ENVIRONMENTAL QUALITY OF WILMINGTON AND NEW HANOVER COUNTY WATERSHEDS, 2018

by

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Executive Summary

This report represents combined results of Year 21 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The 2018 program involved 9 watersheds and 24 sampling stations. In this summary we first present brief water quality overviews for each watershed from data collected between January and December 2018; note that fewer samples were collected at some sites in 2018 because funding did not arrive until late fall; additionally, Hurricane Florence disrupted sampling as well..

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 human population of approximately 12,200. Dissolved oxygen concentrations were good on all sampling occasions, and turbidity was within standard. However, one major and one minor algal bloom occurred. Fecal coliform counts were somewhat elevated on two occasions.

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 2018 there were no significant algal blooms recorded, but there were several incidents of low dissolved oxygen, especially 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 2018. High fecal coliform counts occurred at all three sites in 2018, especially at the uppermost site BMC-AP1 above Anne McCrary Pond and at the lowermost station BMC-PP at princess Place. Several major algal blooms (chlorophyll *a* > 40 µg/L) were recorded in 2018. Dissolved oxygen concentrations were good in the two upper stations and poor in the remaining lower 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 2018. Comparing inflows to outflows, there was a significant increase in dissolved oxygen concentrations as the water passed through the pond due to in-pond algal photosynthesis and physical aeration at the outfall. There was likewise a significant increase in pH due to photosynthesis using up CO_2 (an acid) and driving the water to a more alkaline state. On a positive pollutant –reduction note, ammonium concentrations significantly decreased through the detention pond.

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, ammonium 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 2018. 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), two suffered from low dissolved oxygen problems, although main lake maintained good oxygen concentrations on all sampling occasions (non-hurricane periods).

Algal blooms are periodically problematic in Greenfield Lake, and have occurred during all seasons, but are primarily a problem in spring and summer. In 2018 a massive summer blue-green algal bloom of *Anabaena* occurred late spring – late fall. 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 very high BOD occurred congruent with the blooms in 2018. In 2018 all tributary stations and one of the in-lake stations exceeded the fecal coliform State standard on 66% or more of occasions sampled.

We note that Greenfield Lake suffered a fish kill of about 600 fish in the discharge canal in August, then suffered a massive fish kill involving thousands of fish or many species in late September following Hurricane Florence. Cape Fear River Watch personnel reported low dissolved oxygen in association with the September kill. Nutrient loading from hurricane runoff, coupled with decomposition of dead fish likely contributed nutrients that kept the algal blooms occurring until fall.

Greenfield Lake is currently on the NC 303(d) list for impaired waters due to excessive algal blooms. In the previous report we reported on the thesis work of UNCW graduate student Nick Iraola, who performed 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. In summer 2018 UNCW personnel collected bottom sediment samples at 27 locations within the lake, finding the highest phosphorus levels in Jumping Run and Squash Branch, and lowest levels in areas of significant natural wetlands, again providing guidance for restoration work.

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 2018 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 2018; DO dipped below 5.0 mg/L on several occasions but not below 4.0 mg/L. Turbidity was low and did not exceed the state standard. Two major algal blooms occurred at PVGC-9 following Hurricane Florence, and one bloom occurred in summer at SB-PGR. Fecal coliform bacteria counts exceeded State standard 100% of the time at NB-GLR (the north branch) and MB-PGR (the middle branch), 83% of the time at PVGC-9, and 67% of the time at SB-PGR (the south branch). The geometric means at PVGC-9, MB-PGR, SB-PGR and NB-GLR all 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.

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 2018. The uppermost site HW-DT had two major algal blooms in the 2018 sampling, and the middle creek station had one bloom. The uppermost station HW-DT was rated poor for fecal coliform pollution in 2018, exceeding the state standard on 75% of the times sampled. However, dissolved oxygen concentrations were good at both sites in 2018.

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%. One major and one minor algal bloom occurred at our site in 2018. Dissolved oxygen concentrations were fair in 2018, and turbidity was low. Motts Creek was strongly impacted by high fecal coliform counts in 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 2008-2018. 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 violated three of 11 occasions in our 2018 samples. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded. There were no major algal blooms present in our 2018 sampling. However, fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on 36% of samples in 2017, for a Poor rating, although it should be noted that fecal coliform counts in 2018 were considerably lower than in 2017.

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 2018. 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, and fecal coliform bacteria counts exceeded 200 CFU/100 mL on 50% 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 2018 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 (24 sites sampled for fecal coliforms) showed 4% to be in good condition, 13% in fair condition and **83%** in poor condition, a worsening over the previous year. Dissolved oxygen conditions (measured at the surface) system-wide (24 sites) showed 54% of the sites were in good condition, 8% were in fair condition, and 38% were in poor condition, a worsening from 2017. For algal bloom presence, measured as chlorophyll *a*, 46% of the 24 stations sampled were rated as good, 25% as fair and 29% as poor, again, worse than 2017. For turbidity, 22 sites sampled were rated as good, and two sites as fair. 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. We also note that Hurricane Florence led to worsening of the water quality compared with 2017, as well.

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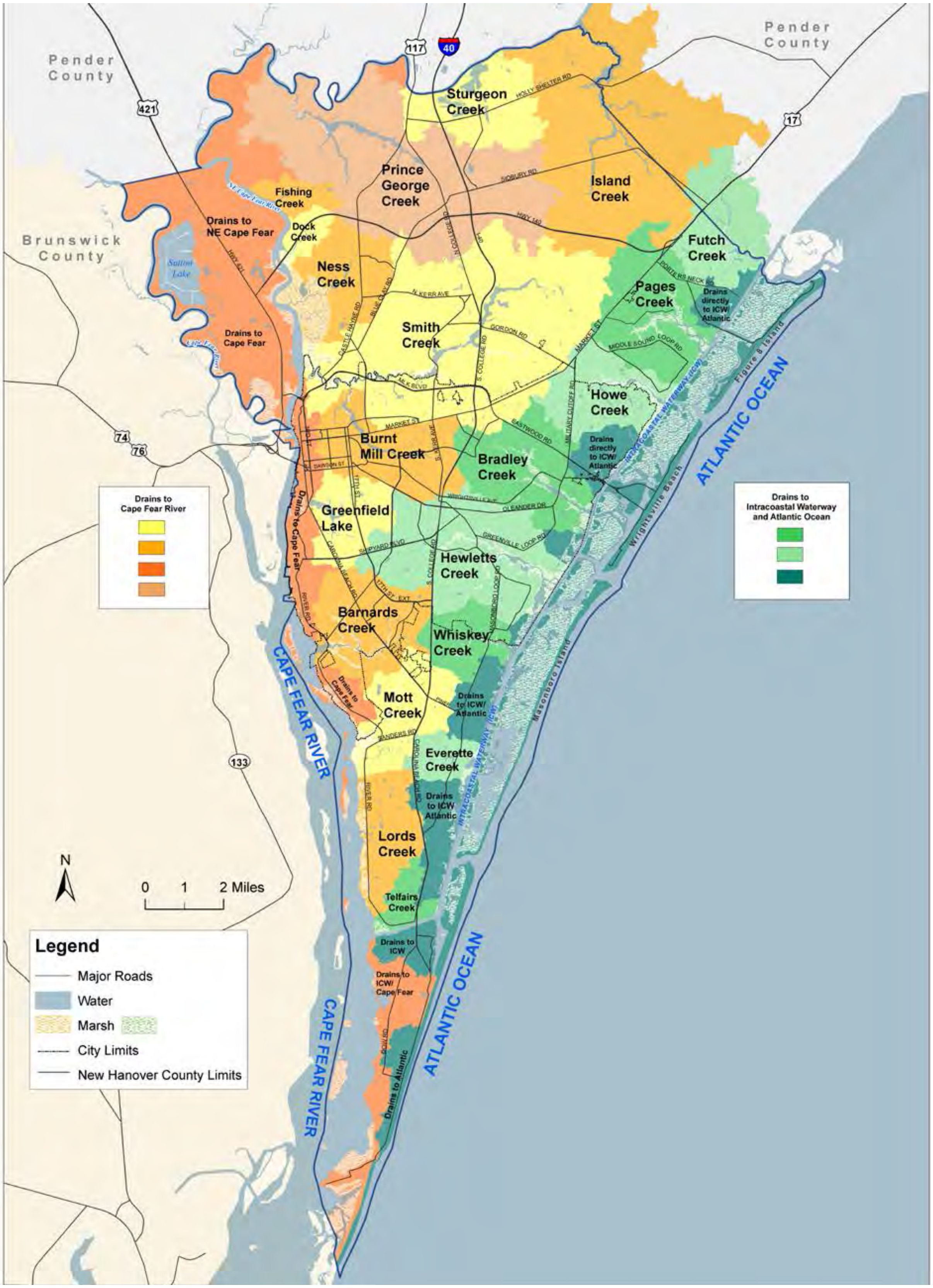


Plate 1. Wilmington and New Hanover County watersheds 2014 map by Wilmington Stormwater Services. Station coordinates are in Appendix C.

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 (see Appendix E). 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 (see Appendix E). In the present report we present results of sampling conducted during 2018, with funding by the City of Wilmington through the N.C. Water Resources Research Institute. Through private funding (the Newland Corporation) we sampled Motts and Barnards Creeks along River Road from 2008-2010, when plans for development were delayed due to the economic slowdown and funding was suspended. There has been road, commercial 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. From 2010-2013 a suite of metals, PAHs and PCBs were assessed in the sediments of the creeks and Greenfield lake. 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 provided in various reports.

1.1 Water Quality Methods

Samples were collected on five occasions at 23 locations within the Wilmington City watersheds between January and December 2018. 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 EXO 3 Multiparameter Water Quality sonde linked to a YSI EXO 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: Algal blooms, and minor fecal coliform problems

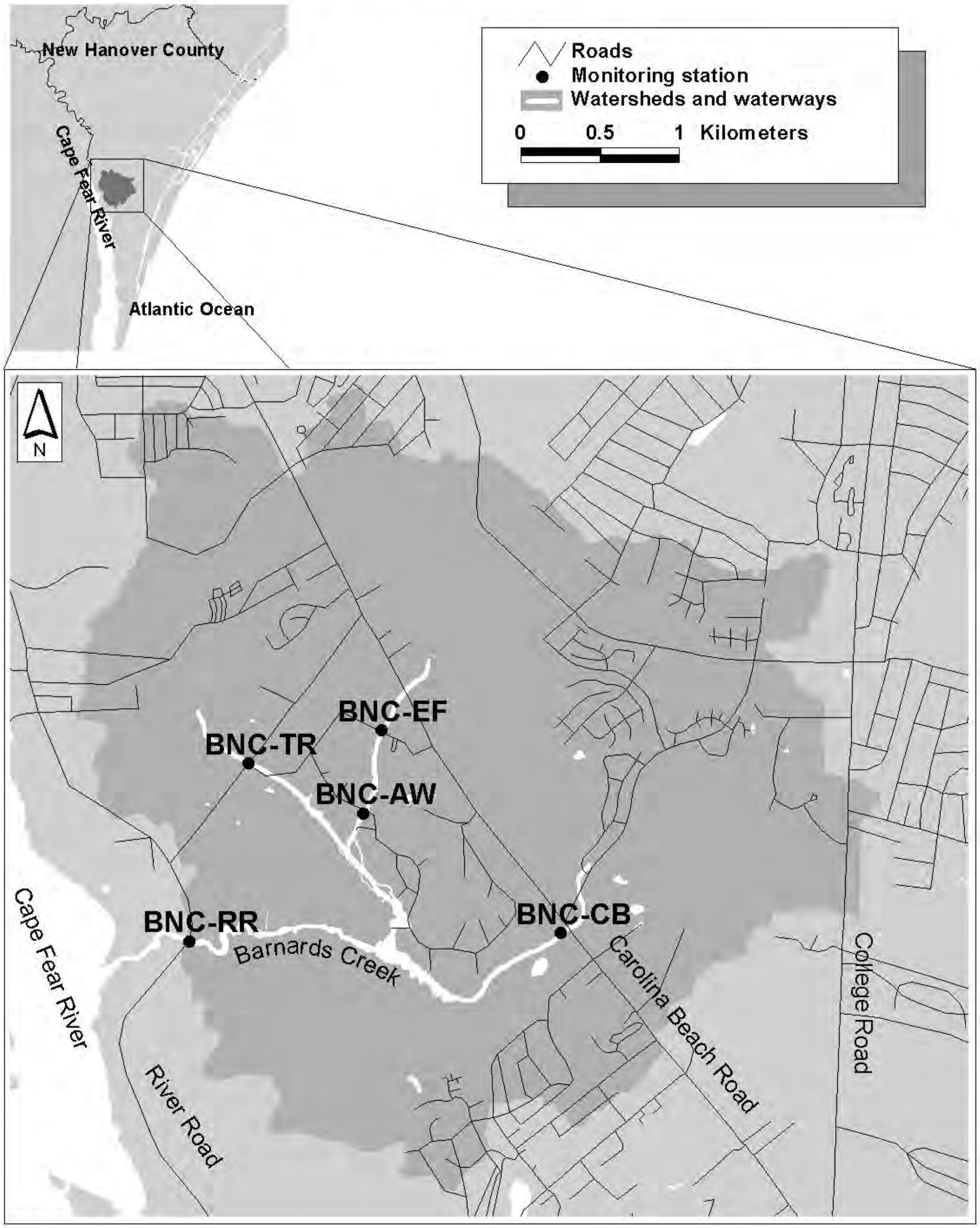
The water quality of lower Barnard's Creek is an important issue as single family and multifamily housing construction has occurred upstream of Carolina Beach Rd. in the St. Andrews Dr. area and along Independence Boulevard near the Cape Fear River. Another major housing development (River Lights) is under construction between Barnards and Motts Creeks. This site was not sampled for several years due to lack of funding. However, renewed funding allowed UNCW to re-initiate sampling of Barnard's Creek at River Road (BNC-RR) in 2018.

Barnards Creek at this site is considered to be oligohaline, which is, maintaining salinities generally less than 5 ppt. Dissolved oxygen was good, with no samples dropping below 5.0 mg/L. We caution that we could not sample right after Hurricane Florence because of logistical restraints, so it may have decreased considerably for some weeks. Turbidity and suspended solids were generally moderate. Ammonium was low except for June, when it exceeded 0.50 mg-N/L. Nitrate concentrations were likewise moderate, just exceeding 0.50 mg/L on two occasions. Total phosphorus and orthophosphate concentrations were relatively low concentrations. There was a minor algal blooms (chlorophyll *a* of 36 µg/L) in late October, but a major bloom (chlorophyll *a* of 51 µg/L) in June. Fecal coliform bacteria were somewhat elevated on two occasions, but not severely.

Table 2.1. Selected water quality parameters in Barnards Creek watershed as mean (standard deviation) and range, 2018, n = 4 samples collected.

Parameter	BNC-RR	
	Mean (SD)	Range
Salinity (ppt)	3.2 (1.4)	1.5-5.0
Dissolved oxygen (mg/L)	7.8 (1.0)	6.6-8.7
Turbidity (NTU)	17 (6)	11-23
TSS (mg/L)	23.6 (8.1)	15.8-33.9
Ammonium (mg/L)	0.23 (0.19)	0.12-0.52
Nitrate (mg/L)	0.47 (0.07)	0.41-0.53
TN (mg/L)	1.19 (0.09)	1.11-1.31
Orthophosphate (mg/L)	0.09 (0.03)	0.06-0.14
TP (mg/L)	0.11 (0.08)	0.02-0.22
N/P ratio (mean and median)	18	16
Chlorophyll *a* (µg/L)	24 (23)	4-51
Fecal col. /100 mL (geomean and range)	120	23-364

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 2018; the standard of 25 NTU was not exceeded (Table 3.1). Total suspended solids (TSS) were slightly elevated (about 18 mg/L) in three samples. 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 three out of five occasions sampled at BC-CA, and on two occasions each at the other two sites (Appendix B).

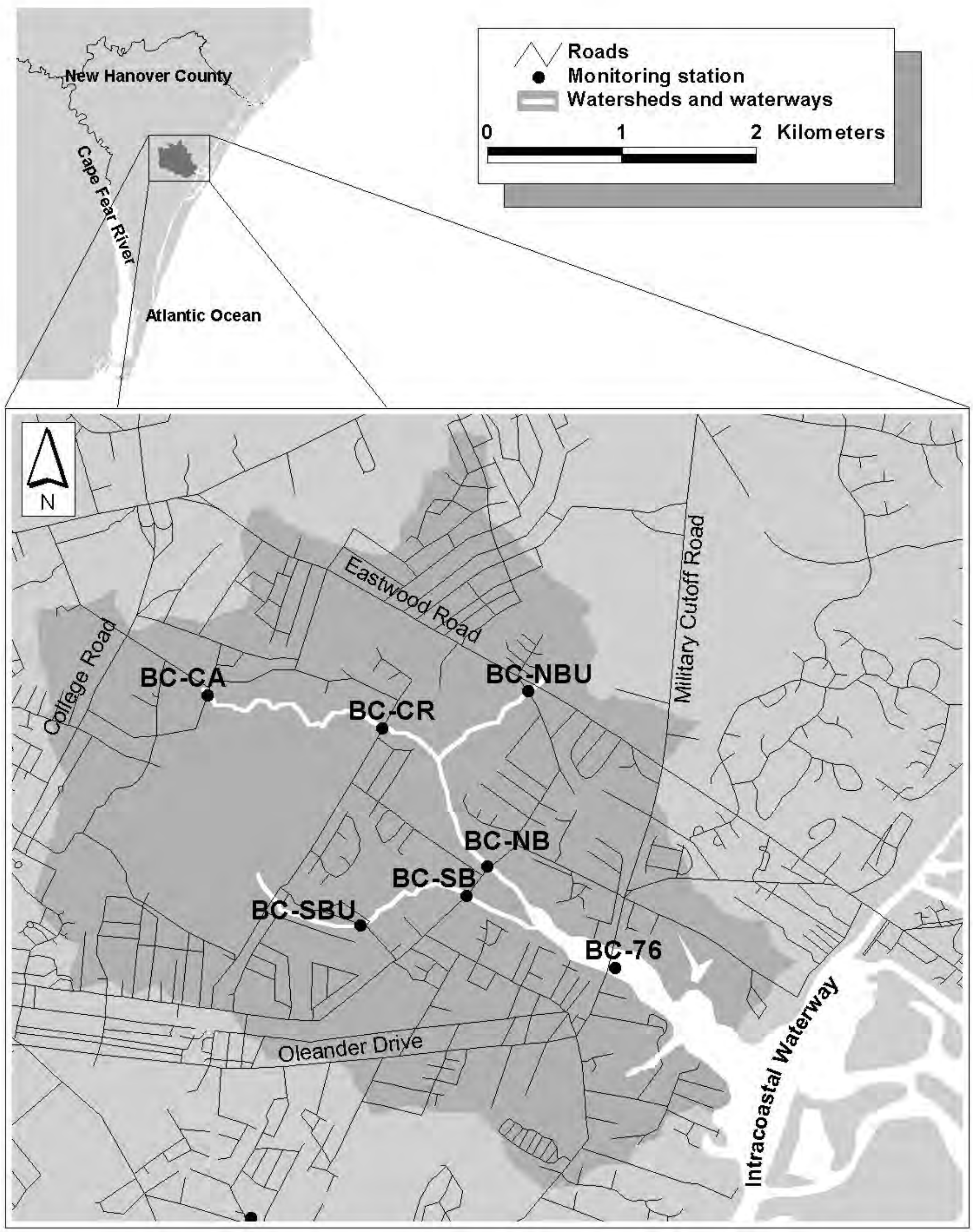
Ammonium concentrations were generally low except for a level of 1.160 mg-N/L at BC-CA in December 2017. Nitrate concentrations were also highest at station BC-CA, but low in general (Table 3.1). Total nitrogen concentrations were low to moderate in general but reached 1.230 mg-N/L at BC-CA in October 2018. 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 2018, just a minor bloom of chlorophyll a of 30 µg/L at BC-CA in October. Median nitrogen to phosphorus ratios at BC-NB and BC-SB were low (<16) 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 2018, as in the previous year. The NC contact standard was exceeded on 100% of occasions sampled at BC-CA, 50% of occasions at BC-NB and 83% of occasions sampled at BC-SB. The geometric means of the fecal coliform counts ranged from 414 CFU/100 mL at BC-NB to about 10X the standard (2,218 CFU/100 mL at BC-CA, Table 3.1).

Table 3.1. Water quality parameter concentrations at Bradley Creek sampling stations, 2018. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 6 samples collected.

Station	BC-CA	BC-NB	BC-SB
Salinity (ppt)	0.1 (0.0) 0.1-0.1	17.7 (11.9) 2.7-27.3	9.3 (9.8) 0.2-23.9
Dissolved Oxygen (mg/L)	4.8 (2.0) 1.5-6.7	6.2 (1.8) 4.2-8.8	6.4 (1.7) 4.4-8.8
Turbidity (NTU)	2 (1) 1-3	5 (3) 2-10	5 (2) 2-7
TSS (mg/L)	5.1 (6.7) 1.3-18.6	12.4 (3.8) 8.6-18.2	10.8 (4.4) 5.2-18.3
Nitrate (mg/L)	0.110 (0.058) 0.030-0.190	0.037 (0.041) 0.010-0.090	0.043 (0.029) 0.010-0.090
Ammonium (mg/L)	0.155 (0.084) 0.030-0.250	0.067 (0.085) 0.010-0.190	0.045 (0.046) 0.010-0.120
TN (mg/L)	0.660 (0.375) 0.110-1.230	0.547 (0.214) 0.300-0.890	0.458 (0.111) 0.360-0.650
Orthophosphate (mg/L)	0.112 (0.191) 0.020-0.500	0.080 (0.147) 0.010-0.380	0.165 (0.331) 0.020-0.840
TP (mg/L)	0.087 (0.037) 0.050-0.140	0.150 (0.149) 0.030-0.420	0.140 (0.118) 0.030-0.300
N/P	15.7 11.1	8.2 6.3	4.7 3.9
Chlorophyll *a* (µg/L)	15 (9) 6-30	11 (4) 6-17	9 (5) 2-16
Fecal coliforms (CFU/100 mL)	2,218 470-11,500	414 100-7,000	805 172-6,000

Figure 3.1. Bradley Creek watershed and sampling sites.



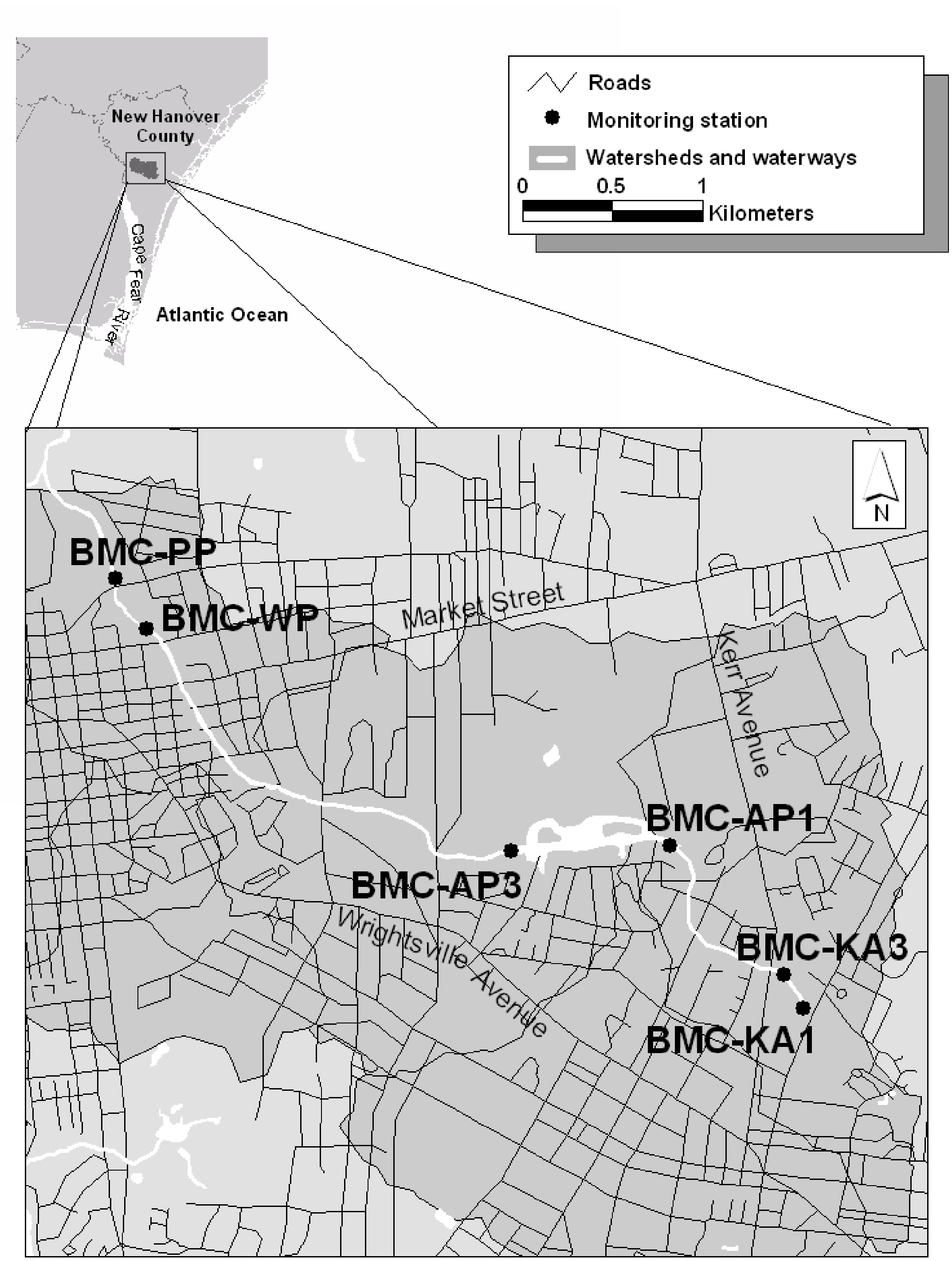
4.0 Burnt Mill Creek

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 on Randall Parkway, 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.

<u>Sampling Sites</u>: During 2018 samples were collected from three stations on the creek (Fig. 4.1). In the upper creek Ann McCrary Pond 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 2018. Dissolved oxygen concentrations were within standard on all sampling occasions at BMC-AP1 and BMC-AP3. There was a statistically-significant increase in DO through the pond. There was a significant increase in pH, likely due to high phytoplankton production consuming CO_2 and driving the pH up. The State standard for turbidity in freshwater is 50 NTU; there were no exceedences of this value in our 2018 samples; there was no significant change through the pond; averages were similar at 5 NTU. Likewise, total suspended solids concentrations were relatively low on all sampling occasions in 2018, 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 83% 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). Although there was an apparent reduction in fecal coliform counts from passage through the regional detention pond, it was not statistically significant due to the high inter-month variability. There was one major algal bloom at BMC-AP1 in November and two major blooms at BMC-AP3 (96 and 148 µg/L, respectively) in October and November, possibly a result of storm-driven nutrients into the pond. There were no statistically-significant changes in most nutrient concentrations between entering and exiting the pond, but ammonium did show a significant decrease (Table 4.1).

Lower Burnt Mill Creek: The Princess Place location (BMC-PP) was the only lower creek station sampled in 2018. One parameter that is key to aquatic life health is dissolved oxygen. Dissolved oxygen at BMC-PP was substandard on four of six sampling occasions, a considerable decrease from 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 2018 this level was not approached at BC-PP.

In 2018 there were two major algal blooms at BMC-PP (47 and 100 µg/L, January and May, respectively) 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 15 and mean ratios were 14. 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 83% of sampling occasions at BMC-PP, same as at BMC-AP1. Whereas geometric mean fecal coliform counts at BMC-ASP3 were around 100 CFU/100 mL, counts then increased along the passage to the Princess Place location (geometric mean 427 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, 2018

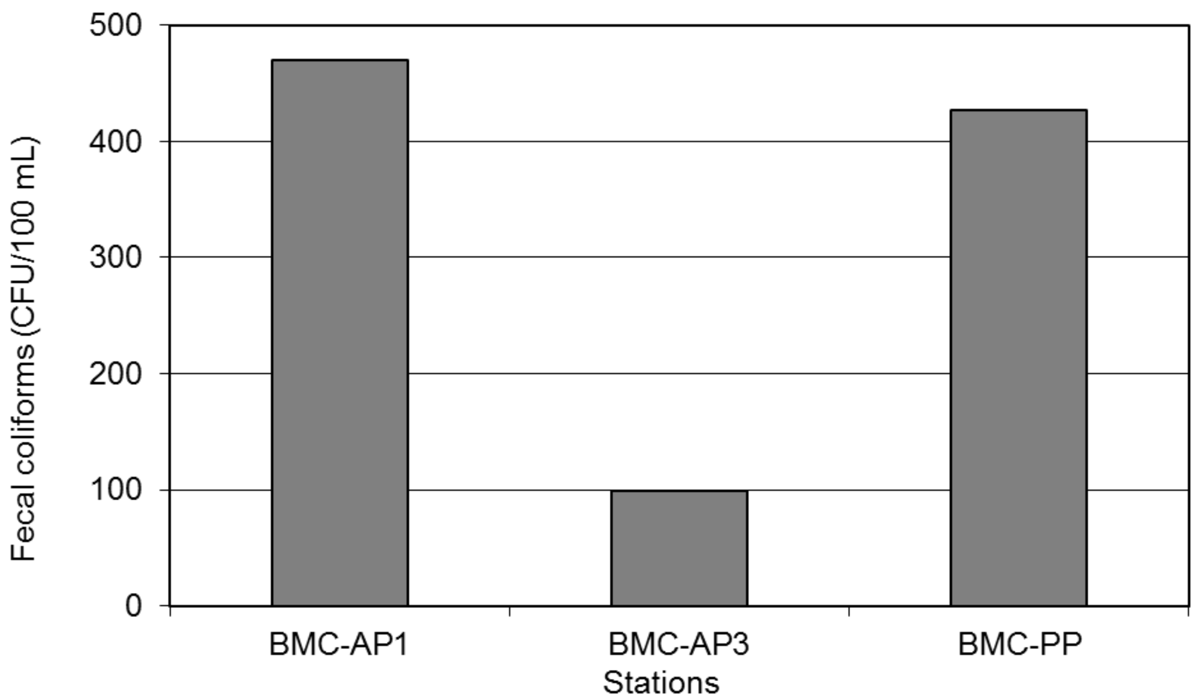


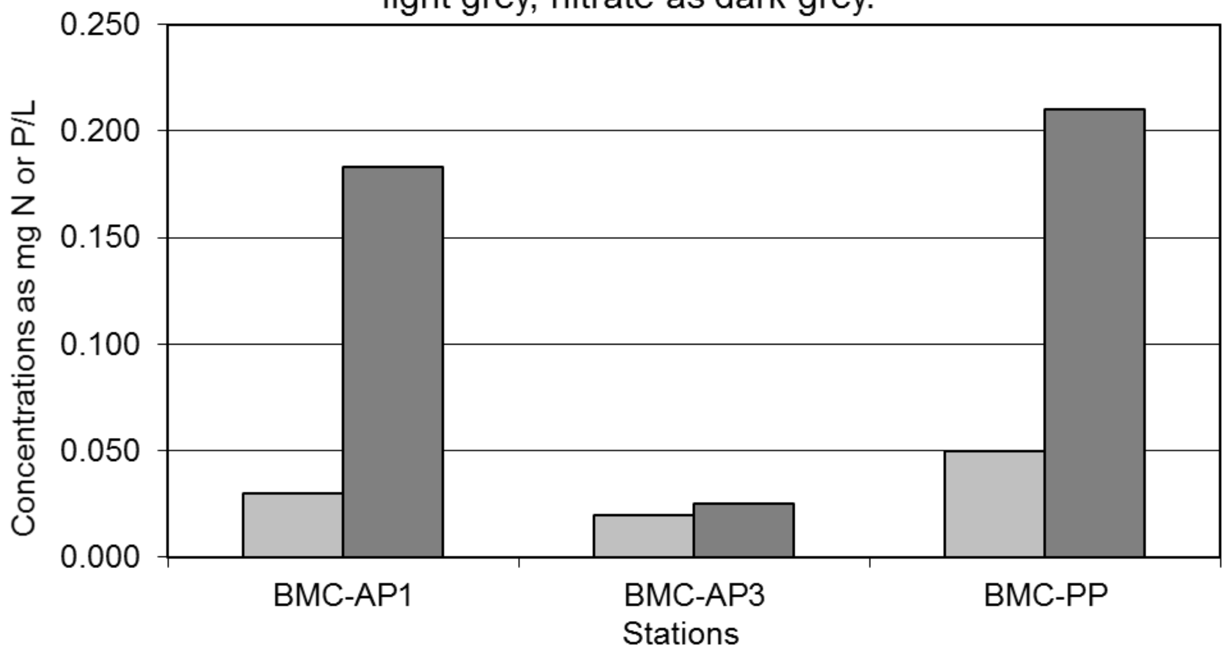
Table 4.1. Water quality data in Burnt Mill Creek, 2018, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as mean/median, n = 6 samples collected.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	7.1 (2.3) 5.5-11.4	10.6 (2.8)** 7.1-14.4	5.0 (2.7) 1.8-8.5
Cond. (μS/cm)	250 (40) 169-274	231 (24) 189-260	311 (57) 199-346
pH	7.0 (0.2) 6.8-7.4	7.6 (0.3)** 7.2-8.0	7.2 (0.1) 7.1-7.4
Turbidity (NTU)	5 (6) 2-18	5 (2) 2-8	4 (6) 0-16
TSS (mg/L)	6.4 (5.7) 1.3-16.7	6.4 (1.9) 4.2-9.1	4.3 (3.8) 1.3-10.5
Nitrate (mg/L)	0.183 (0.058) 0.110-0.280	0.025 (0.020) 0.010-0.060	0.210 (0.067) 0.120-0.310
Ammonium (mg/L)	0.135 (0.045) 0.080-0.180	0.030 (0.020) 0.010-0.060	0.108 (0.046) 0.020-0.150
TN (mg/L)	0.983 (0.915) 0.190-2.780	0.770 (0.861) 0.130-2.500	0.577 (0.165) 0.250-0.710
OrthoPhos. (mg/L)	0.030 (0.014) 0.010-0.050	0.020 (0.006) 0.010-0.030	0.050 (0.009) 0.040-0.060
TP (mg/L)	0.055 (0.035) 0.010-0.110	0.053 (0.036) 0.010-0.100	0.077 (0.053) 0.010-0.150
N/P molar ratio	32.9 26.9	6.4 6.6	14.6 13.7
Chlor. *a* (μg/L)	17 (31) 1-80	54 (56)* 9-148	34 (36) 1-100
FC (CFU/100 mL)	470 100-1,850	99 10-1,270	427 64-1,460

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

To summarize, in some years, including 2018, 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 2018 (as well as in upper stations). The N/P ratios in the lower creek indicate that inputs of phosphorus were likely to stimulate algal bloom formation in 2018, but such ratios have differed in previous years. It is notable that nutrient concentrations increased by 2-10X 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.

Figure 4.3. Average orthophosphate and nitrate concentrations by station for Burnt Mill Creek, 2018; OP as light grey, nitrate as dark grey.

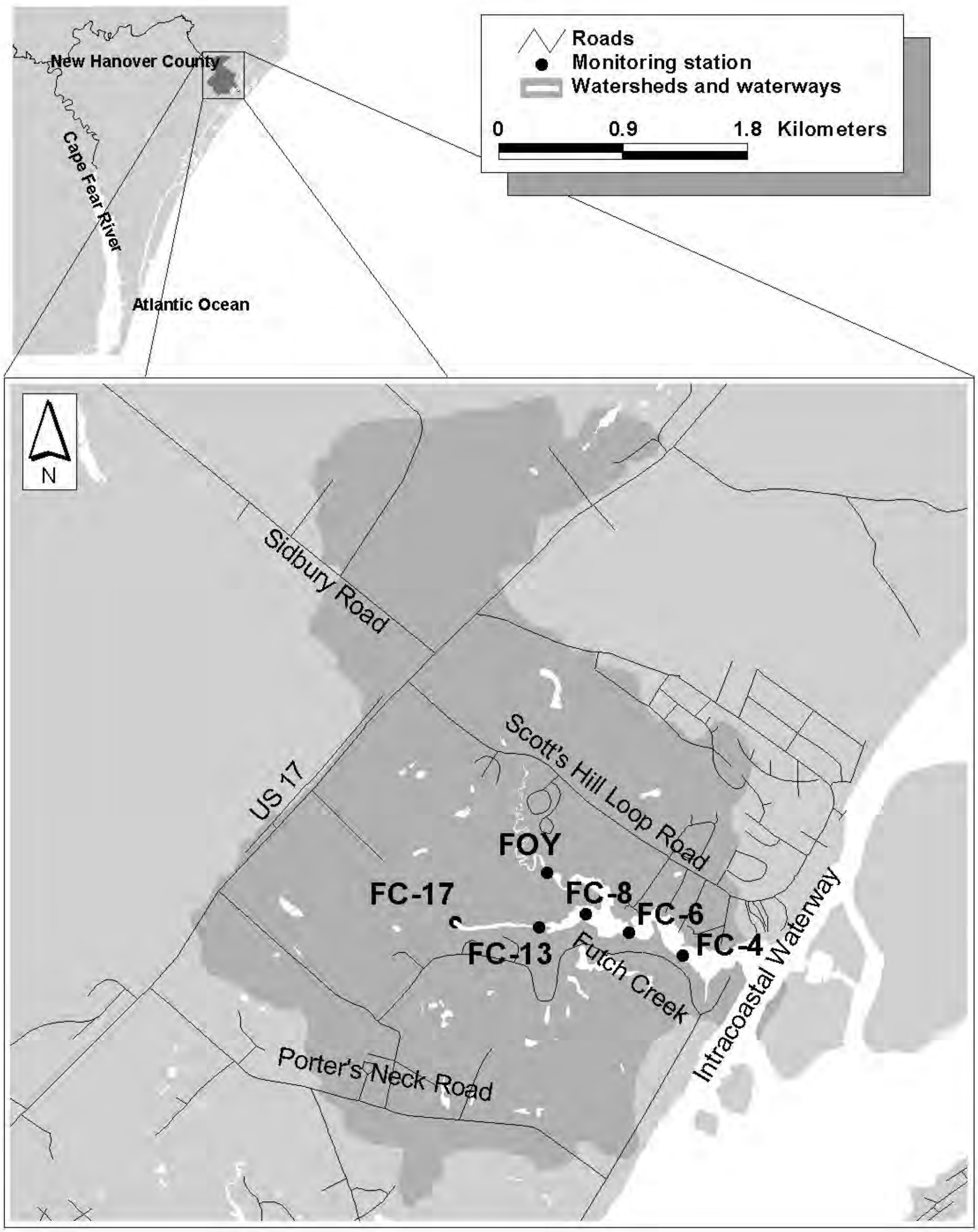


5.0 Futch Creek

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 2018. 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 2018 (Table 6.1, Fig. 6.1). Two tributary sites suffered from severe hypoxia, as GL-LB (creek at Lake Branch Drive, called Squash Branch) and GL-JRB (Jumping Run Branch) showed dissolved oxygen concentrations below the state standard (DO < 5.0 mg/L) on 50% of sampling occasions or more (Table 6.1; Appendix B). Station GL-LC (Clay Bottom Branch) 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 were high in several 2018 samples in conjunction with algal blooms impacting some of the stations (Table 6.1).

Nitrate, ammonium and TN concentrations were highest at GL-LB (Squash Branch), followed by GL-JRB (Table 6.1). Highest phosphorus concentrations occurred at GL-LB (Squash Branch) as well. We note that both JRB-17 and GL-JRB are downstream of a golf course. Chlorophyll *a* concentrations were high at GL-LC, with blooms exceeding 40 µg/L on three of six occasions in 2018 from a large spring-fall algal bloom of the nitrogen-fixing cyanobacterium *Anabaena*; chlorophyll a concentrations were much lower at the other stream stations. The geometric mean fecal coliform bacteria counts exceeded the state standard at all four tributary stations (Table 6.1). The standard was exceeded on five of six sampling dates at GL-JRB. JRB-17 and GL-LB, and on four occasions at GL-LC.

Table 6.1. Mean and (standard deviation) / range of selected field water quality parameters in tributary stations of Greenfield Lake, 2018. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 6 samples collected.

Parameter	JRB-17	GL-JRB	GL-LB (SQB)	GL-LC (CBB)
DO (mg/L)	6.0 (2.8) 3.5-11.3	5.0 (2.8) 3.5-10.9	4.0 (2.5) 2.3-7.9	8.4 (3.6) 4.8-13.7
Turbidity (NTU)	4 (2) 3-8	3 (3) 1-9	6 (7) 2-21	10 (12) 0-30
TSS (mg/L)	4.5 (1.4) 2.7-6.8	2.6 (1.0) 1.3-3.5	7.6 (6.5) 1.3-17.1	19.7 (21.2) 1.3-51.0
Nitrate (mg/L)	0.13 (0.05) 0.07-0.18	0.24 (0.09) 0.10-0.37	0.37 (0.12) 0.15-0.49	0.09 (0.11) 0.01-0.28
Ammon. (mg/L)	0.11 (0.04) 0.05-0.15	0.07 (0.03) 0.02-0.11	0.24 (0.18) 0.05-0.57	0.04 (0.05) 0.01-0.13
TN (mg/L)	0.99 (0.94) 0.28-2.87	0.65 (0.24) 0.26-0.87	1.11 (0.28) 0.85-1.59	0.95 (0.89) 0.20-2.70
Ortho-P. (mg/L)	0.04 (0.01) 0.02-0.05	0.04 (0.01) 0.02-0.06	0.08 (0.04) 0.03-0.15	0.04 (0.01) 0.03-0.07
TP (mg/L)	0.06 (0.04) 0.01-0.10	0.06 (0.04) 0.01-0.14	0.13 (0.07) 0.02-0.24	0.13 (0.17) 0.01-0.46
Inorganic N/P ratio	16.1 15.9	18.0 16.5	21.2 20.1	6.9 2.5
Chlor. *a* (μg/L)	14 (13) 3-38	9 (8) 2-22	7 (8) 0-19	53 (79) 2-210
FC (CFU/100 mL)	379 181-1,270	378 172-682	1,124 190-2,700	529 28-29,000

Three in-lake stations were sampled (Figure 6.1). Station GL-2340 represents an area receiving an influx of urban/suburban runoff (but buffered by wetlands), 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 2018 (see also Section 6.1). Turbidity was at or below the state standard on all sampling occasions, but suspended solids were elevated in May, concurrent with the onset of a blue-green alga bloom of *Anabaena*. In-lake fecal coliform concentrations were very high at GL-2340, exceeding the state standard on four of six occasions, but not problematic at the other two lake sites.

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); the lower two lake stations had very low nitrate, meaning it was rapidly taken up by the algal blooms. 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 in the lake (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). Our previous bioassay experiments indicated that nitrogen was usually the stimulatory nutrient in this lake (Mallin et al. 1999; 2016).

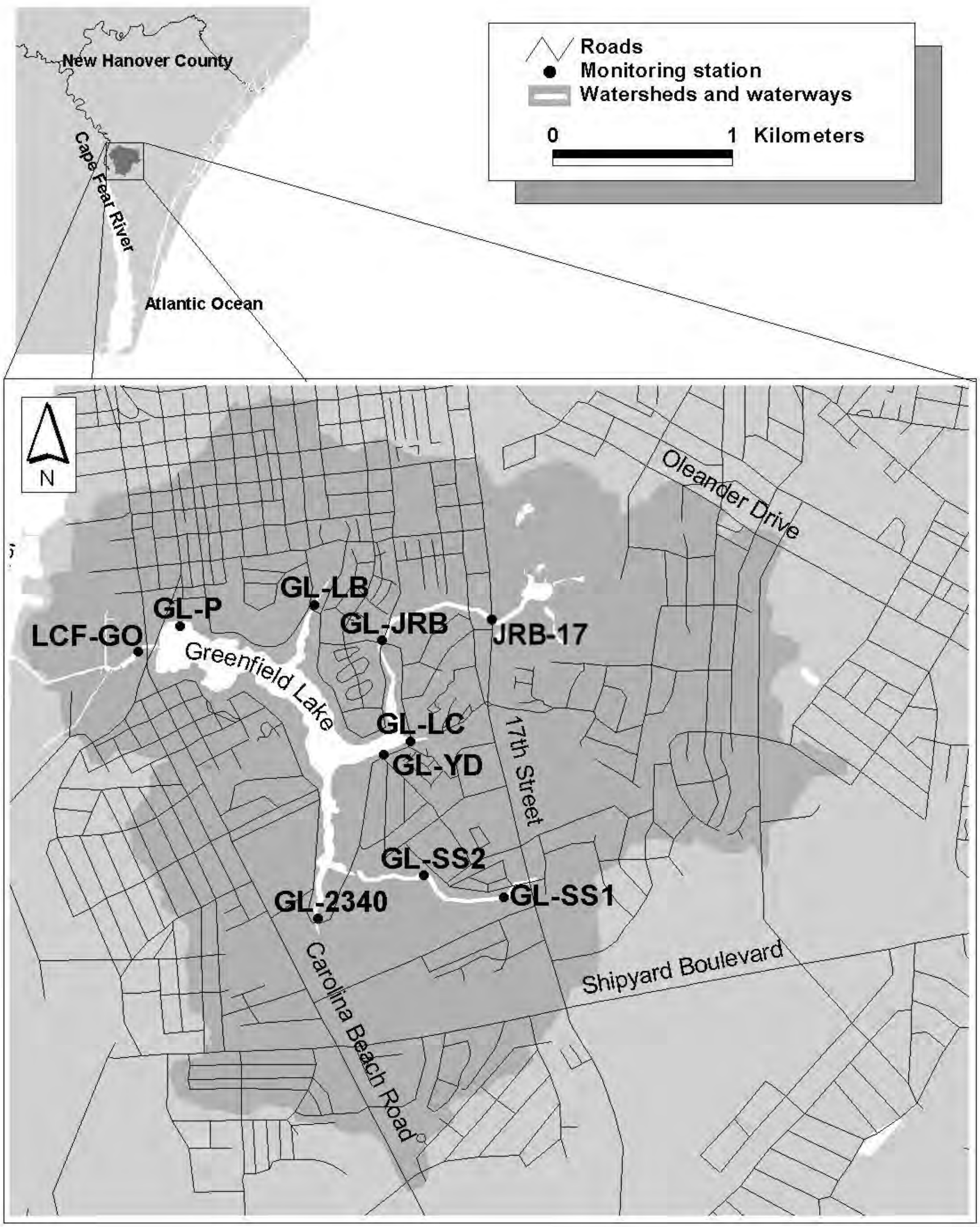
Phytoplankton blooms are problematic in Greenfield Lake (Table 6.2), and usually consist of green or blue-green algal species, or both together. These blooms have occurred during all seasons, but are primarily a problem in spring and summer. In 2018 an extensive bloom of the blue-green *Anabaena spiroides* began in May and lasted for months (see cover photograph); additionally, more blooms occurred following Hurricane Florence in fall. As such, four blooms exceeding the North Carolina water quality standard of 40 μg/L of chlorophyll *a* occurred at GL-YD and two occurred at GL-2340, and one occurred at GL-P with the largest bloom (401 μg/L) occurring at GL-2340. 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 2018 was high, especially at GL-2340 (average = 12.5 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 TP and chlorophyll a concentrations within this lake put it in the eutrophic category for 2018. 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, 2018. 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)	8.0 (2.0) 5.2-10.2	9.8 (3.5) 5.1-15.4	9.9 (4.6) 5.9-16.9
Turbidity (NTU)	11 (12) 1-29	10 (20) 0-50	4 (7) 0-18
TSS (mg/L)	14.4 (12.7) 2.8-35.9	15.4 (20.2) 3.4-45.6	5.4 (5.1) 1.3-13.0
Nitrate (mg/L)	0.16 (0.14) 0.03-0.36	0.03 (0.03) 0.01-0.09	0.02 (0.01) 0.01-0.04
Ammonium (mg/L)	0.06 (0.08) 0.01-0.22	0.02 (0.17) 0.01-0.05	0.01 (0.01) 0.01-0.03
TN (mg/L)	1.10 (0.66) 0.43-2.28	0.52 (0.12) 0.30-0.60	0.62 (0.35) 0.20-1.20
Orthophosphate (mg/L)	0.04 (0.02) 0.03-0.07	0.03(0.01) 0.02-0.05	0.04 (0.02) 0.01-0.05
TP (mg/L)	0.14 (0.09) 0.03-0.23	0.08 (0.05) 0.01-0.16	0.08 (0.06) 0.02-0.18
N/P molar ratio	14.0 9.3	4.5 2.2	2.2 2.0
Fec. col. (CFU/100 mL)	416 10-59,000	31 5-163	23 5-570
Chlor. *a* (µg/L)	101 (157) 1-401	99 (136) 5-368	63 (114) 4-296
BOD5	8.7 (9.1) 1.0-25.0	6.5 (7.7) 2.0-22.0	3.8 (3.5) 1.0-10.0

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). Since then herbicides and algicides were added by city crews and contractors, and on several occasions grass carp were added to control aquatic weeds by grazing. 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.

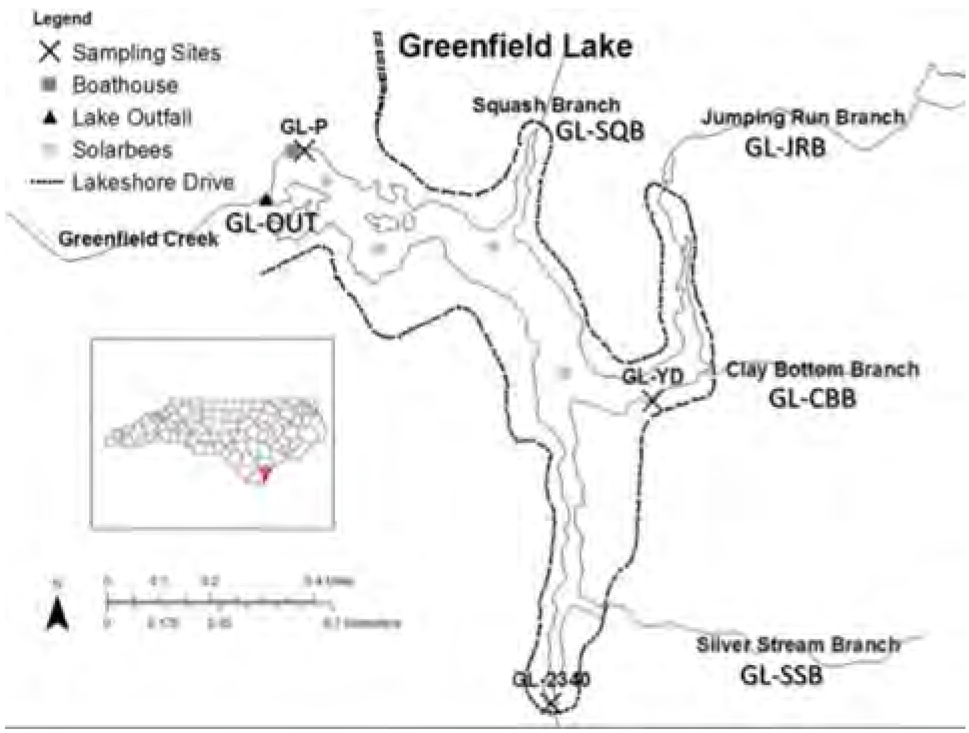
Since the various treatments (artificial circulation, grass carp additions, herbicide use) the lake's water quality has changed, in some ways improving and in some ways deteriorating. The results of a multi-year study were reported in a previous report (Mallin et al. 2015) and in a subsequent peer-reviewed 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.

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

UNCW graduate student Nick Iraola performed a year-long study (July 2016 – June 2017) to quantify the amount of nutrients that are added by the five perennial streams that feed Greenfield Lake (Iraola 2018). 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 during rainy and dry periods.

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 results were detailed in the 2017 report and showed that nutrient concentrations 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 (Iraola 2018). Orthophosphate-P concentrations were highest in GL-JRB and GL-SQB, but were fairly comparable to the other streams.

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

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 6.3). 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.

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).

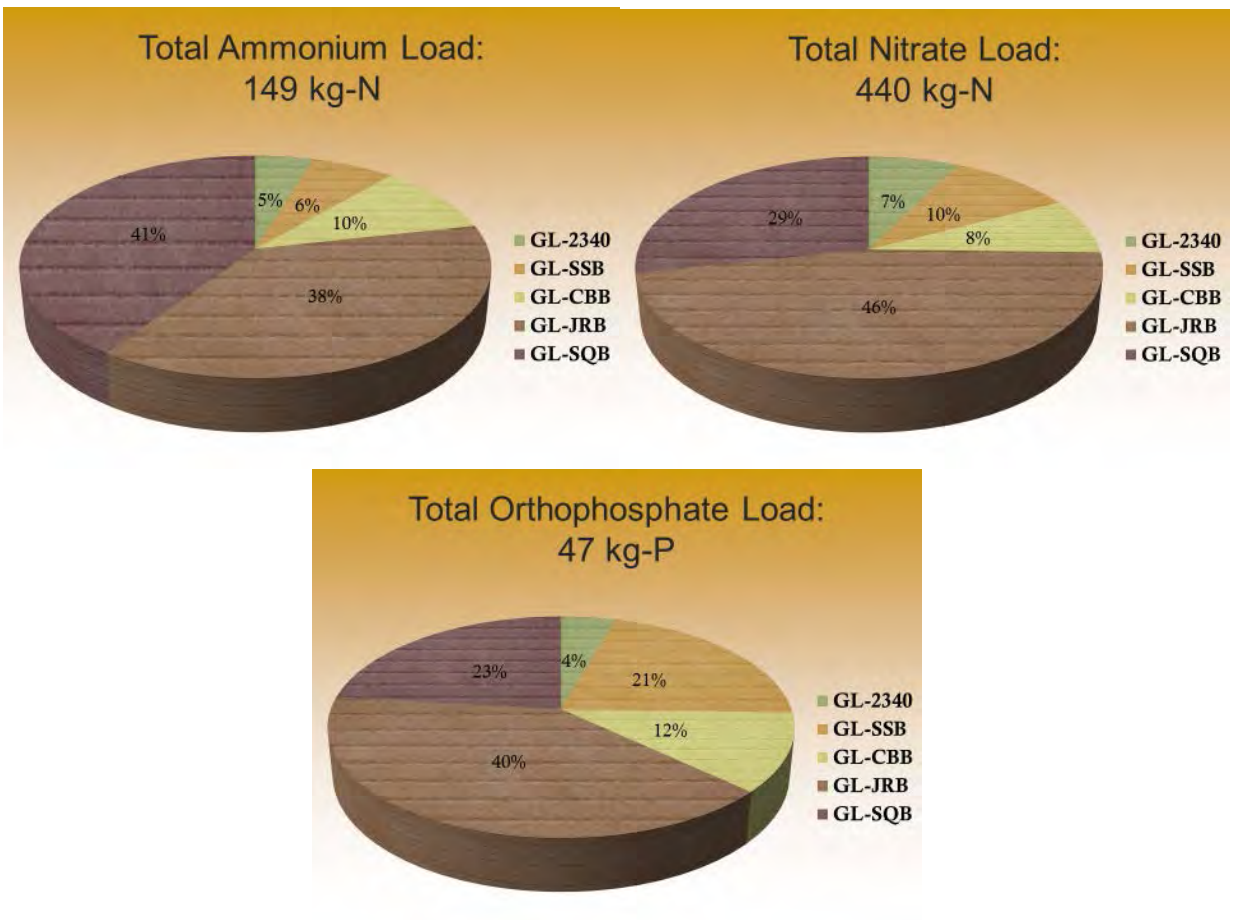


Figure 6.3. Annual wet + dry period inorganic N and P loads to Greenfield Lake as percent of total by individual stream, demonstrating how Squash Branch (GL-SQB) and Jumping Run Branch (GL-JRB) should be prioritized for nutrient reduction BMPs.

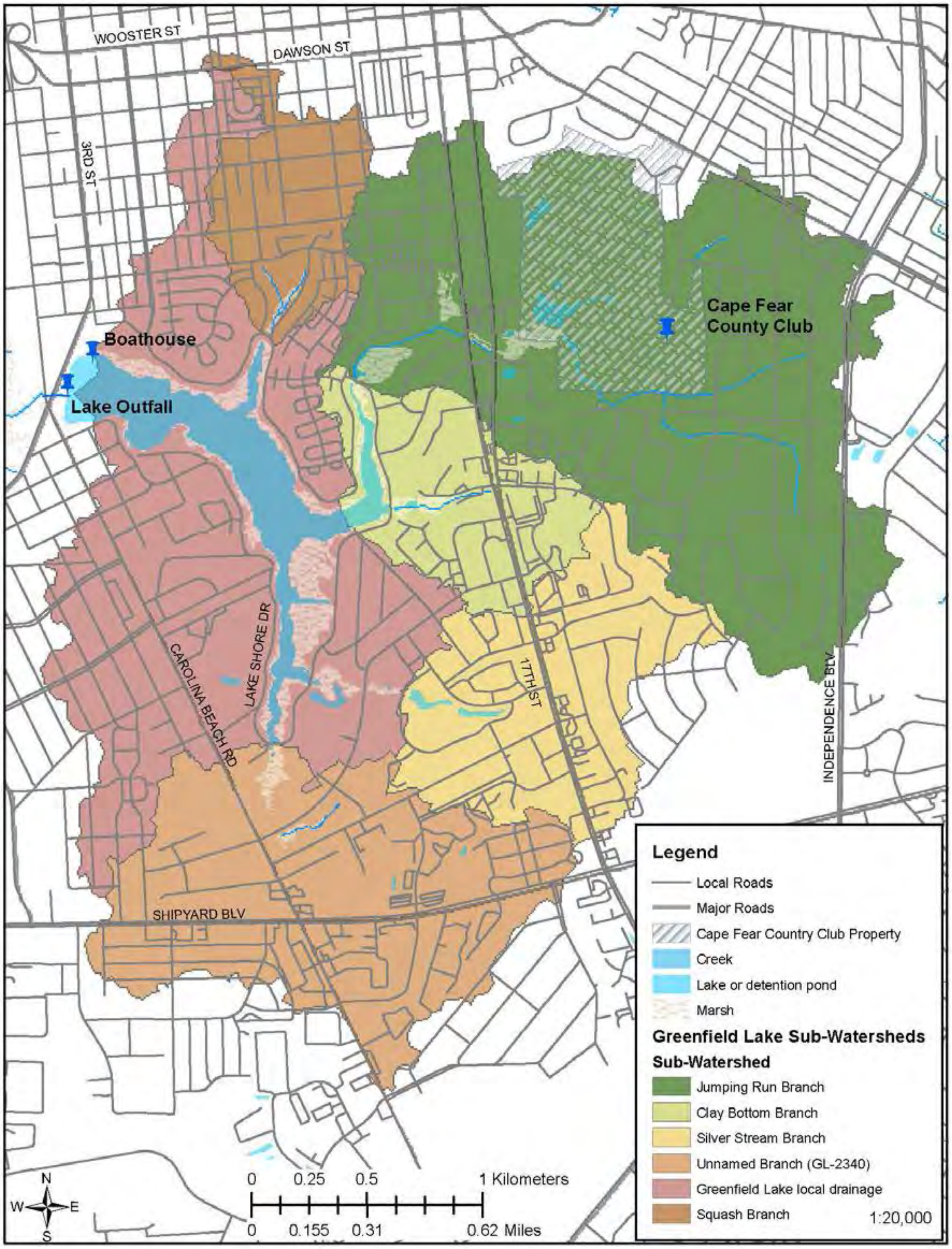


Figure 6.4. Greenfield Lake sub-watersheds; map produced by Saskia Cohick, Wilmington Stormwater Services.

Lake Dissolved Oxygen Profiles

Concurrent with the sediment collections in July 2018, dissolved oxygen profiles at each station were performed 9surface middle, and bottom). A persistent pattern found throughout the lake was near-anoxic water (DO ≤ 0.2 mg/L) in the bottom half-meter or so (Fig. 6.5). Implications of this are that the bottom, in summer, can be inhospitable for many invertebrate and vertebrate species. Furthermore, under anoxic conditions, phosphate can be released from the sediment into the upper water column, further fueling algal blooms.

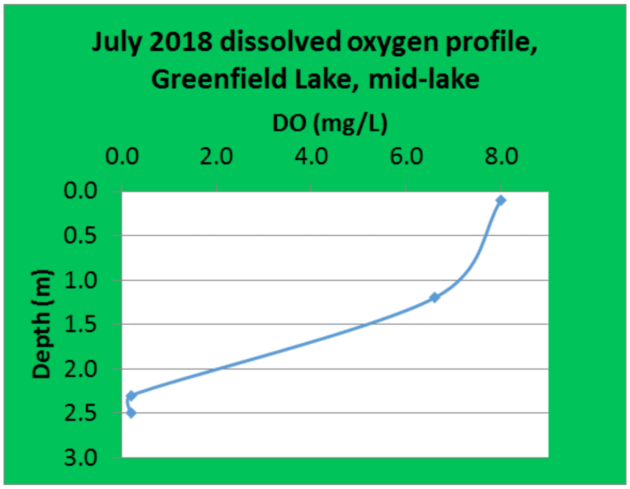


Figure 6.5. Typical mid-lake dissolved oxygen profile, Greenfield Lake, July 2018.

Determining Phosphorus Concentrations in Greenfield Lake Sediments

Bottom sediments collect and hold nutrients, in particular phosphorus. This is important because the type of blue-green algae that blooms most frequently, anabaena, can fix its own nitrogen from the atmosphere as long as it has sufficient phosphorus available. Thus, in July 2018 UNCW researchers sampled 27 bottom sediment sites in Greenfield Lake to determine phosphorus concentrations (see cover photo). The results (Fig. 6.6) demonstrated that sediment phosphorus concentrations were highest in the areas where Squash Branch and Jumping Run Branch entered the lake. Other high-sediment phosphorus areas were associated with the tree islands in the lake. Waterfowl roost in the trees and defecated into the water; additionally, leaves from the trees fall in and decompose, becoming another source of phosphorus. The areas with lowest phosphorus concentrations were located where Silver Stream enters the lake and the un-named branch along Carolina Beach road (GL-2340) enters. Both of those areas have extensive detention ponds and natural wetlands upstream that buffer the nutrient load.

Thus, the phosphorus-rich sediment areas can be targeted for treatment to remove or reduce the phosphorus accumulation. In selected areas, 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.

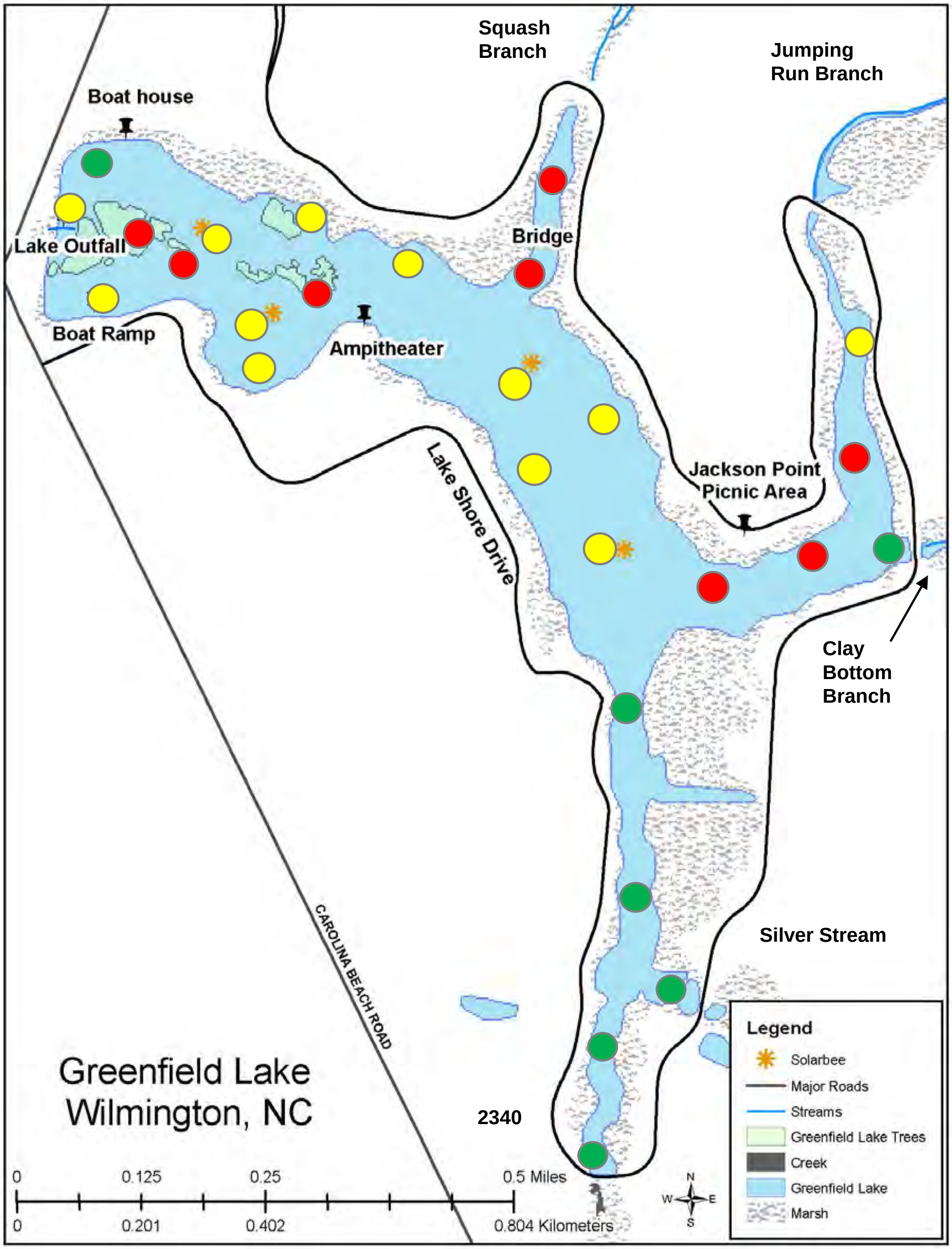


Figure 6.6. Location of sediment sampling points in Greenfield lake, July 2018, and relative sediment phosphorus concentrations (red = high; yellow = moderate, green = low).

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 six 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 a few occasions, with none falling below 4.0 mg/L. Nitrate concentrations were elevated leaving the golf course at PVGC-9 relative to the other stations, (Tables 7.1 and 7.2). From there the next station is MB-PGR, which also receives inputs from the Wilmington Municipal Golf Courses (Fig. 7.1; Mallin and Wheeler 2000). Nitrate was 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 to moderate, as were total phosphorus concentrations. The N/P ratios were high 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 two major blooms occurred at the uppermost station PVGC-9 and one at the south branch SB-PGR; the other stations were free of algal blooms in 2018. Fewer blooms have occurred in the past few years than had previously occurred in upper Hewletts Creek (Mallin et al. 1998a; 2004; 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 100% of the time at MB-PGR and 100% of the time at NB-GLR, 83% of the time at PVGC-9, and 67% 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 53 CFU/100 mL (although above the shellfishing standard of 14 CFU/100 mL).

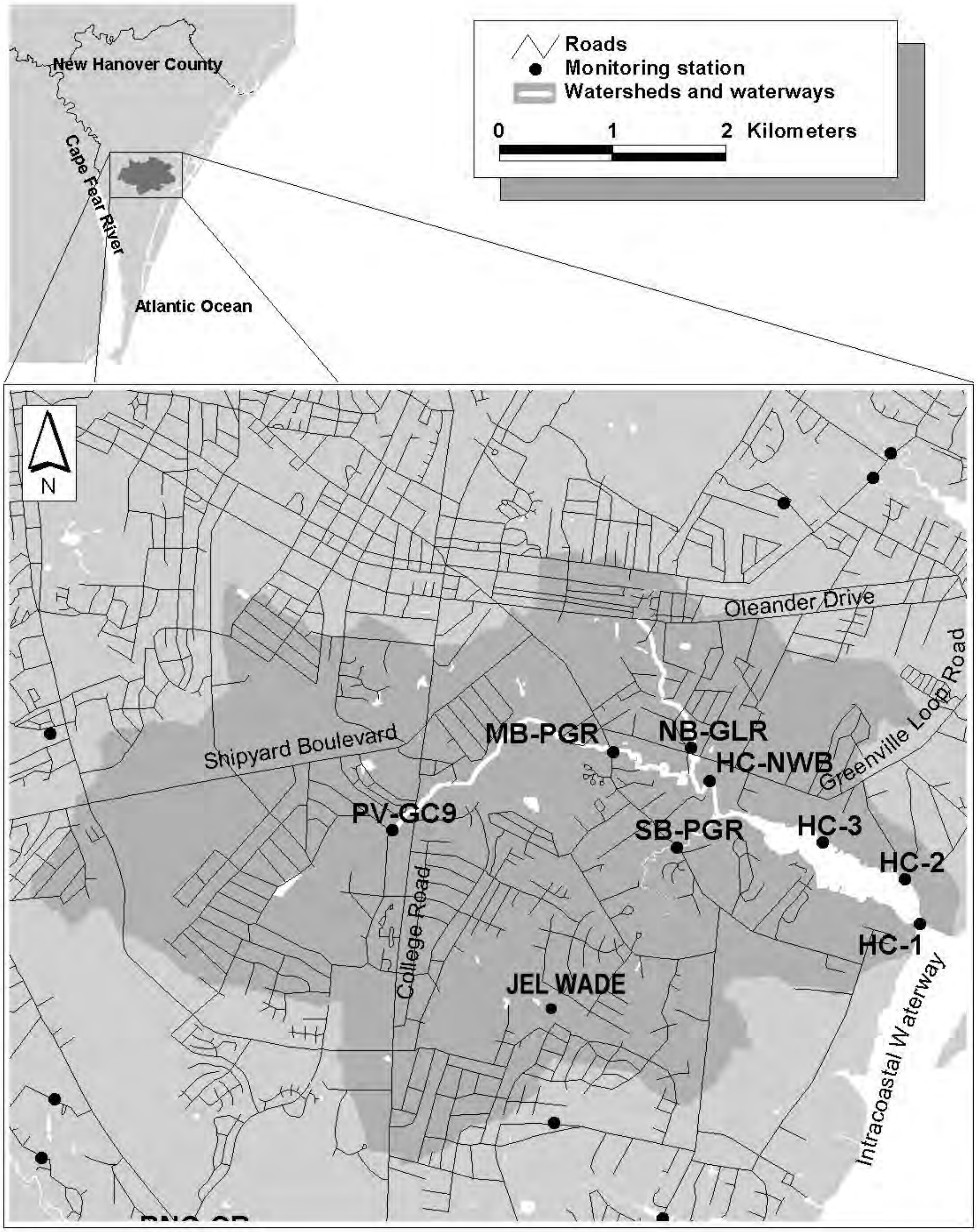


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Figure 7.1. Hewletts Creek watershed.

Table 7.1. Selected water quality parameters at upper and middle creek stations in Hewletts Creek watershed 2018 as mean (standard deviation) / range, N/P ratios as mean / median, fecal coliform bacteria presented as geometric mean / range, n = 6 samples collected.

Parameter	PVGC-9	MB-PGR
Salinity (ppt)	0.1 (0) 0.1-0.1	0.8 (1.3) 0.1- 3.4
Turbidity (NTU)	3 (1) 2-4	4 (2) 2-7
TSS (mg/L)	2.8 (1.2) 1.3-4.4	3.5 (1.3) 1.8-5.3
DO (mg/L)	6.8 (1.2) 5.3-8.0	6.7 (1.3) 4.6-7.9
Nitrate (mg/L)	0.405 (0.076) 0.280-0.490	0.290 (0.060) 0.220-0.360
Ammonium (mg/L)	0.058 (0.043) 0.010-0.110	0.033 (0.044) 0.010-0.120
TN (mg/L)	1.338 (0.764) 0.940-2.890	0.673 (0.225) 0.250-0.860
Orthophosphate (mg/L)	0.168 (0.329) 0.030-0.840	0.147 (0.191) 0.020-0.740
TP (mg/L)	0.187 (0.128) 0.030-0.400	0.100 (0.051) 0.030-0.150
N/P	26.2 30.3	21.5 22.0
Chlorophyll *a* (µg/L)	29 (34) 3-91	8 (7) 1-18
Fecal col. (CFU/100 mL)	779 181-2,450	828 330-2,800

Table 7.2. Selected water quality parameters at stations in Hewletts Creek watershed, 2018, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 6 samples collected.

Parameter	NB-GLR	SB-PGR	HC-3
Salinity (ppt)	10.7 (10.0) 0.4-21.2	19.0 (10.5) 5.5-28.1	28.6 (4.1) 21.8-33.6
Turbidity (NTU)	4 (1) 3-6	5 (2) 3-7	4 (0) 4-5
TSS (mg/L)	9.0 (2.2) 5.7-11.3	12.3 (2.4) 8.7-15.0	15.8 (4.1) 12.7-23.8
DO (mg/L)	6.6 (2.1) 4.6-9.8	6.0 (1.4) 4.4-7.8	6.8 (1.6) 5.1-9.3
Nitrate (mg/L)	0.120 (0.046) 0.060-0.190	0.045 (0.041) 0.010-0.120	0.013 (0.008) 0.010-0.030
Ammonium (mg/L)	0.042 (0.049) 0.010-0.110	0.092 (0.132) 0.010-0.340	0.077(0.115) 0.010-0.300
TN (mg/L)	0.570 (0.168) 0.290-0.750	0.575 (0.282) 0.300-0.950	0.538 (0.342) 0.200-1.200
Orthophosphate (mg/L)	0.147 (0.281) 0.020-0.720	0.085 (0.135) 0.020-0.360	0.037 (0.036) 0.020-0.110
TP (mg/L)	0.107 (0.099) 0.030-0.300	0.135 (0.076) 0.030-0.250	0.103 (0.070) 0.030-0.200
Mean N/P ratio Median	9.6 10.2	7.2 4.4	8.2 2.2
Chlor *a* (µg/L)	14 (8) 3-26	15 (18) 3-50	5 (4) 1-10
Fecal coliforms (CFU/100 mL)	1,407 490-11,000	311 37-1,820	53 10-290

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.

When we have a non-hurricane year we can begin inter-year data comparisons to assess the wetland’s 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 2018 (HW-GP and HW-DT- Fig. 8.1). Salinity levels were mesohaline in the mid-creek station HW-GP and oligohaline in the upper creek station HW-DT. Turbidity was generally low except for very high concentrations (100 NTU+) in June at both sites, well above the North Carolina water quality standard of 25 NTU (Table 8.1; Appendix B). Suspended solids were generally low to moderate (< 17 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 2018 (Appendix B).

Nitrate and ammonium concentrations were both low at both sites in 2018 (Table 8.1). Orthophosphate was also low at the two sites. Mean and median inorganic molar N/P ratios were low (below 11.0), 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 2018 at HW-DT on two of four occasions in 2018, and came close to doing so on a third occasion. The relatively high chlorophyll concentrations in June (31-38 µg/L) may have contributed to the high turbidity that month. A truly dense algal bloom (chlorophyll *a* of 304 µg/L) occurred in late October, possibly driven by nutrient inputs from hurricane runoff.

After wetland enhancement was performed in 1998 above Graham Pond on Landfall Property, for about a 15-year period the creek below the pond at HW-GP has had fewer and smaller algal blooms than before the enhancement. However, 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 three of four occasions, and on one of four occasions at HW-GP for Poor and Fair ratings, respectively. In 2018 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 period (Table 8.1; Fig. 8.3).

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

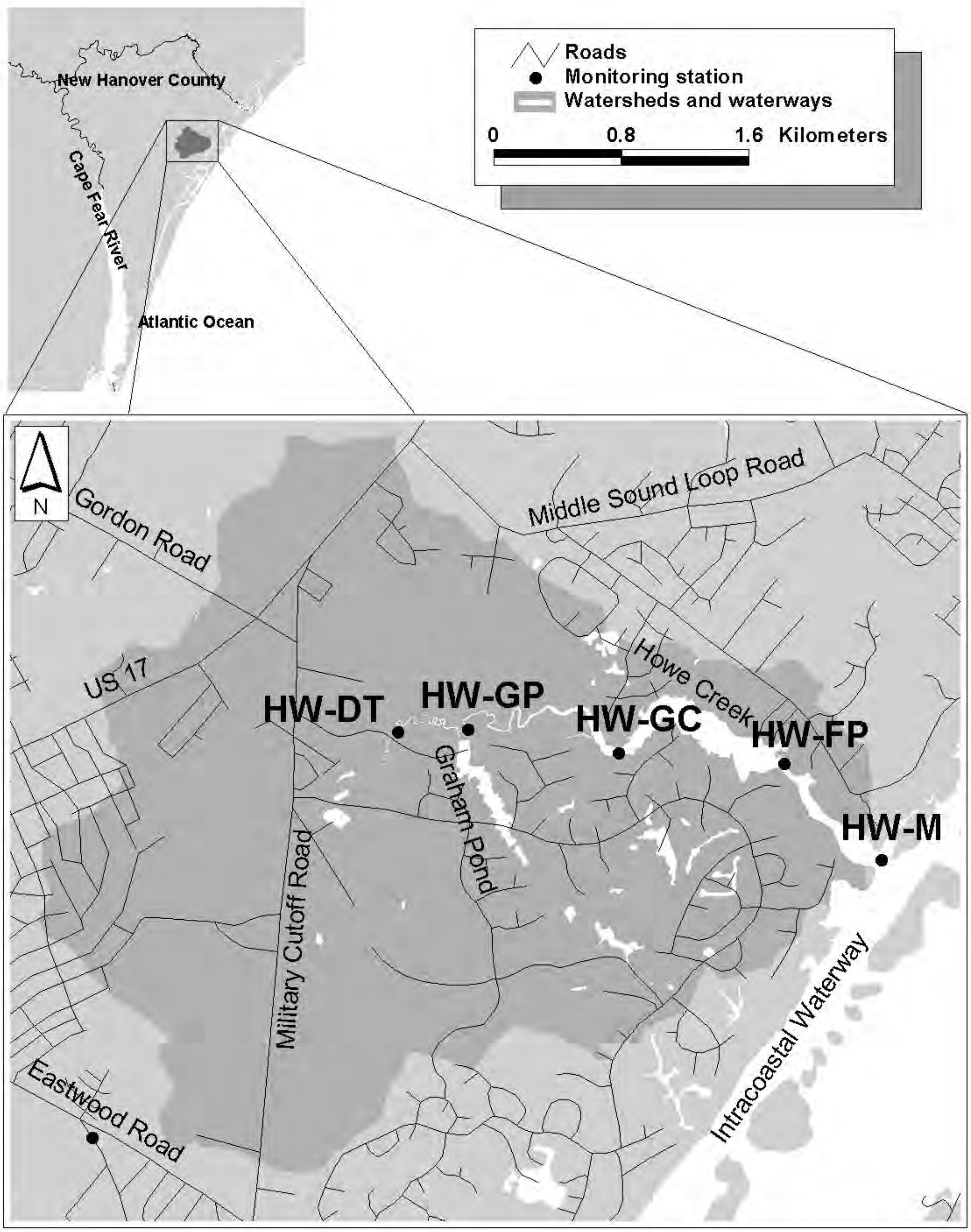


Table 8.1. Water quality summary statistics for Howe Creek, 2018, as mean (st. dev.) / range. Fecal coliform bacteria as geometric mean / range, n = 4 samples collected.

Parameter	HW-DT	HW-GP
Salinity (ppt)	3.2(3.2) 0.3-6.2	17.0(11.2) 2.2-28.8
Dissolved oxygen (mg/L)	8.3(1.2) 7.4-10.0	8.3(2.0) 6.6-11.2
Turbidity (NTU)	31(50) 4-105	30(52) 3-108
TSS (mg/L)	10.6(5.0) 4.2-16.2	8.7(3.7) 3.4-12.0
Nitrate (mg/L)	0.078(0.050) 0.010-0.130	0.075(0.111) 0.010-0.240
Ammonium (mg/L)	0.060(0.087) 0.010-0.190	0.023(0.010) 0.010-0.030
Orthophosphate (mg/L)	0.030(0.000) 0.030-0.030	0.028(0.005) 0.020-0.030
Molar N/P ratio (mean / median)	10.1 9.2	7.6 4.4
Chlor *a* (µg/L)	110(135) 4-304	21(18) 3-41
Fecal coliforms (CFU/100 mL)	256 100-500	103 28-290

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

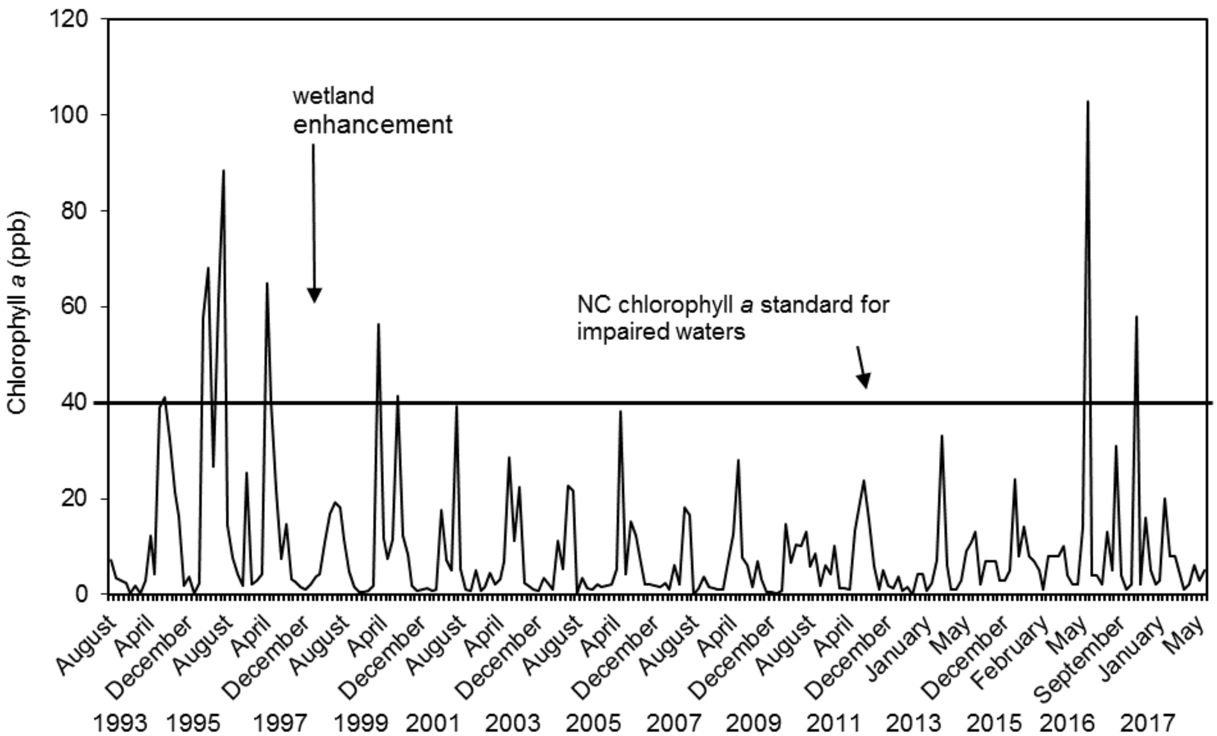
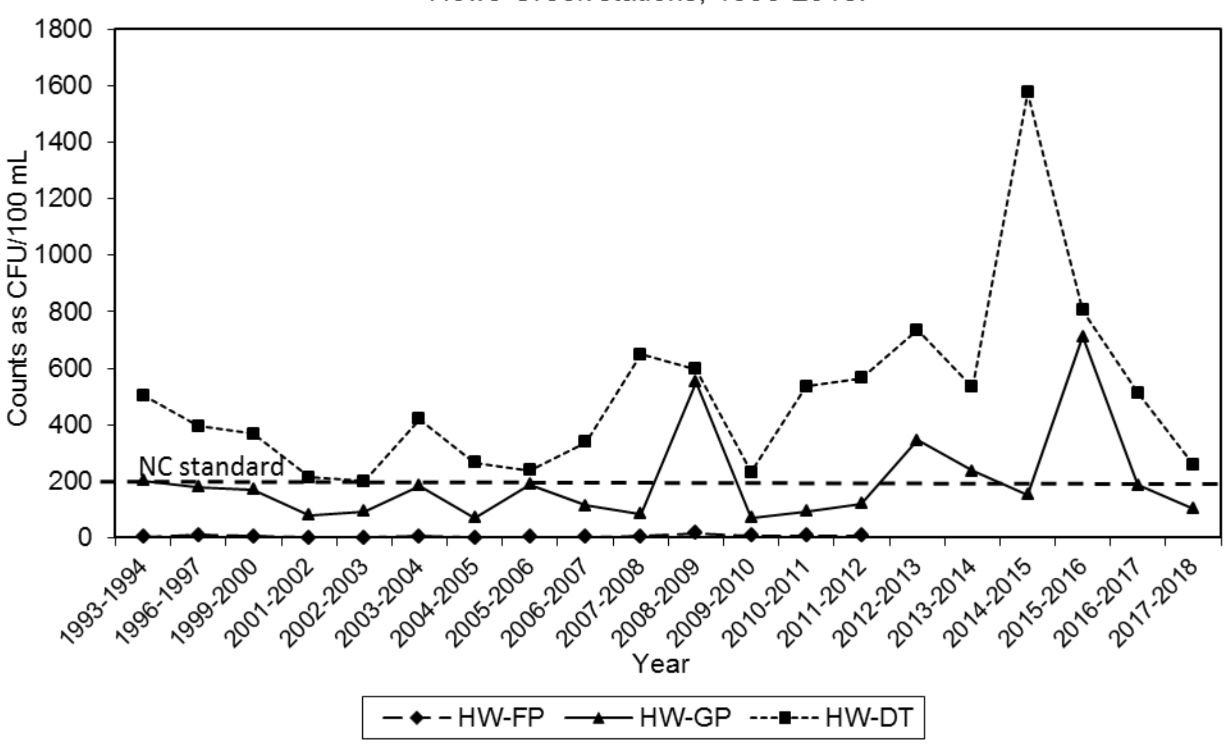


Figure 8.3. Annual fecal coliform counts (as geometric means) over time for Howe Creek stations, 1993-2018.



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

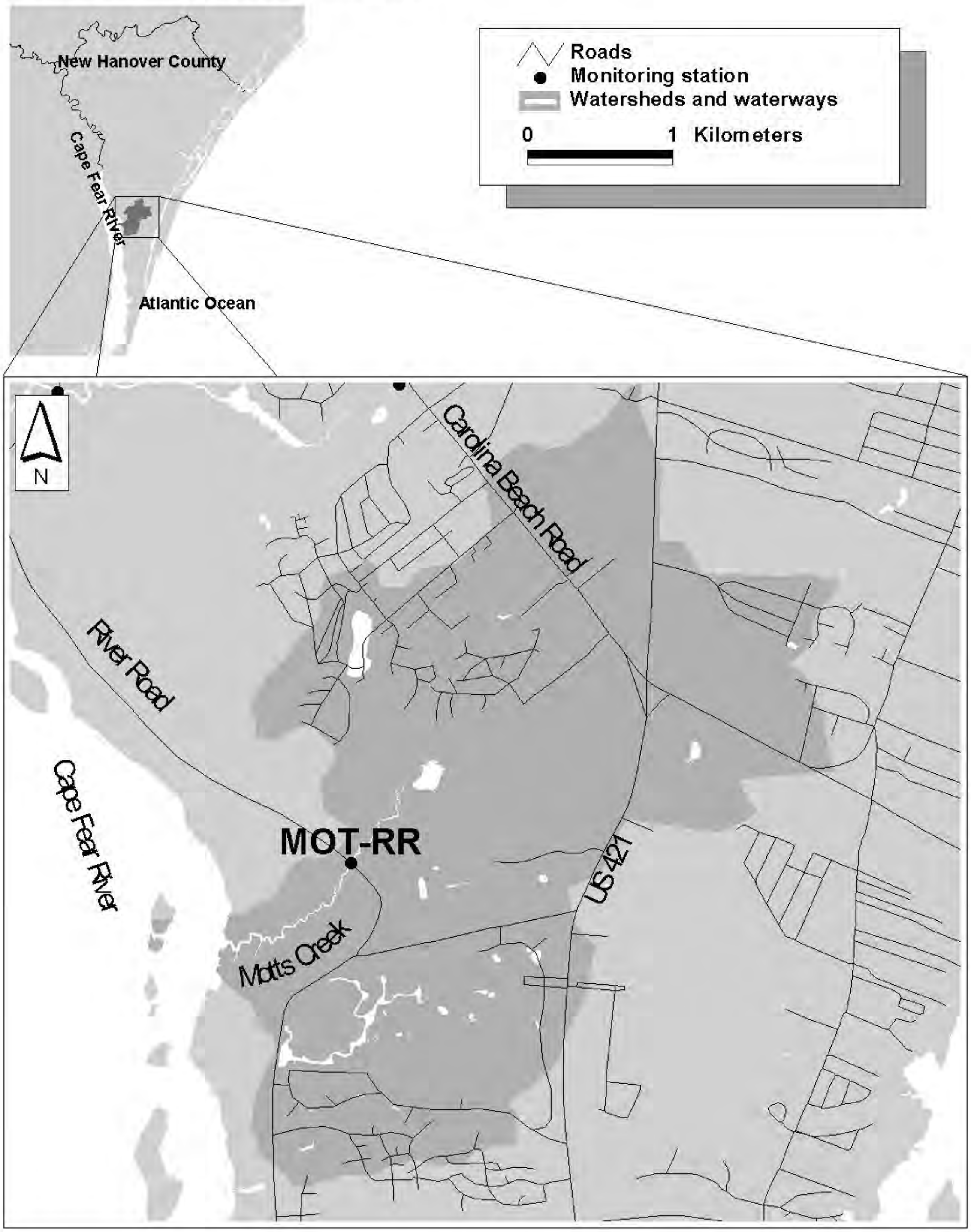
Motts Creek drains into the Cape Fear River Estuary (Fig. 9.1), and the creek area near River Road has been classified by the State of North Carolina as a Natural Heritage Site because of the area's biological attributes. These include the pure stand wetland communities, including a well-developed sawgrass community with large cypress in the swamp forest. City 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.

Motts Creek at this site is considered to be oligohaline, which is, maintaining salinities less than 5 ppt. Dissolved oxygen was generally good, with only one sample of the four dropping below 5.0 mg/L. We caution that we could not sample right after the storm because of logistical restraints, so it may have decreased considerably for some weeks. Turbidity and suspended solids were generally low. Ammonium was low and nitrate concentrations moderate, as were phosphorus concentrations. There was a minor algal blooms (chlorophyll *a* of 23 µg/L) in June, but a major bloom (chlorophyll *a* of 54 µg/L) in late October, possibly due to nutrient inputs from the hurricane. Fecal coliform bacteria were excessive in all sampled months except April.

Table 9.1. Selected water quality parameters in Motts Creek watershed as mean (standard deviation) and range, 2018, n = 4 samples collected.

Parameter	MOT-RR	
	Mean (SD)	Range
Salinity (ppt)	2.5 (1.8)	0.2-4.5
Dissolved oxygen (mg/L)	6.1 (1.5)	4.4-8.0
Turbidity (NTU)	12 (3)	9-16
TSS (mg/L)	13.3 (1.3)	11.8-15.0
Ammonium (mg/L)	0.09 (0.06)	0.01-0.15
Nitrate (mg/L)	0.28 (0.10)	0.20-0.42
TN (mg/L)	0.87 (0.46)	0.20-1.20
Orthophosphate (mg/L)	0.06 (0.01)	0.04-0.07
TP (mg/L)	0.09 (0.03)	0.05-0.12
N/P ratio (mean and median)	14.2	12.3
Chlorophyll *a* (µg/L)	21 (24)	3-54
Fecal col. /100 mL (geomean and range)	330	19-4,100

Figure 9.1 Motts Creeks watershed

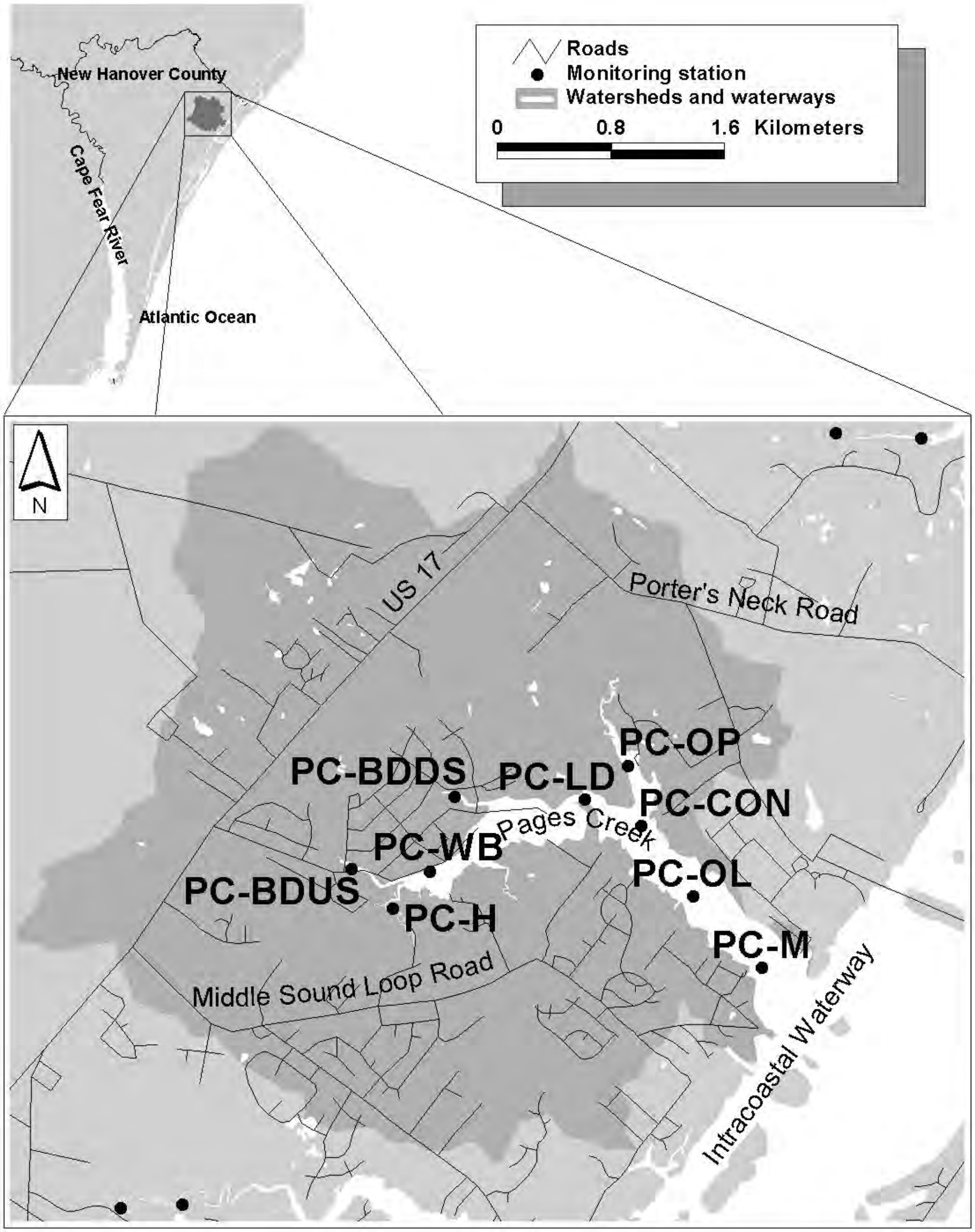


10.0 Pages Creek

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 2018 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).

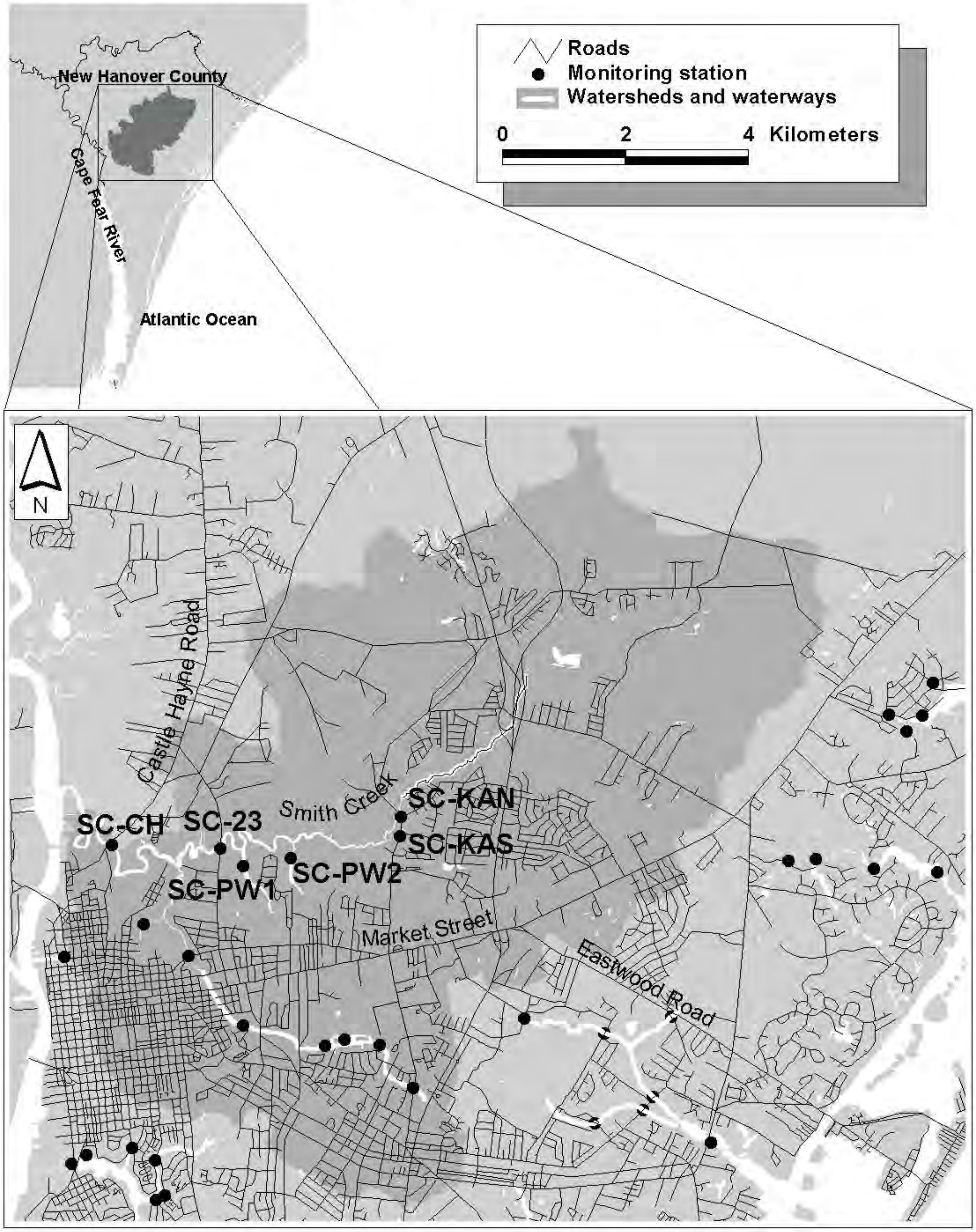
The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters, is 4.0 mg/L, and was violated on three occasions in our 2018 samples for a poor rating. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded in our 2018 samples, and TSS concentrations were not excessive.

Nutrient concentrations were moderate in 2018 (Table 11.1), although elevated in October after the hurricane. There was one minor algal bloom (24.0 µg/L) in October of 2018. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on four of 11 sampling occasions at SC-CH in 2018, for a Poor rating (Table 11.1), although it should be noted that fecal coliform counts in 2018 in general were considerably lower than in 2017.

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range, 2018, n = 11 samples collected.

Parameter	SC-CH	
	Mean (SD)	Range
Salinity (ppt)	0.6 (0.8)	0.1-2.4
Dissolved oxygen (mg/L)	6.4 (3.3)	0.3-10.6
Turbidity (NTU)	8 (3)	4-14
TSS (mg/L)	11.1 (3.4)	5.6-15.8
Ammonium (mg/L)	0.126 (0.093)	0.030-0.380
Nitrate (mg/l)	0.218 (0.105)	0.040-0.380
Orthophosphate (mg/L)	0.030 (0.022)	0.005-0.060
Chlorophyll *a* (µg/L)	6.0 (7.0)	0-24
Fecal col. /100 mL (geomean / range)	127	5-480

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 2018 salinity at this station was relatively high, what scientists consider euhaline, ranging from 21 – 26 ppt and averaging about 24 ppt (Table 12.1).

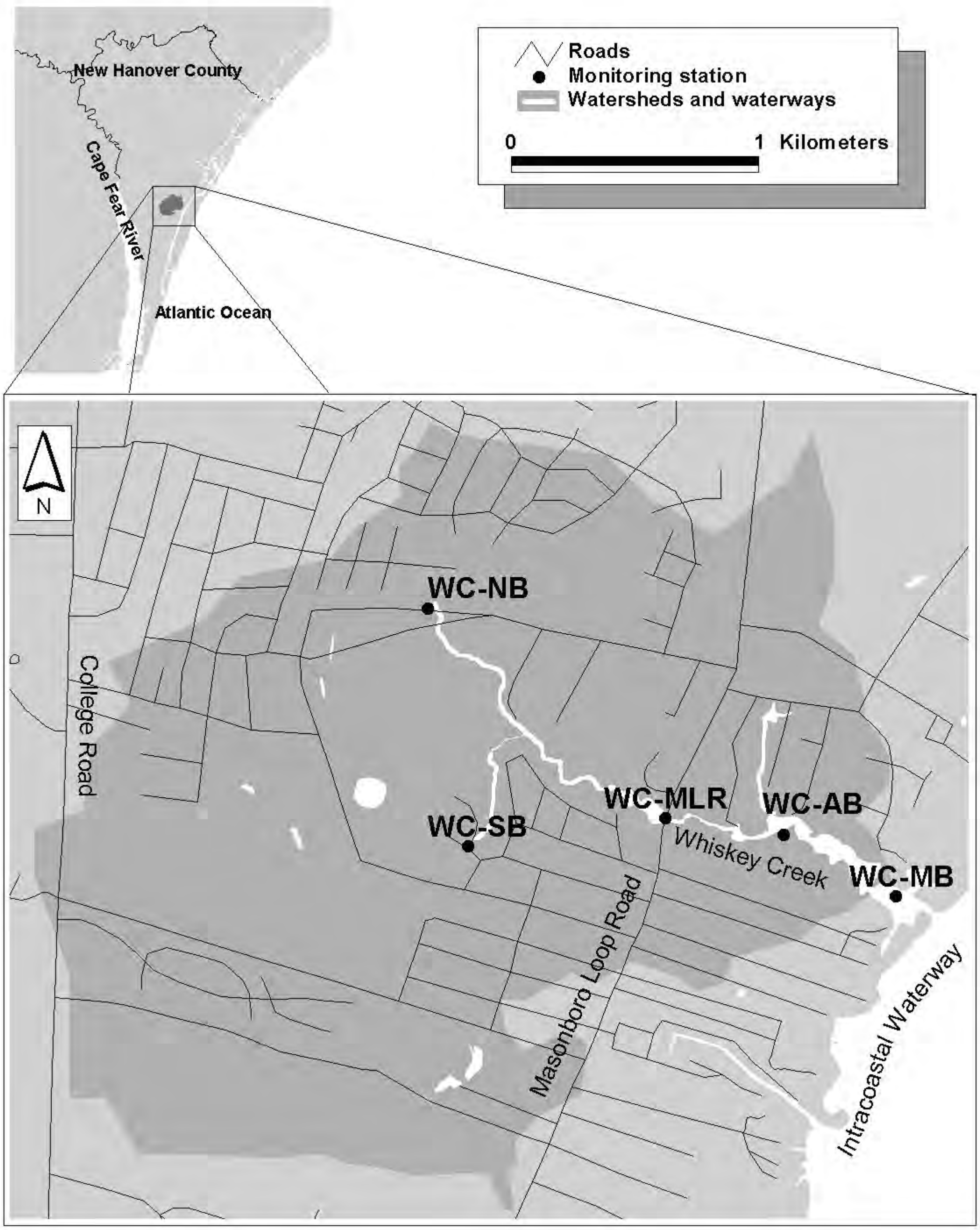
Dissolved oxygen concentrations were below the State standard on one of six sampling occasions at WC-MLR (Table 12.1). Turbidity was within state standards for tidal waters on all sampling occasions (Table 12.1; Appendix B). Suspended solids were moderate in 2018. Algal blooms are rare in this creek and there were no major blooms detected in our 2018 sampling (Table 12.1). Nitrate, ammonium and orthophosphate concentrations were generally low at this station, with some elevated ammonium in October following the hurricane. Total nitrogen was low, and total phosphorus was low except for November, again possibly due to the hurricane. The N/P ratios (Table 12.1) were low, indicating that nitrogen was the factor most limiting to potential algal bloom formation.

In 2018 the standard for fecal coliforms was exceeded on three of six occasions (more than in 2017), with a geometric mean count of 222 CFU/100 mL larger 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.

Table 12.1. Selected water quality parameters in Whiskey Creek watershed as mean (standard deviation) and range, 2018, n = 6 samples collected.

Parameter	WC-MLR	
	Mean (SD)	Range
Salinity (ppt)	23.7 (1.8)	21.3-25.7
Dissolved oxygen (mg/L)	6.2 (2.0)	4.0-8.8
Turbidity (NTU)	5 (1)	4-6
TSS (mg/L)	14.4 (2.9)	10.9-17.7
Ammonium (mg/L)	0.11 (0.12)	0.01-0.34
Nitrate (mg/L)	0.05 (0.04)	0.02-0.12
TN (mg/L)	0.46 (0.24)	0.12-0.74
Orthophosphate (mg/L)	0.10 (0.14)	0.02-0.38
TP (mg/L)	0.14 (0.18)	0.04-0.51
N/P ratio (mean and median)	5.8	4.8
Chlorophyll *a* (µg/L)	12.9 (9.5)	2-23
Fecal col. /100 mL (geomean and range)	222	145-410

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 2018, 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
Barnards Creek	BNC-RR	F	G	G	P
Bradley Creek	BC-CA	G	P	G	P
	BC-SB	G	P	G	P
	BC-NB	G	P	G	P
Burnt Mill Creek	BMC-AP1	F	G	G	P
	BMC-AP3	P	G	G	P
	BMC-PP	P	P	G	P
Greenfield Lake	JRB-17	G	G	G	P
	GL-JRB	G	P	G	P
	GL-LC	P	G	G	P
	GL-LB	G	P	G	P
	GL-2340	P	G	G	P
	GL-YD	P	G	G	G
	GL-P	F	G	G	F
Hewletts Creek	HC-3	G	G	G	G
	NB-GLR	G	P	G	P
	MB-PGR	G	F	G	P
	SB-PGR	F	P	G	P
	PVGC-9	P	G	G	P
Howe Creek	HW-GP	F	G	F	F
	HW-DT	P	G	F	P
Motts Creek	MOT-RR	F	F	G	P
Smith Creek	SC-CH	G	P	G	P
Whiskey Creek	WC-MLR	G	F	G	P

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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