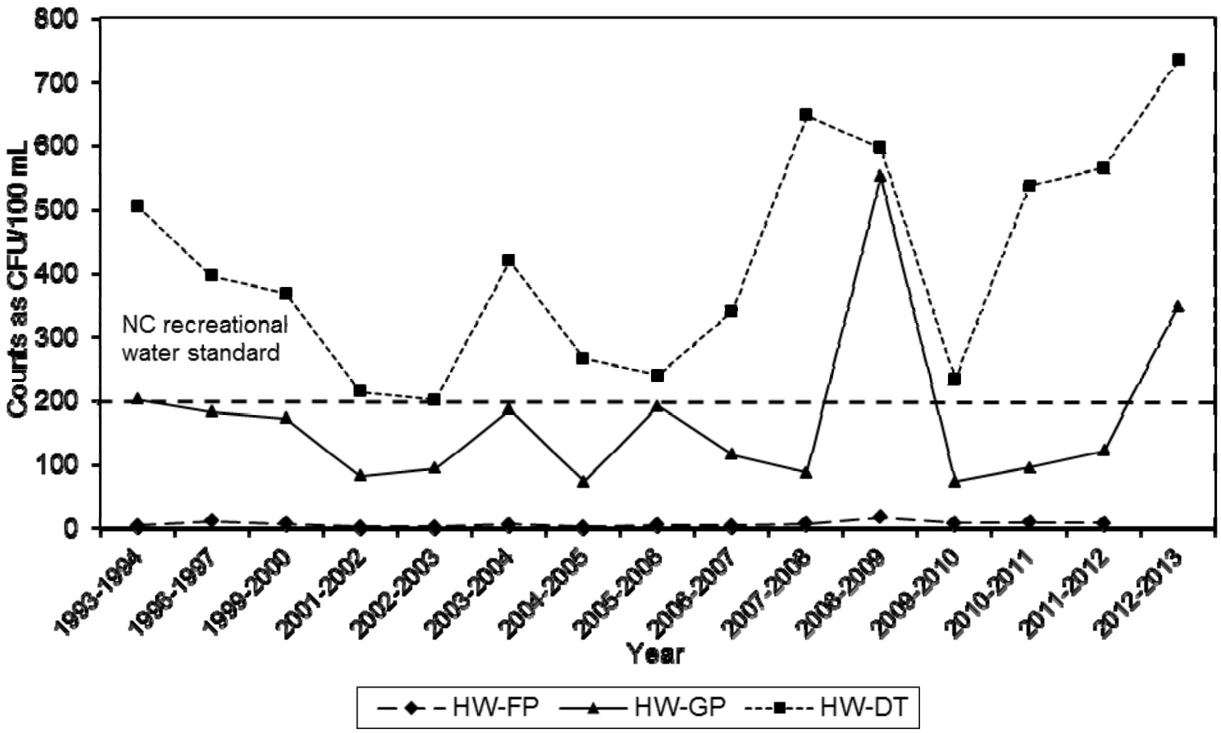


Figure 8.3. Fecal coliform counts over time for Howe Creek stations, 1993-2013.



Sediment Metals and Chemical Toxins in Howe Creek

Wilmington Stormwater Services and the UNCW Aquatic Ecology Laboratory are interested in potential toxicants buried in or adhering to the creek sediments in City watersheds. Thus, we collected sediment samples on one occasion at two sites in Howe Creek for analysis of sediment metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) as well some basic chemical parameters including total nitrogen, total phosphorus and total organic carbon. The State of North Carolina has no official guidelines for sediment concentrations of metals and organic pollutants in reference to protection of invertebrates, fish and wildlife. However, academic researchers (Long et al. 1995) have produced guidelines (Table 8.3) based on extensive field and laboratory testing that are used by the US Environmental Protection Agency in their National Coastal Condition Report II (US EPA 2004).

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 8.3. 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

Howe Creek sediments were sampled at two sites on October 7. None of the parameters sampled exceeded the ERL or ERM for metals and toxicants (Table 8.4).

Table 8.4. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Howe Creek, 2013. Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur according to Long et al. (1995).

Parameter	HW-GP	HW-DT
	Dry wt., ppm = µg/g = mg/kg	
Antimony	<2.64	<2.84
Arsenic	<2.64	<2.84
Beryllium	<2.64	<2.84
Cadmium	<2.64	<2.84
Chromium	12.6	11.7
Copper	2.67	3.86
Lead	3.48	7.56
Mercury	<0.046	<0.052
Nickel	3.86	4.41
Selenium	<2.64	<2.84
Silver	<2.64	<2.84
Thallium	<2.64	<2.84
Zinc	35.4	69.0
TN (mg/kg)	29.9	48.5
TP	1.39	3.9
TOC	50,700	32,400
	Dry wt., ppb = ng/g = µg/kg	
Total PAH	BDL	BDL
Phenanthrene	BDL	BDL
Fluoranthene	BDL	BDL
Pyrene	BDL	BDL
B(a)anthracene	BDL	BDL
Chrysene	BDL	BDL
Benzo(b)fluoranthene	BDL	BDL
Benzo(a)pyrene	BDL	BDL
Total PCBs	BDL	BDL

BDL = below detection limit

9.0 Motts Creek

Snapshot
Watershed area: 3,328 acres (1,347 ha)
Impervious surface coverage: 23.1%
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 2013 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.

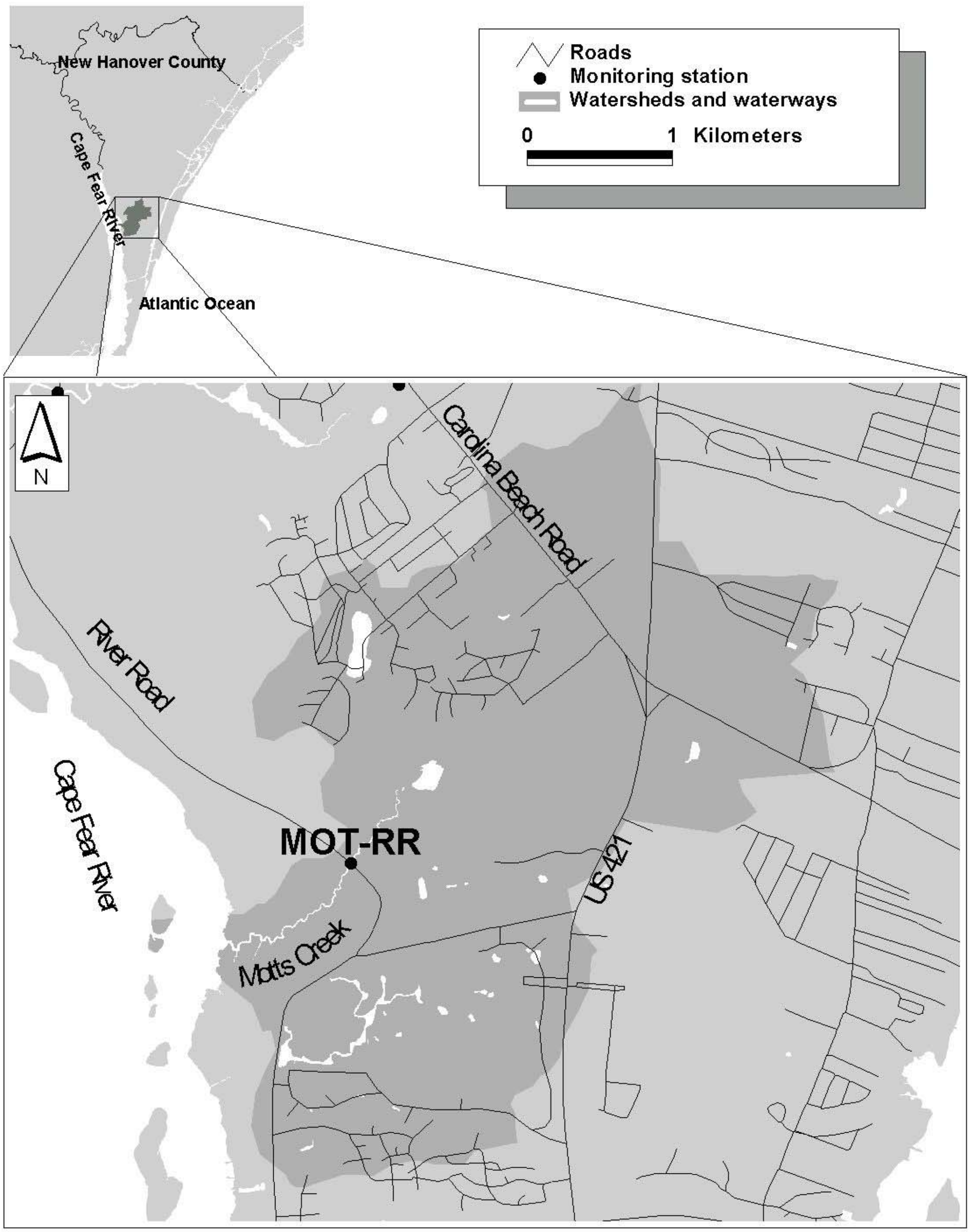
However, in May 2013 UNCW sampled the Mott's Creek sediments at Station MOT-RR, the bridge where Mott's Creek passes under River Road. Based on the suggested guideline for potential toxicity of metals, PCBs and PAHs (Table 8.3), the creek sediments at that location were of good quality to support aquatic life (Table 9.1).

Table 9.1. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Motts Creek, 2013. Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur according to Long et al. (1995).

Parameter	MOT-RR
	Dry wt., ppm = µg/g = mg/kg
Antimony	<2.55
Arsenic	<2.55
Beryllium	<2.55
Cadmium	<2.55
Chromium	6.65
Copper	4.89
Lead	<2.55
Mercury	<0.020
Nickel	<2.55
Selenium	<2.55
Silver	<2.55
Thallium	<2.55
Zinc	24.8
TN (mg/kg)	382.0
TP	110.0
TOC	21,400
	Dry wt., ppb = ng/g = µg/kg
Total PAH	BDL
Phenanthrene	BDL
Fluoranthene	BDL
Pyrene	BDL
B(a)anthracene	BDL
Chrysene	BDL
Benzo(b)fluoranthene	BDL
Benzo(a)pyrene	BDL
Total PCBs	BDL

BDL = below detection limit

Figure 9.1 Motts Creeks watershed

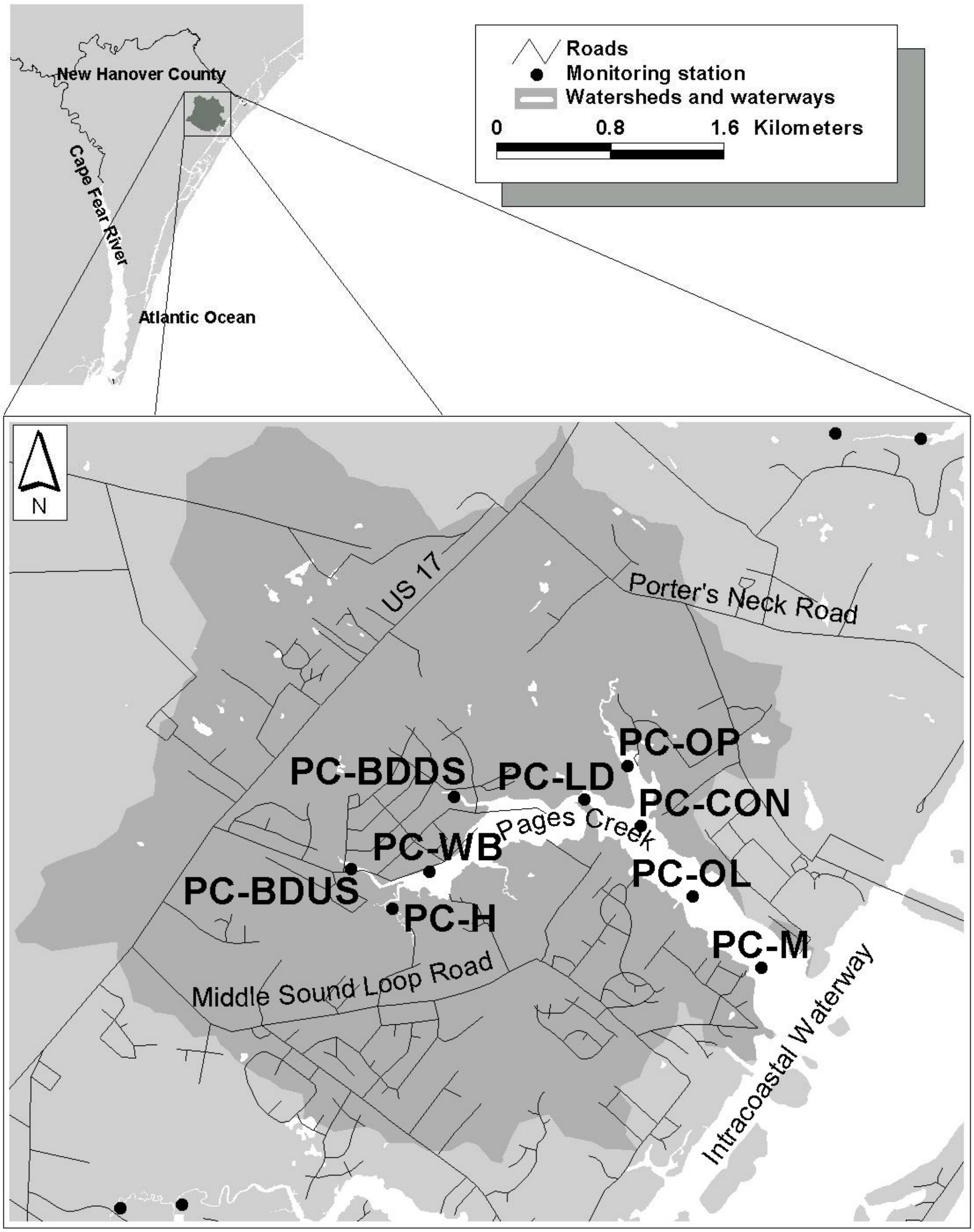


10.0 Pages Creek

Snapshot
Watershed area: 4,100 acres (1,659 ha)
Impervious surface coverage: 15.8 %
Watershed population: Approximately 8,390

The University of North Carolina Wilmington was not funded by the County in 2013 to sample Pages Creek. Subsequent County-sponsored sampling of this creek was performed by Coastal Planning & Engineering of North Carolina, Inc., with data and information for this creek available on the County Planning Department website: http://www.nhcgov.com/AgnAndDpt/PLNG/Pages/WaterQualityMonitoring.aspx.

Figure 10.1. Pages Creek watershed and sampling sites.



11.0 Smith Creek

Snapshot
Watershed area: 13,896 acres (5,624 ha)
Impervious surface coverage: 33% (2013 data)
Watershed population: 31,780
Overall water quality: Fair
Problematic pollutants: some 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 shown below (Table 11.1).

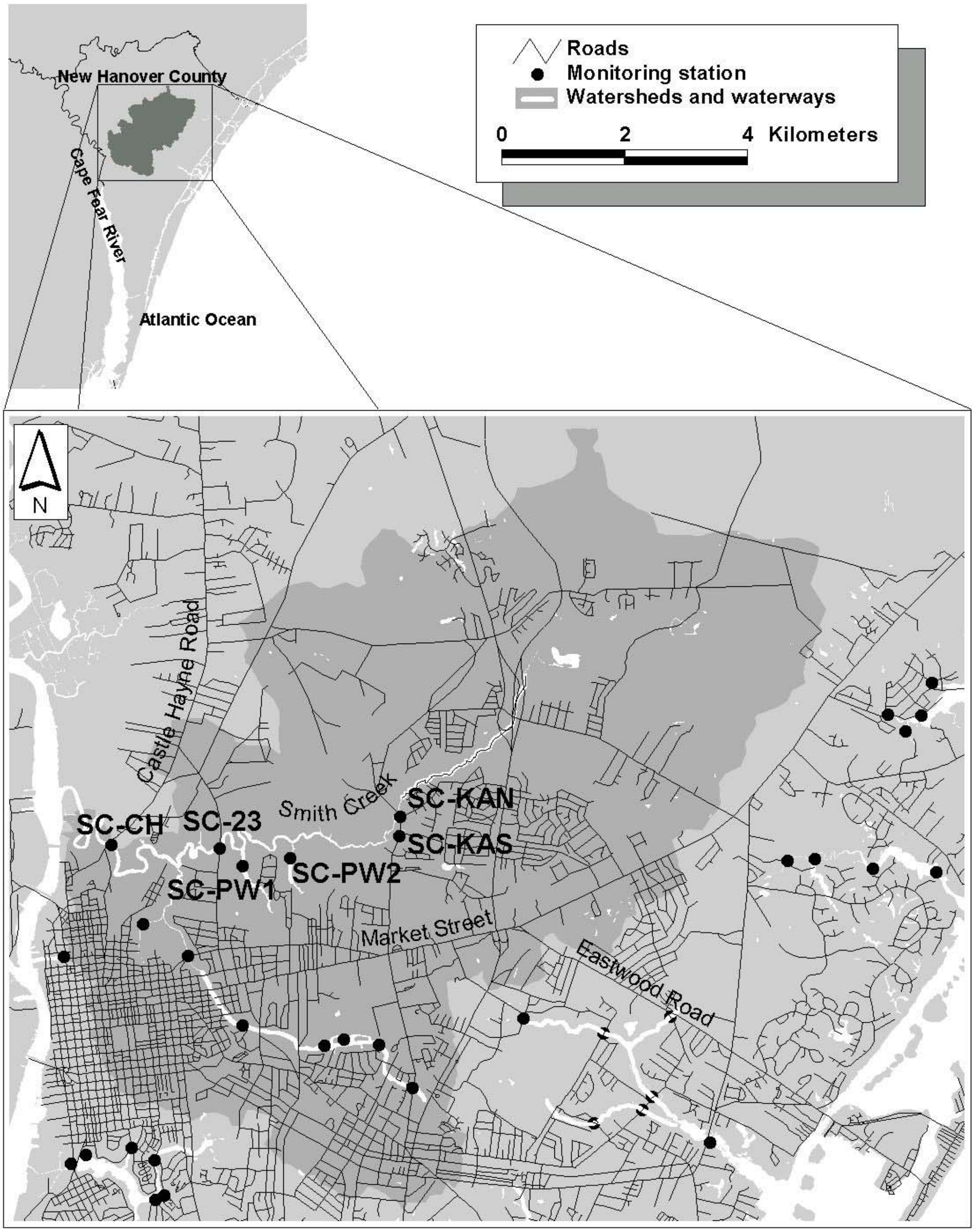
The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters, is 4.0 mg/L, violated one time in our 2013 samples. The North Carolina turbidity standard for estuarine waters (25 NTU) was exceeded one of 12 sampling occasions.

Nutrient concentrations were low to moderate in 2013 (Table 11.1). There were no algal blooms present upon any of our 2013 sampling occasions. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on four sampling occasions at SC-CH in 2013, for a Poor rating; although no samples were unusually high (Table 11.1).

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range, 2013, n = 12 months.

Parameter	SC-CH	
	Mean (SD)	Range
Salinity (ppt)	3.3 (5.1)	0.1-15.9
Dissolved oxygen (mg/L)	6.4 (2.5)	2.0-9.9
Turbidity (NTU)	13 (9)	1-32
TSS (mg/L)	22.1 (9.8)	10.3-43.3
Ammonium (mg/L)	0.088 (0.028)	0.040-0.120
Nitrate (mg/l)	0.155 (0.093)	0.010-0.260
Orthophosphate (mg/L)	0.037 (0.013)	0.020-0.070
Chlorophyll a (µg/L)	5.0 (3.0)	1-11
Fecal col. /100 mL (geomean / range)	126	37-728

Figure 11.1 Smith Creek watershed



12.0 Whiskey Creek

Snapshot
Watershed area: 2,095 acres (848 ha)
Impervious surface coverage: 26.3%
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 2013 salinity at this station was relatively high, what scientists consider euhaline, ranging from 15 – 34 ppt and averaging about 26 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). High suspended solids (46.3 mg/L) were found on the June 24 sample trip. Algal blooms are relatively rare in this creek and there were no blooms detected in our 2013 sampling (Table 12.1). Nitrate and orthophosphate concentrations were generally low at this station, although ammonium was increased from the previous year. Total nitrogen and total phosphorus were low, similar to previous years.

Whereas in 2012 fecal coliform bacteria were acceptable for human contact at this site and below the North Carolina standard of 200 CFU/100 mL on all six occasions, in 2013 fecal coliforms slightly exceeded that standard on three of six occasions (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, 2013, presented as mean (standard deviation) / range, fecal coliforms as geometric mean / range.

	Salinity (ppt)	DO (mg/L)	Turbidity (NTU)	TSS (mg/L)	Chlor *a* (μg/L)	FC CFU/100 mL
WC-MLR	25.8 (6.5)	7.5 (1.7)	3 (2)	19.9 (13.6)	7 (6)	119
	15.2-34.2	4.8-9.3	0-5	6.6-46.3	2-18	46-310

Table 12.2. Nutrient concentration summary statistics for Whiskey Creek, 2013, as mean (standard deviation) / range, N/P ratio as mean / median.

	Nitrate (mg/L)	Ammonium (mg/L)	TN (mg/L)	Phosphate (mg/L)	TP (mg/L)	N/P ratio
WC-MLR	0.02 (0.036	0.17 (0.11)	0.25 (0.20)	0.02 (0.01)	0.05 (0.05)	26.3
	0.01-0.05	0.02-0.29	0.20-0.60	0.01-0.03	0.01-0.14	18.5

<u>Sediment Metals and Chemical Toxins</u>

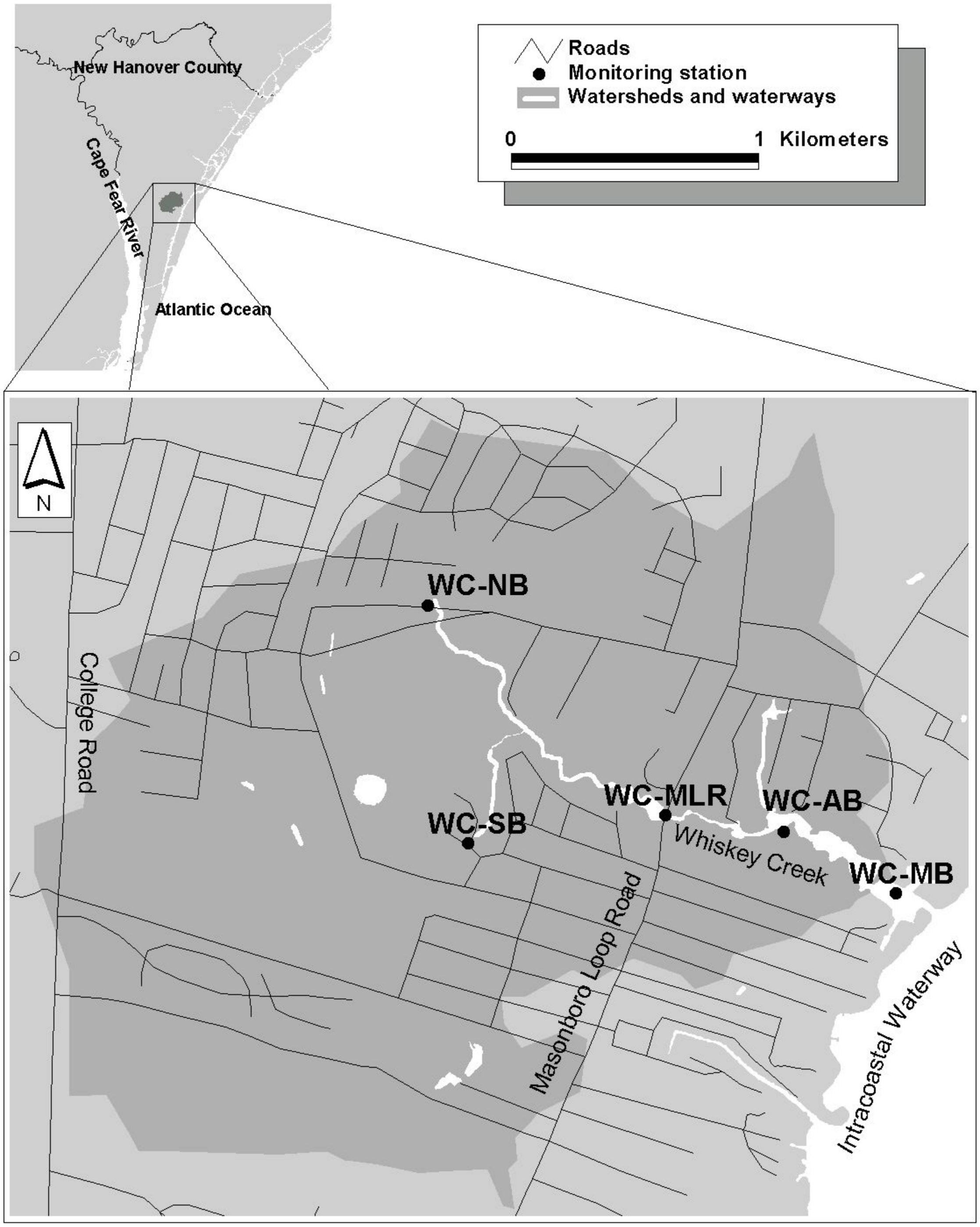
Sediment metals and toxicants were collected on one occasion (5/31/13) from Whiskey Creek (Table 12.3). The upper two tributary stations, WC-NB and WC-SB, had no levels of metals, PCBs, or PAHs that were in excess of concentrations known to be toxic to benthic organisms (see Table 8.3 for explanation). However, Station WB-MLR, at the Masonboro Loop Road bridge crossing the creek, had excessive concentrations of total PAHs, as well as the following individual PAHs: benzo(a)anthracene, benzo(a)pyrene, fluoranthene, phenanthrene and pyrene. PAHs are often associated with automobile use, and the location at the bridge may have accounted for these elevated PAHs. Downstream at the Whiskey Creek Marina (WC-MR) the only parameter found in excessive sediment concentrations was copper. It is likely that leachate of copper from boat paints accounted for the excessive concentrations.

Table 12.3. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Whiskey Creek, 2013. Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur according to Long et al. (1995).

Parameter	WC-NB	WC-SB	WB-MLR	WB-MR
		Dry wt., ppm = µg/g = mg/kg		
Antimony	<0.123	<0.129	<0.202	<5.72
Arsenic	<0.123	<0.129	<2.01	<5.72
Beryllium	<0.123	<0.129	<2.01	<5.72
Cadmium	<0.123	<0.129	<2.01	<5.72
Chromium	0.805	0.324	4.76	44.4
Copper	0.317	0.475	4.42	**44.0**
Lead	0.164	<0.129	13.0	<5.72
Mercury	0.008	<0.004	<0.010	0.064
Nickel	0.325	0.275	<2.01	7.28
Selenium	<0.123	<0.129	<2.01	<5.72
Silver	<0.123	<0.129	<2.01	<5.72
Thallium	<0.123	<0.129	<2.01	<5.72
Zinc	2.45	4.80	13.1	86.3
		Dry wt., ppb = ng/g = µg/kg		
Total PAH	BDL	BDL	**4,855**	BDL
Anthracene	BDL	BDL	BDL	BDL
Phenanthrene	BDL	BDL	**500**	BDL
Fluoranthene	BDL	BDL	**1,610**	BDL
Pyrene	BDL	BDL	**1,070**	BDL
B(a)anthracene	BDL	BDL	**1,000**	BDL
Chrysene	BDL	BDL	BDL	BDL
B(a)pyrene	BDL	BDL	**6750**	BDL
Total PCBs	BDL	BDL	BDL	BDL
TN	27.8	22.8	99.7	318.0
TP	10.2	4.86	39.0	136.0
TOC	1,350	1,110	1,470	21,900

BDL = below detection limit

Figure 12.1. Whiskey Creek. Watershed and sampling sites.



13.0 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.

On March 1 Matthew McIver and Dr. Mike Mallin accompanied Beth Nunnally of City stormwater staff to two locations on Burnt Mill Creek in the vicinity of Shirley Road drainage to test for potential sewer leakage. Here are the data for that investigation:

BMC SR-1 ammonium = 0.040 mg/L BOD5 = 1.41 mg/L fecal coliforms = 172 CFU/100 mL

BMC-SR2 ammonium = 0.070 mg/L BOD5 = 0.920 mg/L fecal coliforms = 145 CFU/100 mL

The data indicated no active sewer leak in the vicinity

14.0 Report References Cited

APHA. 1995. Standard Methods for the Examination of Water and Wastewater, 19th ed. American Public Health Association, Washington, D.C.

Burkholder, J.M. 2001. Eutrophication and Oligotrophication. *In* "Encyclopedia of Biodiversity", Vol. 2, pp 649-670. Academic Press.

Duernberger, K.A. 2009. Tracing nitrogen through the food chain in an urbanized tidal creek. M.S. Thesis, University of North Carolina Wilmington, Center for Marine Science.

Hecky, R.E. and P. Kilham. 1988. Nutrient limitation of phytoplankton in freshwater and marine environments: A review of recent evidence on the effects of enrichment. *Limnology and Oceanography* 33:796-822.

Long, E.R., D.D. McDonald, S.L. Smith and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19:81-97.

Mallin, M.A., L.B. Cahoon, J.J. Manock, J.F. Merritt, M.H. Posey, R.K. Sizemore, W.D. Webster and T.D. Alphin. 1998a. *A Four-Year Environmental Analysis of New Hanover County Tidal Creeks, 1993-1997.* CMSR Report No. 98-01, Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, J.J. Manock, J.F. Merritt, M.H. Posey, T.D. Alphin, D.C. Parsons and T.L. Wheeler. 1998b. *Environmental Quality of Wilmington and New Hanover County Watersheds, 1997-1998*. CMSR Report 98-03. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., S.H. Ensign, D.C. Parsons and J.F. Merritt. 1999. *Environmental Quality of Wilmington and New Hanover County Watersheds, 1998-1999.* CMSR Report No. 99-02. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A. and T.L. Wheeler. 2000. Nutrient and fecal coliform discharge from coastal North Carolina golf courses. *Journal of Environmental Quality* 29:979-986.

Mallin, M.A., K.E. Williams, E.C. Esham and R.P. Lowe. 2000a. Effect of human development on bacteriological water quality in coastal watersheds. *Ecological Applications* 10:1047-1056.

Mallin, M.A., S.H. Ensign, D.C. Parsons, V.L. Johnson and J.F. Merritt. 2000b. *Environmental Quality of Wilmington and New Hanover County Watersheds, 1999-2000.* CMSR Report No. 00-02. Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., S.H. Ensign, M.R. McIver, G.C. Shank and P.K. Fowler. 2001. Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal waters. *Hydrobiologia* 460:185-193.

Mallin, M.A., L.B. Cahoon, M.H. Posey, L.A. Leonard, D.C. Parsons, V.L. Johnson, E.J. Wambach, T.D. Alphin, K.A. Nelson and J.F. Merritt. 2002a. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2000-2001*. CMS Report 02-01, Center for Marine Science, UNC Wilmington, Wilmington, N.C.

Mallin, M.A., S.H. Ensign, T.L. Wheeler and D.B. Mayes. 2002b. Pollutant removal efficacy of three wet detention ponds. *Journal of Environmental Quality* 31:654-660.

Mallin, M.A., L.B. Cahoon, M.H. Posey, D.C. Parsons, V.L. Johnson, T.D. Alphin and J.F. Merritt. 2003. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2001-2002*. CMS Report 03-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, M.H. Posey, V.L. Johnson, T.D. Alphin, D.C. Parsons and J.F. Merritt. 2004. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2002-2003*. CMS Report 04-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

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

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

Mallin, M.A., L.B. Cahoon, T.D. Alphin, M.H. Posey, B.A. Rosov, D.C. Parsons, R.M. Harrington and J.F. Merritt. 2007. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2005-2006*. CMS Report 07-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., M.R. McIver, M.I.H. Spivey, M.E. Tavares, T.D. Alphin and M.H. Posey. 2008. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2006-2007*. CMS Report 08-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., M.R. McIver, M.I.H. Spivey and B. Song. 2009a. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2008*. CMS Report 09-03, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

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

Mallin, M.A., M.R. McIver, M.I. Haltom, E.A. Steffy and B. Song. 2010a. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2009*. CMS Report 10-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., J. McAuliffe, M.R. McIver, D. Mayes and M.R. Hanson. 2012. High pollutant removal efficacy of a large constructed wetland leads to receiving stream improvements. *Journal of Environmental Quality* 41:2046-2055.

Mallin, M.A., E.A. Steffy, M.R. McIver and M.I. Haltom. 2011. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2010*. CMS Report 11-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

NCDENR. 2005. Cape Fear River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh, N.C.

Perrin, C., J. Wright, W.F. Hunt, P. Beggs, M.A. Mallin and M. Burchell. 2008. *Restoring the Burnt Mill Creek Watershed through Stormwater Management and Community Development*. FY04 EPA 319 Grant Final Report.

Schlotzhauer, S.D. and R.C. Littell. 1997. SAS system for elementary statistical analysis, 2nd Edition. SAS Institute, Inc., SAS Campus Dr., Cary, N.C.

Tavares, M.E., M.I.H. Spivey, M.R. McIver and M.A. Mallin. 2008. Testing for optical brighteners and fecal bacteria to detect sewage leaks in tidal creeks. *Journal of the North Carolina Academy of Science* 124:91-97.

U.S. EPA. 1997. Methods for the Determination of Chemical Substances in Marine and Estuarine Environmental Matrices, 2nd Ed. EPA/600/R-97/072. National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

US EPA 2000. Guidance for assessing chemical contaminant data for use In fish advisories, Volume 2: Risk assessment and fish consumption limits. EPA-823-B-00-008. United States Environmental Protection Agency, Office of Research and Development, Office of Water, Washington, D.C.

US EPA. 2004. National Coastal Condition Report II. EPA-620/R-03/002. United States Environmental Protection Agency, Office of Research and Development, Office of Water, Washington, D.C.

Welschmeyer, N.A. 1994. Fluorometric analysis of chlorophyll *a* in the presence of chlorophyll *b* and phaeopigments. *Limnology and Oceanography* 39:1985-1993.

15.0 Acknowledgments

Funding for this research was provided by the City of Wilmington, with facilitation by the Water Resources Research Institute of the University of North Carolina. For project facilitation and helpful information we thank David Mayes, Beth Nunnally and Matt Hayes of Wilmington Stormwater Services. For field, laboratory and GIS assistance we thank Dr. Amanda Kahn Dickens and Anna R. Robuck.

16.0 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

17.0 Appendix B. UNCW ratings of sampling stations in Wilmington watersheds based on 2013, 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	G	G	P
	BC-SB	G	F	F	P
	BC-NB	G	G	G	P
Burnt Mill Creek	BMC-AP1	F	G	G	P
	BMC-AP3	G	G	G	G
	BMC-PP	G	P	G	P
Greenfield Lake	JRB-17	G	G	G	P
	GL-JRB	G	P	G	P
	GL-LC	G	P	G	P
	GL-LB	G	P	G	P
	GL-2340	G	G	G	F
	GL-YD	P	G	G	G
	GL-P	P	G	G	F
Hewletts Creek	HC-3	G	G	G	F
	NB-GLR	G	G	G	P
	MB-PGR	G	G	G	P
	SB-PGR	G	G	G	P
	PVGC-9	G	G	G	P
Howe Creek	HW-GP	F	G	G	P
	HW-DT	P	F	G	P
Smith Creek	SC-CH	G	G	G	P
Whiskey Creek	WC-MLR	G	F	G	P

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

Watershed	Station	GPS coordinates	
Barnard's Creek	BNC-RR	N 34.15867	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

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

Reports

Merritt, J.F., L.B. Cahoon, J.J. Manock, M.H. Posey, R.K. Sizemore, J. Willey and W.D. Webster. 1993. *Futch Creek Environmental Analysis Report*. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, E.C. Esham, J.J. Manock, J.F. Merritt, M.H. Posey and R.K. Sizemore. 1994. *Water Quality in New Hanover County Tidal Creeks, 1993-1994*. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C. 62 pp.

Mallin, M.A., L.B. Cahoon, J.J. Manock, J.F. Merritt, M.H. Posey, T.D. Alphin and R.K. Sizemore. 1995. *Water Quality in New Hanover County Tidal Creeks, 1994-1995*. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C. 67 pp.

Mallin. M.A., L.B. Cahoon, J.J. Manock, J.F. Merritt, M.H., Posey, R.K. Sizemore, T.D. Alphin, K.E. Williams and E.D. Hubertz. 1996. *Water Quality in New Hanover County Tidal Creeks, 1995-1996*. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C. 67 pp.

Mallin, M.A., L.B. Cahoon, J.J. Manock, J.F. Merritt, M.H. Posey, R.K. Sizemore, W.D. Webster and T.D. Alphin. 1998. *A Four-Year Environmental Analysis of New Hanover County Tidal Creeks, 1993-1997.* CMSR Report No. 98-01, Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, J.J. Manock, J.F. Merritt, M.H. Posey, T.D. Alphin, D.C. Parsons and T.L. Wheeler. 1998. *Environmental Quality of Wilmington and New Hanover County Watersheds, 1997-1998*. CMSR Report 98-03. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., S.H. Ensign, D.C. Parsons and J.F. Merritt. 1999. *Environmental Quality of Wilmington and New Hanover County Watersheds, 1998-1999*. CMSR Report No. 99-02. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, S.H. Ensign, D.C. Parsons, V.L. Johnson and J.F. Merritt. 2000. *Environmental Quality of Wilmington and New Hanover County Watersheds, 1999-2000*. CMS Report No. 00-02. Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, M.H. Posey, L.A. Leonard, D.C. Parsons, V.L. Johnson, E.J. Wambach, T.D. Alphin, K.A. Nelson and J.F. Merritt. 2002. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2000-2001*. CMS Report 02-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., H.A. CoVan and D.H. Wells. 2003. *Water Quality Analysis of the Mason inlet Relocation Project*. CMS Report 03-02. Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, M.H. Posey, D.C. Parsons, V.L. Johnson, T.D. Alphin and J.F. Merritt. 2003. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2001-2002*. CMS Report 03-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, M.H. Posey, V.L. Johnson, T.D. Alphin, D.C. Parsons and J.F. Merritt. 2004. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2002-2003*. CMS Report 04-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., H.A. Wells and M.R. McIver. 2004. *Baseline Report on Bald Head Creek Water Quality*. CMS Report No. 04-03, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., H.A. Wells, T.A. MacPherson, T.D. Alphin, M.H. Posey and R.T. Barbour. 2004. *Environmental Assessment of Surface Waters in the Town of Carolina Beach*. CMS Report No. 04-02, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, M.H. Posey, V.L. Johnson, D.C. Parsons, T.D. Alphin, B.R. Toothman and J.F. Merritt. 2005. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2003-2004*. CMS Report 05-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A. 2006. Wading in waste. *Scientific American* 294:52-59.

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

Mallin, M.A., B.R. Toothman, M.R. McIver and M.S. Hayes. 2007. *Bald Head Creek Water Quality: Before and After Dredging*. Final Report to the Village of Bald Head Island. CMS report 07-02. Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.B. Cahoon, T.D. Alphin, M.H. Posey, B.A. Rosov, D.C. Parsons, R.M. Harrington and J.F. Merritt. 2007. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2005-2006*. CMS Report 07-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., M.R. McIver, M.I.H. Spivey, M.E. Tavares, T.D. Alphin and M.H. Posey. 2008. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2006-2007*. CMS Report 08-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., M.R. McIver, M.I.H. Spivey and B. Song. 2009. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2008*. CMS Report 09-03, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., M.I.H. Spivey and B. Song. 2009. *Sources of Fecal Bacterial Pollution to Upper Pages Creek, N.C*. Report to Coastal Planning & Engineering of North Carolina, Inc. UNCW-CMS Report 09-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., J.A. McAuliffe, Y. Shirazi and M.R. McIver. 2010. Pollutant Removal Efficacy of a Constructed Wetland: The Clean Water Management Trust Fund 2004B-707 Wilmington Bethel Road Wetlands Project, UNCW CMS Report 10-03, University of North Carolina Wilmington, Wilmington, N.C.

Mallin, M.A., M.R. McIver, M.I. Haltom, E.A. Steffy and B. Song. 2010. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2009*. CMS Report 10-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., E.A. Steffy, M.R. McIver and M.I. Haltom. 2011. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2010*. CMS Report 11-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., E.A. Steffy, M.R. McIver and E. Clay. 2012. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2011*. UNCW-CMS Report 12-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Mallin, M.A., L.E. Bohrer, M.R. McIver and S. Protopappas. 2013. *Environmental Quality of Wilmington and New Hanover County Watersheds, 2012*. UNCW-CMS Report 13-01, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C.

Peer-Reviewed Journal Papers

Mallin, M.A., E.C. Esham, K.E. Williams and J.E. Nearhoof. 1999. Tidal stage variability of fecal coliform and chlorophyll *a* concentrations in coastal creeks*. Marine Pollution Bulletin* 38:414-422.

Mallin, M.A. and T.L. Wheeler. 2000. Nutrient and fecal coliform discharge from coastal North Carolina golf courses. *Journal of Environmental Quality* 29:979-986.

Mallin, M.A., K.E. Williams, E.C. Esham and R.P. Lowe. 2000. Effect of human development on bacteriological water quality in coastal watersheds. *Ecological Applications* 10:1047-1056.

Mallin, M.A., L.B. Cahoon, R.P. Lowe, J.F. Merritt, R.K. Sizemore and K.E. Williams. 2000. Restoration of shellfishing waters in a tidal creek following limited dredging. *Journal of Coastal Research* 16:40-47.

Mallin, M.A., J.M. Burkholder, L.B. Cahoon and M.H. Posey. 2000. The North and South Carolina coasts. *Marine Pollution Bulletin* 41:56-75.

Mallin, M.A., S.H. Ensign, M.R. McIver, G.C. Shank and P.K. Fowler. 2001. Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal waters. *Hydrobiologia* 460:185-193.

Mallin, M.A., S.H. Ensign, T.L. Wheeler and D.B. Mayes. 2002. Pollutant removal efficacy of three wet detention ponds. *Journal of Environmental Quality* 31:654-660.

Posey, M.H., T.D. Alphin, L.B. Cahoon, D.G. Lindquist, M.A. Mallin and M.E. Nevers. 2002, Resource availability versus predator control: questions of scale in benthic infaunal communities. *Estuaries* 25:999-1014.

Cressman, K.A., M.H. Posey, M.A. Mallin, L.A. Leonard and T.D. Alphin. 2003. Effects of oyster reefs on water quality in a tidal creek estuary. *Journal of Shellfish Research* 22:753-762.

Mallin, M.A. and A.J. Lewitus. 2004. The importance of tidal creek ecosystems. *Journal of Experimental Marine Biology and Ecology* 298:145-149.

Mallin, M.A., D.C. Parsons, V.L. Johnson, M.R. McIver and H.A. CoVan. 2004. Nutrient limitation and algal blooms in urbanizing tidal creeks. *Journal of Experimental Marine Biology and Ecology* 298:211-231.

Nelson, K.A., L.A. Leonard, M.H. Posey, T.D. Alphin and M.A. Mallin. 2004. Transplanted oyster (*Crassostrea virginica*) beds as self-sustaining mechanisms for water quality improvement in small tidal creeks. *Journal of Experimental Marine Biology and Ecology* 298:347-368.

Mallin, M.A., S.H. Ensign, D.C. Parsons, V.L. Johnson, J.M. Burkholder and P.A. Rublee. 2005. Relationship of *Pfiesteria* spp. and *Pfiesteria*-like organisms to environmental factors in tidal creeks draining urban watersheds. pp 68-70 in Steidinger, K.A., J.H. Landsberg, C.R. Tomas and G.A. Vargo, (Eds.) *XHAB, Proceedings of the Tenth Conference on Harmful Algal Blooms, 2002*, Florida Fish and Wildlife Conservation Commission, Florida Institute of Oceanography, and Intergovernmental Commission of UNESCO.

Mallin, M.A., L.B. Cahoon, B.R. Toothman, D.C. Parsons, M.R. McIver, M.L. Ortwine and R.N. Harrington. 2006. Impacts of a raw sewage spill on water and sediment quality in an urbanized estuary. *Marine Pollution Bulletin* 54:81-88.

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

Mallin, M.A., L.B. Cahoon, B.R. Toothman, D.C. Parsons, M.R. McIver, M.L. Ortwine and R.N. Harrington. 2007. Impacts of a raw sewage spill on water and sediment quality in an urbanized estuary. *Marine Pollution Bulletin* 54:81-88.

Cahoon, L.B., M.A. Mallin, B. Toothman, M. Ortwine, R. Harrington, R. Gerhart, S. Gill and J. Knowles. 2007. Is there a relationship between phosphorus and fecal microbes in aquatic sediments? Report No. 366, Water Resources Research Institute of the University of North Carolina.

Dafner, E.V., M.A. Mallin, J.J. Souza, H.A. Wells and D.C. Parsons. 2007. Nitrogen and phosphorus species in the coastal and shelf waters of southeastern North Carolina, Mid-Atlantic U.S. coast. *Marine Chemistry*. 103:289-303.

MacPherson, T.A., M.A. Mallin and L.B. Cahoon. 2007. Biochemical and sediment oxygen demand: patterns of oxygen depletion in tidal creeks. *Hydrobiologia* 586: 235-248.

Tavares, M.E., M.I.H. Spivey, M.R. McIver and M.A. Mallin. 2008. Testing for optical brighteners and fecal bacteria to detect sewage leaks in tidal creeks. *Journal of the North Carolina Academy of Science* 124:91-97.

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

Toothman, B.R., L.B. Cahoon and M.A. Mallin. 2009. Phosphorus and carbohydrate limitation of fecal coliform and fecal enterococcus within tidal creek sediments. *Hydrobiologia* 636:401-412.

Duernberger, K., C. Tobias and M.A. Mallin. 2012. Tracing nitrogen transformations through the food chain in an urbanized tidal creek. Report No. 405. Water Resources Research Institute of the University of North Carolina, Raleigh, N.C.

Mallin, M.A., J. McAuliffe, M.R. McIver, D. Mayes and M.R. Hanson. 2012. High pollutant removal efficacy of a large constructed wetland leads to receiving stream improvements. *Journal of Environmental Quality* 41:2046-2055.

Chudoba, E.A., M.A. Mallin, L.B. Cahoon and S.A. Skrabal. 2013. Stimulation of fecal bacteria in ambient waters by experimental inputs of organic and inorganic phosphorus. *Water Research* 47:3455-3466.