ENVIRONMENTAL QUALITY OF WILMINGTON AND NEW HANOVER COUNTY WATERSHEDS, 2017

by

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Executive Summary

This report represents combined results of Year 20 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The 2017 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 2017; note that fewer samples were collected in 2017 because funding did not arrive until late fall.

Barnards Creek – Barnards Creek drains into the Cape Fear River Estuary. It drains a 4,173 acre watershed that consists of 22.3% impervious surface coverage, and a population of approximately 12,200. Water column sampling was not funded during 2017, but new funding from the City allowed UNCW to re-initiate sampling of Barnards Creek in January 2018.

Bradley Creek – Bradley Creek drains a watershed of 4,583 acres, including much of the UNCW campus, into the Atlantic Intracoastal Waterway (AICW). The watershed contains about 27.8% impervious surface coverage, with a population of about 16,470. Three sites were sampled, all from shore. In 2017 there were no significant algal blooms recorded, but there were several incidents of low dissolved oxygen at the uppermost site BC-CA on College Acres. All three sites sampled were rated poor due to high fecal coliform bacteria, with the College Acres station BC-CA having especially high counts.

Burnt Mill Creek – Burnt Mill Creek drains a 4,207 acre watershed with a population of about 23,700. Its watershed is extensively urbanized (39.8% impervious surface coverage) and drains into Smith Creek. Three locations were sampled during 2017. High fecal coliform counts occurred at only one of the three sites in 2017, much better than previous years. Two major and one minor algal blooms were recorded in 2017. Dissolved oxygen concentrations were good in two stations and fair in the remaining mid-creek site.

The effectiveness of Ann McCrary wet detention pond on Randall Parkway as a pollution control device for upper Burnt Mill Creek was mixed for 2017. Comparing inflows to outflows, there was a good bit of variability in parameter concentrations and hence no significant differences between inflow and outflow. 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, orthophosphate and nitrate.

Futch Creek – Futch Creek is situated on the New Hanover-Pender County line and drains a 3,813 acre watershed (12.3% impervious coverage) into the ICW. UNC Wilmington was not funded to regularly sample this creek in 2017. New Hanover County employed a consulting firm to sample this creek and data may be requested from the County.

Greenfield Lake – This lake drains a watershed of 2,465 acres, covered by about 37% impervious surface area with a population of about 10,630. This urban lake has suffered from low dissolved oxygen, algal blooms, periodic fish kills and high fecal bacteria counts over the years. The lake was sampled at four tributary sites and three in-lake sites. Of the four tributaries of Greenfield Lake, Squash Branch (near Lake Branch Drive), Jumping Run Branch at 17th Street, Jumping Run Branch at lakeshore Dr., and Clay Bottom Branch (near Lakeshore Commons Apartments), three suffered from low dissolved oxygen problems, although main lake oxygen problems were only minor.

Algal blooms are periodically problematic in Greenfield Lake, and have occurred during all seasons, but are primarily a problem in spring and summer. In 2017 a filamentous green algal bloom occurred in early spring and a massive summer blue-green algal bloom of *Anabaena* occurred late spring - summer. In the period 2007-2013 there was a statistically significant relationship within the lake between chlorophyll *a* and five-day biochemical oxygen demand (BOD5) meaning that the algal blooms are an important cause of low dissolved oxygen in this lake, and high BOD occurred congruent with the blooms in 2017. Stormwater runoff into the streams also contributes BOD materials into the lake. In 2017 all tributary stations and all of the in-lake stations exceeded the fecal coliform State standard on 40% or more of occasions sampled.

Greenfield Lake is currently on the NC 303(d) list for impaired waters due to excessive algal blooms. Thus, in 2016-17 UNCW graduate student Nick Iraola, as part of his MS Thesis, conducted wet-period and dry-period sampling of the five main inflowing tributaries to the lake to assess where the principal nutrient inputs came from. The results showed that the largest inorganic nutrient loads came in from Jumping Run Branch and Squash Branch, and best management practices (BMPs) to reduce nutrient loading should be targeted for those streams.

Hewletts Creek – Hewletts Creek drains a large (7,478 acre) watershed into the Atlantic Intracoastal Waterway. This watershed has about 25.1% impervious surface coverage with a population of about 20,210. In 2017 the creek was sampled at four tidal sites and one non-tidal freshwater site (PV-GC-9).

Incidents of low dissolved oxygen were rare at Hewletts Creek in 2017. Turbidity was low, and only one minor algal bloom was documented in 2017. Fecal coliform bacteria counts exceeded State standard 100% of the time at NB-GLR (the north branch), 80% of the time at MB-PGR (the middle branch), 60% of the time at PVGC-9, and 80% of the time at SB-PGR (the south branch). The geometric means at PVGC-9, MB-PGR, SB-PGR and NB-GLR all well exceeded 200 CFU/100 mL for a poor rating for this pollutant parameter, but the geometric mean of fecal bacteria counts at HC-3 was well under the state standard.

During 2015-16 a wetland was created along Sharon and Patricia Drives, upstream of the sampling location NB-GLR along the north branch of Hewletts Creek. Vegetation was sparse until summer 2017. In future reports statistical comparisons will be made between pre-and-post wetland parameter concentrations to measure wetland efficacy as a pollutant removal feature.

Howe Creek – Howe Creek drains a 3,516 acre watershed into the AICW. This watershed hosts a population of approximately 6,460 with about 21.4% impervious surface coverage. Two stations were sampled in Howe Creek in 2017. The uppermost site HW-DT had one major algal bloom in the 2017 sampling. Both the uppermost station HW-DT and the mid-creek station HW-GP were rated poor for high fecal coliform bacteria counts, exceeding the state standard on 50-100% of the times sampled. However, dissolved oxygen concentrations were good at both sites in 2017.

Motts Creek – Motts Creek drains a watershed of 3,342 acres into the Cape Fear River Estuary with a population of about 9,530; impervious surface coverage 23.4%. This creek was not sampled for water quality by UNCW in 2017, but new funding from the City allowed UNCW to resume sampling of Motts Creek in January 2018.

Pages Creek – Pages Creek drains a 5,025 acre watershed with 17.8% impervious surface coverage into the ICW. UNC Wilmington was not funded to sample this creek from 2008-2017. New Hanover County employed a private firm to sample this creek and data may be requested from the County.

Smith Creek – Smith Creek drains into the lower Northeast Cape Fear River just upstream of where it merges with the Cape Fear River. It has a watershed of 16,650 acres that has about 21.3% impervious surface coverage, with a population of about 31,780. One estuarine site on Smith Creek, SC-CH, was sampled by UNCW under the auspices of the Lower Cape Fear River Program (LCFRP).

The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters is 4.0 mg/L, which was not violated in our 2017 samples. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded. There were no major algal blooms present in our 2017 sampling. However, fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on 75% of samples in 2017, for a Poor rating.

Whiskey Creek – Whiskey Creek is the southernmost large tidal creek in New Hanover County that drains into the AICW. It has a watershed of 2,078 acres, a population of about 8,000, and is covered by approximately 25.1% impervious surface area. One station, on Masonboro Loop Road, was sampled from shore along this creek in 2017. 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 five occasions sampled, and fecal coliform bacteria counts exceeded 200 CFU/100 mL on 20% of occasions sampled.

Water Quality Station Ratings – The UNC Wilmington Aquatic Ecology Laboratory utilizes a quantitative system with four parameters (dissolved oxygen, chlorophyll *a*, turbidity, and fecal coliform bacteria) to rate water quality at our sampling sites. If a site exceeds the North Carolina water quality standard (see Appendix A) for a parameter less than 10% of the time sampled, it is rated Good; if it exceeds the standard 10-25% of the time it is rated Fair, and if it exceeds the standard > 25% of the time it is rated Poor for that parameter. We applied these numerical standards to the water bodies described in this report, based on 2017 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 18% to be in good condition, 18% in fair condition and **68%** in poor condition, an improvement over the previous year. Dissolved oxygen conditions (measured at the surface) system-wide (22 sites) showed 64% of the sites were in good condition, 18% were in fair condition, and 18% were in poor condition, an improvement from 2016. For algal bloom presence, measured as chlorophyll *a*, 68% of the 22 stations sampled were rated as good, 23% as fair and 9% as poor. For turbidity, all of the 22 sites sampled were rated as good. It is important to note that the water bodies with the worst water quality in the system also have the most developed watersheds with the highest impervious surface coverage; Burnt Mill Creek – 39% impervious coverage; Greenfield Lake – 37% impervious coverage; Bradley Creek – 28% impervious coverage.

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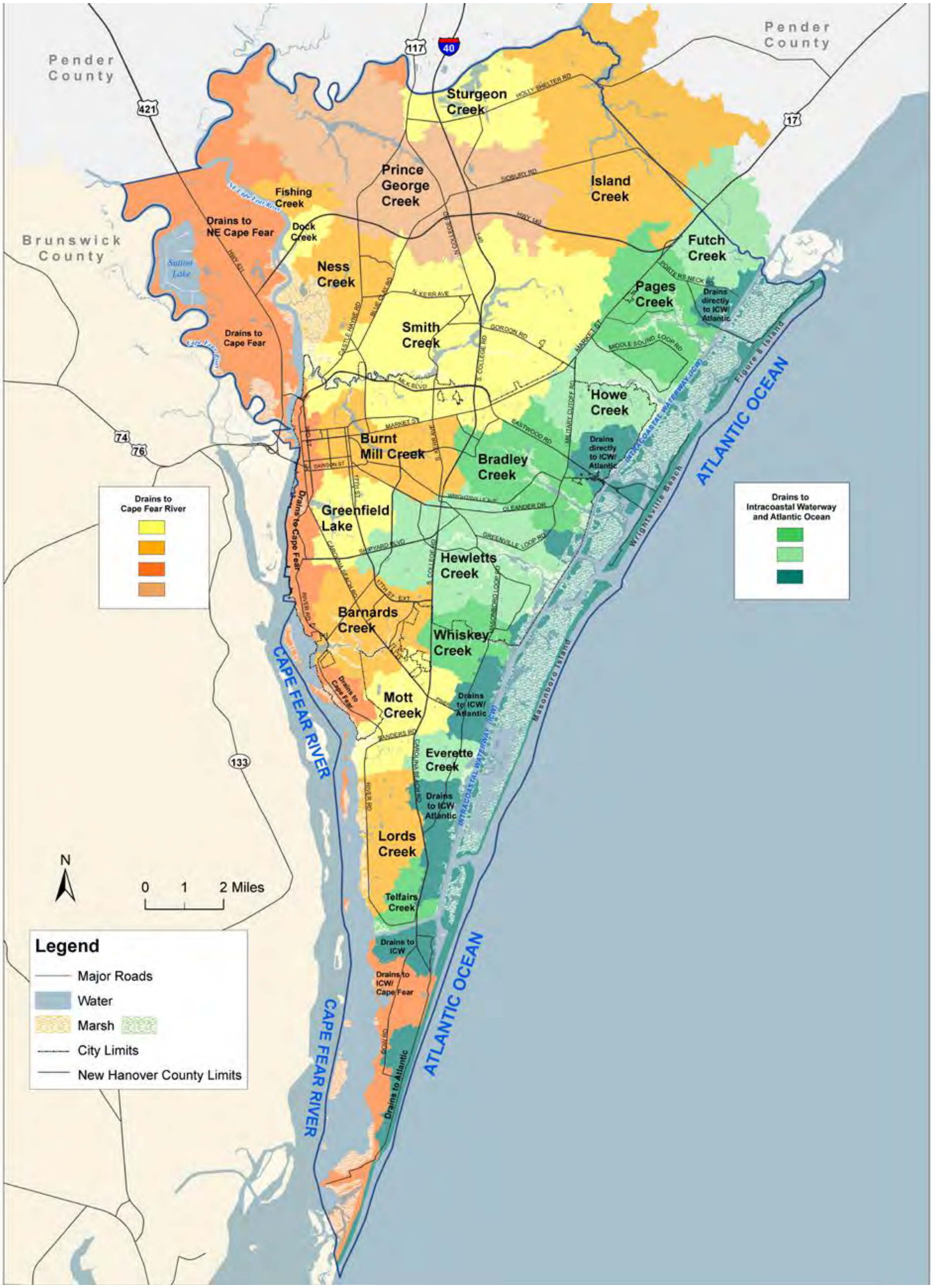


Plate 1. Wilmington and New Hanover County watersheds 2014 map by Wilmington Stormwater Services. Station coordinates are in Appendix C.

1.0 Introduction

In 1993 scientists from the Aquatic Ecology Laboratory at the UNC Wilmington Center for Marine Science Research began studying five tidal creeks in New Hanover County. This project, funded by New Hanover County, the Northeast New Hanover Conservancy, and UNCW, yielded a comprehensive report detailing important findings from 1993-1997, and produced a set of management recommendations for improving creek water quality (Mallin et al. 1998a). Data from that report were later published in the peer-reviewed literature (Mallin et al. 2000a; Mallin et al. 2001) and were used in 2006-2009 by the N.C. General Assembly (Senate Bill 1967) as the scientific basis to redefine low density coastal areas as 12% impervious surface coverage instead of the previously used 25% impervious cover. In 1999-2000 Whiskey Creek was added to the program.

In October 1997 the Center for Marine Science began a project (funded by the City of Wilmington Engineering Department) with the goal of assessing water quality in Wilmington City watersheds under base flow conditions. Also, certain sites were analyzed for sediment heavy metals concentrations (EPA Priority Pollutants). In the past 20 years we 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; 2014; 2015; 2016; 2017). In the present report we present results of sampling conducted during 2017, 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 that was interested in environmentally sound development, the Newland Corporation. The Newland Corporation is building a large residential project called River Lights along River Road between Barnards and Motts Creeks. Through this funding we sampled Motts and Barnards Creeks along River Road until July 2010, when plans for development were delayed due to the economic slowdown and funding was suspended. There has been road and residential construction between the creeks thus far, a lake has been dug in mid-site, and offices and commercial operations have been constructed along the river. We note that the City of Wilmington is providing funding for renewed sampling of those two creeks beginning in January 2018.

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. The 2014 report presented summary material regarding that study.

From 2010-2014 Wilmington Stormwater Services collaborated with UNCW to investigate potential sewage spills and leaks and illicit sanitary connections potentially polluting city waterways; the results of those sample collections have been reported in the various reports.

1.1 Water Quality Methods

Samples were collected on five occasions at 21 locations within the Wilmington City watersheds between January and December 2017. In addition, one station on Smith Creek was also sampled during 12 months as part of the Lower Cape Fear River Program and reported here as well. Field parameters were measured at each site using a YSI 6920 Multiparameter Water Quality Probe (sonde) linked to a YSI 650 MDS display unit. Individual probes within the instrument measured water temperature, pH, dissolved oxygen, turbidity, salinity, and conductivity. The YSI 6920 was calibrated prior to each sampling trip to ensure accurate measurements. The UNCW Aquatic Ecology laboratory is State-Certified for field measurements (temperature, conductivity, dissolved oxygen and pH). Samples were collected on-site for State-certified laboratory analysis of ammonium, nitrate+nitrite (referred to within as nitrate), total Kjeldahl nitrogen (TKN), orthophosphate, total phosphorus, total suspended solids (TSS), fecal coliform bacteria, and chlorophyll *a*.

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

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

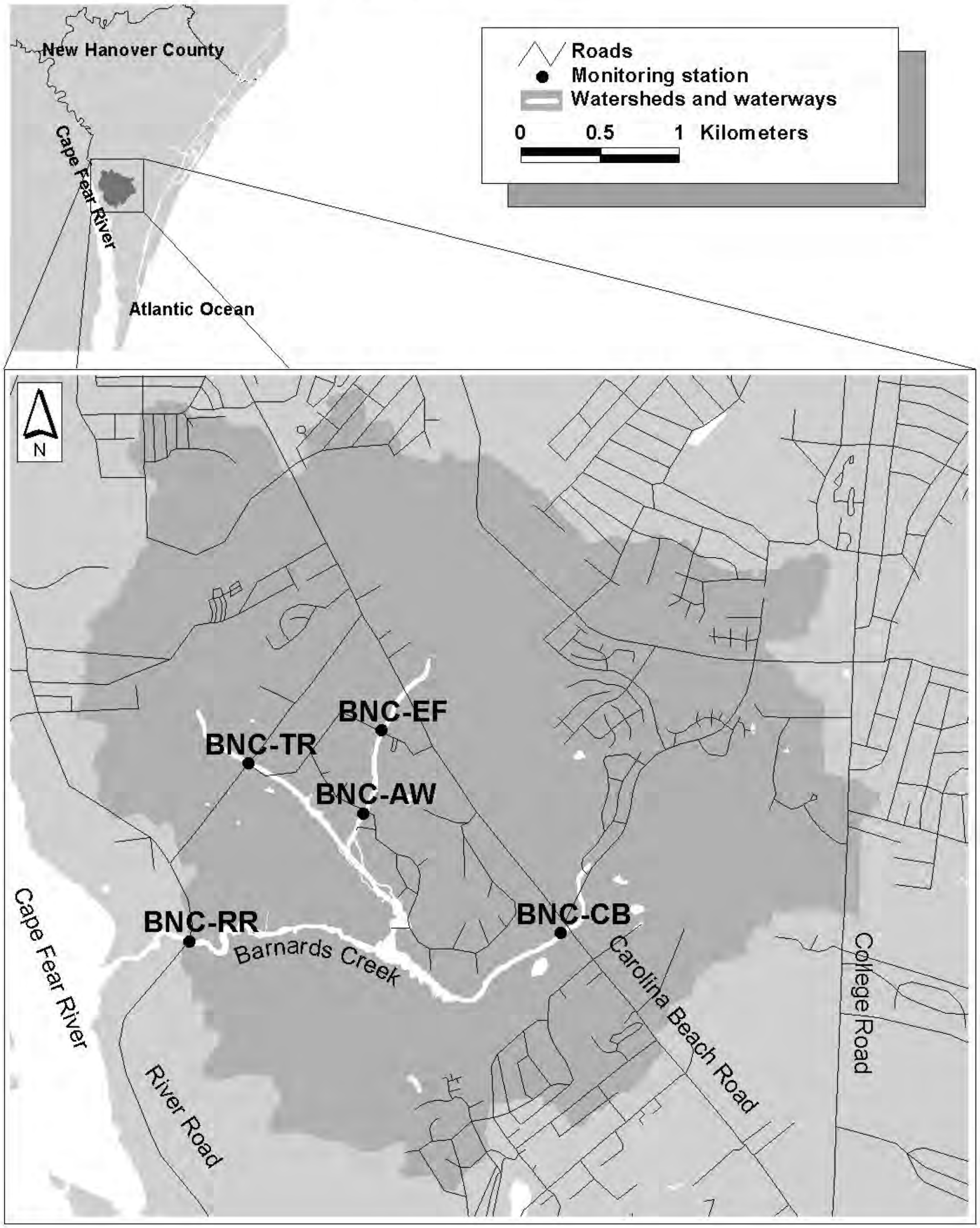
For a large wet detention pond (Ann McCrary Pond on Burnt Mill Creek) we collected data from input and outfall stations. We used these data to test for statistically significant differences in pollutant concentrations between pond input and output stations. The data were first tested for normality using the Shapiro-Wilk test. Normally distributed data parameters were tested using the paired-difference t-test, and non-normally distributed data parameters were tested using the Wilcoxon Signed Rank test. Statistical analyses were conducted using SAS (Schlotzhauer and Littell 1997).

2.0 Barnards Creek

Snapshot
Watershed area: 4,161 acres (1,690 ha)
Impervious surface coverage: 22.3%
Watershed population: Approximately 12,200
Overall water quality: not measured in 2017

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 under construction between Barnards and Motts Creeks. In 2017 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/. Note that supplemental funding received in late 2017 has allowed UNCW to re-initiate sampling of lower Barnards Creek at River Road (BNR-RR) beginning January 2018.

Figure 2.1 Barnards Creek watershed



3.0 Bradley Creek

Snapshot
Watershed area: 4,583 acres (1,856 ha)
Impervious surface coverage: 27.8% (2014 data)
Watershed population: Approximately 16,470
Overall water quality: fair-poor
Problematic pollutants: high fecal bacteria, occasional low dissolved oxygen, occasional algal blooms

The Bradley Creek watershed was previously 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 2017; the standard of 25 NTU was not exceeded (Table 3.1). Total suspended solids (TSS) were slightly elevated (22.5 mg/L) on one occasion only (at BC-NB). There are no NC ambient standards for TSS, but UNCW considers 25 mg/L high for the Coastal Plain. Dissolved oxygen (hypoxia) was below the 5.0 mg/L standard four out of five occasions sampled at BC-CA, but within standard at the other two sites (Appendix B).

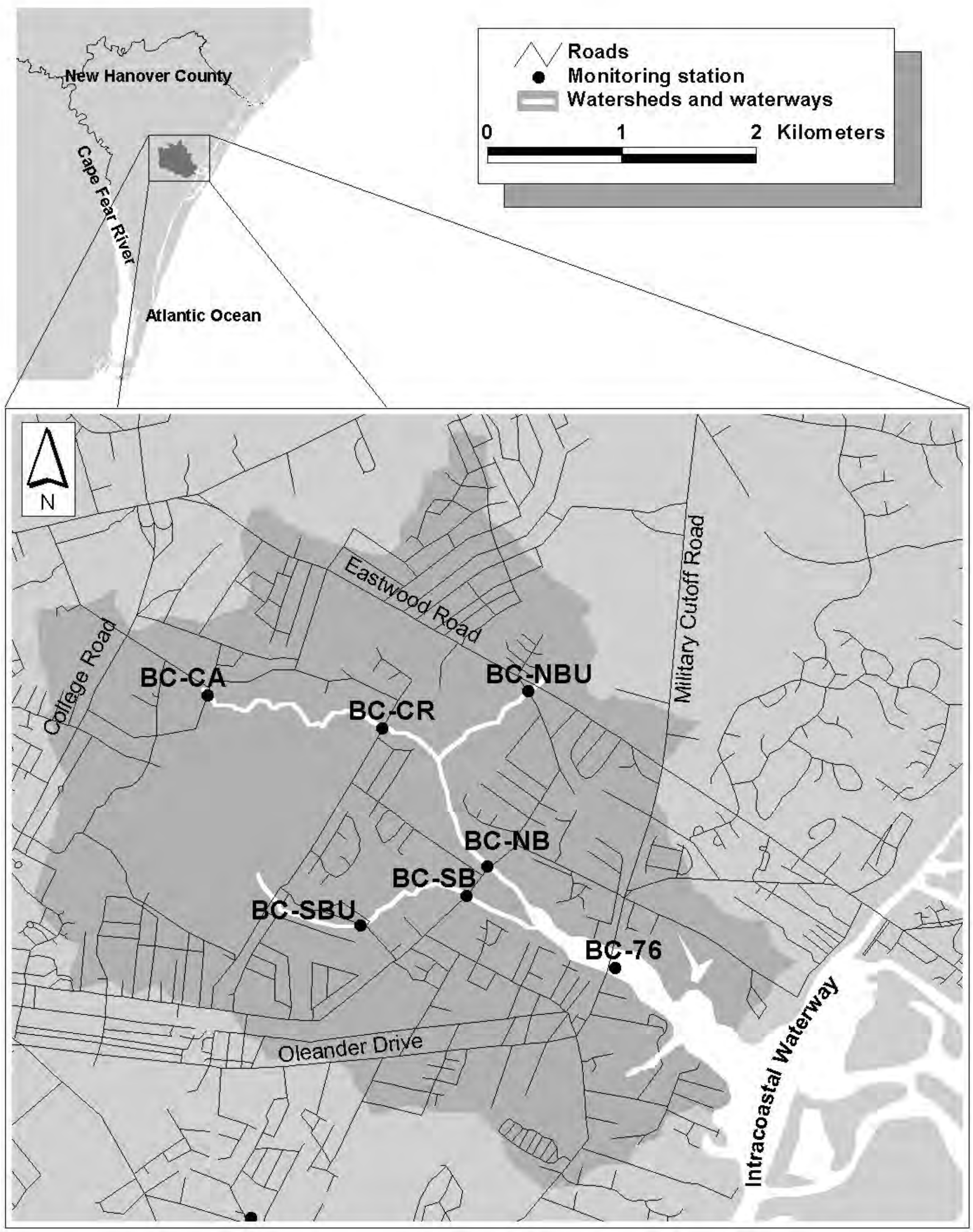
Ammonium concentrations were generally low except for a level of 1.160 mg-N/L at BC-CA in December 2017. Nitrate concentrations were also highest at station BC-CA, but low in general (Table 3.1). Total nitrogen concentrations were low to moderate in general but reached 2.800 mg-N/L at BC-CA in December 2017. Orthophosphate concentrations were low with highest levels at BC-CA; TP levels were likewise low in general. Our Bradley Creek stations did not host significant algal blooms in 2017. Median nitrogen to phosphorus ratios at BC-NB and BC-SB were low (<6) indicating that inputs of inorganic nitrogen are likely to stimulate algal blooms in the lower creek.

Fecal coliform bacteria counts were excessive at all three stations sampled during 2017, and higher than 2016. The NC contact standard was exceeded on 100% of occasions sampled at BC-CA, 80% of occasions at BC-NB and 60% of occasions sampled at BC-SB. The geometric means of the fecal coliform counts ranged from 418 CFU/100 mL at BC-NB to about 35X the standard (6,995 CFU/100 mL at BC-CA, Table 3.1).

Table 3.1. Water quality parameter concentrations at Bradley Creek sampling stations, 2017. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 5 samples collected.

Station	BC-CA	BC-NB	BC-SB
Salinity (ppt)	0.1 (0.1) 0.0-0.2	12.7 (10.5) 3.4-30.5	3.5 (5.9) 0.5-14.1
Dissolved Oxygen (mg/L)	4.1 (1.9) 0.8-5.7	7.2 (1.2) 5.6-8.4	7.6 (0.6) 6.8-8.4
Turbidity (NTU)	3 (3) 1-8	5 (3) 1-10	5 (2) 1-7
TSS (mg/L)	3.9 (2.0) 1.5-5.5	14.1 (7.3) 6.1-22.5	8.5 (3.3) 3.7-12.0
Nitrate (mg/L)	0.068 (0.063) 0.010-0.160	0.060 (0.080) 0.010-0.200	0.064 (0.056) 0.010-0.150
Ammonium (mg/L)	0.288 (0.491) 0.020-1.160	0.022 (0.018) 0.010-0.050	0.030 (0.031) 0.010-0.080
TN (mg/L)	0.896 (1.106) 0.050-2.800	0.398 (0.381) 0.050-1.040	0.322 (0.127) 0.150-0.480
Orthophosphate (mg/L)	0.060 (0.046) 0.030-0.140	0.026 (0.011) 0.010-0.040	0.040 (0.023) 0.020-0.080
TP (mg/L)	0.158 (0.209) 0.040-0.530	0.044 (0.023) 0.010-0.070	0.050 (0.047) 0.010-0.130
N/P	11.6 5.9	7.8 4.4	5.9 4.4
Chlorophyll *a* (μg/L)	10 (6) 1-17	11 (10) 1-23	10 (7) 1-20
Fecal coliforms (CFU/100 mL)	6,995 910-60,000	418 19-7,000	591 73-15,000

Figure 3.1. Bradley Creek watershed and sampling sites.



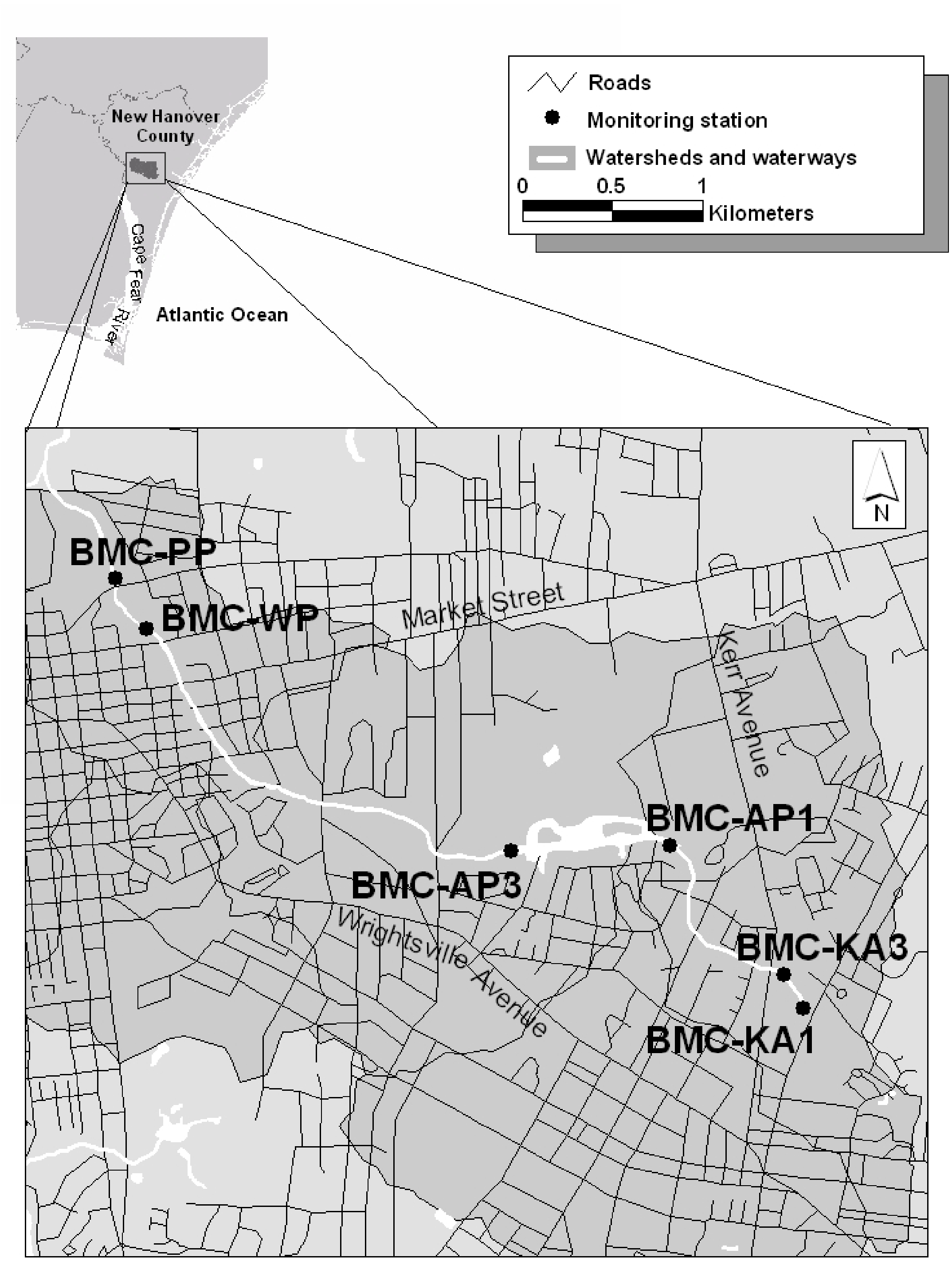
4.0 Burnt Mill Creek

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

Burnt Mill Creek is an urban creek flowing entirely through the City of Wilmington. Its high impervious surface coverage (about 39%) puts it at risk for excessive pollutant loads. A prominent feature in the Burnt Mill Creek watershed (Fig. 4.1) is the Ann McCrary Pond, which is a large (28.8 acres) regional wet detention pond draining 1,785 acres, with a large apartment complex (Mill Creek Apts.) at the upper end. The pond itself has periodically hosted 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. Sediment toxicant analysis (summarized in Mallin et al. 2015) found elevated concentrations of polycyclic aromatic hydrocarbons (PAHs), mercury, lead and zinc at several locations in this creek.

Sampling Sites: During 2017 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 five occasions in 2017. Dissolved oxygen concentrations were within standard on all sampling occasions at BMC-AP1 and BMC-AP3, except for one incident of hypoxia (1.7 mg/L) at BMC-AP3 in May 2017. There was no statistically-significant change in DO through the pond. The State standard for turbidity in freshwater is 50 NTU; there were no exceedences of this value in our 2017 samples; there was no significant change through the pond; averages went from 8 to 4 NTU. Likewise, total suspended solids concentrations were relatively low on all sampling occasions in 2017, and there was no significant change through the pond (Table 4.1). Fecal coliform concentrations entering Ann McCrary Pond at BMC-AP1 were high, exceeding the state standard 60% of the time sampled (Table 4.1). These high counts were possibly a result of pet waste (very visible to the observer) runoff from the Mill Creek apartment complex and runoff from urban upstream areas (including the Kerr Avenue wetland). There was no statistically significant decrease in fecal coliform counts from passage through the regional detention pond (Table 4.1). There were no major algal blooms at BMC-AP1 but one minor bloom at BMC-AP3 (37 µg/L). There were no statistically-significant changes in nutrient concentrations between entering and exiting the pond.

Lower Burnt Mill Creek: The Princess Place location (BMC-PP) was the only lower creek station sampled in 2017. One parameter that is key to aquatic life health is dissolved oxygen. Dissolved oxygen at BMC-PP was in good condition on all sampling occasions in 2017. 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 2017 this level was not approached at BC-PP.

In 2017 there were two documented algal blooms at BMC-PP (54 and 65 µg/L) that exceeded the North Carolina water quality standard for chlorophyll *a* of 40 µg/L. Algal blooms can cause disruptions in the food web, depending upon the species present (Burkholder 2001), and decomposing blooms can contribute to low dissolved oxygen (Mallin et al. 2006b).

It is important to determine what drives algal bloom formation in Burnt Mill Creek. Nitrate and orthophosphate concentrations were somewhat elevated at BMC-PP, relative to AP-3. Examination of inorganic nitrogen to phosphorus ratios (Table 4.1) shows that median N/P ratios at BMC-PP were 13 and mean ratios were 11. In waters where the N/P ratio is well below 16 (the Redfield Ratio for algal nutrient composition) it is generally considered that algal production is limited by the availability of nitrogen (i.e. phosphorus levels are sufficient); where N/P ratios are well above 16, additions of phosphate should encourage algal blooms. If such values are near the Redfield Ratio, as at BMC-PP, inputs of either N or P could drive an algal bloom.

Important from a public health perspective are fecal coliform bacteria counts, which maintained geometric means exceeding the State standard for human contact waters (200 CFU/100 mL) at BMC-AP1 and BMC-PP. Fecal coliform counts were greater than the State standard on 60% of occasions sampled at BMC-AP1. 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 25 CFU/100 mL) to the Princess Place location (geometric mean 243 CFU/100 mL; Fig. 4.2), as in previous years. It is likewise notable that nitrate and orthophosphate concentrations increased from the outflow from Ann McCrary Pond downstream to the lower main stem station (Table 4.1; Fig. 4.3).

Figure 4.2. Fecal coliform bacteria geometric means for Burnt Mill Creek, 2017

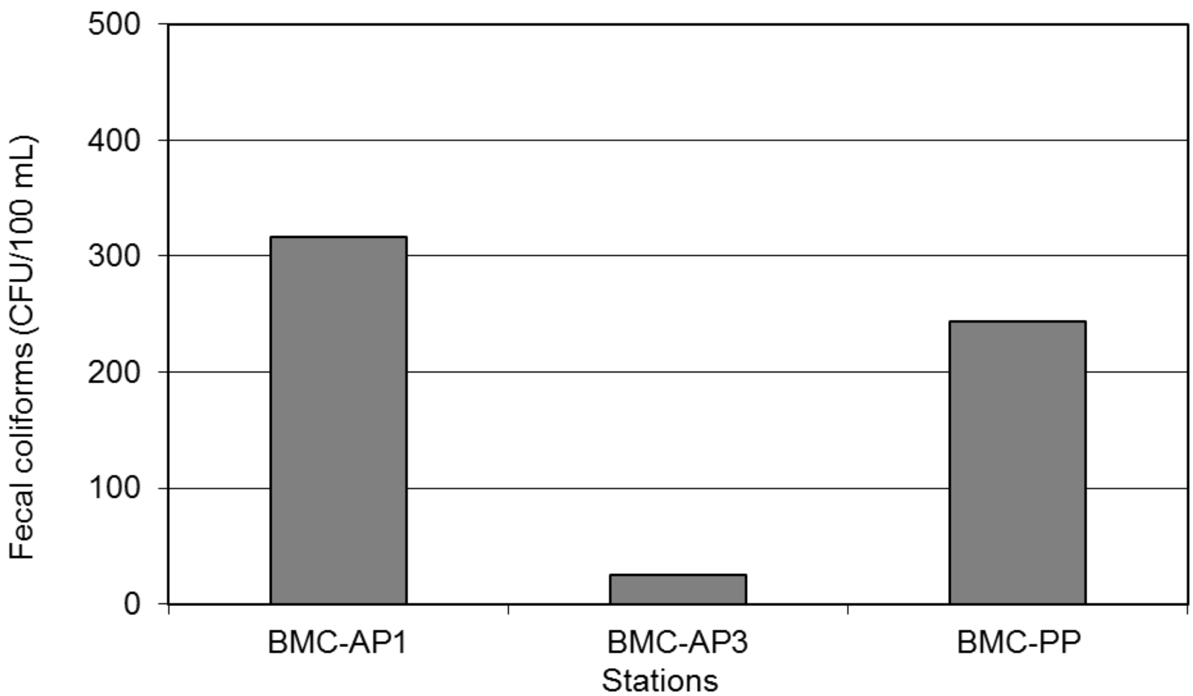
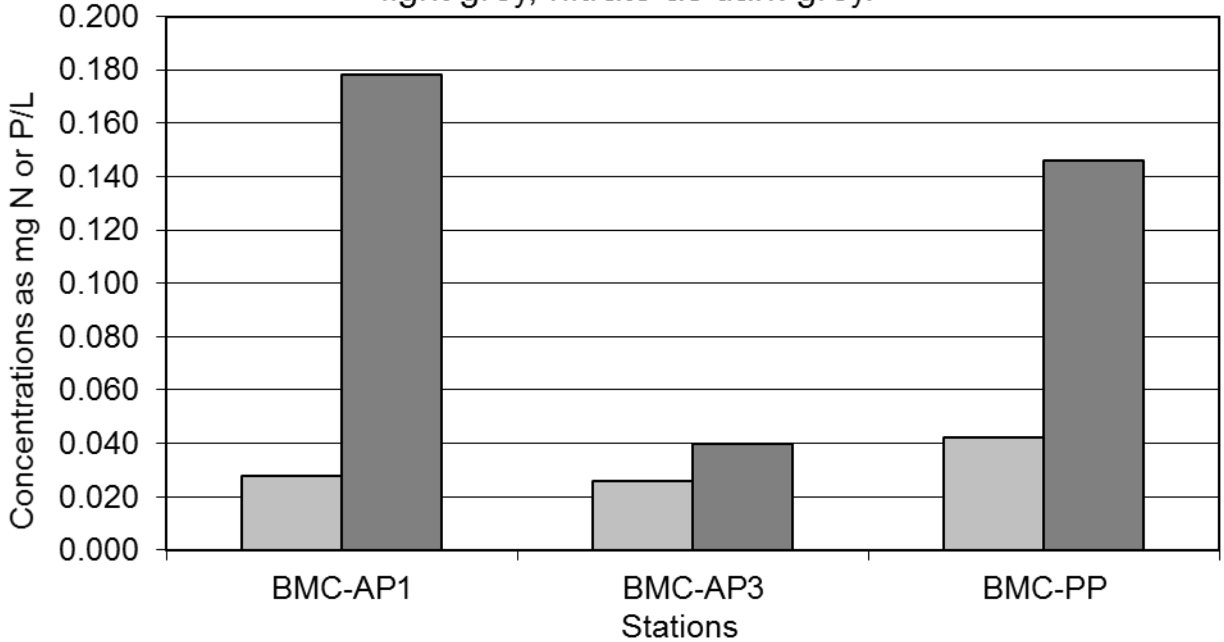


Table 4.1. Water quality data in Burnt Mill Creek, 2017, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as mean/median, n = 5 samples collected.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	7.6 (0.8) 6.4-8.4	9.5 (4.6) 1.7-13.0	6.5 (0.9) 5.3-7.4
Cond. (µS/cm)	283 (6) 275-290	258 (94) 164-408	345 (32) 298-378
pH	7.1 (0.2) 6.9-7.3	7.7 (0.4) 7.2-8.2	7.4 (0.1) 7.2-7.5
Turbidity (NTU)	8 (8) 1-20	4 (1) 3-6	2 (1) 1-4
TSS (mg/L)	4.3 (4.3) 1.3-11.0	5.4 (1.3) 4.4-6.9	5.2 (4.1) 1.3-9.8
Nitrate (mg/L)	0.178 (0.097) 0.010-0.260	0.040 (0.045) 0.010-0.110	0.146 (0.080) 0.020-0.230
Ammonium (mg/L)	0.088 (0.080) 0.010-0.210	0.164 (0.311) 0.010-0.720	0.056 (0.036) 0.010-0.100
TN (mg/L)	0.466 (0.251) 0.050-0.710	0.534 (0.380) 0.300-1.210	0.626 (0.300) 0.320-1.120
OrthoPhos. (mg/L)	0.028 (0.008) 0.020-0.040	0.026 (0.019) 0.010-0.060	0.042 (0.004) 0.040-0.050
TP (mg/L)	0.044 (0.047) 0.010-0.120	0.038 (0.013) 0.030-0.060	0.062 (0.029) 0.030-0.110
N/P molar ratio	23 17	12 8	11 13
Chlor. *a* (µg/L)	1 (0) 1-2	16 (13)* 4-37	25 (32) 1-65
FC (CFU/100 mL)	316 118-2,800	25 5-91	243 91-2,700

* Statistically significant difference between inflow (AP1) and outflow (AP3) at $p<0.05$; ** $p < 0.01$.

Figure 4.3. Average orthophosphate and nitrate concentrations by station for Burnt Mill Creek, 2017; OP as light grey, nitrate as dark grey.



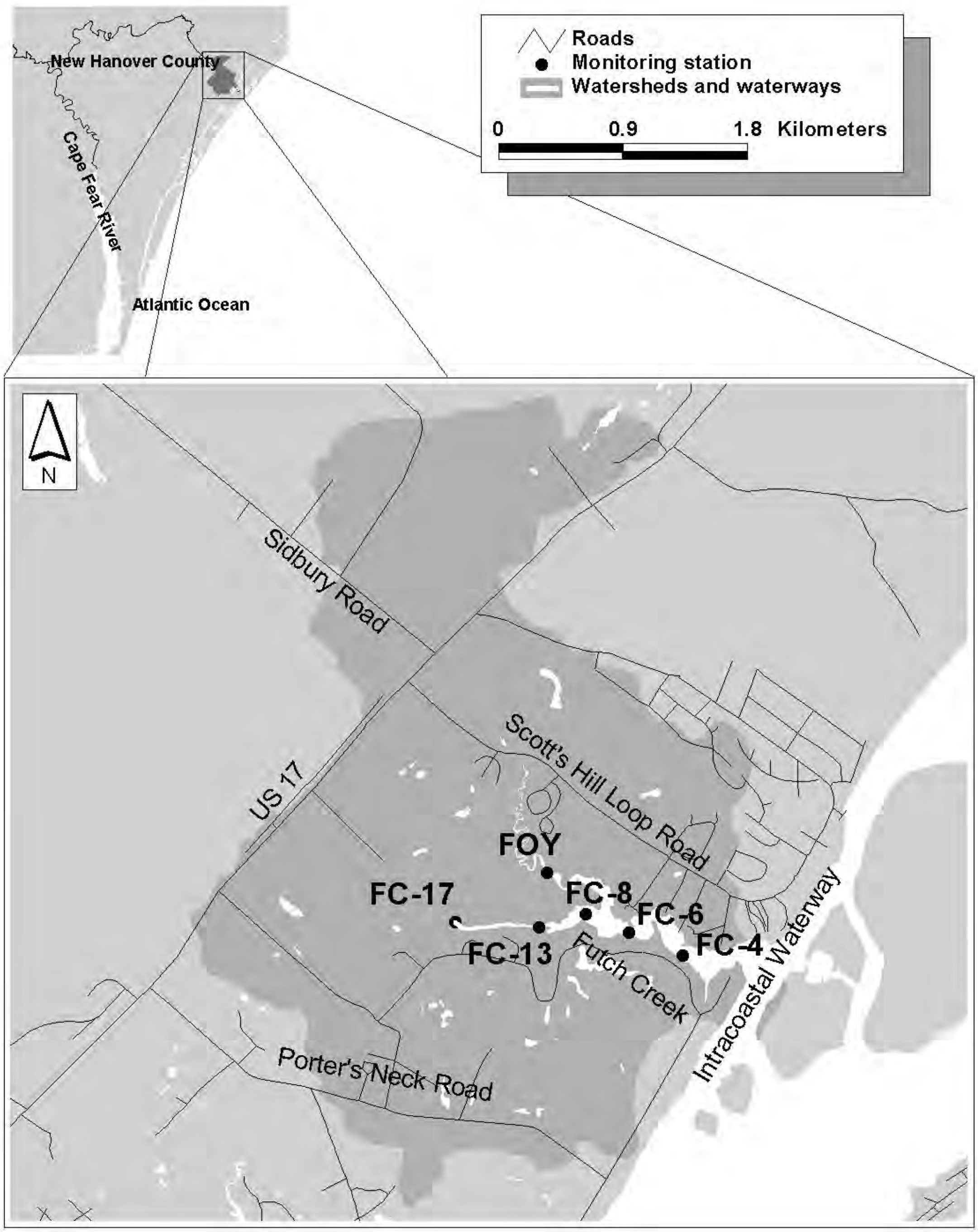
To summarize, in some years Burnt Mill Creek has had problems with low dissolved oxygen (hypoxia) at the Princess Place station BMC-PP. Algal blooms continued to occur in the creek in 2017. The N/P ratios in the lower creek indicate that inputs of nitrogen are likely to stimulate algal bloom formation, depending upon location, season and inputs of phosphorus. It is notable that nutrient concentrations increased by 2-4X from the outfall of the regional Ann McCrary wet detention pond as one moves downstream toward the lower creek. An important human health issue is the periodic high fecal bacteria counts found at two of the three sampling stations, the exception being BMC-AP3 below the detention pond. As NPDES point source discharges are not directed into this creek, the fecal bacteria (and nutrient) loading appears to be caused either by non-point source stormwater runoff, illegal discharges, or leakage from sanitary sewer lines. We note that strong statistical correlations between fecal coliform counts, TSS, BOD and rainfall have been demonstrated for this creek (Mallin et al. 2009b). As this is one of the most heavily-developed creeks in the Wilmington area, it also remains one of the most polluted.

5.0 Futch Creek

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

Six stations were sampled by the University of North Carolina Wilmington's Aquatic Ecology Laboratory in Futch Creek from 1993 through 2007. UNCW was not funded by the County to sample Futch Creek in 2017. We present the above information and map below purely for informational purposes. Water quality information for the creek can be obtained from the County.

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, sediments contaminated with metals and PAHs

Four tributary stations to Greenfield Lake were sampled for a full suite of physical, chemical and biological parameters in 2017 (Table 6.1, Fig. 6.1). Three tributary sites suffered from severe hypoxia, as GL-LB (creek at Lake Branch Drive, called Squash Branch), GL-LC (creek beside Lakeshore Commons, called Clay Bottom Branch) and GL-JRB (Jumping Run Branch) showed dissolved oxygen concentrations below the state standard (DO < 5.0 mg/L) on 40% of sampling occasions or more (Table 6.1; Appendix B). Station JRB-17, located in upper Jumping Run Branch at 17th Street, had substandard dissolved oxygen on one sampling occasion. Turbidity concentrations were generally low in the tributary stations, with no violations of the freshwater standard of 50 NTU (Table 6.1). Suspended solids increased in 2017 relative to 2016 due to algal blooms impacting some of the tributary streams (Table 6.1).

Nitrate, ammonium and TN concentrations were highest at GL-LB (Squash Branch), followed by GL-JRB (Table 6.1). There were no differences in orthophosphate or TP concentrations among the stream stations with the exception of somewhat higher TP levels at JRB-17. We note that both JRB-17 and GL-JRB are downstream of a golf course. There were no differences in inorganic nutrients between the two sites but TN and TP were both notably higher upstream of the golf course. Chlorophyll *a* concentrations were low at most tributary stream sites except for a large May algal bloom of the nitrogen-fixing cyanobacterium *Anabaena* at GL-LC (Clay Bottom Branch) of 259 µg/L. The geometric mean fecal coliform bacteria counts exceeded the state standard at all four tributary stations (Table 6.1). The standard was exceeded on all five sampling dates at GL-LB, on four occasions at JRB-17, and on three of five occasions at GL-JRB and GL-LC.

Table 6.1. Mean and (standard deviation) / range of selected field water quality parameters in tributary stations of Greenfield Lake, 2017. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 5 samples collected.

Parameter	JRB-17	GL-JRB	GL-LB (SQB)	GL-LC (CBB)
DO (mg/L)	7.4 (2.0) 4.8-9.6	5.0 (2.1) 2.3-8.1	3.9 (3.9) 0.7-9.7	6.1 (1.9) 3.9-6.1
Turbidity (NTU)	3 (1) 2-4	4 (5) 1-14	3 (1) 2-3	5 (5) 1-14
TSS (mg/L)	10.1 (13.7) 1.4-33.7	3.6 (4.9) 1.3-12.4	7.4 (7.7) 1.3-16.0	8.0 (9.6) 1.3-24.8
Nitrate (mg/L)	0.14 (0.09) 0.01-0.24	0.14 (0.12) 0.01-0.33	0.22 (0.13) 0.01-0.37	0.10 (0.09) 0.01-0.18
Ammon. (mg/L)	0.09 (0.09) 0.01-0.25	0.08 (0.07) 0.01-0.18	0.27 (0.15) 0.10-0.47	0.09 (0.07) 0.01-0.21
TN (mg/L)	0.77 (0.41) 0.20-1.35	0.56 (0.30) 0.10-0.93	1.01 (0.93) 0.40-1.93	0.73 (0.69) 0.05-1.90
Ortho-P. (mg/L)	0.05 (0.02) 0.03-0.08	0.05 (0.03) 0.03-0.09	0.07 (0.02) 0.03-0.09	0.04 (0.01) 0.03-0.06
TP (mg/L)	0.11 (0.08) 0.04-0.22	0.06 (0.03) 0.03-0.11	0.06 (0.02) 0.04-0.08	0.05 (0.04) 0.02-0.09
Inorganic N/P ratio	11 12	11 13	17 19	13 16
FC (CFU/100 mL)	428 145-2,300	954 145-29,000	1,121 290-16,000	389 10-16,000
Chlor. *a* (μg/L)	4 (3) 1-9	2 (2) 1-5	1 (0) 1-2	54 (115) 2-259

Three in-lake stations were sampled (Figure 6.1). Station GL-2340 represents an area receiving an influx of urban/suburban runoff, GL-YD is downstream and receives some outside impacts, and GL-P is at the Greenfield Lake Park boathouse, away from inflowing streams but in a high-use waterfowl area (Fig. 6.1). Low dissolved oxygen was not a problem in-lake in 2017(see also Section 6.1). Turbidity was below the state standard on all sampling occasions, but suspended solids were elevated in May and June, concurrent with a blue-green alga bloom of *Anabaena*. In-lake fecal coliform concentrations were not problematic in 2017, and all three sites were rated fair to good.

Concentrations of nitrate in-lake were highest at the upstream station GL-2340, where concentrations were similar to those of the tributary streams (Table 6.2). Ammonium levels in the lake were generally low. Total N was highest at GL-2340, likely reflecting biomass from the spring-summer cyanobacterial bloom. Total phosphorus (TP) and orthophosphate concentrations were similar among the three sites, and none of the concentrations were remarkable (Table 6.2). Inorganic N/P molar ratios can be computed from ammonium, nitrate, and orthophosphate data and can help determine what the potential limiting nutrient can be in a water body. Ratios well below 16 (the Redfield ratio) can indicate potential nitrogen limitation, and ratios well above 16 can indicate potential phosphorus limitation (Hecky and Kilham 1988). Based on the moderate to low mean and median N/P ratios at GL-P and GL-YD (Table 6.2), phytoplankton growth in much of Greenfield Lake can be readily stimulated by nitrogen (i.e. inputs of nitrogen can cause algal blooms). However, in the uppermost station GL-2340 the high N/P ratios indicated that P inputs could also cause algal blooms at that site. Our previous bioassay experiments indicated that nitrogen was usually the stimulatory nutrient in this lake (Mallin et al. 1999; 2016).

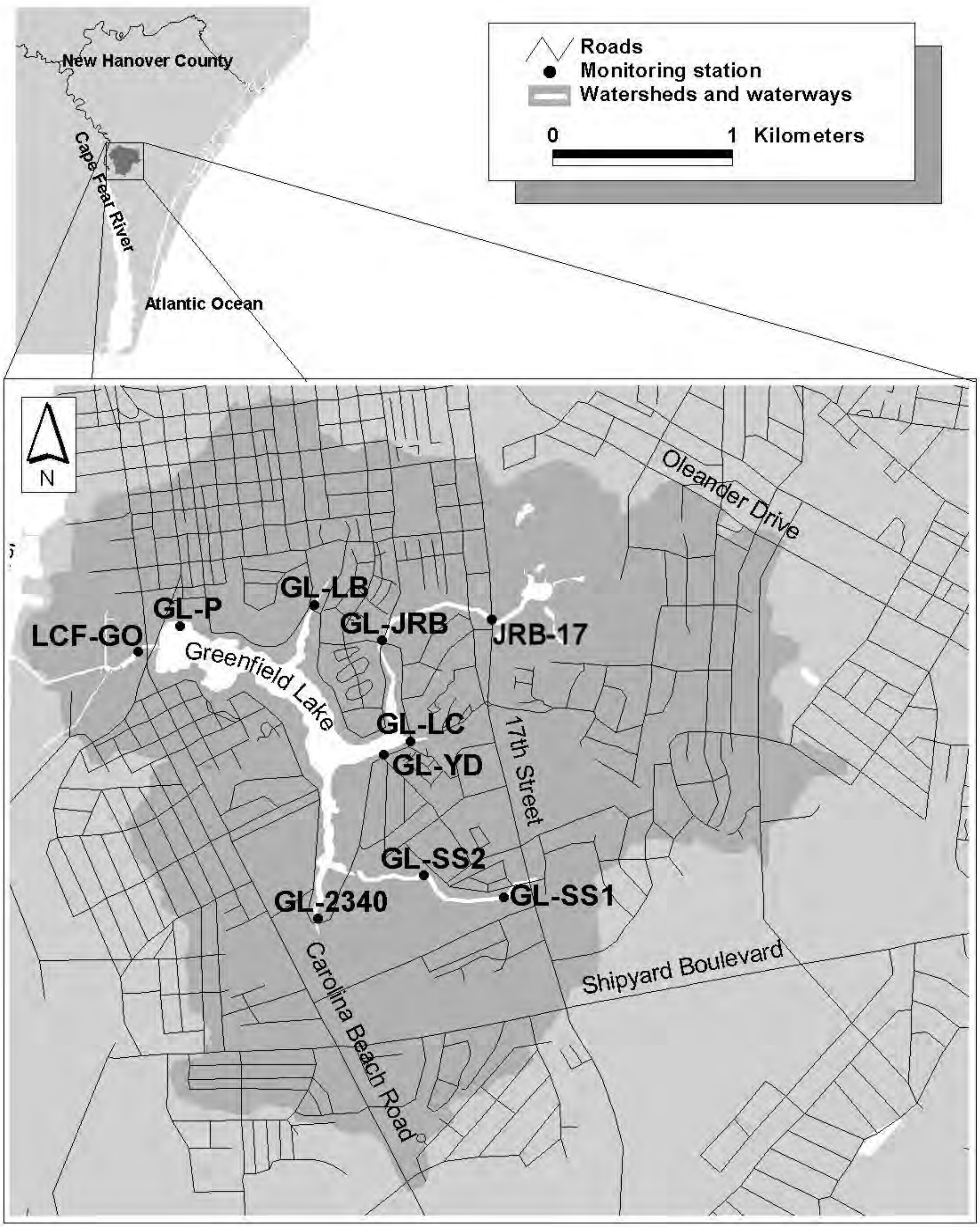
Phytoplankton blooms are problematic in Greenfield Lake (Table 6.2), and usually consist of green or blue-green algal species, or both together. These blooms have occurred during all seasons, but are primarily a problem in spring and summer. In 2017 a large surface bloom of filamentous green algae (*Mougeotia* and *Spirogyra*) occurred in early spring, and was later followed by an extensive bloom of the blue-green *Anabaena spiroides* in late spring and in summer (see cover photograph). As such, four blooms exceeding the North Carolina water quality standard of 40 μg/L of chlorophyll *a* occurred at GL-P and GL-2340, and one occurred at GL-YD with the largest bloom (122 μg/L) occurring among the three in-lake stations. For the past several years chlorophyll *a* has exceeded the state standard approximately >30% of occasions sampled. Based on these data, the North Carolina Division of Water Resources placed this lake on the 303(d) list for 2014. Average biochemical oxygen demand (BOD5) for 2017 was high, especially at GL-YD (average = 5.2 mg/L; Table 6.1). Because phytoplankton (floating microalgae) are easily-decomposed sources of BOD, the blooms in this lake are a periodic driver of low dissolved oxygen; chlorophyll *a* is strongly correlated with BOD in this lake (Mallin et al. 2016).

Based on summary literature values (summarized in Wetzel 2001) the average TN, TP and chlorophyll a concentrations within this lake put it in the eutrophic category for 2017. Previous research (summarized in Mallin et al. 2015) found excessive concentrations of polycyclic aromatic hydrocarbons (PAHs), lead and zinc in the sediments of this lake.

Table 6.2. Mean and (standard deviation) / range of selected field water quality parameters in lacustrine stations of Greenfield Lake, 2017. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 5 samples collected.

Parameter	GL-2340	GL-YD	GL-P
DO (mg/L)	6.1 (1.0) 5.2-7.6	8.7 (2.1) 6.0-11.0	9.1 (2.6) 5.4-12.2
Turbidity (NTU)	4 (5) 1-13	5 (8) 0-19	3 (4) 0-10
TSS (mg/L)	4.4 (4.3) 1.3-9.6	4.8 (5.4) 1.3-13.5	3.8 (3.4) 1.3-8.6
Nitrate (mg/L)	0.21 (0.16) 0.01-0.41	0.06 (0.07) 0.01-0.16	0.05 (0.05) 0.01-0.10
Ammonium (mg/L)	0.12 (0.18) 0.01-0.44	0.03 (0.03) 0.01-0.08	0.04 (0.04) 0.01-0.08
TN (mg/L)	1.02 (0.61) 0.55-2.10	0.68 (0.56) 0.30-1.70	0.74 (0.50) 0.30-1.60
Orthophosphate (mg/L)	0.03 (0.02) 0.01-0.06	0.03(0.01) 0.02-0.04	0.04 (0.02) 0.01-0.06
TP (mg/L)	0.06 (0.04) 0.02-0.11	0.05 (0.03) 0.02-0.10	0.07 (0.02) 0.04-0.09
N/P molar ratio	28 30	8 4	13 16
Fec. col. (CFU/100 mL)	122 37-546	23 5-91	26 5-172
Chlor. *a* (μg/L)	30 (39) 1-82	26 (41) 2-97	21 (34) 0-80
BOD5	3.8 (4.1) 1.0-10.0	5.2 (6.7) 1.0-17.0	4.0 (4.1) 1.0-11.0

Figure 6.1. Greenfield Lake watershed.



Continuing Efforts to Restore Water Quality in Greenfield Lake

Beginning in 2005 several steps were taken by the City of Wilmington to restore viability to the lake. During February one thousand sterile grass carp were introduced to the lake to control (by grazing) the overabundant aquatic macrophytes. During that same month four SolarBee water circulation systems (SB10000v12 units) were installed in the lake with the general objectives of providing algae control, improving water quality and the fishery, reducing and/or compacting soft organics in the littoral zone and enhance nuisance macrophyte control. Such solar-driven circulators have been found to reduce cyanobacterial abundance in some nutrient-rich reservoirs, but in other situations they have failed to control harmful algal blooms (Hudnell 2010). From April through June 2005 and in March and July 2006 herbicides and algicides were added by city crews and contractors, and in April 2006 500 additional grass carp were added. In March 2007, 200 more grass carp were added to the lake, and more since. Cape Fear River Watch does monthly shoreline inspections of the lake, and city crews and contract firms have spot treated areas of the lake to control macrophyte and nuisance phytoplankton blooms with herbicide annually since 2007.

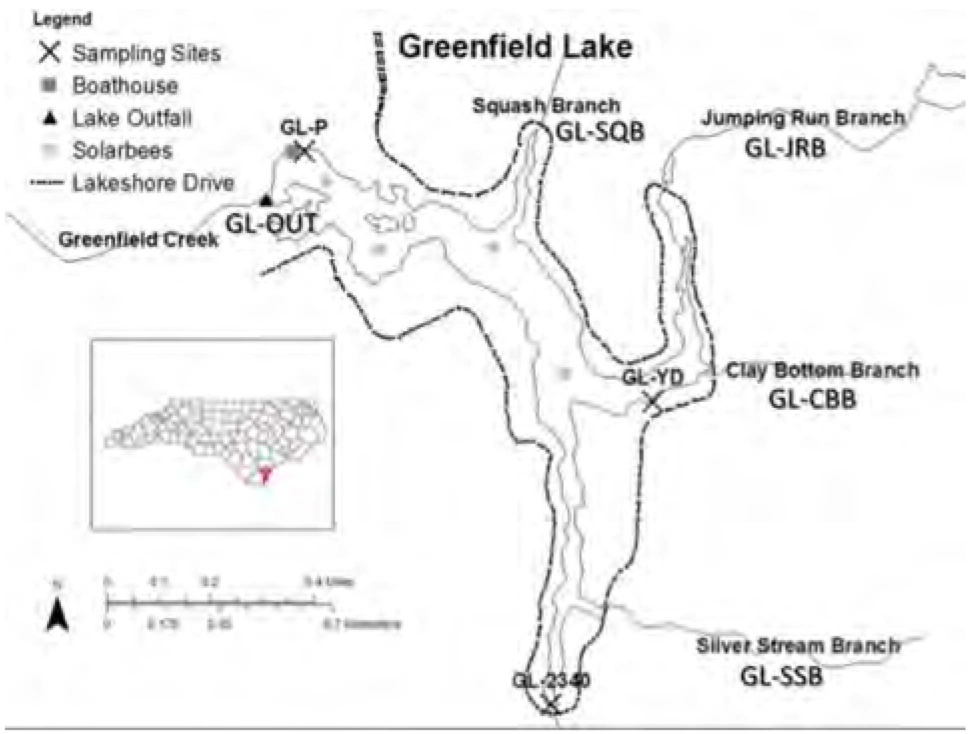
Since the various treatments (artificial circulation, grass carp additions, herbicide use) the lake's water quality has changed, in some ways improving and in some ways deteriorating. The results of a multi-year study were reported in a previous report (Mallin et al. 2015) and in a subsequent peer-reviewed professional paper (Mallin et al. 2016). Rehabilitation measures performed to-date on Greenfield Lake have improved the appearance of the lake to the public, and have improved dissolved oxygen concentrations by eliminating near-anoxia incidents and reducing water quality standard violations by 26%. However, they have significantly increased chlorophyll *a* concentrations in the lake and led to a tripling of chlorophyll *a* violations that have gotten this lake placed on the NC 303(d) list. Chlorophyll *a* is strongly correlated with BOD5 in this lake; thus, the algal blooms work to reduce DO. At present, the solar-powered mixers bring hypolimnetic water to the surface for aeration; should they be removed, DO standard violations would likely considerably increase.

UNC Wilmington researchers have been performing research designed to investigate the input of nutrients to the lake from the various inflowing streams, as well as other sources. Such information will be used to determine location and type of future best management practices (BMPs), and help prioritize the various efforts. We note that, in addition to City funds, a contribution toward this aspect of research is also coming from the U.S. Fish and Wildlife Service.

Determining Nutrient Loads from Streams Entering Greenfield Lake

As part of UNCW graduate student Nick Iraola's M.S. thesis, a year-long study was performed from July 2016 – June 2017 to quantify the amount of nutrients that are added by the five perennial streams that feed Greenfield Lake. The lake is listed on the NC 303(d) list for excessive chlorophyll *a* violations, but had expressed other chronic water quality symptoms for decades. These issues are related to eutrophication (algal blooms and elevated BOD), which is driven by excessive nutrient inputs such as nitrogen and phosphorus. Therefore, the five perennial streams that drain the highly impervious and developed Greenfield Lake watershed were evaluated for their nutrient contributions to the lake. The streams were studied during baseflow (dry periods) and after rainfall to compare "normal" conditions against stormwater loading. In addition, the lake's outfall was also studied to quantify the nutrient load that leaves the lake. Overall, the goal of the study was to determine which streams carry the greatest nutrient load, and to inform future restoration efforts as to which best management practices (BMPs) would be most effective in nutrient reductions to remove the lake from the 303(d) list.

Figure 6.2. Greenfield Lake feeder stream stations sampled in 2016-2017. Note that GL-SQB is also known as GL-LB, and GL-CBB is also known as GL-LC.



The five stream stations (Fig. 6.2) and the outfall to Greenfield Lake were sampled monthly for physical, chemical, and biological parameters from 2016-2017 during periods of dry weather; after a rainfall of at least an inch, a second monthly sample was taken to assess stormwater loading. Results showed that nutrient concentrations varied among streams and between periods (Tables 6.3 and 6.4), but were consistently higher in Jumping Run Branch (GL-JRB) and Squash Branch (GL-SQB; also known as GL-LB). Ammonium-N concentration was highest in GL-SQB and GL-JRB, while nitrate-N was highest in GL-SQB, GL-JRB, and GL-2340 (Tables 6.3; 6.4). Orthophosphate-P concentrations were highest in GL-JRB and GL-SQB, but were fairly comparable to the other streams. Total nitrogen and total phosphorus concentrations were highest in GL-2340 during dry weather, and highest in Clay Bottom Branch (GL-CBB; also known as GL-LC), Silver Stream Branch (GL-SSB), and GL-JRB during rainfall. High TN and TP in GL-2340 were the result of a massive, lake-wide cyanobacteria bloom (*Anabaena)* that occurred in May-June 2017. During this bloom, GL-2340 mainatined a chlorophyll *a* concentration of 1,851 µg/L, which is 45 times the state standard of 40 µg/L. The high TN and TP concentrations in GL-SSB and GL-CBB were also the result of high chlorophyll *a* during dry weather, and included high TSS during stormwater loading.

Table 6.3. Nutrient concentrations at all Greenfield Lake inflowing stations and the outfall during dry events (n = 12) from July 2016 – June 2017. Presented as mean ± standard deviation (range).

Parameters	**GL-2340**	**GL-SSB**	**GL-CBB**	**GL-JRB**	**GL-SQB**	**GL-OUT**
Ammonium *(mg-N/L)*	0.05 ± 0.04 (0.01 – 0.15)	0.02 ± 0.01 (0.01– 0.03)	0.05 ± 0.07 (0.01 – 0.26)	0.06 ± 0.03 (0.03 – 0.13)	0.15 ± 0.07 (0.06 – 0.28)	0.04 ± 0.3 (0.02 – 0.12)
Nitrate *(mg-N/L)*	0.19 ± 0.13 (0.004 – 0.38)	0.06 ± 0.09 (0.003 – 0.27)	0.06 ± 0.07 (0.001 – 0.17)	0.19 ± 0.06 (0.10 – 0.28)	0.27 ± 0.10 (0.12 – 0.45)	0.03 ± 0.03 (0.01 – 0.10)
Total Nitrogen *(mg-N/L)*	4.01 ± 11.72 (0.41 – 41.22)	0.56 ± 0.27 (0.21 – 0.92)	0.81 ± 0.67 (0.29 – 2.47)	0.52 ± 0.13 (0.33 – 0.78)	0.69 ± 0.10 (0.53 – 0.89)	0.62 ± 0.40 (0.27 – 1.52)
Orthophosphate *(mg-P/L)*	0.02 ± 0.03 (0.004 – 0.10)	0.01 ± 0.01 (0.004 – 0.03)	0.01 ± 0.01 (0.01 – 0.03)	0.02 ± 0.01 (0.01 – 0.05)	0.02 ± 0.02 (0.01 – 0.08)	0.01 ± 0.01 (0.005 – 0.05)
Total Phosphorus *(mg-P/L)*	0.29 ± 0.87 (0.02 – 3.07)	0.05 ± 0.02 (0.03 – 0.09)	0.07 ± 0.07 (0.02 – 0.22)	0.04 ± 0.02 (0.03 – 0.10)	0.05 ± 0.02 (0.03 – 0.11)	0.05 ± 0.03 (0.02 – 0.11)
DIN/DIP *(molar ratio)*	31.4 ± 26.9 (2.1 – 81.1)	6.0 ± 6.9 (0.8 – 23.0)	11.2 ± 11.9 (0.7 – 29.7)	15.5 ± 9.9 (5.8 – 30.2)	25.5 ± 15.4 (7.0 – 51.0)	6.7 ± 6.0 (0.6 – 15.0)
TN/TP *(molar ratio)*	16.7 ± 3.9 (11.7 – 25.0)	10.2 ± 2.6 (6.7 – 15.0)	12.1 ± 3.1 (8.1 – 18.0)	14.5 ± 6.0 (5.2 – 22.7)	15.4 ± 5.8 (5.6 – 28.1)	13.5 ± 6.5 (4.9 – 27.9)

Table 6.4. Nutrient concentrations at all inflowing Greenfield Lake stations and the outfall during rain events (n = 9) from July 2016 – June 2017. Presented as mean ± standard deviation (range).

Parameters	**GL-2340**	**GL-SSB**	**GL-CBB**	**GL-JRB**	**GL-SQB**	**GL-OUT**
Ammonium *(mg-N/L)*	0.03 ± 0.02 (0.01 – 0.08)	0.01 ± 0.01 (0.003 – 0.04)	0.04 ± 0.03 (004 – 0.08)	0.05 ± 0.03 (0.02 – 0.1)	0.07 ± 0.05 (0.02 – 0.18)	0.02 ± 0.01 (0.003 – 0.03)
Nitrate *(mg-N/L)*	0.15 ± 0.07 (0.07 – 0.27)	0.07 ± 0.05 (0.004 – 0.18)	0.09 ± 0.08 (0.04 – 0.22)	0.21 ± 0.09 (0.11 – 0.37)	0.20 ± 0.13 (0.08 – 0.41)	0.01 ± 0.01 (0.01 – 0.03)
Total Nitrogen *(mg-N/L)*	0.34 ± 0.07 (0.24 – 0.45)	0.41 ± 0.28 (0.22 – 1.11)	0.59 ± 0.41 (0.18 – 1.51)	0.53 ± 0.11 (0.34 – 0.70)	0.45 ± 0.19 (0.20 – 0.54)	0.64 ± 0.88 (0.26 – 2.98)
Orthophosphate *(mg-P/L)*	0.01 ± 0.003 (0.004 – 0.01)	0.02 ± 0.01 (0.01 – 0.03)	0.01 ± 0.01 (0.01 – 0.02)	0.02 ± 0.01 (0.01 – 0.03)	0.02 ± 0.01 (0.01 – 0.03)	0.01 ± 0.01 (0.01 – 0.04)
Total Phosphorus *(mg-P/L)*	0.03 ± 0.01 (0.01 – 0.03)	0.06 ± 0.04 (0.02 – 0.16)	0.05 ± 0.03 (0.02 – 0.09)	0.05 ± 0.03 (0.02 – 0.11)	0.04 ± 0.02 (0.02 – 0.10)	0.05 ± 0.05 (0.01 – 0.18)
DIN/DIP *(molar ratio)*	23.4 ± 12.7 (8.2 – 50.9)	6.0 ± 4.6 (1.0 – 14.5)	10.7 ± 9.4 (1.4 – 25.1)	18.6 ± 10.4 (5.7 – 31.0)	18.0 ± 15.3 (5.9 – 46.2)	2.5 ± 1.6 (0.4 – 4.9)
TN/TP *(molar ratio)*	15.0 ± 5.5 (10.9 – 29.3)	7.9 ± 2.4 (4.7 – 12.9)	12.1 ± 3.1 (8.2 – 17.2)	14.0 ± 6.9 (5.4 – 26.2)	11.5 ± 5.8 (5.4 – 24.1)	14.7 ± 13.0 (4.9 – 47.3)

Nutrient loading by streams was determined by multiplying nutrient concentrations by the total volumetric loading rate (i.e. discharge) of each respective stream. Overall, GL-JRB was the highest nutrient loader of nitrate-N, orthophosphate-P, total nitrogen, and total phosphorus (Table 6.5). GL-SQB was the highest ammonium-N loader and second highest in nitrate-N and orthophosphate-P. GL-JRB and GL-SQB were the two highest loaders of dissolved inorganic nitrogen and phosphorus, which accounted for a higher percentage of their overall total nitrogen and total phosphorus compared to other streams. Inorganic forms of N and P are most critical because these are the nutrient forms most readily taken up by algae and bacteria. GL-JRB loaded the most total nitrogen and phosphorus, with GL-SQB and GL-SSB loading the second most total nitrogen and total phosphorus, respectively. The total N and P concentrations also include organic nutrients locked up in algal biomass, and the blooms at times were backed up into certain upper creek areas including GL-SSB, GL-CBB and GL-2340.

Table 6.5. Nutrient load of each stream and the dry period + wet period combined 'total stream input' in kilograms per year in Greenfield Lake from July 2016 – June 2017.

	GL-2340	GL-SSB	GL-CBB	GL-JRB	GL-SQB	Total Stream Input
Ammonium-N	7	10	15	56	60	149
Nitrate-N	32	44	36	203	125	440
TN	301	292	250	529	304	1,675
Ortho-P	2	10	5	19	11	47
TP	22	37	22	45	25	151

Since GL-JRB and GL-SQB (Fig. 6.3) combined were responsible for loading 75% of the inorganic nitrogen and 64% of the inorganic phosphorus to the lake these two streams (Fig. 6.4) should be prioritized for reductions in inorganic nutrient loading. Best management practices in/at GL-JRB will primarily need to buffer and treat stormwater flow. However, GL-SQB maintains high concentration and loading of dissolved N and P even under baseflow conditions (Tables 6.3; 6.5). Thus, BMPs should be able to improve the upper groundwater moving toward the lake (a constructed wetland with rooted vegetation may be a potential choice here). A lower priority would be enhancements to GL-2340 and GL-SSB (Figs. 6.3; 6.4), which, despite smaller loads due to low flow, also contribute to lake nutrient loading. As there are natural wetlands near the lake, and wet detention ponds in upstream areas, targeting open stream channels upstream (Fig. 6.4) may be of use.

Future work is recommended to investigate other pathways by which nutrients enter Greenfield Lake. The lake's outfall (GL-OUT) discharged more ammonium-N, orthophosphate-P, total nitrogen, and total phosphorus than the five streams contributed (Tables 6.3; 6.4). Therefore, other pathways besides streamflow are loading nutrients into Greenfield Lake, and play a role in the lake's eutrophic state. Other nutrient loading pathways to consider include, but are not limited to, groundwater flows and fluxes from nutrient-rich bottom sediments. Bottom sediments may be of particular interest, as long-term stream loading and algal blooms have been recorded for years, and may have resulted in the accumulation of in-lake organic material and enrichment of bottom sediments, especially by phosphorus. UNCW is funded by US Fish and Wildlife Service to collect bottom sediment samples over a grid of the lake bottom and analyze them for N and P sediment concentrations. If there are areas of accumulation of nutrients, in-lake actions could be considered such as dredging to remove P accumulations, or chemical treatment with alum or another substance to bind the P and make it unavailable to the overlying water and organisms within.

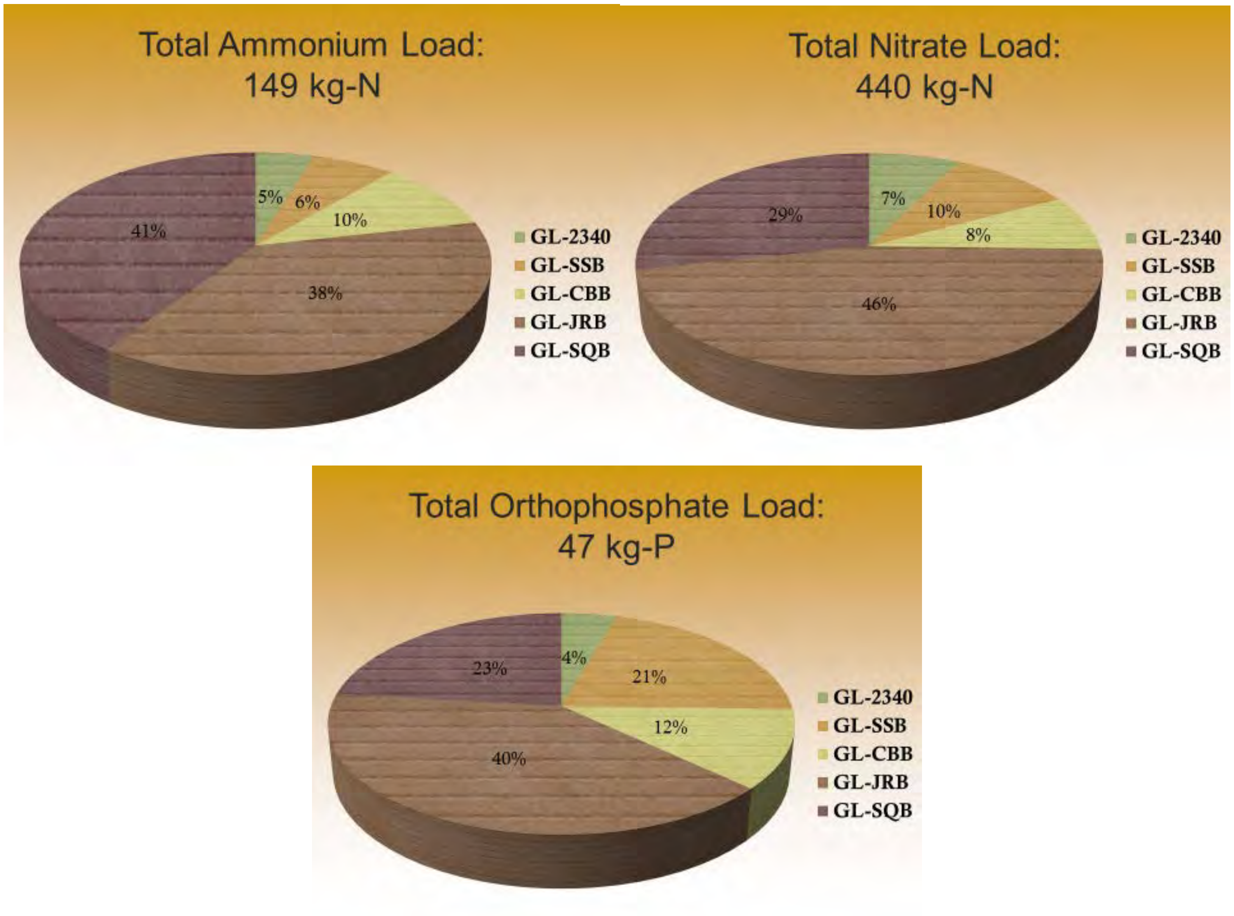


Figure 6.3. Annual wet + dry period inorganic N and P loads to Greenfield Lake as percent of total by individual stream, demonstrating how Squash Branch (GL-SQB) and Jumping Run Branch (GL-JRB) should be prioritized for nutrient reduction BMPs.

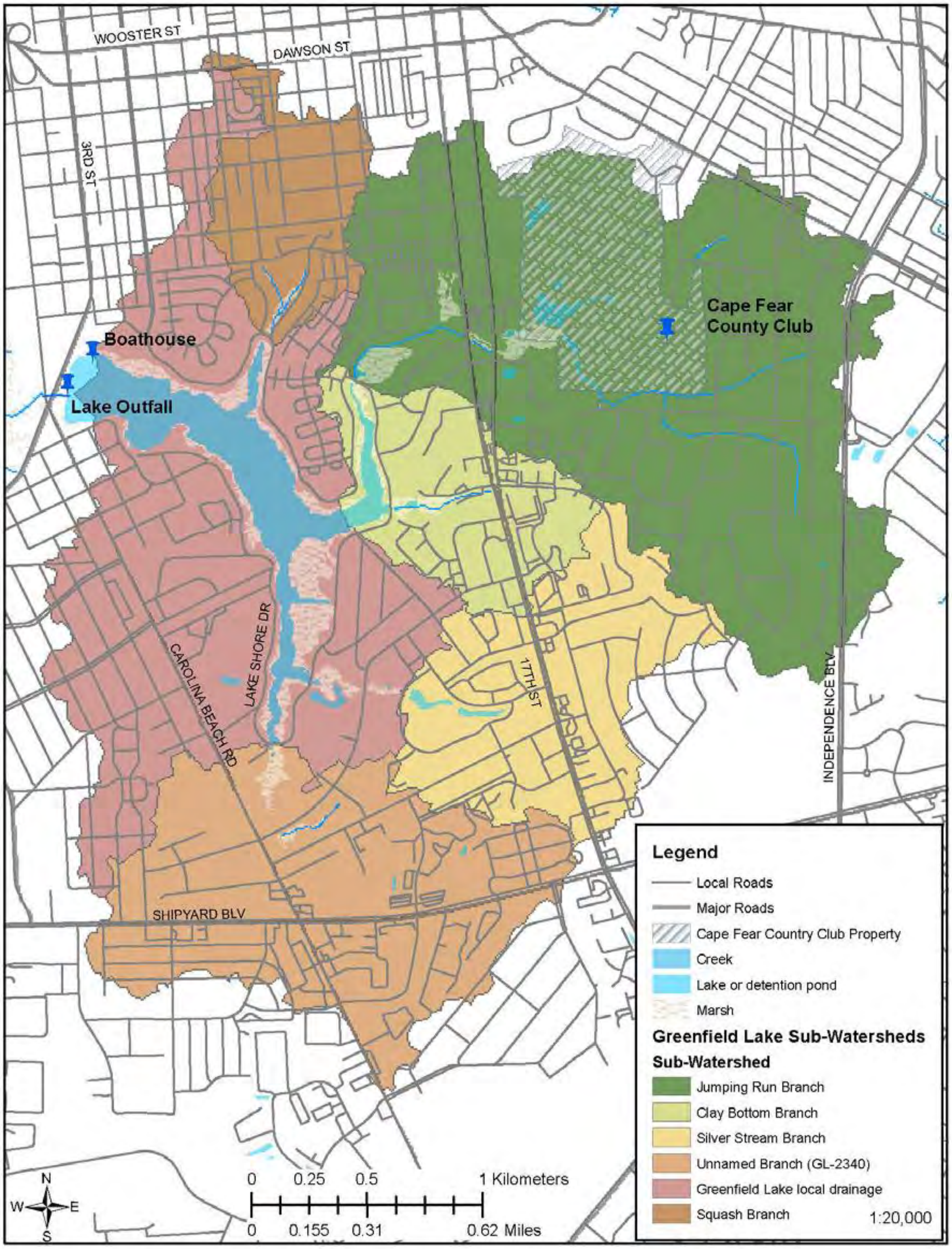


Figure 6.4. Greenfield Lake sub-watersheds; map produced by Saskia Cohick, Wilmington Stormwater Services.

7.0 Hewletts Creek

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

Hewletts Creek was sampled five times 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). Slight hypoxia was detected in our samples on one occasion at SB-PGR, where DO was between 4.0 and 5 mg/L. Nitrate concentrations were somewhat elevated leaving the golf course at PVGC-9 relative to the other stations, (Tables 7.1 and 7.2). From there the next station is MB-PGR, which also receives inputs from the Wilmington Municipal Golf Courses (Fig. 7.1; Mallin and Wheeler 2000). Nitrate was slightly elevated at MB-PGR; however, none of the other stations had particularly elevated nitrate concentrations. Ammonium concentrations were generally low in all creek areas. Total nitrogen was low except for the middle branch station, but variable. Orthophosphate concentrations were low, as were total phosphorus concentrations. The N/P ratios were elevated in the middle branch coming from the golf course, but median N/P ratios were low at the lower creek sites indicating that inputs of inorganic nitrogen could cause algal blooms. The chlorophyll *a* data (Tables 7.1 and 7.2) showed that the Hewletts Creek samples were free of major algal blooms in 2017, except for a bloom of 23 µg/L as chlorophyll *a* at NB-PGR. Fewer blooms have occurred in the past few years than had previously occurred in upper Hewletts Creek (Mallin et al. 1998a; 1999; 2002a; 2004; 2006a; 2008; Duernberger 2009). We note that water quality in the south branch of Hewletts Creek improved significantly following construction of a large stormwater treatment wetland in 2007 (Mallin et al. 2012).

Fecal coliform bacteria counts exceeded State standards 80% of the time at MB-PGR and 100% of the time at NB-GLR, 60% of the time at PVGC-9, and 80% of the time at SB-PGR. The geometric means at PVGC-9, MB-PGR, SB-PGR and NB-GLR all well exceeded 200 CFU/100 mL for a poor rating for this pollutant parameter, but the geometric means of fecal bacteria counts at HC-3 was well under the standard at 24 CFU/100 mL (although above the shellfishing standard of 14 CFU/100 mL).

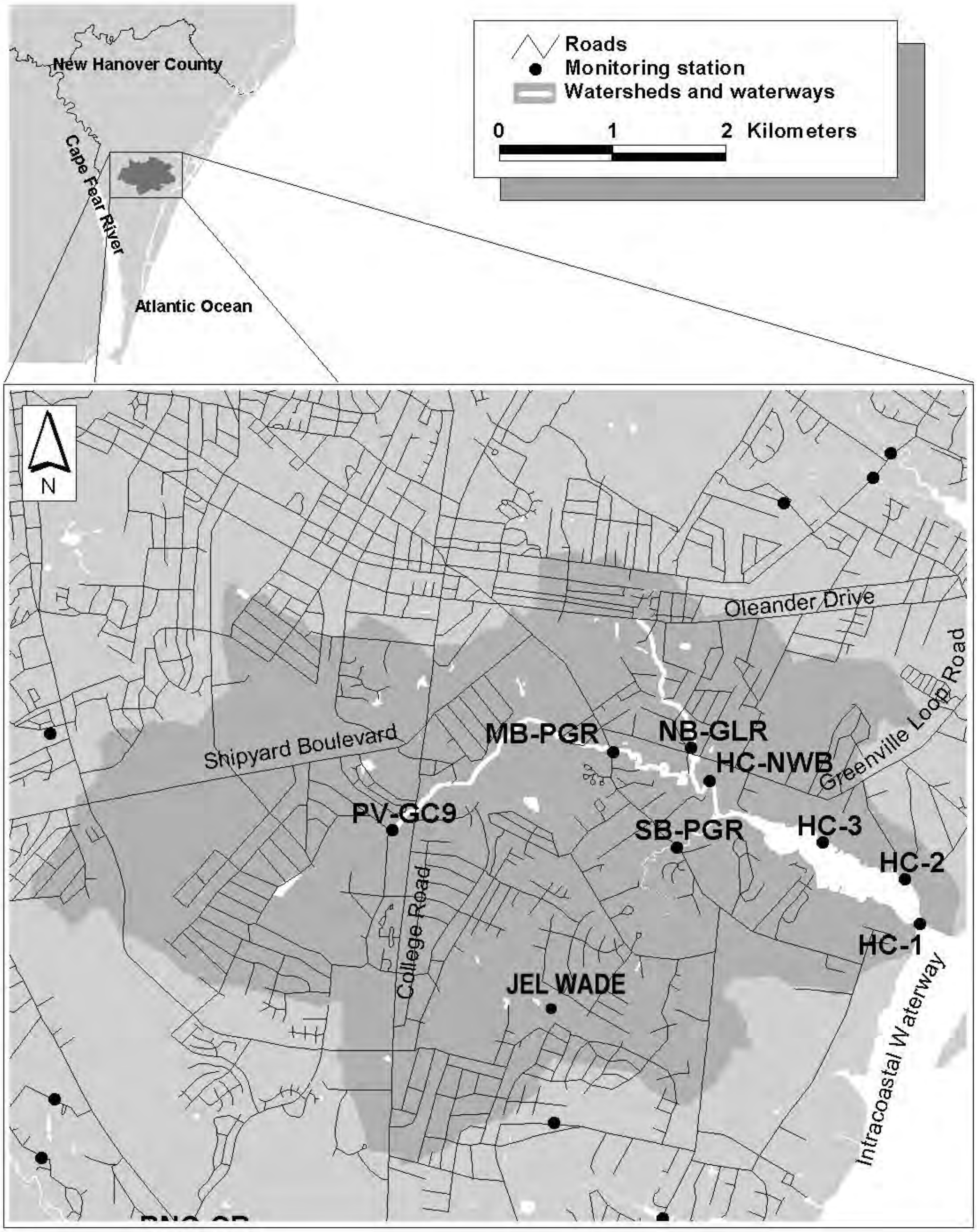


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Figure 7.1. Hewletts Creek watershed.

Table 7.1. Selected water quality parameters at upper and middle creek stations in Hewletts Creek watershed 2017 as mean (standard deviation) / range, N/P ratios as mean / median, fecal coliform bacteria presented as geometric mean / range, n = 5 samples collected.

Parameter	PVGC-9	MB-PGR
Salinity (ppt)	0.1 (0) 0.1-0.1	0.1 (0.0) 0.1- 0.1
Turbidity (NTU)	3 (2) 1-5	1 (1) 0-2
TSS (mg/L)	2.2 (1.2) 1.3-3.6	3.1 (2.3) 1.3-7.0
DO (mg/L)	7.0 (0.9) 6.0-7.9	7.3 (1.0) 6.1-8.5
Nitrate (mg/L)	0.322 (0.192) 0.010-0.480	0.244 (0.141) 0.010-0.390
Ammonium (mg/L)	0.044 (0.032) 0.010-0.080	0.026 (0.021) 0.010-0.060
TN (mg/L)	0.700 (0.322) 0.310-1.030	0.782 (0.495) 0.200-1.560
Orthophosphate (mg/L)	0.026 (0.005) 0.020-0.030	0.030 (0.010) 0.020-0.040
TP (mg/L)	0.036 (0.015) 0.020-0.060	0.042 (0.015) 0.020-0.060
N/P	33 35	24 24
Chlorophyll *a* (µg/L)	9 (6) 2-17	2 (1) 1-4
Fecal col. (CFU/100 mL)	527 190-7,000	439 172-1,180

Table 7.2. Selected water quality parameters at stations in Hewletts Creek watershed, 2017, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 5 samples collected.

Parameter	NB-GLR	SB-PGR	HC-3
Salinity (ppt)	7.9 (7.7) 1.3-21.1	16.9 (8.2) 10.0-30.9	28.1 (4.4) 22.1-34.1
Turbidity (NTU)	4 (2) 0-6	4 (3) 0-7	3 (2) 0-6
TSS (mg/L)	7.8 (2.4) 5.1-9.9	13.7 (1.8) 12.1-15.8	16.7 (3.7) 13.0-22.2
DO (mg/L)	7.0 (1.6) 5.3-8.6	6.8 (1.9) 4.3-8.9	7.3 (1.6) 5.8-9.2
Nitrate (mg/L)	0.146 (0.130) 0.010-0.360	0.030 (0.019) 0.010-0.060	0.118 (0.241) 0.010-0.550
Ammonium (mg/L)	0.034 (0.043) 0.010-0.110	0.040 (0.057) 0.010-0.140	0.010 (0.000) 0.010-0.010
TN (mg/L)	0.320 (0.179) 0.200-0.600	0.970 (1.162) 0.050-3.000	0.160 (0.129) 0.050-0.300
Orthophosphate (mg/L)	0.034 (0.011) 0.020-0.050	0.030 (0.014) 0.010-0.040	0.020 (0.007) 0.010-0.030
TP (mg/L)	0.038 (0.023) 0.010-0.070	0.046 (0.026) 0.010-0.080	0.024 (0.013) 0.010-0.040
Mean N/P ratio Median	15 11	6 7	26 2
Chlor *a* (µg/L)	11 (11) 2-23	7 (5) 1-12	4 (4) 1-11
Fecal coliforms (CFU/100 mL)	647 390-1,730	438 5-23,000	24 5-172

The City of Wilmington has recently (2015-16) installed a stormwater treatment wetland (Figure 4.2) at the intersection of Patricia and Sharon Drives just upstream of NB-GLR. In 2017 the vegetation was improving but still too sparse for effective treatment so we will wait for a later date to begin inter-year data comparisons to assess its effectiveness in pollutant reduction.

Figure 4.2. Installed wetland in the north branch of Hewletts Creek, March 2018 (photo by M. Mallin).

8.0 Howe Creek Water Quality

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

Howe Creek was sampled at two locations on four occasions during 2017 (HW-GP and HW-DT- Fig. 8.1). Salinity levels were generally lower than in 2016. 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 low to moderate (< 23 mg/L). Dissolved oxygen concentrations were within the NC standard of 5 mg/L on all five sampling occasions at HW-DT and HW-GP in 2017 (Appendix B).

Nitrate and ammonium concentrations were both low at both sites in 2017 (Table 8.1). Orthophosphate was also low at the two sites. Mean and median inorganic molar N/P ratios were low (below 7.0), indicating that nitrogen was probably the principal nutrient limiting phytoplankton growth at both stations. Previously Mallin et al. (2004) demonstrated that nitrogen was the primary limiting nutrient in Howe Creek. Chlorophyll *a* concentrations exceeded the NC standard during 2017 at HW-DT on one of four occasions in 2017. Since wetland enhancement was performed in 1998 above Graham Pond on Landfall Property, the creek below the pond at HW-GP has had fewer and smaller algal blooms than before the enhancement, although in recent years some blooms have started to appear again (Fig. 8.2). For fecal coliform bacteria, the creek at HW-DT exceeded the water contact standard of 200 CFU/100 mL on four of four occasions, and on two of four occasions at HW-GP for Poor ratings. In 2017 the geometric mean fecal coliform counts at the uppermost creek site exceeded the NC standard, but counts overall were considerably lower than in 2014-2016 (Table 8.1; Fig. 8.3).

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

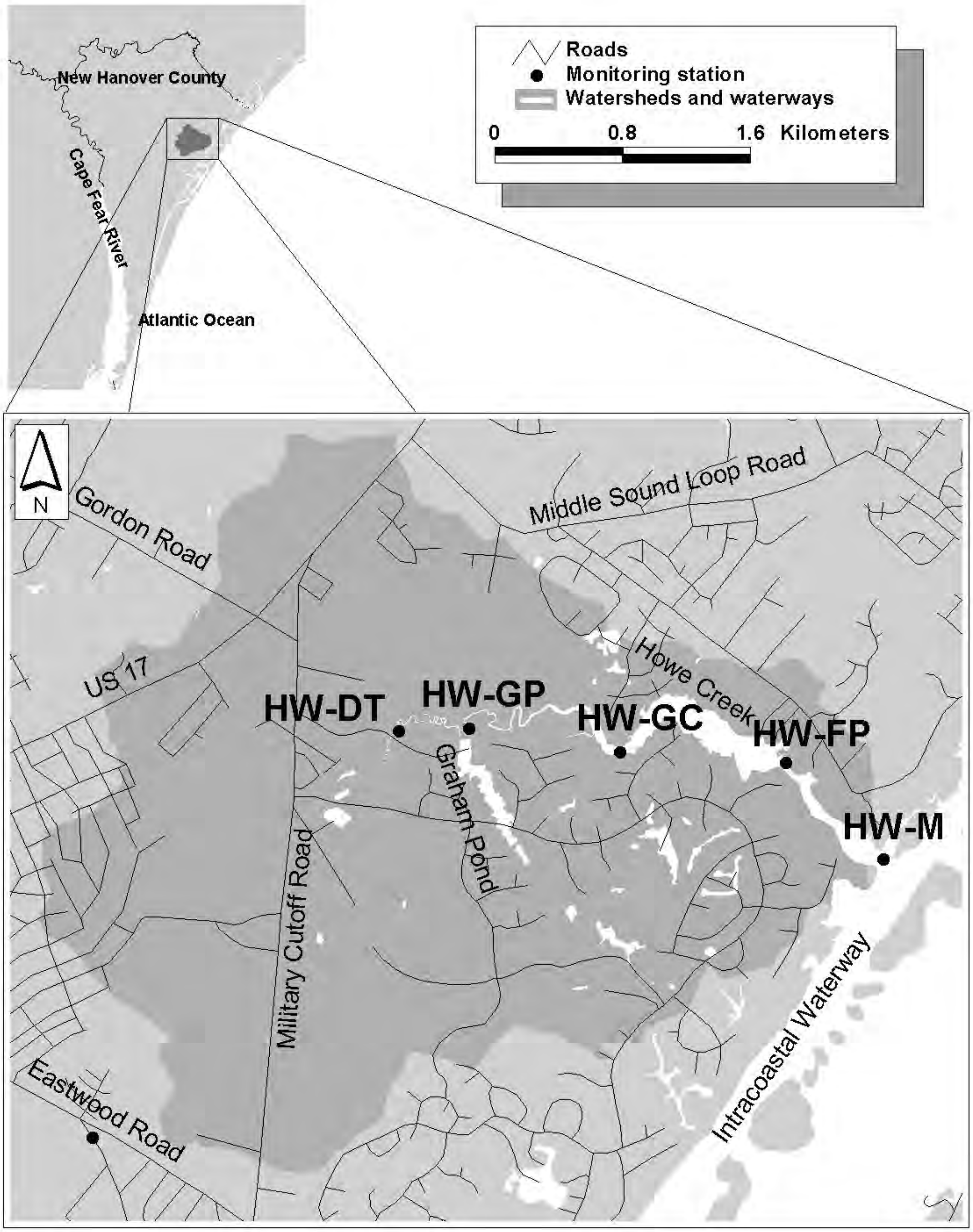


Table 8.1. Water quality summary statistics for Howe Creek, 2017, as mean (st. dev.) / range. Fecal coliform bacteria as geometric mean / range, n = 5 samples collected.

Parameter	HW-DT	HW-GP
Salinity (ppt)	1.9(1.3) 1.1-3.8	11.6(1.3) 10.5-13.5
Dissolved oxygen (mg/L)	7.3(1.6) 5.9-8.9	7.5(1.2) 5.6-9.9
Turbidity (NTU)	7(3) 3-10	5(1) 3-5
TSS (mg/L)	12.4(7.2) 5.1-22.2	10.7(3.7) 6.2-15.0
Chlor *a* (µg/L)	19(18) 4-45	4(2) 2-6
Fecal coliforms (CFU/100 mL)	512 270-955	187 118-295
Nitrate (mg/L)	0.080(0.104) 0.010-0.230	0.048(0.052) 0.010-0.120
Ammonium (mg/L)	0.025(0.019) 0.010-0.050	0.028(0.035) 0.010-0.080
Orthophosphate (mg/L)	0.035(0.010) 0.030-0.050	0.028(0.005) 0.020-0.030
Molar N/P ratio	6 6	6 3

Figure 8.2. Chlorophyll *a* concentrations (algal blooms) in Howe Creek below Graham Pond before and after 1998 wetland enhancement in Pond, 1993-2017.

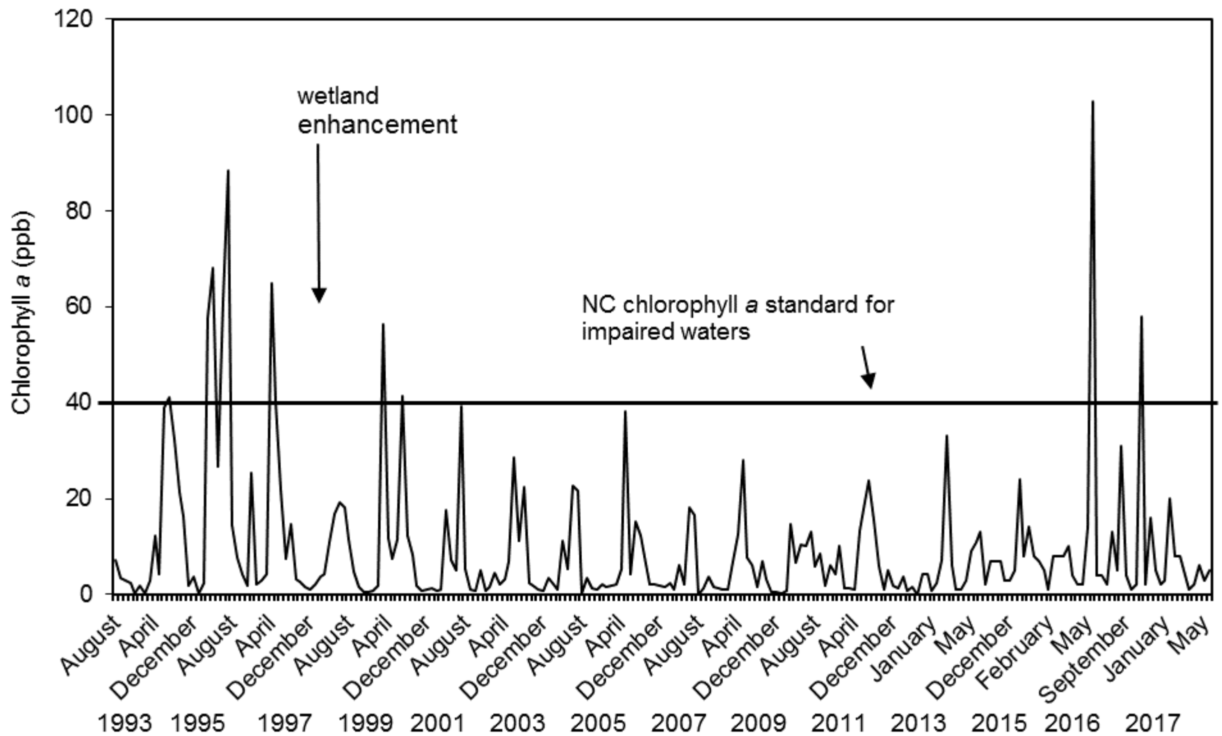
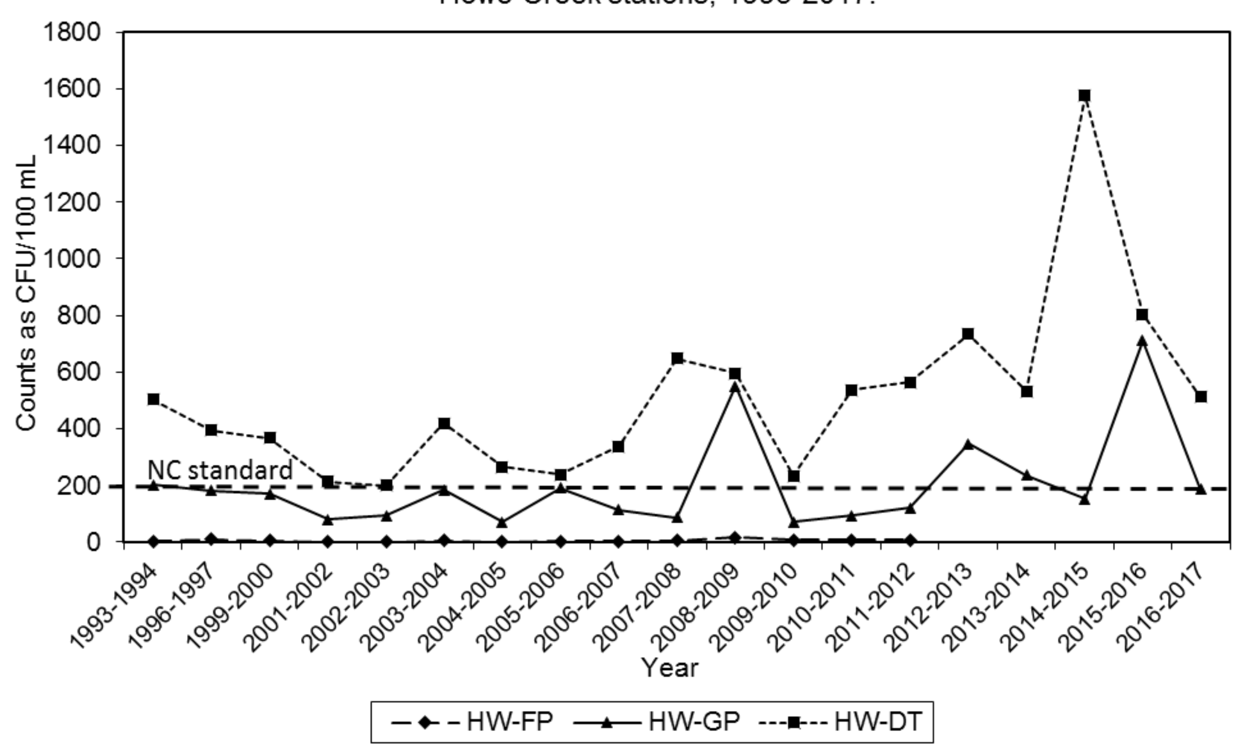


Figure 8.3. Annual fecal coliform counts (as geometric means) over time for Howe Creek stations, 1993-2017.

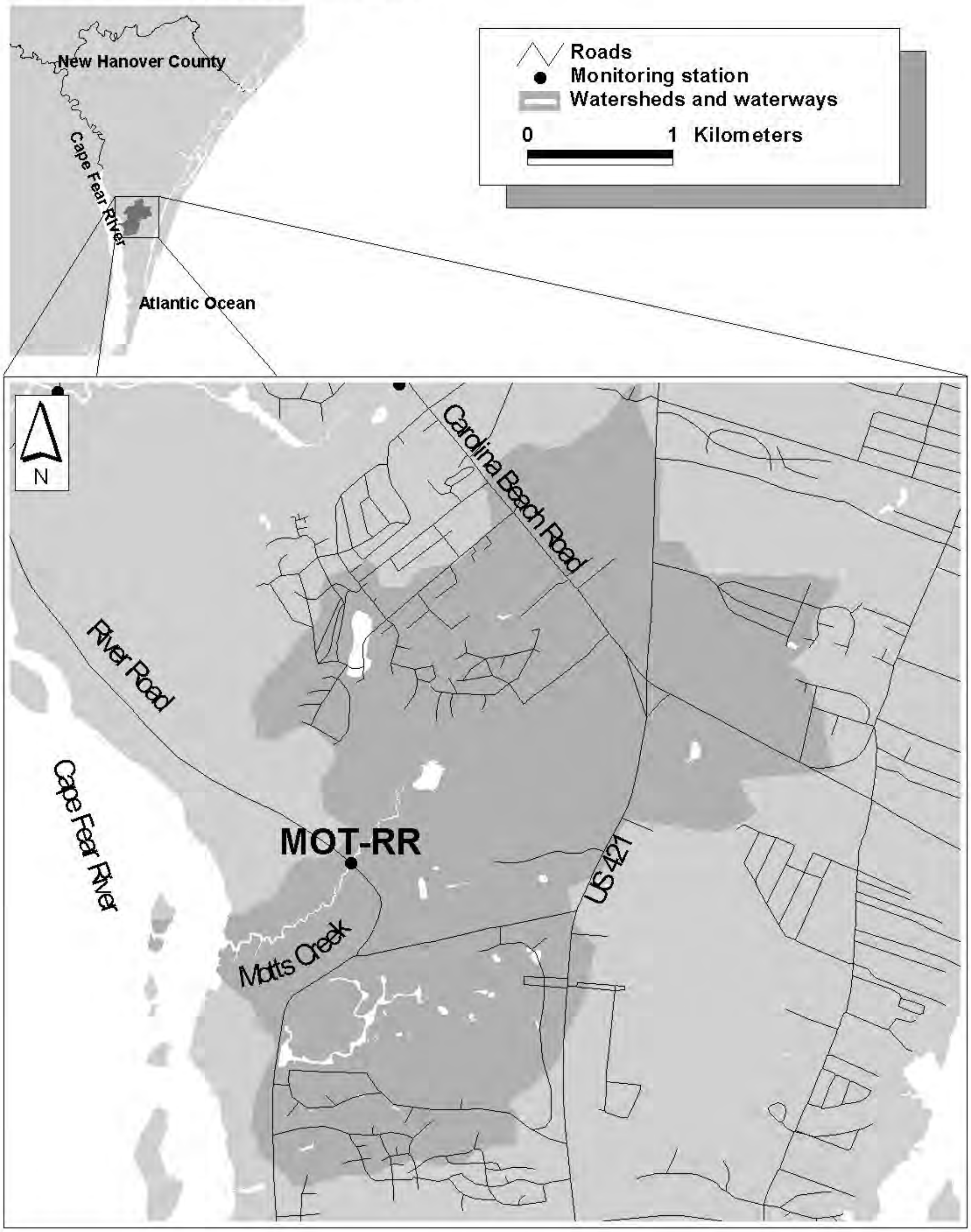


9.0 Motts Creek

Snapshot
Watershed area: 3,328 acres (1,354 ha)
Impervious surface coverage: 23.4%
Watershed population: 9,530
Overall water quality: poor
Problematic pollutants: Periodic algal blooms; high fecal coliform bacteria

Motts Creek drains into the Cape Fear River Estuary (Fig. 9.1), and the creek area near River Road has been classified by the State of North Carolina as a Natural Heritage Site because of the area’s biological attributes. These include the pure stand wetland communities, including a well-developed sawgrass community and unusually large flats dominated by *Lilaeopsis chinensis* and spider lily, with large cypress in the swamp forest. During 2017 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. Note that supplemental funding received by UNCW in late 2017 has allowed us to re-initiate sampling of Motts Creek at River Road (MOT-RR) beginning January 2018.

Figure 9.1 Motts Creeks watershed

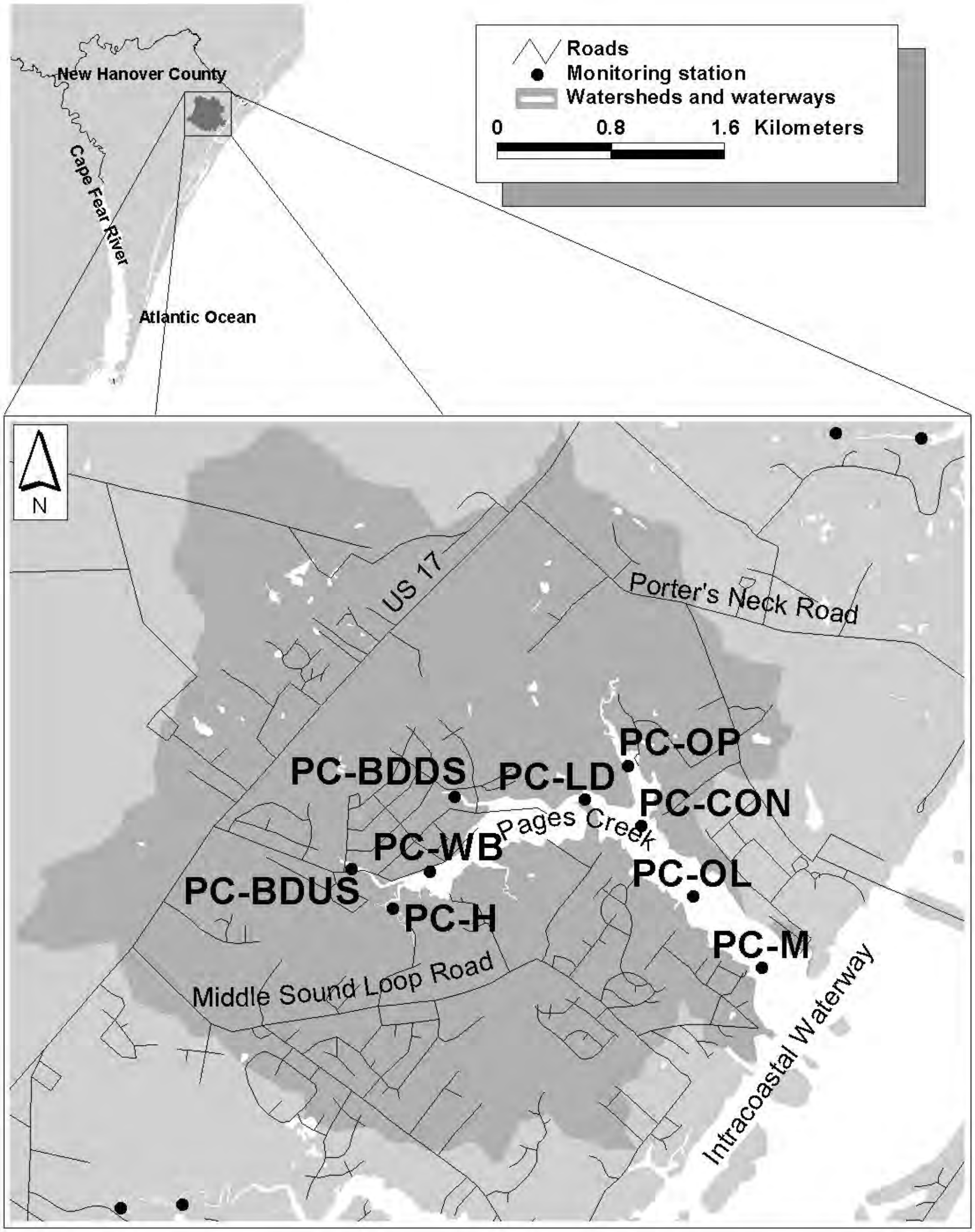


10.0 Pages Creek

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

The University of North Carolina Wilmington was not funded by the County in 2017 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 from the County.

Figure 10.1. Pages Creek watershed and sampling sites.



11.0 Smith Creek

Snapshot
Watershed area: 16,650 acres (6,743 ha)
Impervious surface coverage: 21.3% (2014 data)
Watershed population: 31,780
Overall water quality: Fair
Problematic pollutants: occasional turbidity and low dissolved oxygen, primarily problems with fecal coliform pollution

Smith Creek drains into the lower Northeast Cape Fear River just before it joins with the mainstem Cape Fear River at Wilmington (Fig. 11.1). One location on Smith Creek, SC-CH at Castle Hayne Road (Fig. 11.1) is sampled monthly by UNCW under the auspices of the Lower Cape Fear River Program for selected parameters (field physical parameters, nutrients, chlorophyll and fecal coliform bacteria) and these data are summarized below (Table 11.1).

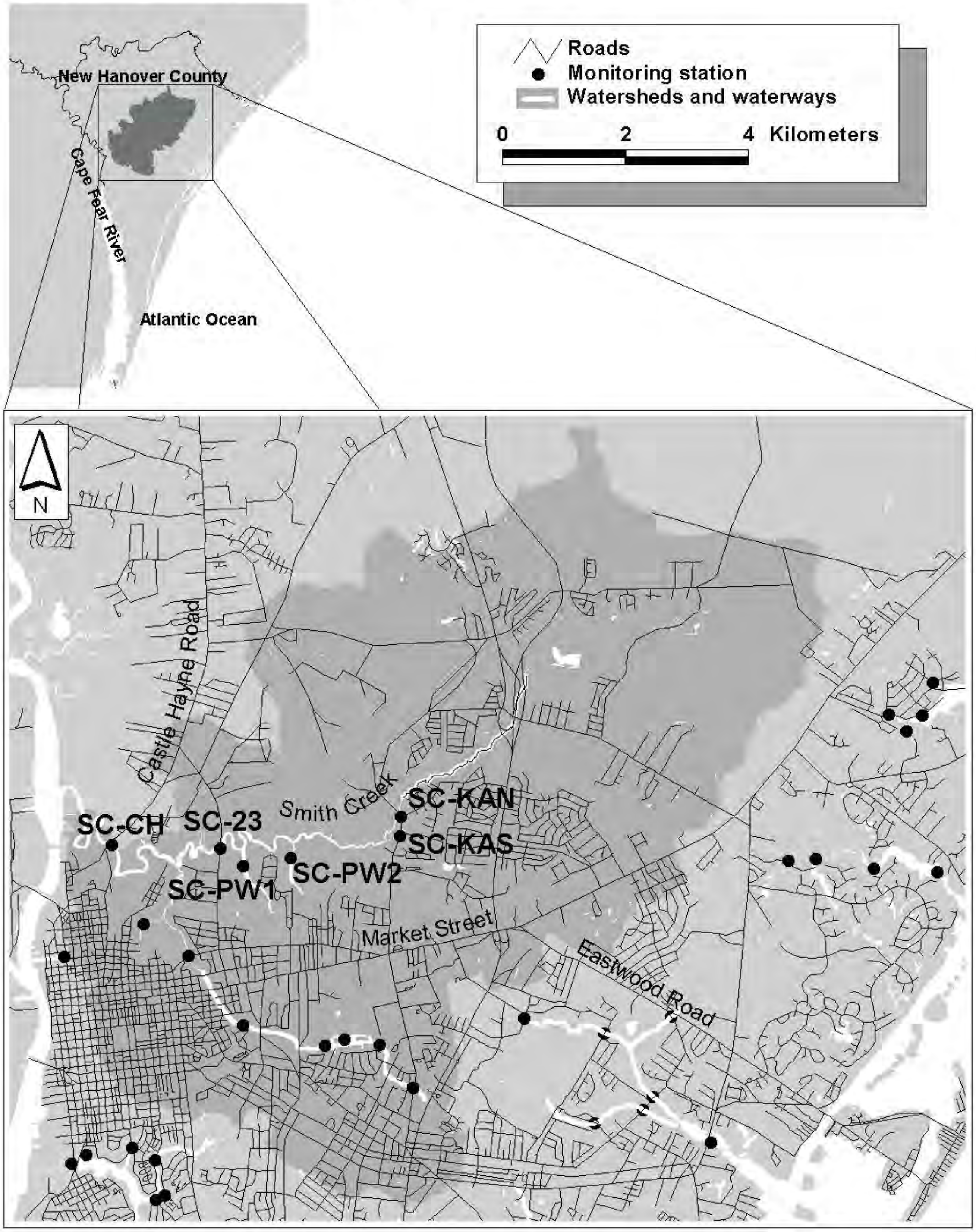
The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters, is 4.0 mg/L, and was not violated in our 2017 samples for a good rating. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded in our 2017 samples, and TSS concentrations were not excessive.

Nutrient concentrations were moderate in 2017 (Table 11.1). There was one minor algal bloom (18.0 µg/L) in April of 2017. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on eight sampling occasions at SC-CH in 2017, for a Poor rating (Table 11.1).

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range, 2017, n = 12 samples collected.

Parameter	SC-CH Mean (SD)	Range
Salinity (ppt)	2.6 (3.8)	0.1-12.9
Dissolved oxygen (mg/L)	6.3 (2.0)	4.3-9.1
Turbidity (NTU)	10 (6)	3-24
TSS (mg/L)	15.0 (9.0)	6.2-34.8
Ammonium (mg/L)	0.055 (0.055)	0.010-0.100
Nitrate (mg/l)	0.218 (0.115)	0.010-0.680
Orthophosphate (mg/L)	0.039 (0.036)	0.023-0.067
Chlorophyll *a* (µg/L)	4.0 (3.0)	1-18
Fecal col. /100 mL (geomean / range)	301	19-9,000

Figure 11.1 Smith Creek watershed



12.0 Whiskey Creek

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

Whiskey Creek drains into the AICW. 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 2017 salinity at this station was relatively high, what scientists consider euhaline, ranging from 19 – 29 ppt and averaging about 23 ppt (Table 12.1).

Dissolved oxygen concentrations were below the State standard on one of five sampling occasions at WC-MLR (Table 12.1). Turbidity was within state standards for tidal waters on all sampling occasions (Table 12.1; Appendix B). Suspended solids were low to moderate in 2017. Algal blooms are rare in this creek and there were no blooms detected in our 2017 sampling (Table 12.1). Nitrate, ammonium and orthophosphate concentrations were generally low at this station. Total nitrogen and total phosphorus were low, similar to previous years. The N/P ratios (Table 12.1) were low, indicating that nitrogen was the factor most limiting to potential algal bloom formation.

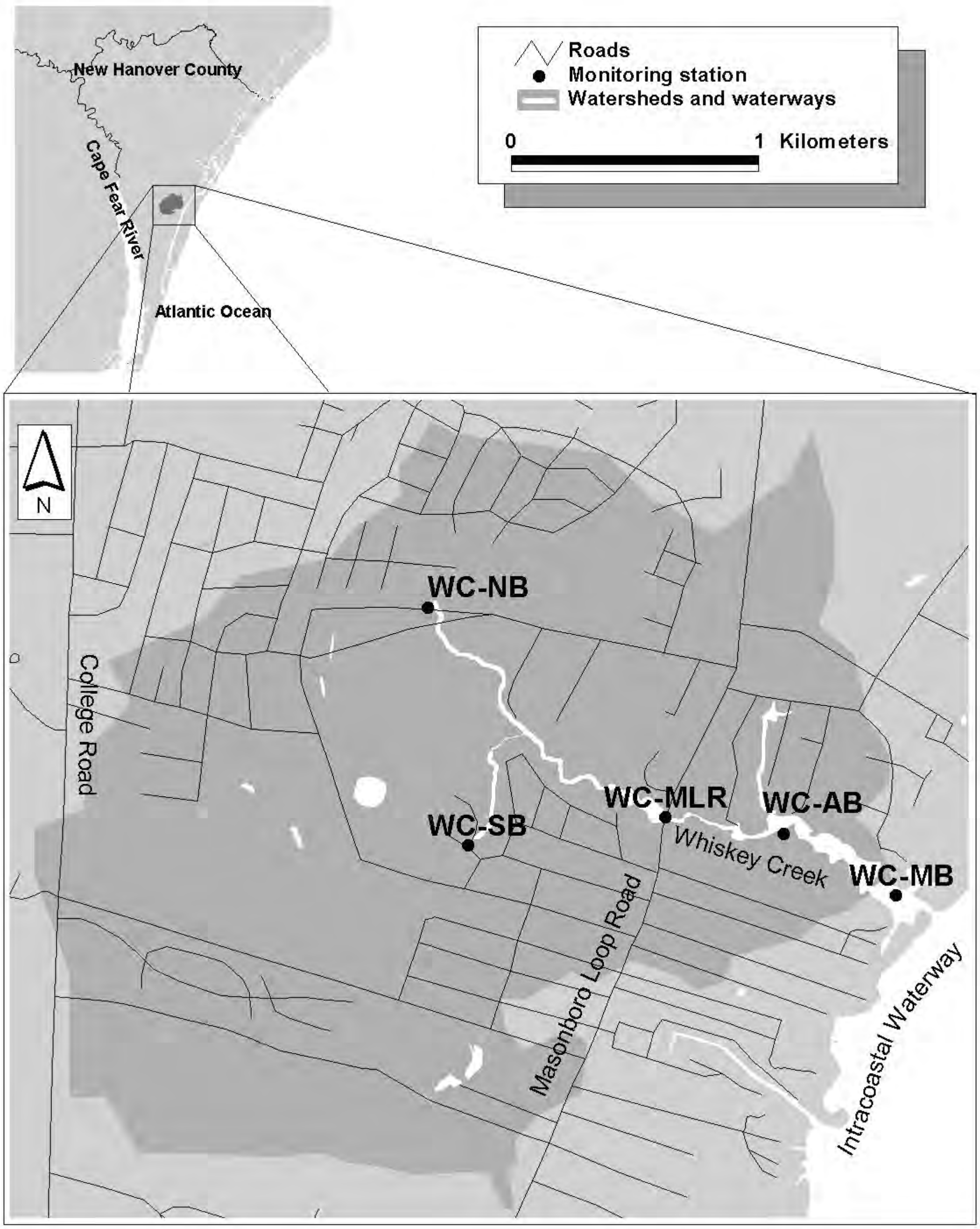
In 2017 the standard for fecal coliforms was exceeded on one of five occasions (less than in 2016), with a geometric mean count less than the state standard of 200 CFU/100 mL (Table 12.1). Whiskey Creek is presently closed to shellfishing by the N.C. Division of Marine Fisheries.

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. Selected water quality parameters in Whiskey Creek watershed as mean (standard deviation) and range, 2017, n = 5 samples collected.

Parameter	WC-MLR	
	Mean (SD)	Range
Salinity (ppt)	23.5 (3.9)	19.7-29.1
Dissolved oxygen (mg/L)	6.8 (2.0)	4.3-9.0
Turbidity (NTU)	4 (2)	1-6
TSS (mg/L)	15.5 (3.4)	10.6-20.0
Ammonium (mg/L)	0.04 (0.05)	0.01-0.13
Nitrate (mg/L)	0.04 (0.02)	0.01-0.06
TN (mg/L)	0.43 (0.17)	0.20-0.65
Orthophosphate (mg/L)	0.03 (0.07)	0.02-0.04
TP (mg/L)	0.04 (0.02)	0.01-0.06
N/P ratio (mean and median)	6	5
Chlorophyll *a* (µg/L)	4.8 (4.5)	1-12
Fecal col. /100 mL (geomean and range)	77	10-638

Figure 12.1. Whiskey Creek. Watershed and sampling sites.



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14.0 Acknowledgments

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15.0 Appendix A. North Carolina Water Quality standards for selected parameters (NCDENR 2003; 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); for designated "swamp" waters it is 4.0 ppm
Turbidity	25 NTU (tidal saltwater) 50 NTU (freshwater)
Fecal coliform counts	14 CFU/100 mL (shellfishing waters), and more than 10% of the samples cannot exceed 43 CFU/100 mL. 200 CFU/100 mL (human contact waters)
Chlorophyll *a*	40 ppb (μg/L)

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

16.0 Appendix B. UNCW ratings of sampling stations in Wilmington watersheds based on 2017, 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	P	G	P
	BC-SB	G	G	G	P
	BC-NB	G	G	G	P
Burnt Mill Creek	BMC-AP1	G	G	G	P
	BMC-AP3	F	F	G	G
	BMC-PP	P	G	G	F
Greenfield Lake	JRB-17	G	F	G	P
	GL-JRB	G	P	G	P
	GL-LC	F	P	G	P
	GL-LB	G	P	G	P
	GL-2340	P	G	G	F
	GL-YD	F	G	G	G
	GL-P	F	G	G	g
Hewletts Creek	HC-3	G	G	G	G
	NB-GLR	G	G	G	P
	MB-PGR	G	G	G	P
	SB-PGR	G	F	G	P
	PVGC-9	G	G	G	P
Howe Creek	HW-GP	G	G	G	P
	HW-DT	F	g	G	P
Smith Creek	SC-CH	G	G	G	P
Whiskey Creek	WC-MLR	G	F	G	F

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

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

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

Sampling Station	**Catchment Polygon Area (acres)**	**Percent Impervious**
Hewletts Creek		
PVGC-9	1296.1	27.5%
MB-PGR	2044.5	27.5%
NB-GLR	876.4	29.8%
SB-PGR	1480.2	27.4%
HC-NWB	3185.1	27.4%
HC-3	5117.5	26.6%
HC-2	5557.1	25.3%
HC-M	5642.2	25.0%
Barnards Creek		
BNC-EF	154.6	20.8%
BNC-TR	277.4	25.5%
BNC-AW	196.0	22.2%
BNC-CB	1077.8	31.6%
BNC-RR	3437.3	25.3%
Burnt Mill Creek		
BMC-KA1	191.4	63.3%
BMC-KA3	195.1	62.3%
BMC-AP1	995.1	46.2%
BMC-AP2	1036.4	44.9%
BMC-AP3	1537.2	42.3%
BMC-GS	256.9	47.8%
BMC-WP	2981.9	39.5%
BMC-PP	3030.8	39.3%
BMC-ODC	772.0	47.8%
Bradley Creek		
BC-SBU	439.5	28.0%
BC-NBU	683.6	33.5%
BC-CA	372.1	82.0%
BC-CR	649.7	46.3%
BC-SB	1022.3	28.9%
BC-NB	2047.6	31.9%
BC-76	3589.0	29.8%
Whiskey Creek		
WC-NB	211.6	31.1%
WC-SB	734.7	25.2%
WC-MLR	1378.1	26.0%

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

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

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