ENVIRONMENTAL QUALITY OF WILMINGTON AND NEW HANOVER COUNTY WATERSHEDS, 2019

by

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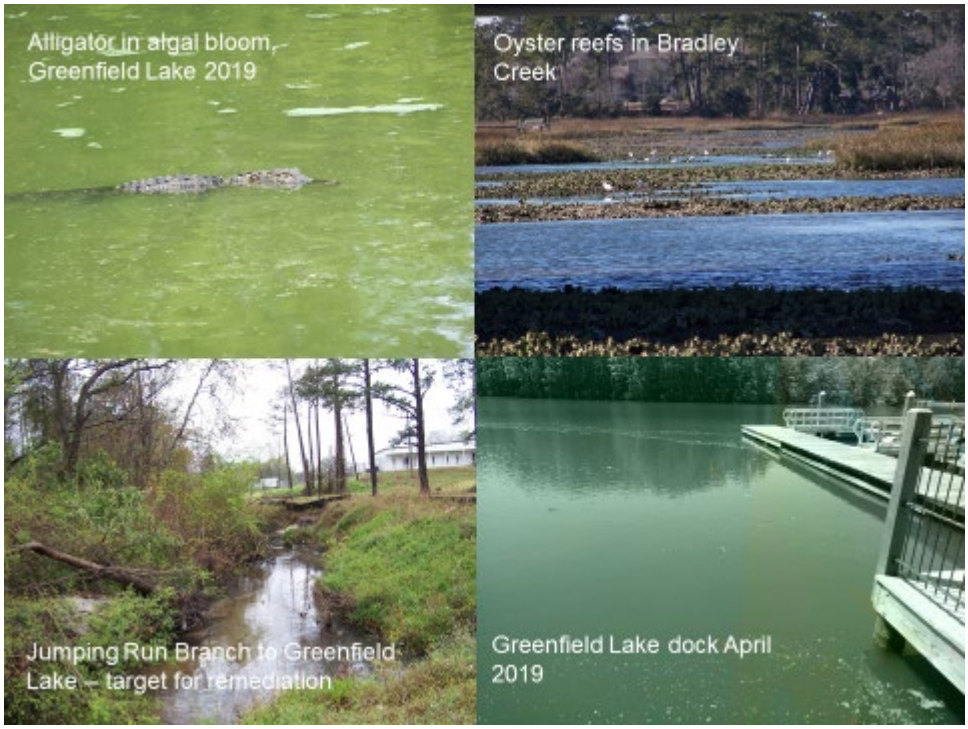

Executive Summary

This report represents results of Year 22 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The 2019 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 July 2019; note that fewer samples were collected at some sites in 2019 because funding did not arrive until 2020.

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. Due to late funding this site was only sampled twice, so limited conclusions can be drawn. Dissolved oxygen was good, and turbidity and suspended solids were generally moderate. Ammonium was low, but nitrate concentrations were relatively high among tidal creeks in this area. There was a minor algal bloom (chlorophyll *a* of 28 µg/L) in May 2019. Fecal coliform bacteria were low on both sampling 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, on two occasions in spring.

Turbidity was not a problem and total suspended solids (TSS) were slightly elevated (about 17 mg/L) in one sample. Dissolved oxygen was within standard (> 5.0 mg/L) on both sampling occasions. Ammonium and nitrate concentrations were low to moderate and highest at the upstream station BC-CA (where the tributary crosses under College Acres Dr.). Total nitrogen concentrations were low to moderate in general and highest at BC-CA. Orthophosphate concentrations were low with highest levels at BC-CA; total phosphorus levels were likewise low in general. Our Bradley Creek stations did not host significant algal blooms during the spring sampling trips in 2019, just a minor bloom of chlorophyll *a* of 21 µg/L at BC-CA in February. Fecal coliform bacteria counts were within standard at BC-NB (north branch of creek at Wrightsville Ave.), exceeded the standard of 200 CFU/100 mL slightly on one trip at BC-SB (south branch of creek at Wrightsville Ave.), and were well over standard on both occasions at BC-CA, with a geometric mean of 1,956 CFU/100 mL, about 10X the NC standard for safe waters.

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 2019, on four occasions. High fecal coliform counts occurred at two sites in 2019, especially at the uppermost site BMC-AP1 above Anne McCrary Pond and at the lowermost station BMC-PP at Princess Place. One major and one minor algal bloom were recorded in 2019 at the Princess Place location. Dissolved oxygen concentrations were good in the two upper stations and fair in the remaining lower creek site. Several water quality parameters showed an increase in pollutant levels along the creek from the exit from the detention pond to the downstream Princess Place sampling station, including fecal

coliform bacteria, nitrogen and phosphorus, indicating non-point pollution sources continue to pollute the lower creek.

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 sample this creek in 2019. 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 on four occasions. Of the 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 stations maintained good oxygen concentrations.

Algal blooms are periodically problematic in Greenfield Lake, and have occurred during all seasons, but are primarily a problem in spring and summer. In 2019 a massive spring-summer blue-green algal bloom of *Anabaena* occurred. 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 2019. In 2019 three tributary stations exceeded the fecal coliform State standard on 50% of occasions sampled, but the in-lake stations were in good condition.

Greenfield Lake is currently on the NC 303(d) list for impaired waters due to excessive algal blooms. In the previous report (for 2018) 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. We are pleased to say that a coalition of stakeholders (the City, Cape Fear River Watch, UNCW, NCSU and a consulting firm) have been awarded funds for 2020-2022 to begin nutrient reduction efforts on Jumping Run Branch.

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 2019 the creek was sampled at four tidal sites and one non-tidal freshwater site (PV-GC-9) on two occasions in spring.

Incidents of low dissolved oxygen did not occur at Hewletts Creek in 2019 during the spring samples. Turbidity was low and did not exceed the state standard, and no algal blooms occurred. Fecal coliform bacteria counts exceeded State standard 100% of the time at NB-GLR (the north branch) and MB-PGR (the middle branch) and PVGC-9. The

geometric means at PVGC-9, MB-PGR, and NB-GLR all exceeded 200 CFU/100 mL for a Poor rating for this pollutant parameter, but the geometric mean of fecal bacteria counts at HC-3 was well under the state shellfishing standard.

Howe Creek – Howe Creek drains a 3,516 acre watershed into the ICW. This watershed hosts a population of approximately 6,460 with about 21.4% impervious surface coverage. Howe Creek was sampled at two locations on two occasions during spring 2019 (HW-GP and HW-DT- Fig. 8.1). Turbidity and suspended solids were generally low to moderate (< 17 mg/L). Dissolved oxygen concentrations dropped slightly below the NC standard of 5 mg/L on one sampling occasion at both HW-DT and HW-GP in 2019. Nitrate, ammonium and orthophosphate concentrations were low at both sites in 2019. Chlorophyll *a* concentrations exceeded the NC standard at the uppermost station HW-DT on one of the two occasions in 2019, with a bloom (chlorophyll *a* of 85 µg/L) that doubled the state standard. Fecal coliform bacteria counts were below the water contact standard of 200 CFU/100 mL on both sampling occasions.

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 site was sampled twice in spring. Dissolved oxygen was generally good, and turbidity and suspended solids were generally low. Ammonium was low and nitrate concentrations moderate, as were phosphorus concentrations. There were no notable algal blooms. Fecal coliform bacteria were somewhat high in one of the two months sampled.

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 2008-2019. 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 on two of 12 occasions in our 2019 samples for a fair rating. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded. There were no major algal blooms present in our 2019 sampling. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on only one of 12 sampling occasions in 2019 for a Good 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 the bridge over this creek in 2019. This creek was sampled twice in spring. Turbidity was very low on both sampling occasions, and total suspended solids (TSS) not a problem. Dissolved oxygen was

within standard (> 5.0 mg/L) on both sampling occasions. Nitrogen and phosphorus concentrations were low on both sampling occasions. Our Whiskey Creek station did not host significant algal blooms during the two spring sampling trips in 2019. Fecal coliform bacteria counts were within standard on both sampling occasions.

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 2019 data, and have designated each station as good, fair, and poor accordingly (Appendix B). Again, note that data are limited for 2019 and should be viewed in that light.

Fecal coliform bacterial conditions for the entire Wilmington City and New Hanover County Watersheds system (24 sites sampled for fecal coliforms) showed 50% to be in good condition, 8% in fair condition and 42**%** in poor condition, an improvement over the previous year. Dissolved oxygen conditions (measured at the surface) system-wide (24 sites) showed 75% of the sites were in good condition, 12% were in fair condition, and 13% were in poor condition, but we note the most stressful season, mid-summer and early fall was not sampled. For algal bloom presence, measured as chlorophyll *a*, 75% of the 24 stations sampled were rated as good, 8% as fair and 17% as poor. 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.

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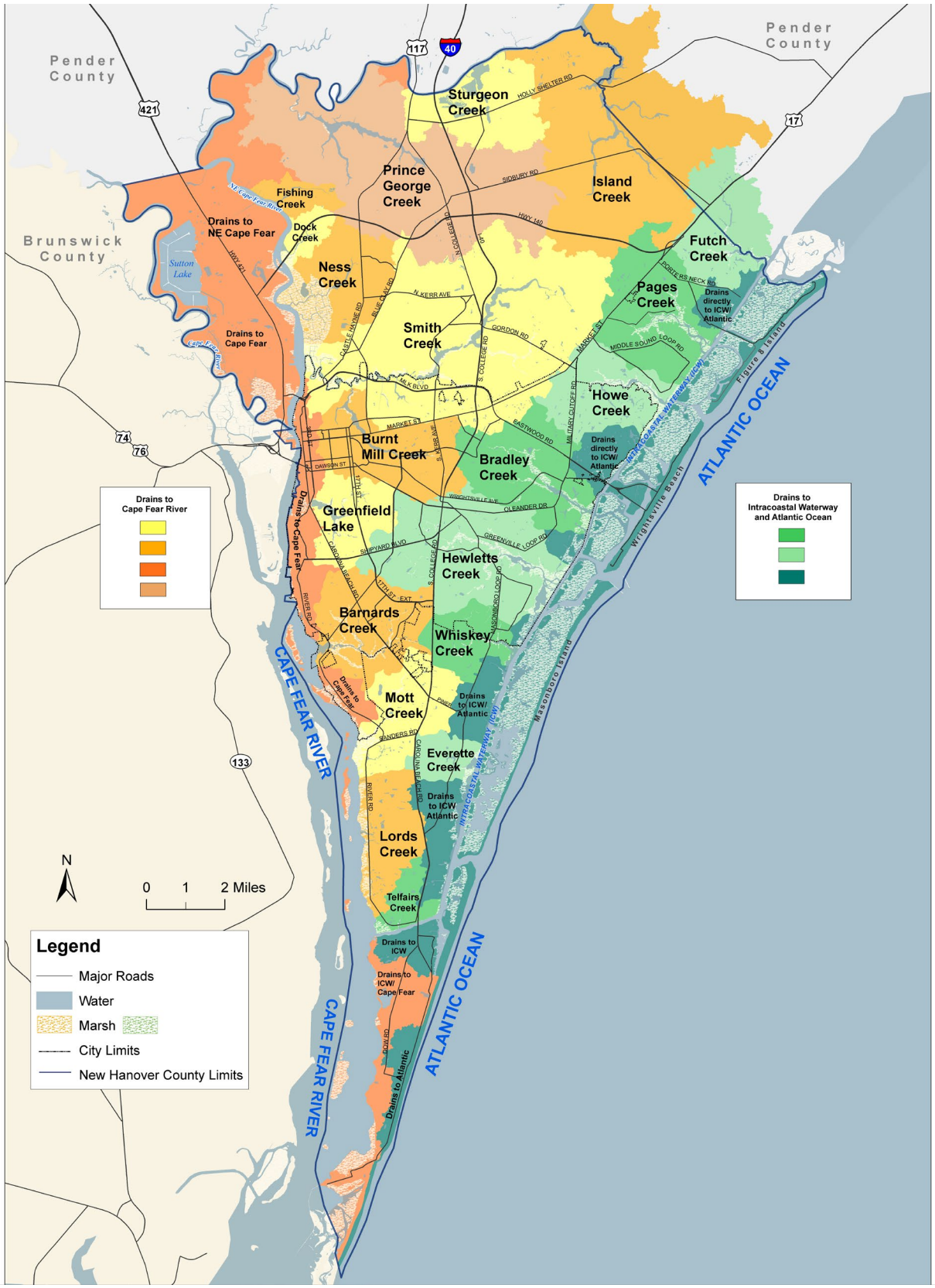


Plate 1. Wilmington and New Hanover County watersheds 2014 map by Wilmington Stormwater Services. Station coordinates are in Appendix C.

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. 1998). Data from that report were later published in the peer-reviewed literature (Mallin et al. 2000; 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 22 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 2019, 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. 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 provided funding for sampling of those two creeks in 2018-2019.

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 two to four occasions at 23 locations within the Wilmington City watersheds between January and July 2019. 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 EXO 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

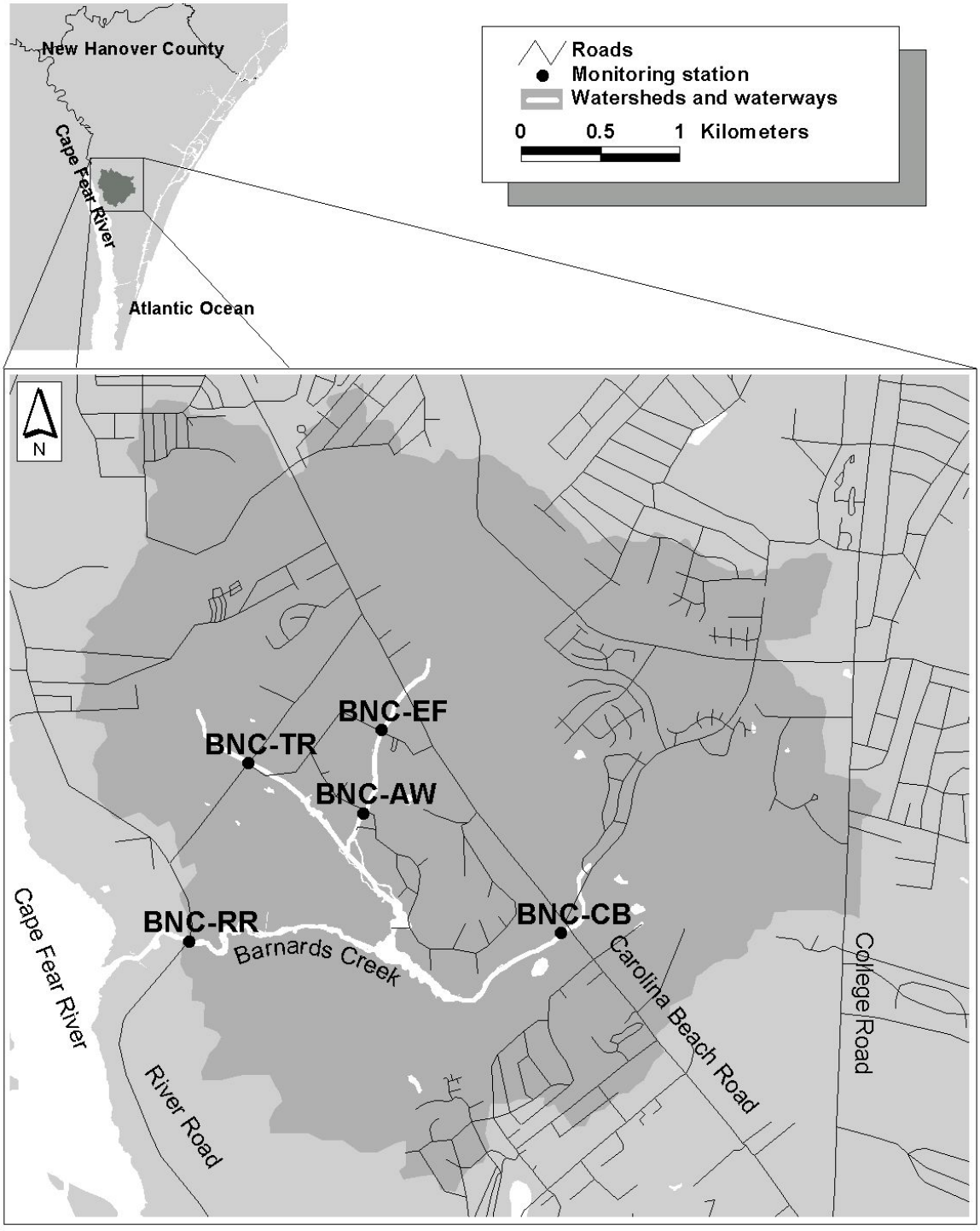
The water quality of lower Barnard's Creek is an important issue as single family and multifamily housing construction has occurred upstream of Carolina Beach Rd. in the St. Andrews Dr. area and along Independence Boulevard near the Cape Fear River. Another major housing development (River Lights) is 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 Barnards Creek at River Road (BNC-RR) in 2018-2019.

Barnards Creek at this site is considered to be oligohaline, which is, maintaining salinities generally less than 5 ppt. Due to funding issues this site was only sampled twice, so limited conclusions can be drawn. Dissolved oxygen was good, with no samples dropping below 5.0 mg/L. Turbidity and suspended solids were generally moderate. Ammonium was low, but nitrate concentrations were relatively high among tidal creeks in this area. Total phosphorus was high on one occasion (> 1.0 mg-P/L) but low on the second occasion. Orthophosphate concentrations were relatively low. There was a minor algal bloom (chlorophyll *a* of 28 µg/L) in May 2019. Fecal coliform bacteria were low on both sampling occasions.

Table 2.1. Selected water quality parameters in Barnards Creek watershed as mean (standard deviation) and range, 2019, n = 2 samples collected.

Parameter	BNC-RR	
	Mean (SD)	Range
Salinity (ppt)	2.1 (2.2)	0.5-3.6
Dissolved oxygen (mg/L)	7.4 (2.3)	5.8-9.0
Turbidity (NTU)	13 (1)	12-13
TSS (mg/L)	15.9 (6.4)	11.4-20.4
Ammonium (mg/L)	0.22 (0.06)	0.18-0.26
Nitrate (mg/L)	0.44 (0.07)	0.39-0.49
TN (mg/L)	1.24 (0.21)	1.09-1.39
Orthophosphate (mg/L)	0.06 (0.03)	0.04-0.08
TP (mg/L)	0.55 (0.65)	0.09-1.01
N/P ratio (mean and median)	29	29
Chlorophyll *a* (µg/L)	19 (13)	9-28
Fecal col. /100 mL (geomean and range)	28	28-28

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 and development across Eastwood Road; this is of concern in terms of the 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. 2000) 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). Due to funding issues this creek was only sampled twice, so limited conclusions can be drawn.

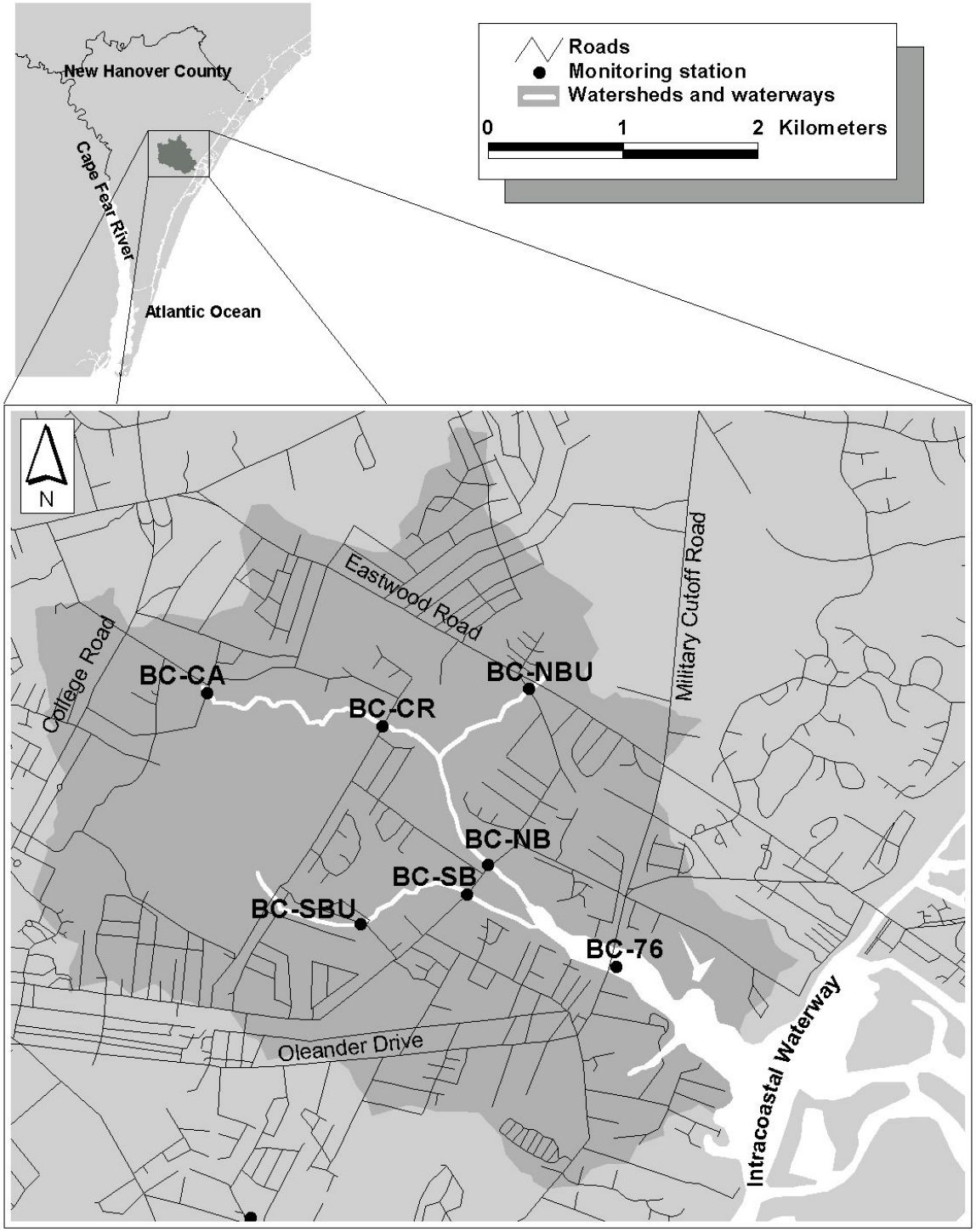
Turbidity was not a problem during 2019; the standard of 25 NTU was not exceeded (Table 3.1). Total suspended solids (TSS) were slightly elevated (about 17 mg/L) in one sample. There are no NC ambient standards for TSS, but UNCW considers 25 mg/L high for the Coastal Plain. Dissolved oxygen was within standard (> 5.0 mg/L) on both sampling occasions (Appendix B).

Ammonium and nitrate concentrations were low to moderate on both occasions, and highest at the upstream station BC-CA (Table 3.1). Total nitrogen concentrations were low to moderate in general and highest at BC-CA. 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 during the two spring sampling trips in 2019, just a minor bloom of chlorophyll *a* of 21 µg/L at BC-CA in February. Median nitrogen to phosphorus ratios at BC-NB and BC-SB were low (<10) indicating that inputs of inorganic nitrogen are likely to stimulate algal blooms in the lower creek. Fecal coliform bacteria counts were within standard at BC-NB, exceeded the standard slightly on one trip at BC-SB, and were well over standard on both occasions at BC-CA, with a geometric mean of 1,956 CFU (colony-forming units)/100 mL (Table 3.1); this a about 10X the NC standard of 200 CFU/100 mL for freshwater safety.

Table 3.1. Water quality parameter concentrations at Bradley Creek sampling stations, 2019. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 2 samples collected.

Station	BC-CA	BC-NB	BC-SB
Salinity (ppt)	0.1 (0.0) 0.1-0.1	17.1 (0.6) 16.7-17.5	2.2 (1.4) 1.2-3.2
Dissolved Oxygen (mg/L)	6.0 (1.0) 5.3-6.7	8.5 (2.3) 6.9-10.1	9.4 (0.6) 9.0-9.8
Turbidity (NTU)	3 (1) 2-3	4 (3) 2-6	6 (0) 6-6
TSS (mg/L)	1.4 (0.1) 1.3-1.4	9.1 (11.0) 1.3-16.8	9.8 (2.5) 8.0-11.6
Nitrate (mg/L)	0.175 (0.035) 0.150-0.200	0.015 (0.017) 0.010-0.020	0.055 (0.064) 0.010-0.100
Ammonium (mg/L)	0.240 (0.099) 0.170-0.310	0.025 (0.021) 0.010-0.040	0.020 (0.014) 0.010-0.030
TN (mg/L)	0.825 (0.389) 0.550-1.100	0.250 (0.710) 0.200-0.300	0.425 (0.530) 0.050-0.800
Orthophosphate (mg/L)	0.040 (0.000) 0.040-0.040	0.015 (0.070) 0.010-0.020	0.025 (0.007) 0.020-0.030
TP (mg/L)	0.115 (0.078) 0.060-0.170	0.100 (0.099) 0.030-0.170	0.060 (0.014) 0.050-0.070
N/P	23.0 23.0	6.1 6.1	7.6 7.6
Chlorophyll *a* (μg/L)	1 (1) 0-1	3 (1) 2-3	15 (8) 9-21
Fecal coliforms (CFU/100 mL)	1,956 1,700-2,250	120 115-125	141 73-273

Figure 3.1. Bradley Creek watershed and sampling sites.



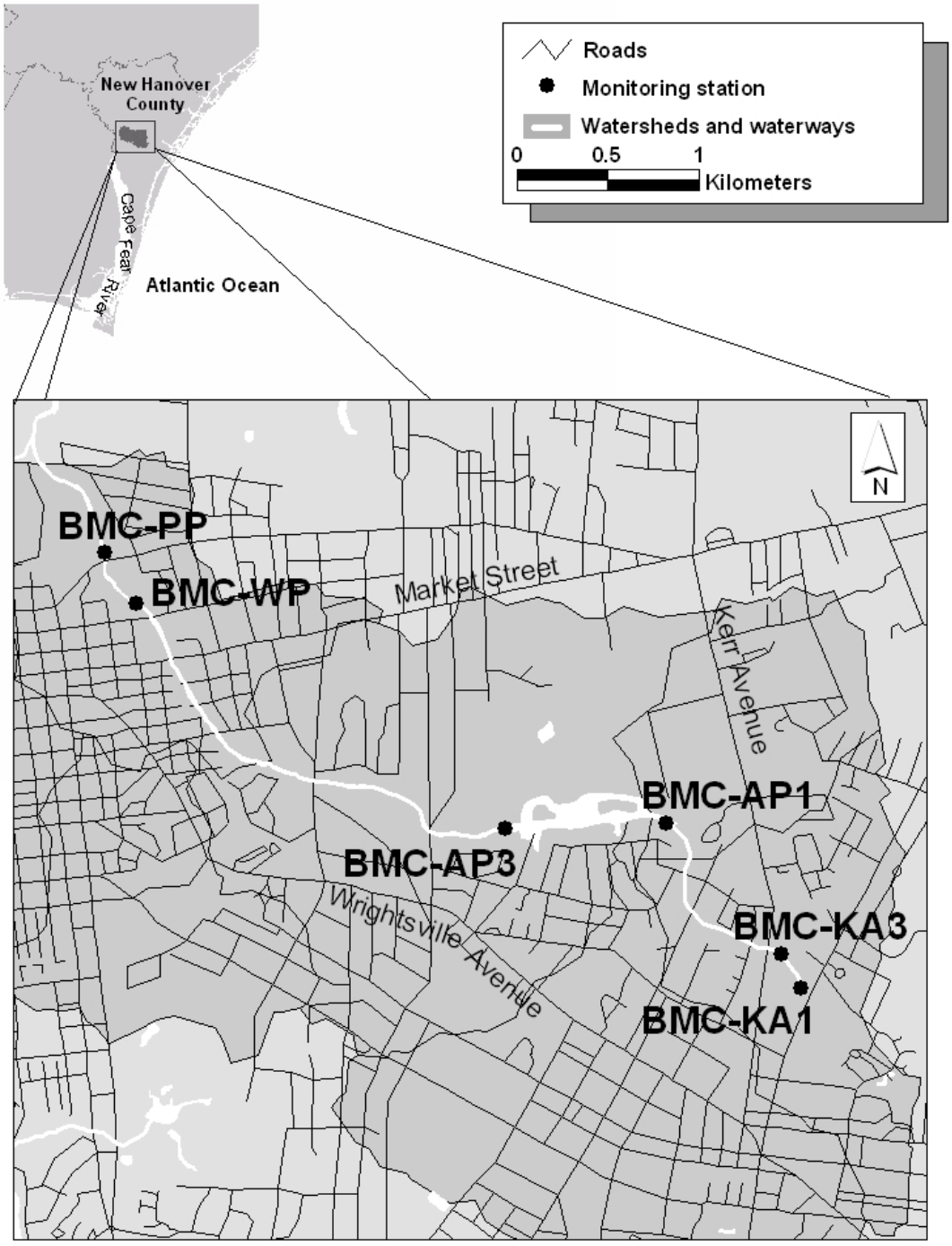
4.0 Burnt Mill Creek

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. 2002). Numerous waterfowl utilize this pond as well. Burnt Mill Creek has been studied by a number of researchers, and 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. 2010; 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 2019 samples were collected on four occasions from three stations on the creek (Fig. 4.1). The upper creek was sampled just upstream (BMC-AP1) and about 40 m downstream (BMC-AP3) of Ann McCrary 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 four occasions in 2019. Dissolved oxygen concentrations were within standard on all sampling occasions at BMC-AP1 and BMC-AP3. There were no statistically-significant changes in either DO or pH through the pond. The NC standard for turbidity in freshwater is 50 NTU; there was one exceedence of this value during January at BMC-AP1 of 130 NTU, although on average there was no significant change through the pond. Total suspended solids concentrations were relatively low on all sampling occasions in 2019, except for a high concentration of 56 mg/L at AP1 in January, and there was no significant change through the pond on average (Table 4.1). Fecal coliform concentrations entering Ann McCrary Pond at BMC-AP1 were high, exceeding the state standard 50% 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 minor algal bloom at BMC-AP3 in May of 29 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 2019. One parameter that is key to aquatic life health is dissolved oxygen. Dissolved oxygen at BMC-PP was substandard on one of four sampling occasions. Turbidity concentrations at BMC-PP did not exceed the State standard on any of our sampling occasions and total suspended solids (TSS) were low.

In 2019 there was one major algal bloom at BMC-PP (42 µg/L, June) and a minor bloom of 25 µg/L in May. The North Carolina water quality standard for chlorophyll *a* is 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. 2006).

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 BMC-AP-3. Examination of inorganic nitrogen to phosphorus ratios (Table 4.1) shows that mean and median N/P ratios at all three stations were <13. 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, inputs of either N or P could drive an algal bloom.

Important from a public health perspective are fecal coliform bacteria counts, which had geometric means exceeding the State standard for human contact waters (200 CFU/100 mL) only at BMC-AP1 in 2019. Fecal coliform counts were greater than the

State standard on 25% of sampling occasions at BMC-PP, and 50% at BMC-AP1. Whereas geometric mean fecal coliform counts at BMC-AP3 were 19 CFU/100 mL, counts then increased along the passage to the Princess Place location (geometric mean 149 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). Clearly, there are inputs of pollutants to this creek as it passes from the large detention pond to its lower reaches.

Figure 4.2. Fecal coliform bacteria geometric means for Burnt Mill Creek, 2019

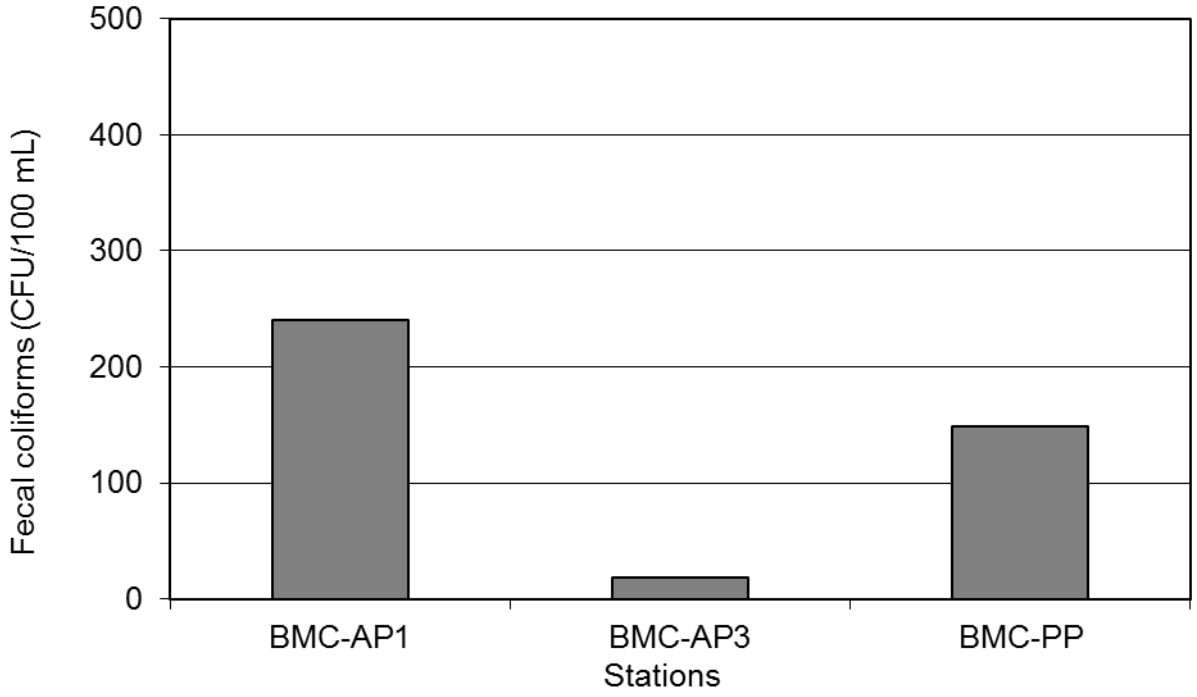


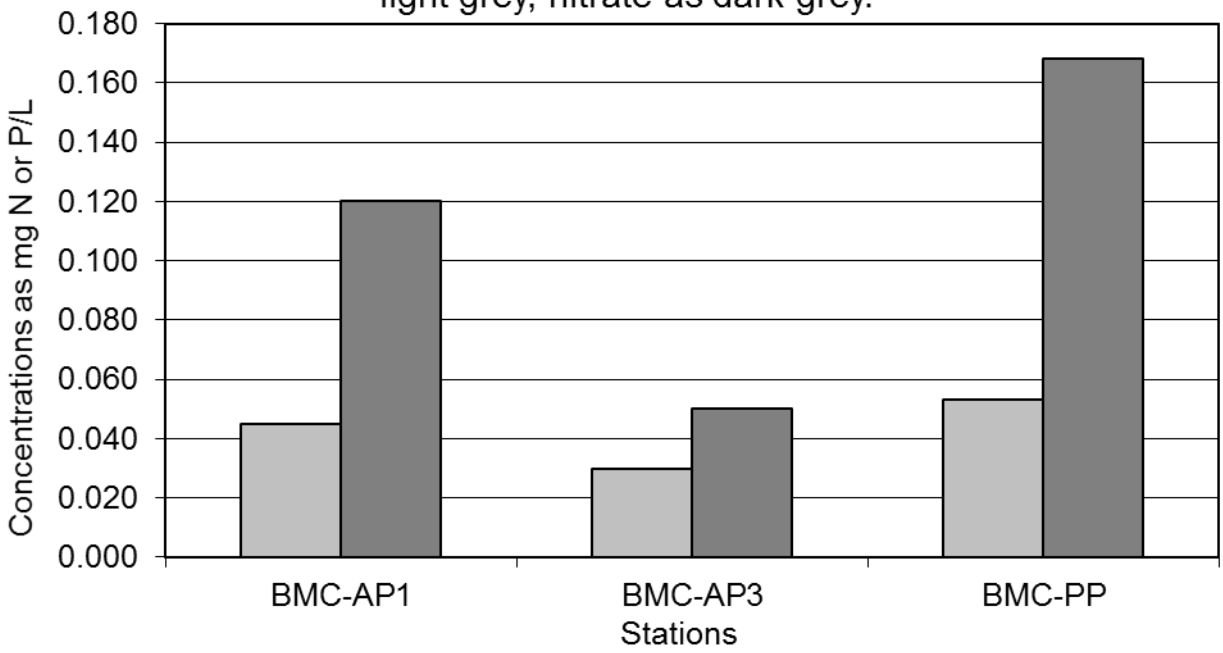
Table 4.1. Water quality data in Burnt Mill Creek, 2019, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as mean/median, n = 4 samples collected.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	8.4 (2.4) 5.9-11.7	10.8 (2.3) 9.2-14.2	5.5 (1.4) 3.6-6.9
Cond. (μS/cm)	258 (25) 226-284	225 (41) 172-271	358 (69) 301-443
pH	7.0 (0.1) 6.9-7.1	7.8 (0.7) 7.2-8.7	7.3 (0.1) 7.1-7.5
Turbidity (NTU)	35 (63) 2-130	11 (8) 5-23	5 (3) 2-9
TSS (mg/L)	23.9 (41.4) 2.9-56.0	10.2 (5.0) 5.4-17.1	5.4 (2.7) 2.9-9.2
Nitrate (mg/L)	0.120 (0.060) 0.030-0.220	0.050 (0.052) 0.010-0.120	0.168 (0.114) 0.010-0.280
Ammonium (mg/L)	0.075 (0.042) 0.030-0.120	0.063 (0.039) 0.010-0.100	0.073 (0.019) 0.060-0.100
TN (mg/L)	1.488 (2.147) 0.100-4.690	0.580 (0.376) 0.100-1.000	0.815 (0.766) 0.100-1.900
OrthoPhos. (mg/L)	0.045 (0.025) 0.020-0.080	0.030 (0.008) 0.020-0.040	0.053 (0.026) 0.030-0.090
TP (mg/L)	0.298 (0.191) 0.070-0.490	0.108 (0.069) 0.060-0.210	0.260 (0.193) 0.110-0.154
N/P molar ratio	12.4 12.2	8.6 8.3	12.4 12.6
Chlor. *a* (μg/L)	4 (3) 2-9	16 (11) 5-29	18 (20) 1-42
FC (CFU/100 mL)	240 86-6812	19 10-59	149 46-1,000

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

To summarize, in some years, including 2019, 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 2019 at BMC-PP. The N/P ratios in the lower creek indicate that inputs of nitrogen were likely to stimulate algal bloom formation in 2019, but such ratios have differed in previous years. 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 (Fig. 4.3). 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), indicating as stormwater runoff pollution problem. 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, 2019; OP as light grey, nitrate as dark grey.

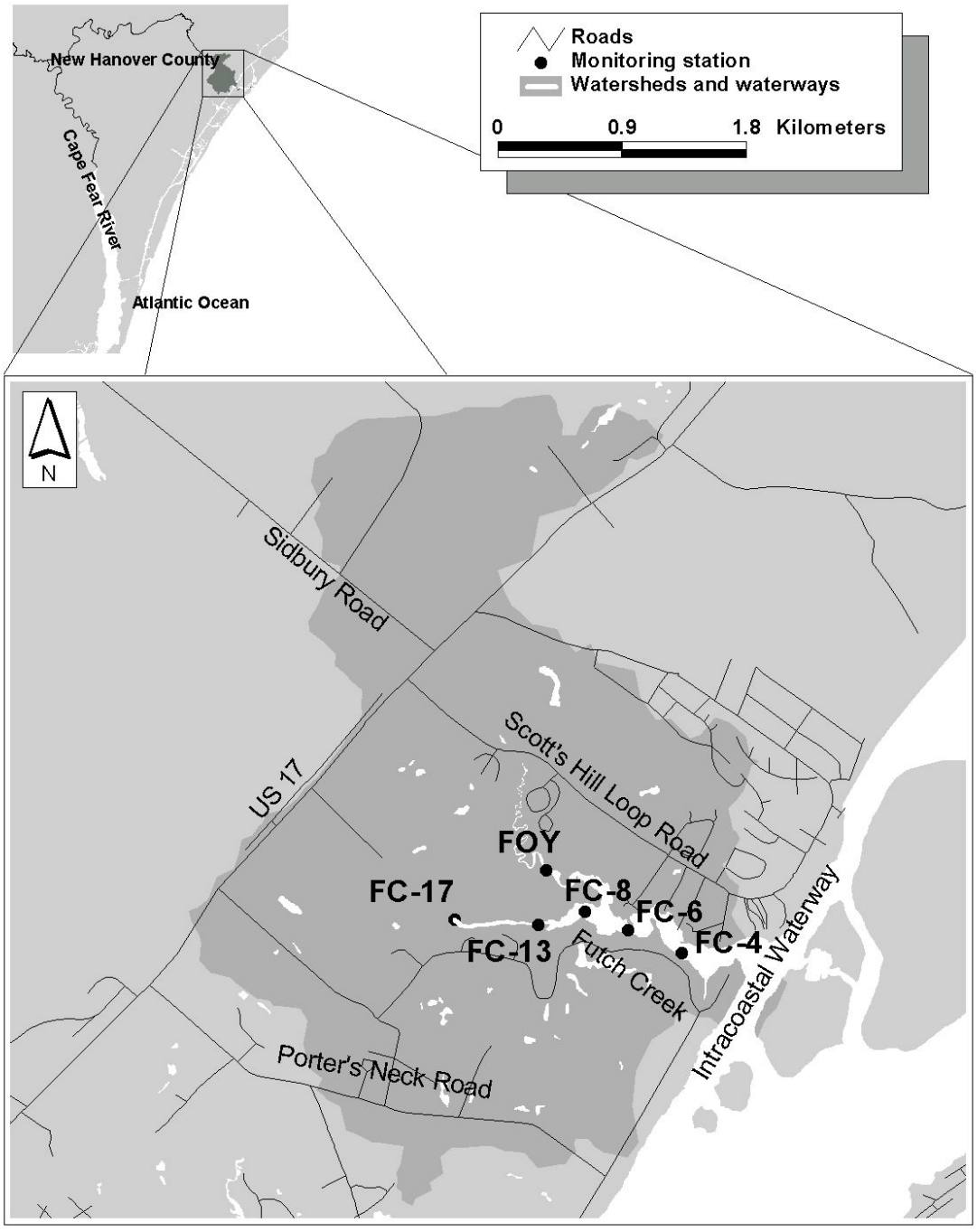


5.0 Futch Creek

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 2019. 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 stations on tributaries to Greenfield Lake were sampled for a full suite of physical, chemical and biological parameters on four occasions in 2019 (Table 6.1, Fig. 6.1). One tributary site suffered from hypoxia, as GL-LB (creek at Lake Branch Drive, called Squash 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-JRB (Jumping Run Branch) had substandard dissolved oxygen on one sampling occasion. Turbidity concentrations were generally low in the tributary stations, with one violation of the freshwater standard (75 NTU in May at GL-JRB, Table 6.1). Suspended solids were elevated in GL-JRB in May (Table 6.1).

Nitrate, ammonium and TN concentrations were highest at GL-JRB (Table 6.1). Highest phosphorus concentrations occurred at that site as well. We note that both JRB-17 and GL-JRB are downstream of a golf course, which covers 22% of the Jumping Run Branch watershed surface area. Chlorophyll *a* concentrations were elevated at GL-LC, with a bloom exceeding 40 µg/L in June from a large spring-summer algal bloom of the nitrogen-fixing cyanobacterium (blue-green alga) *Anabaena*; chlorophyll *a* concentrations were much lower at the other stream stations. The geometric mean fecal coliform bacteria counts exceeded the state standard at three of the four tributary stations (Table 6.1). The standard was exceeded on two of four sampling dates at GL-JRB, JRB-17 and GL-LB, and on one occasion at GL-LC.

Table 6.1. Mean and (standard deviation) / range of selected field water quality parameters in tributary stations of Greenfield Lake, 2019. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 4 samples collected.

Parameter	JRB-17	GL-JRB	GL-LB (SQB)	GL-LC (CBB)
DO (mg/L)	6.7 (1.9) 5.0-8.8	6.3 (2.2) 3.1-7.9	3.4 (2.2) 1.0-5.6	7.0 (1.2) 5.8-8.5
Turbidity (NTU)	23 (35) 3-75	3 (1) 2-5	3 (1) 2-4	3 (2) 1-6
TSS (mg/L)	20.8 (30.7) 3.1-66.7	2.8 (1.5) 1.4-2.8	3.8 (2.0) 1.5-6.2	5.5 (4.7) 1.3-9.7
Nitrate (mg/L)	0.19 (0.14) 0.01-0.36	0.23 (0.14) 0.03-0.34	0.21 (0.14) 0.08-0.36	0.09 (0.09) 0.01-0.18
Ammon. (mg/L)	0.29 (0.25) 0.06-0.59	0.08 (0.05) 0.03-0.12	0.13 (0.08) 0.05-0.24	0.06 (0.03) 0.01-0.09
TN (mg/L)	1.02 (0.81) 0.05-1.86	0.98 (0.55) 0.53-1.77	1.15 (1.41) 0.05-3.21	1.07 (1.39) 0.05-3.10
Ortho-P. (mg/L)	0.09 (0.08) 0.03-0.20	0.04 (0.02) 0.02-0.05	0.06 (0.02) 0.04-0.09	0.03 (0.01) 0.02-0.03
TP (mg/L)	0.30 (0.28) 0.05-0.69	0.20 (0.31) 0.04-0.71	0.20 (0.28) 0.05-0.62	0.27 (0.33) 0.03-0.73
Inorganic N/P ratio	12.7 9.0	22.3 23.6	14.6 13.2	12.5 11.4
Chlor. *a* (μg/L)	9 (4) 4-14	4 (3) 2-8	3 (2) 1-5	22 (29) 1-65
FC (CFU/100 mL)	338 105-2,420	222 130-500	299 55-1,300	73 5-411

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 2019 (see also Section 6.1). Turbidity was at or below the state standard on all sampling occasions except for a peak of 45 NTU in June at GL-2340, when suspended solids were likewise, concurrent with

the onset of a blue-green alga bloom of *Anabaena* (see below). In-lake fecal coliform concentrations were not problematic at the lake sites in 2019.

Concentrations of all inorganic nutrients in-lake were generally low but highest at the upstream station GL-2340 (Table 6.2). Total N was highest at GL-2340, likely reflecting biomass from the spring-summer cyanobacterial bloom. Total phosphorus (TP) and orthophosphate concentrations were highest at GL-2340, concurrent with late spring algal blooms (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 mean and median N/P ratios in the lake (Table 6.2), phytoplankton growth in much of Greenfield Lake (i.e. GL-YD and GL-P) can be readily stimulated by nitrogen (i.e. inputs of nitrogen can cause algal blooms); however note that at the uppermost station GL-2340 such ratios were >24, indicating at least periodic P limitation at this site. Our previous bioassay experiments indicated that nitrogen was usually the stimulatory nutrient in this lake (Mallin et al. 1999; 2016).

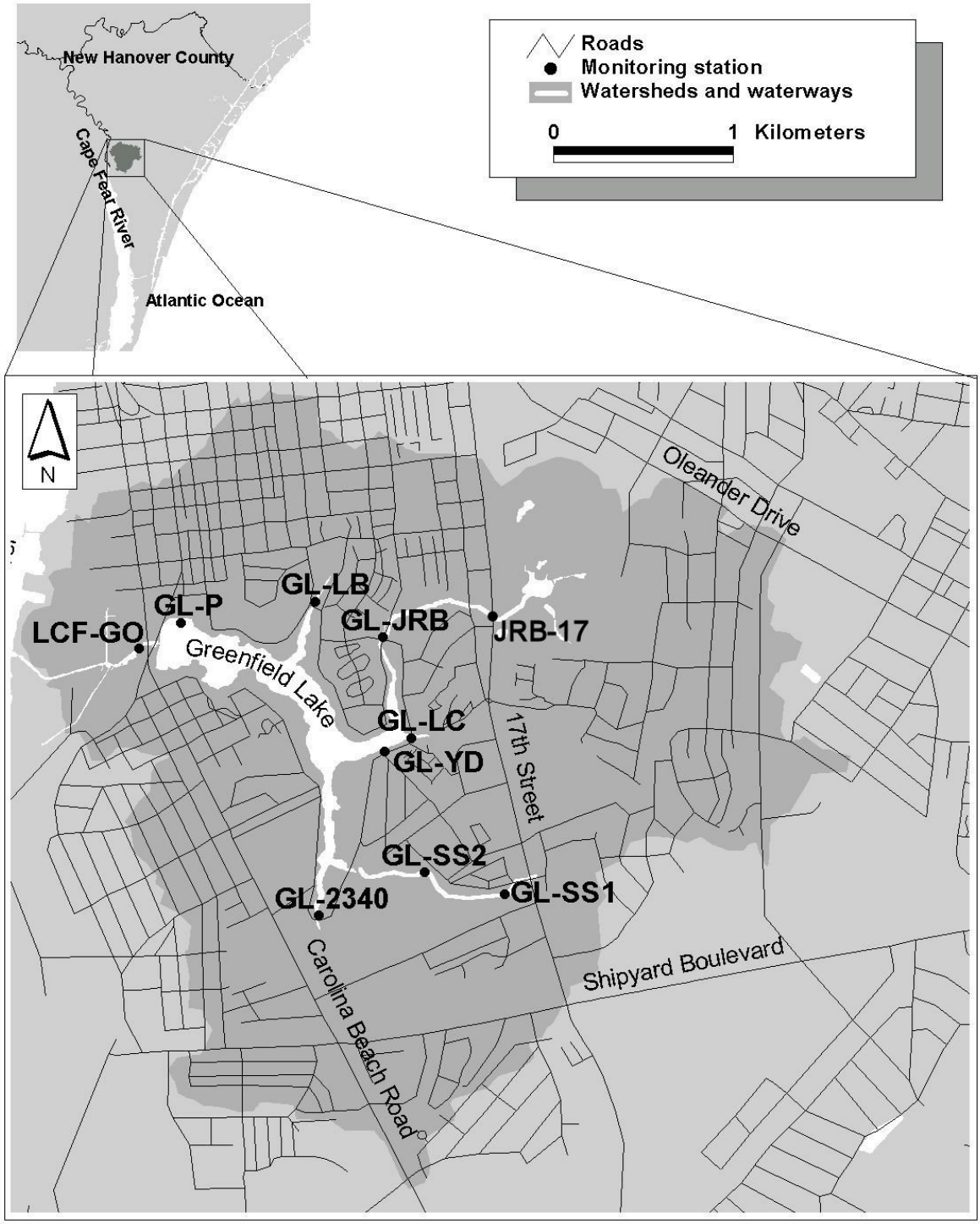
Phytoplankton blooms are problematic in Greenfield Lake (Table 6.2), and usually consist of green or blue-green algal species, or both together. These blooms have occurred during all seasons, but are primarily a problem in spring and summer. In 2019 an extensive bloom of the blue-green *Anabaena spiroides* began in May and lasted for months (see cover photograph). As such, two blooms exceeding the North Carolina water quality standard of 40 μg/L of chlorophyll *a* occurred at each of GL-YD, GL-2340, and GL-P with the largest bloom (364 μg/L) occurring at GL-2340. For the past several years chlorophyll *a* has exceeded the state standard >30% of occasions sampled. Based on these data, the North Carolina Division of Environmental Quality placed this lake on the 303(d) list in 2014. Average biochemical oxygen demand (BOD5) for 2019 was elevated, especially at GL-2340 (average = 7.3 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 (highly enriched) category for 2019. We also note that 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, 2019. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 4 samples collected.

Parameter	GL-2340	GL-YD	GL-P
DO (mg/L)	7.9 (2.8) 6.1-12.1	8.8 (2.2) 6.4-11.4	9.6 (1.2) 7.9-10.6
Turbidity (NTU)	12 (22) 0-45	5 (4) 1-9	6 (6) 0-11
TSS (mg/L)	14.3 (20.8) 1.3-45.0	6.2 (5.0) 1.4-11.9	4.7 (3.7) 1.4-8.8
Nitrate (mg/L)	0.12 (0.16) 0.01-0.35	0.02 (0.02) 0.01-0.04	0.01 (0.01) 0.01-0.01
Ammonium (mg/L)	0.11 (0.15) 0.01-0.34	0.04 (0.04) 0.01-0.10	0.04 (0.05) 0.01-0.11
TN (mg/L)	2.27 (2.72) 0.05-6.10	0.93 (0.65) 0.05-1.43	0.81 (0.71) 0.05-1.70
Orthophosphate (mg/L)	0.03 (0.06) 0.02-0.03	0.02 (0.01) 0.01-0.03	0.02 (0.01) 0.01-0.03
TP (mg/L)	0.44 (0.38) 0.07-0.84	0.19 (0.13) 0.06-0.33	0.20 (0.18) 0.05-0.44
N/P molar ratio	24.5 25.1	8.8 8.3	8.1 2.2
Fec. col. (CFU/100 mL)	13 1-118	5 3-14	11 3-49
Chlor. *a* (μg/L)	113 (172) 1-364	44 (44) 3-97	34 (26) 6-57
BOD5	7.3 (7.8) 1.0-17.0	4.3 (4.0) 1.0-10.0	4.0 (2.8) 1.0-8.0

Figure 6.1. Greenfield Lake watershed.



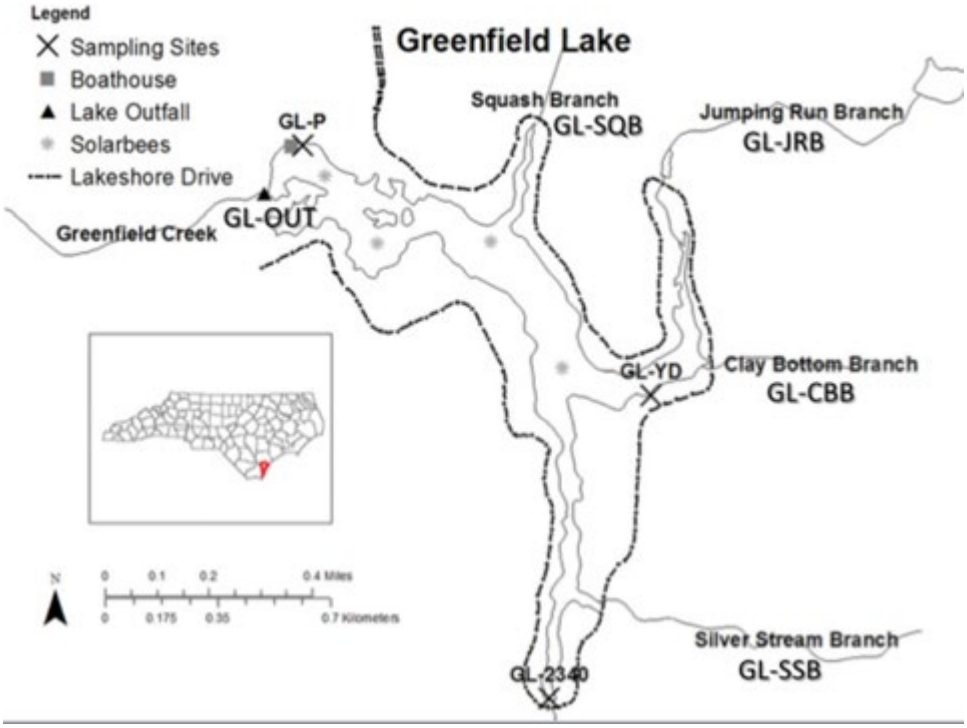
Continuing Efforts to Restore Water Quality in Greenfield Lake

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 (DO) concentrations by eliminating near-anoxia incidents and reducing DO 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 can result in lowered DO.

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). Lake eutrophication (algal blooms and elevated BOD), 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. Nutrient load to Greenfield Lake is computed by multiplying nutrient concentration and water flow for each inflowing stream. As such, GL-JRB was the highest nutrient loader of nitrate-N, orthophosphate-P, total nitrogen, and total phosphorus. 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. We are pleased to note here that a coalition including the City of Wilmington, Cape Fear River Watch, UNC Wilmington, NCSU and a private consulting firm (Moffat & Nichol) will be receiving funds from 2020-2022 through the NC Division of Environmental Quality via the EPA-sponsored 319 Program to begin nutrient reduction measures on Jumping Run Branch.

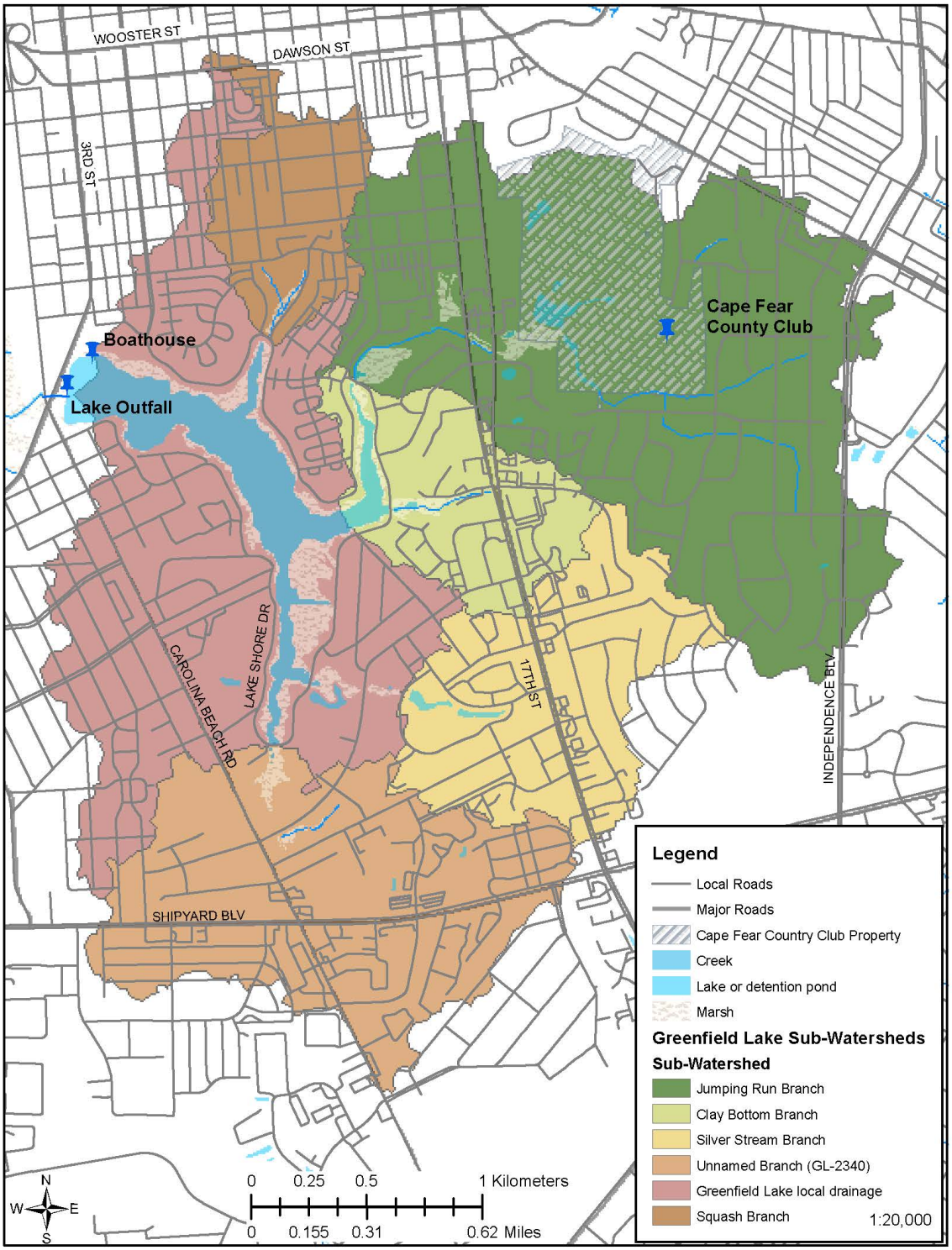


Figure 6.4. Greenfield Lake sub-watersheds; map produced by Saskia Cohick, Wilmington Stormwater Services.

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 twice 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). Based on these data, 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). Dissolved oxygen was within standard on both sampling occasions. 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 except HC-3 in the estuary; oyster reefs are present there and the ammonium may be a waste product from oyster excretion. Total nitrogen was low in general and highest in the middle branch station. 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 SB-PGR and NB-GLR, indicating that inputs of inorganic nitrogen could cause algal blooms. Ratios were high at HC-3, due to elevated ammonium, indicating that at times P can stimulate algal growth at this lower site. The chlorophyll *a* data (Tables 7.1 and 7.2) showed that no blooms occurred during the two spring sampling runs. Fewer blooms have occurred in the past few years than had previously occurred in upper Hewletts Creek (Mallin et al. 1998; 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 both times sampled at MB-PGR, NB-GLR, and PVGC-9, but were low at SB-PGR and HC-3. The geometric means at PVGC-9, MB-PGR, and NB-GLR all exceeded 200 CFU/100 mL for a Poor rating for this pollutant parameter. The geometric mean of fecal bacteria counts at HC-3 was well under the shellfishing standard of 14 CFU/100 mL

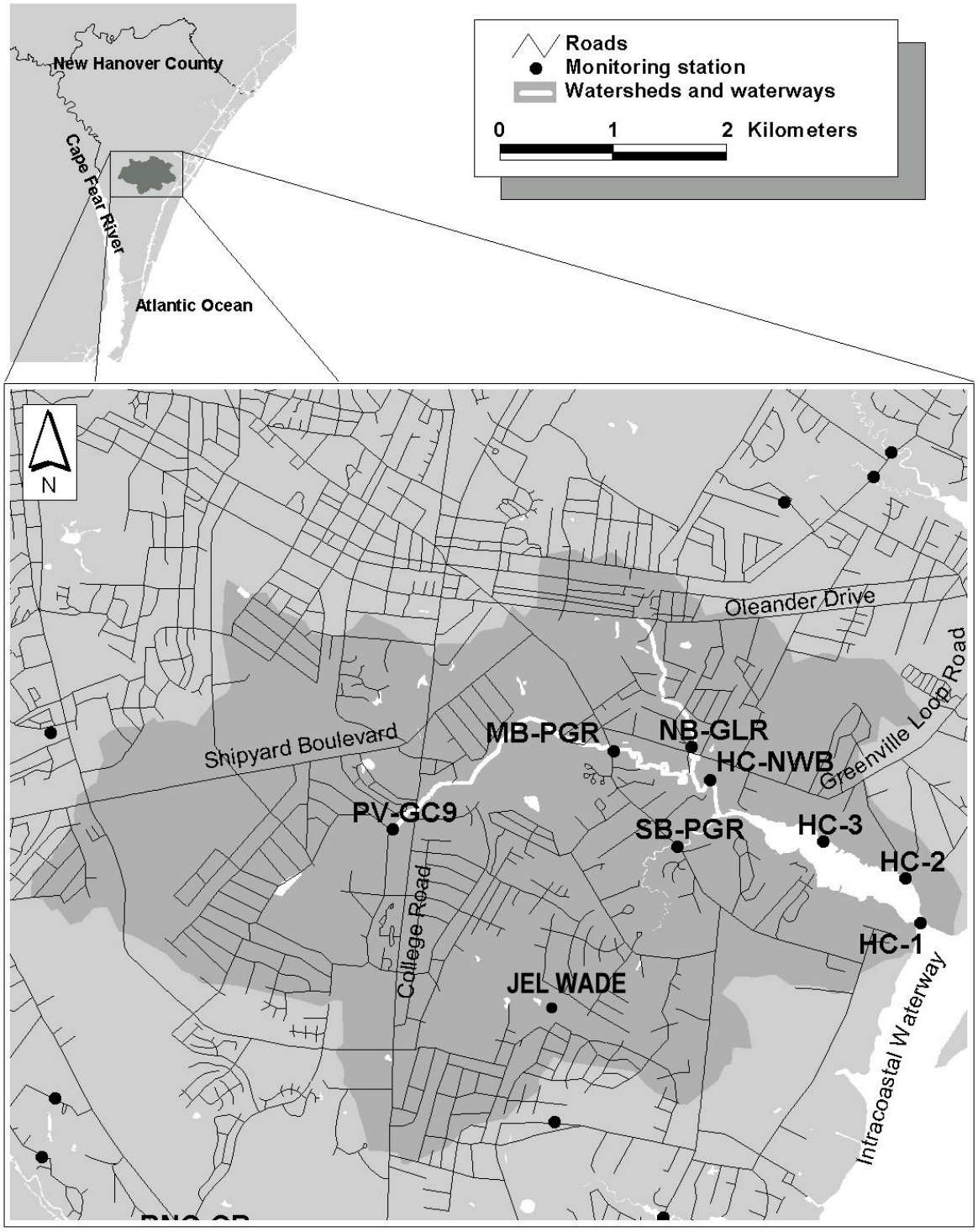


Figure 7.1. Hewletts Creek watershed.

Table 7.1. Selected water quality parameters at upper and middle creek stations in Hewletts Creek watershed 2019 as mean (standard deviation) / range, inorganic N/P ratios as mean / median, fecal coliform bacteria presented as geometric mean / range, n = 2 samples collected.

Parameter	PVGC-9	MB-PGR
Salinity (ppt)	0.1 (0) 0.1-0.1	0.1 (0) 0.1- 1
Turbidity (NTU)	3 (1) 2-4	2 (0) 2-2
TSS (mg/L)	1.3 (0) 1.3-1.3	2.9 (0.1) 2.8-3.0
DO (mg/L)	7.8 (0.8) 7.2-8.4	8.1 (0.8) 7.5-8.6
Nitrate (mg/L)	0.400 (0.057) 0.360-0.440	0.240 (0.014) 0.230-0.250
Ammonium (mg/L)	0.050 (0.014) 0.040-0.060	0.060 (0.014) 0.050-0.070
TN (mg/L)	0.850 (0.269) 0.660-1.040	0.740 (0.014) 0.730-0.750
Orthophosphate (mg/L)	0.017 (0.007) 0.010-0.020	0.020 (0.0) 0.010-0.020
TP (mg/L)	0.080 (0.014) 0.070-0.090	0.100 (0.127) 0.010-0.190
N/P inorganic	73.1 73.1	33.2 33.2
Chlorophyll *a* (μg/L)	3 (1) 2-4	1 (0) 1-1
Fecal col. (CFU/100 mL)	205 205-205	280 270-290

Table 7.2. Selected water quality parameters at stations in Hewletts Creek watershed, 2019, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 2 samples collected.

Parameter	NB-GLR	SB-PGR	HC-3
Salinity (ppt)	6.9 (0.8) 6.3-7.4	17.4 (2.8) 15.4-19.4	29.1 (2.1) 27.6-30.5
Turbidity (NTU)	6 (4) 3-8	3 (1) 2-4	2 (1) 1.3
TSS (mg/L)	5.2 (0.5) 4.8-5.5	9.9 (4.9) 6.4-13.4	10.3 (2.3) 8.7-11.9
DO (mg/L)	8.6 (1.3) 7.7-9.5	8.3 (2.0) 6.9-9.7	8.6 (1.3) 7.6-9.5
Nitrate (mg/L)	0.090 (0.028) 0.070-0.110	0.025 (0.021) 0.010-0.040	0.015 (0.007) 0.010-0.020
Ammonium (mg/L)	0.020 (0.014) 0.010-0.030	0.025 (0.021) 0.010-0.040	0.240 (0.156) 0.130-0.350
TN (mg/L)	0.640 (0.240) 0.470-810	0.320 (0.028) 0.300-0.340	0.350 (0.071) 0.300-0.400
Orthophosphate (mg/L)	0.020 (0.000) 0.020-0.020	0.020 (0.000) 0.020-0.020	0.015 (0.007) 0.010-0.020
TP (mg/L)	0.065 (0.007) 0.060-0.070	0.110 (0.085) 0.050-0.170	0.080 (0.099) 0.010-0.150
Mean N/P ratio Median	12.2 12.2	5.5 5.5	36.0 36.0
Chlor *a* (μg/L)	8 (8) 2-13	5 (2) 3-6	1 (0) 1-1
Fecal coliforms (CFU/100 mL)	322 228-455	125 120-130	7 5-10

The City of Wilmington has (2015-16) installed a stormwater treatment wetland (Figure 4.2) at the intersection of Patricia and Sharon Drives just upstream of NB-GLR. Regular sampling has been re-initiated in 2020 so 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 two occasions during spring 2019 (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 and suspended solids were generally low to moderate (< 17 mg/L). Dissolved oxygen concentrations dropped slightly below the NC standard of 5 mg/L on one sampling occasion at both HW-DT and HW-GP in 2019 (Appendix B).

Nitrate and ammonium concentrations were both low at both sites in 2019 (Table 8.1). Orthophosphate was also low at the two sites. Mean and median inorganic molar N/P ratios were relatively high (>18), indicating that, at least in spring, phosphorus 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 at HW-DT on one of the two occasions in 2019, with a bloom (chlorophyll *a* of 85 µg/L) that doubled the state standard.

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, both sites stayed below the water contact standard of 200 CFU/100 mL on both sampling occasions. In 2019 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.

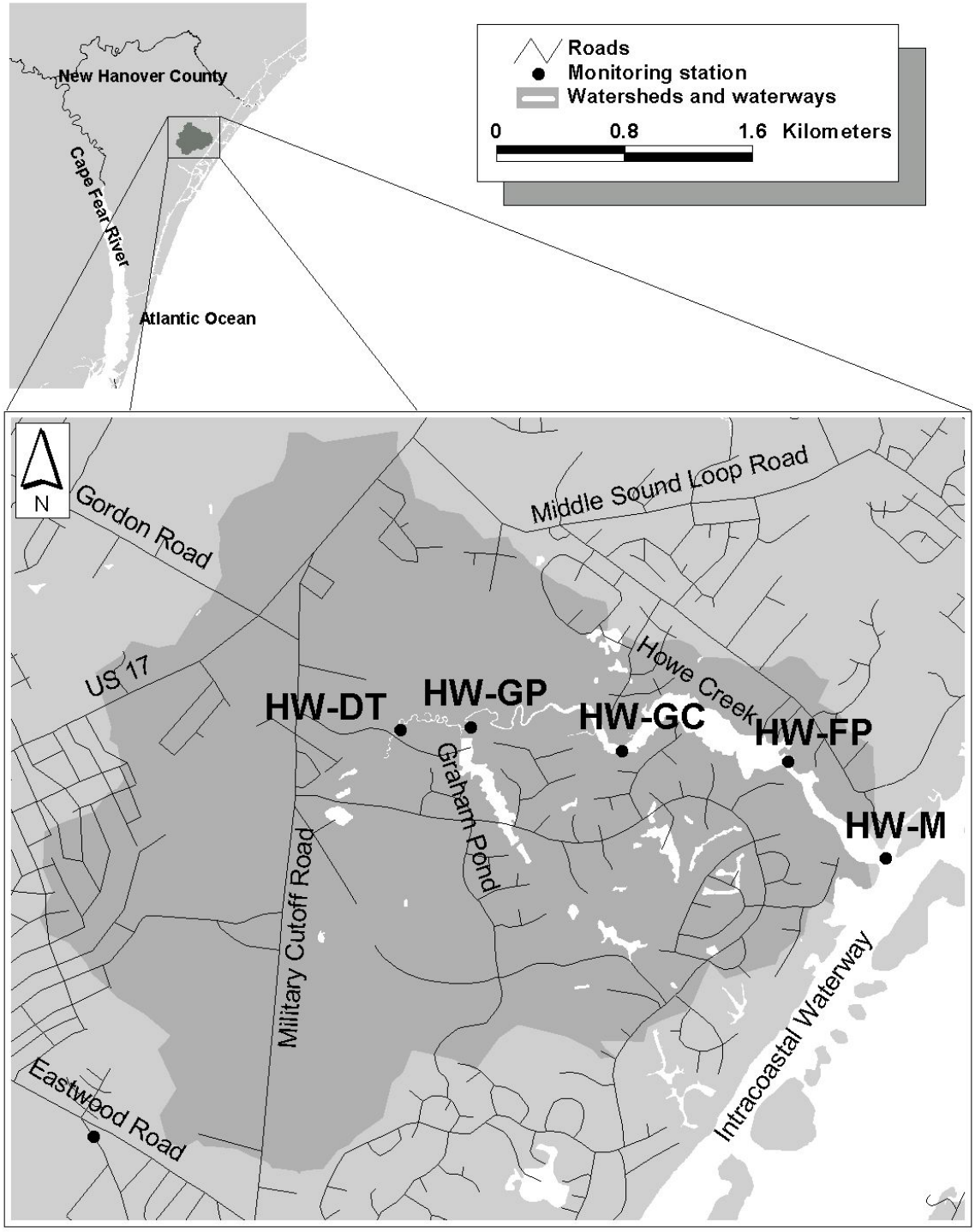


Table 8.1. Water quality summary statistics for Howe Creek, 2019, as mean (st. dev.) / range. Fecal coliform bacteria as geometric mean / range, n = 2 samples collected.

Parameter	HW-DT	HW-GP
Salinity (ppt)	7.5(8.1) 1.7-13.2	23.7(10.0) 16.6-30.8
Dissolved oxygen (mg/L)	8.7(5.7) 4.6-12.7	7.2(3.3) 4.9-9.5
Turbidity (NTU)	5(2) 4-7	3(2) 1-4
TSS (mg/L)	11.9(3.5) 9.4-14.3	10.5(6.1) 6.2-14.8
Nitrate (mg/L)	0.045(0.049) 0.010-0.080	0.040(0.042) 0.010-0.070
Ammonium (mg/L)	0.165(0.035) 0.140-190	0.175(0.177) 0.050-0.300
Orthophosphate (mg/L)	0.025(0.007) 0.020-0.030	0.015(0.007) 0.010-0.020
Molar N/P ratio (mean / median)	19.6 19.6	30.4 30.4
Chlor *a* (μg/L)	48(53) 10-85	8(5) 4-11
Fecal coliforms (CFU/100 mL)	186 182-190	46 46-46

Figure 8.2. Howe Creek chlorophyll *a* concentrations (algal blooms) below Graham Pond before and after 1998 wetland enhancement, 1993-2019.

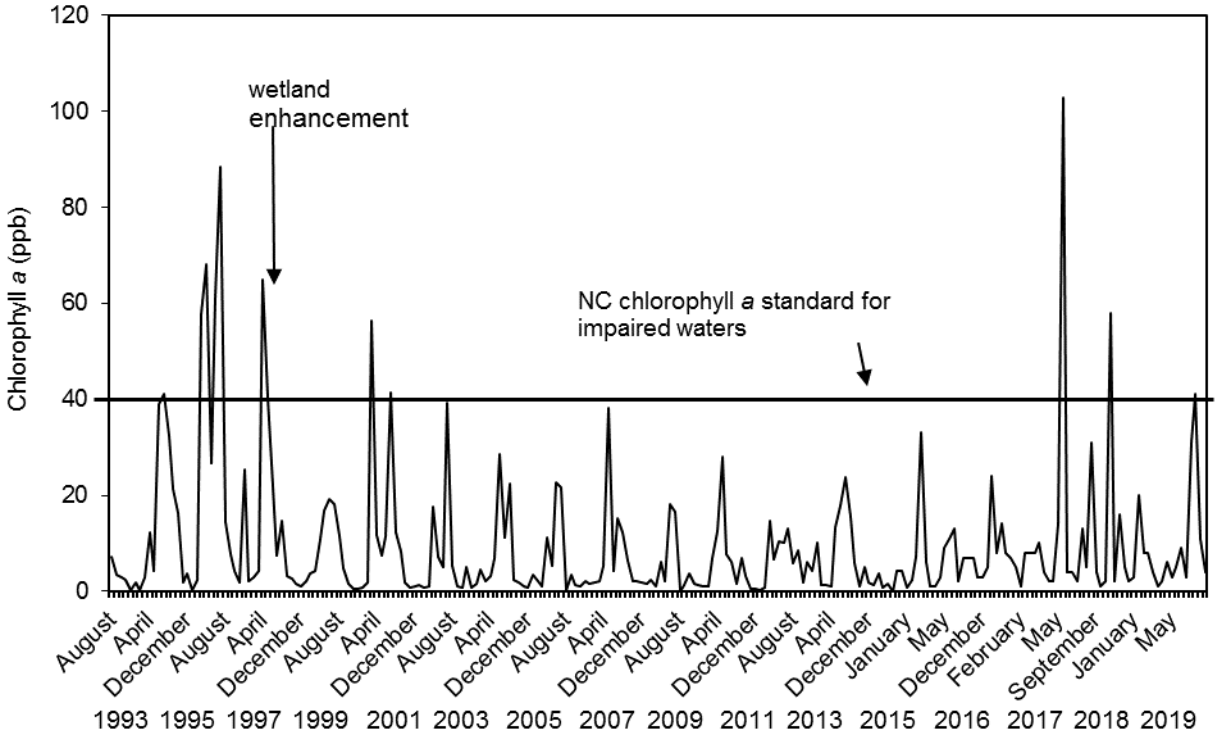
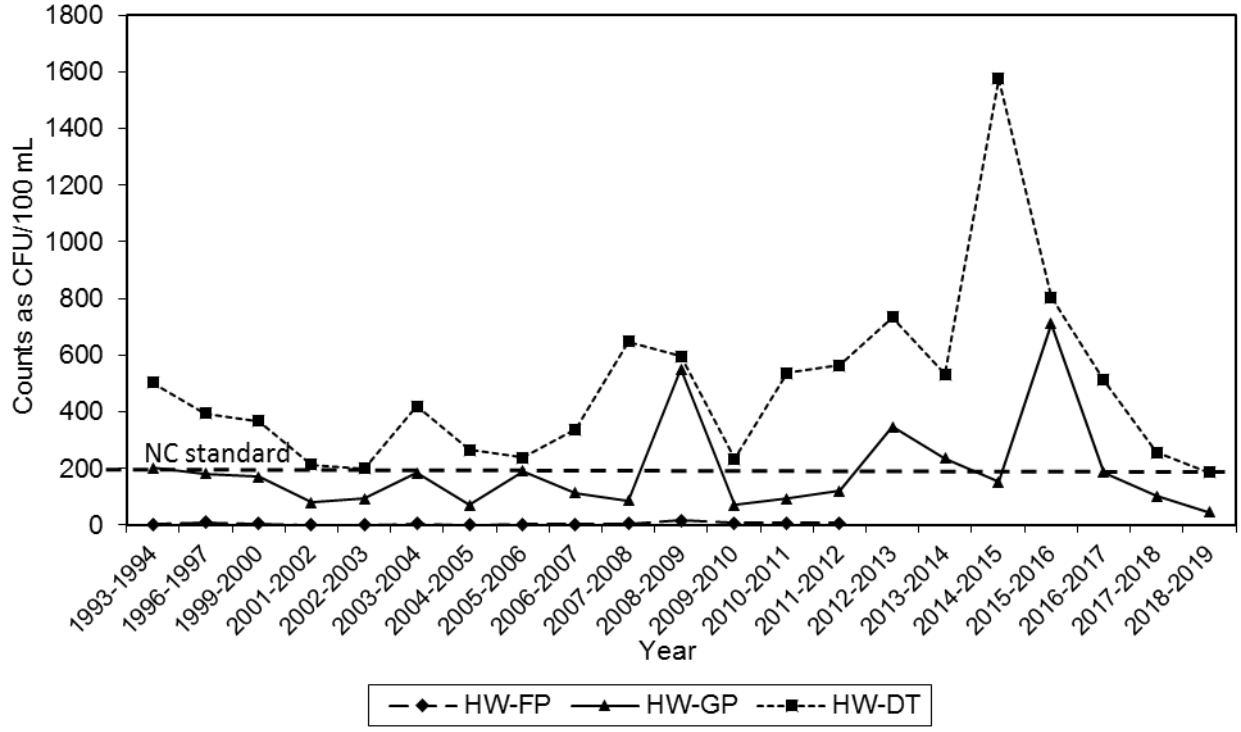


Figure 8.3. Annual fecal coliform counts (as geometric means) over time for Howe Creek stations, 1993-2019.



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

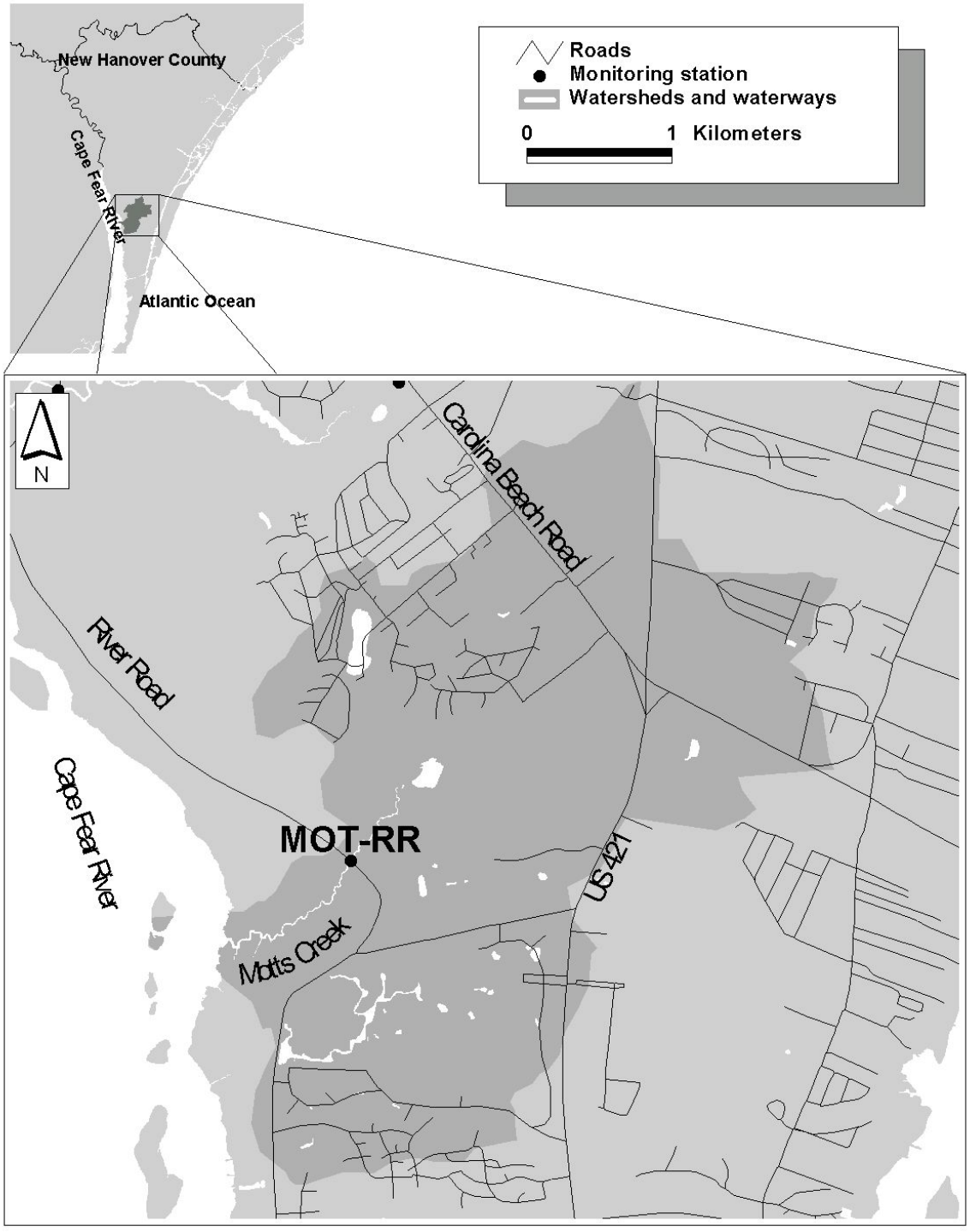
Motts Creek drains into the Cape Fear River Estuary (Fig. 9.1), and the creek area near River Road has been classified by the State of North Carolina as a Natural Heritage Site because of the area's biological attributes. These include the pure stand wetland communities, including a well-developed sawgrass community with large cypress in the swamp forest. City funding received by UNCW in late 2017 allowed us to re-initiate sampling of Motts Creek at River Road (MOT-RR) 2018-2019.

Motts Creek at this site is considered to be oligohaline, which is, maintaining salinities less than 5 ppt. We caution that due to funding issues this site was only sampled twice, so limited conclusions can be drawn. Dissolved oxygen was generally good, and turbidity and suspended solids were generally low. Ammonium was low and nitrate concentrations moderate, as were phosphorus concentrations. There were no notable algal blooms. Fecal coliform bacteria were somewhat high in one of the two months sampled.

Table 9.1. Selected water quality parameters in Motts Creek watershed as mean (standard deviation) and range, 2019, n = 2 samples collected.

Parameter	MOT-RR	
	Mean (SD)	Range
Salinity (ppt)	2.4 (2.8)	0.4-4.4
Dissolved oxygen (mg/L)	6.4 (1.0)	5.7-7.1
Turbidity (NTU)	9 (2)	7-10
TSS (mg/L)	12.8 (7.1)	7.8-17.8
Ammonium (mg/L)	0.12 (0.01)	0.11-0.12
Nitrate (mg/L)	0.20 (0.10)	0.13-0.27
TN (mg/L)	0.85 (0.17)	0.73-0.97
Orthophosphate (mg/L)	0.04 (0.03)	0.02-0.06
TP (mg/L)	0.49 (0.46)	0.16-0.81
N/P ratio (mean and median)	20.5	20.5
Chlorophyll *a* (µg/L)	11 (8)	5-16
Fecal col. /100 mL (geomean and range)	210	110-401

Figure 9.1 Motts Creeks watershed

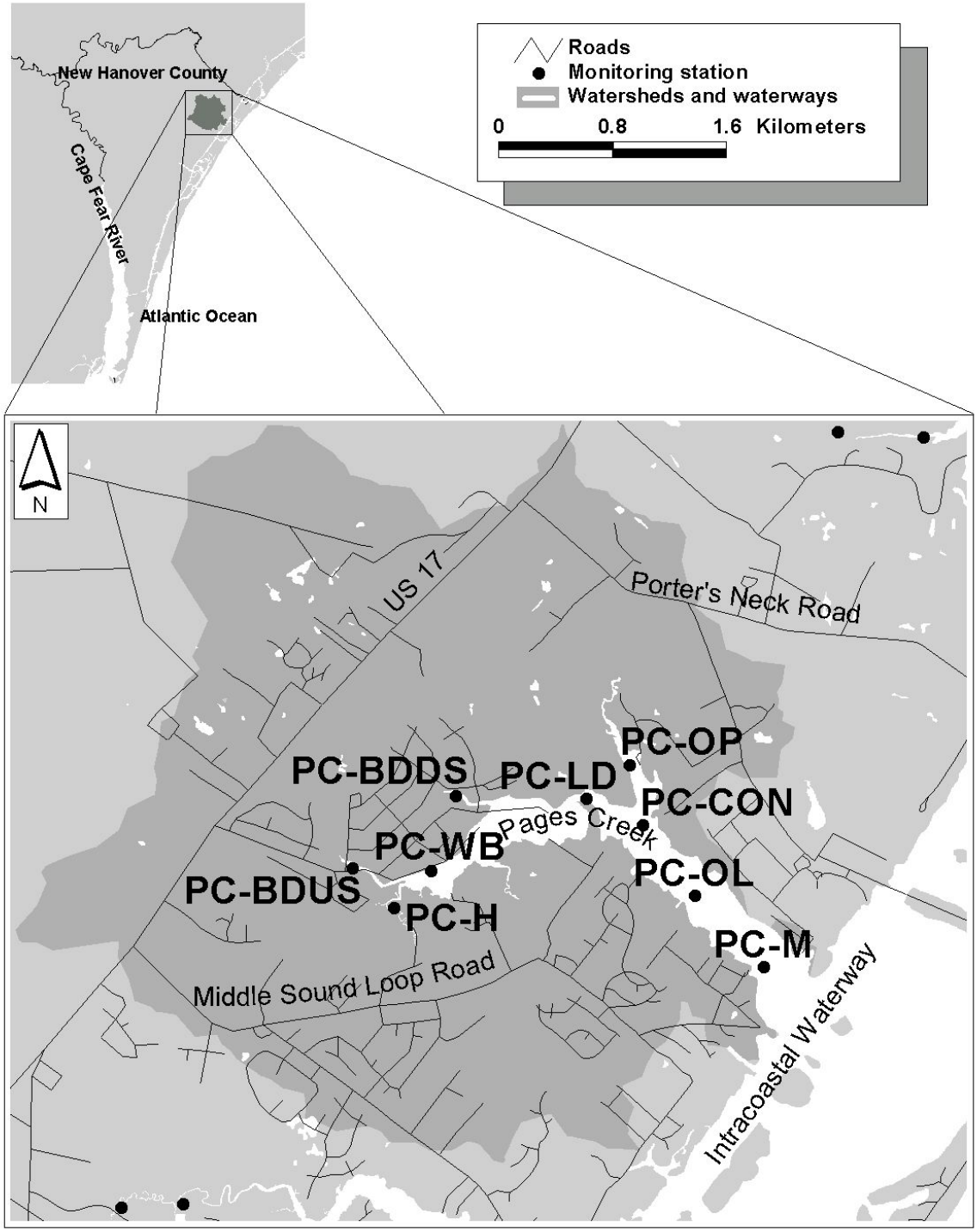


10.0 Pages Creek

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 2019 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).

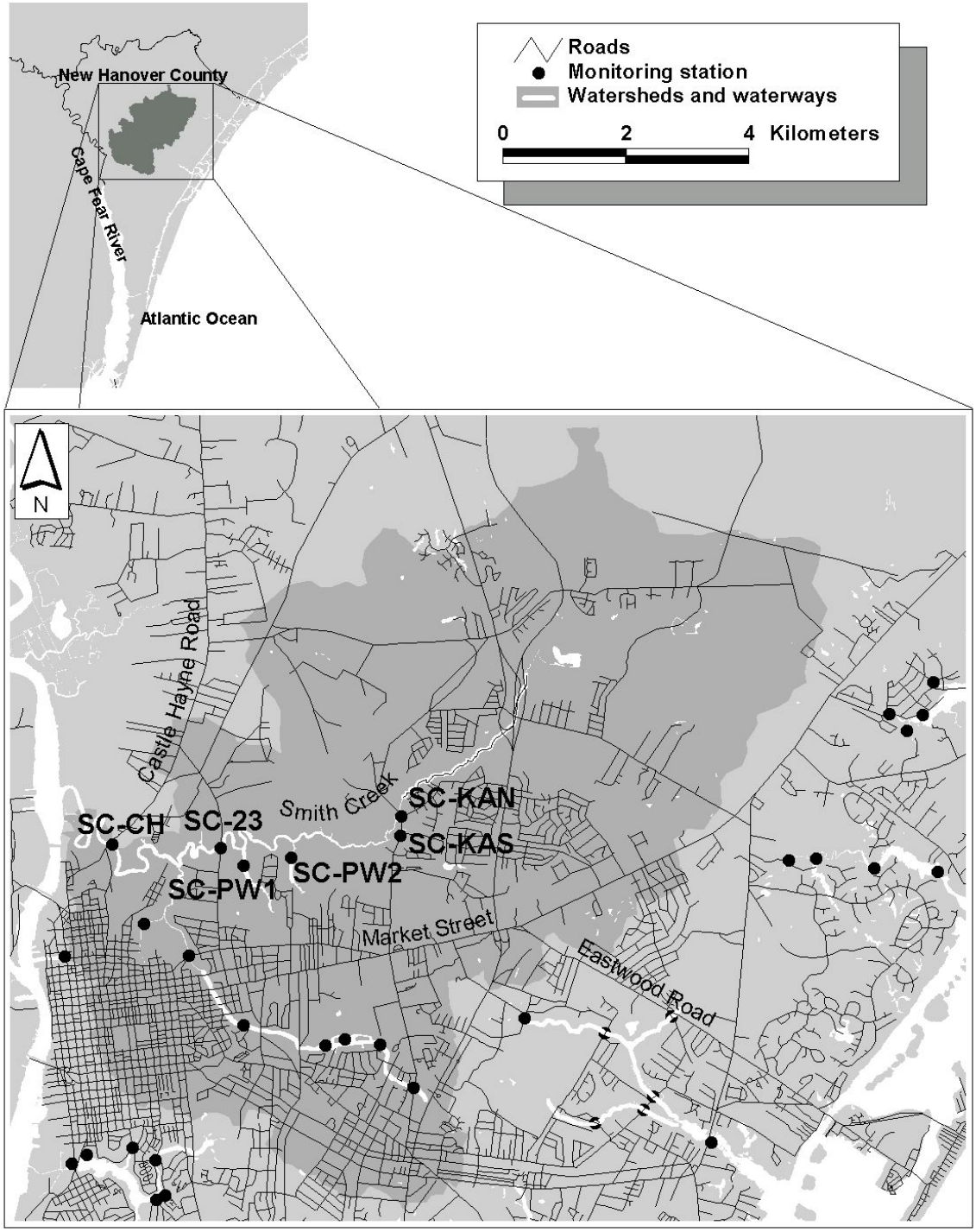
The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters, is 4.0 mg/L, and was violated on three occasions in our 2019 samples for a Fair rating. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded in our 2019 samples, and TSS concentrations were not excessive.

Ammonium and phosphate were low in 2019 (Table 11.1), although nitrate in this creek is relatively high compared to other tidal creeks. There was one minor algal bloom (23.0 µg/L) in August of 2019. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on only one of 12 sampling occasions at SC-CH in 2019, for a Good rating (Table 11.1).

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range, 2019, n = 12 samples collected.

Parameter	SC-CH Mean (SD)	Range
Salinity (ppt)	4.7 (5.0)	0.1-15.2
Dissolved oxygen (mg/L)	6.2 (2.1)	3.7-9.4
Turbidity (NTU)	9 (4)	3-14
TSS (mg/L)	15.6 (7.6)	1.3-24.0
Ammonium (mg/L)	0.063 (0.048)	0.010-0.170
Nitrate (mg/l)	0.299 (0.217)	0.010-0.620
Orthophosphate (mg/L)	0.030 (0.006)	0.020-0.040
Chlorophyll *a* (µg/L)	7.0 (6.0)	1-23
Fecal col. /100 mL (geomean / range)	25	5-240

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; occasional minor low dissolved oxygen issue

Whiskey Creek drains into the ICW. Sampling of this creek began in August 1999, at five stations. One station was dropped due to access issues in 2005; four stations were sampled until and including 2007; in 2008 this was reduced to one station, WC-MLR (from the bridge at Masonboro Loop Road – Fig. 12.1). In 2019 salinity at this station was relatively high, what scientists consider euhaline, ranging from 21 – 25 ppt and averaging about 23 ppt (Table 12.1). Due to funding issues this creek was only sampled twice, so only limited conclusions can be drawn.

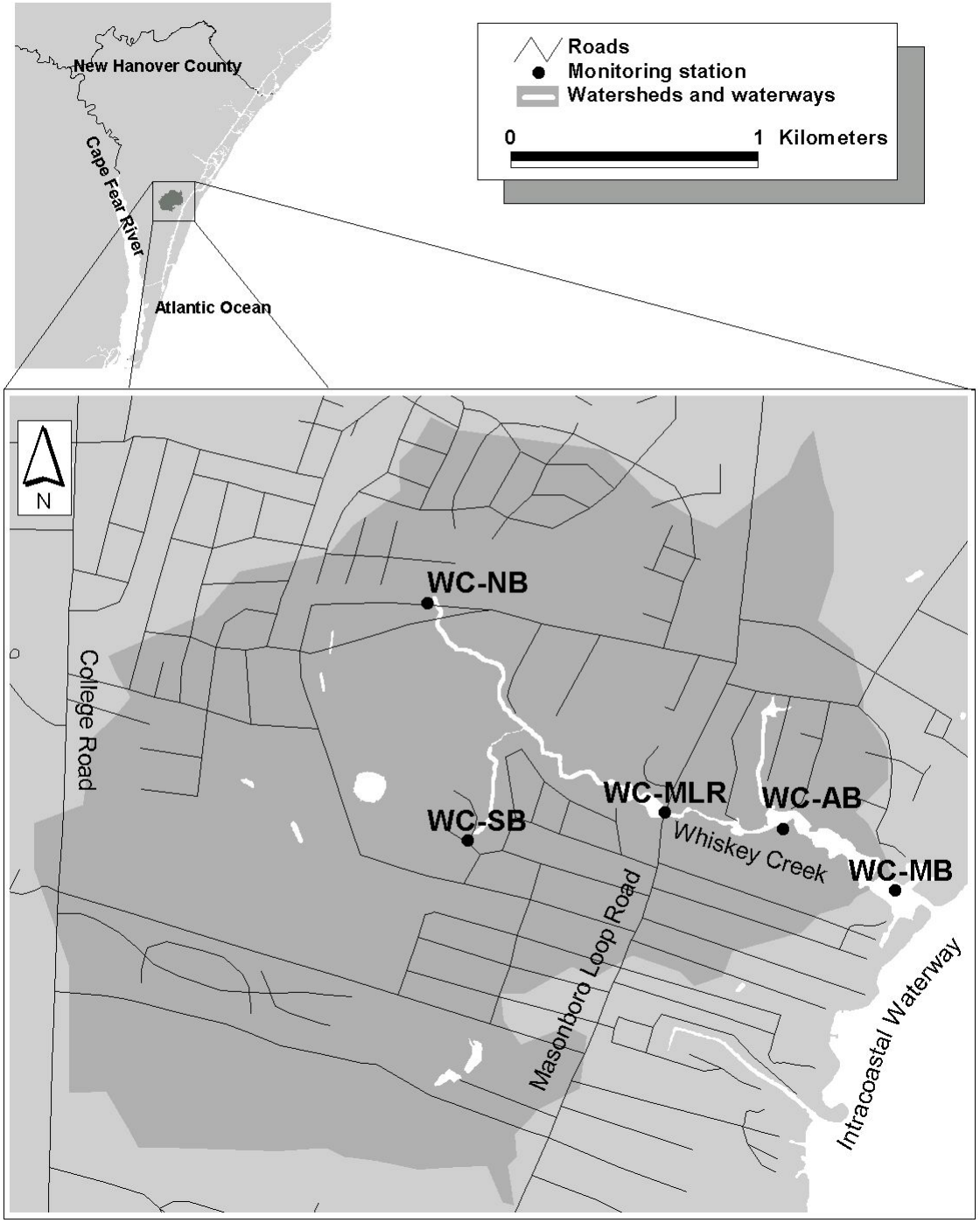
Turbidity was very low on both sampling occasions, and total suspended solids (TSS) not a problem during 2019 (Table 3.1). Dissolved oxygen was within standard (> 5.0 mg/L) on both sampling occasions (Appendix B).

Ammonium and nitrate concentrations were low on both occasions, and total nitrogen concentrations were likewise low. Orthophosphate and TP concentrations were also low. Our Whiskey Creek station did not host significant algal blooms during the two spring sampling trips in 2019. 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 growth in the lower creek. Fecal coliform bacteria counts were within standard on both sampling occasions (Table 3.1).

Table 12.1. Selected water quality parameters in Whiskey Creek watershed as mean (standard deviation) and range, 2019, n = 2 samples collected.

Parameter	WC-MLR	
	Mean (SD)	Range
Salinity (ppt)	23.1 (2.2)	21.5-24.6
Dissolved oxygen (mg/L)	8.6 (1.6)	7.5-9.7
Turbidity (NTU)	4 (1)	3-5
TSS (mg/L)	12.5 (3.4)	10.1-14.9
Ammonium (mg/L)	0.03 (0.00)	0.03-0.03
Nitrate (mg/L)	0.05 (0.01)	0.04-0.05
TN (mg/L)	0.45 (0.13)	0.35-0.54
Orthophosphate (mg/L)	0.02 (0.00)	0.02-0.02
TP (mg/L)	0.08 (0.05)	0.04-0.11
N/P ratio (mean and median)	8.3	8.3
Chlorophyll *a* (µg/L)	1.5 (0.7)	1-2
Fecal col. /100 mL (geomean and range)	92	73-115

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 2019, 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	G	G	G	G
Bradley Creek	BC-CA	G	G	G	P
	BC-SB	G	G	G	P
	BC-NB	G	G	G	G
Burnt Mill Creek	BMC-AP1	G	G	F	P
	BMC-AP3	G	G	G	G
	BMC-PP	F	F	G	F
Greenfield Lake	JRB-17	G	G	F	P
	GL-JRB	G	F	G	P
	GL-LC	F	G	G	F
	GL-LB	G	P	G	P
	GL-2340	P	G	F	G
	GL-YD	P	G	G	G
	GL-P	P	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	G	G	G
	PVGC-9	G	G	G	P
Howe Creek	HW-GP	G	P	G	G
	HW-DT	P	P	G	G
Motts Creek	MOT-RR	G	G	G	P
Smith Creek	SC-CH	G	F	G	G
Whiskey Creek	WC-MLR	G	G	G	G

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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