ENVIRONMENTAL QUALITY OF WILMINGTON AND
NEW HANOVER COUNTY WATERSHEDS, 2021

by

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Executive Summary

This report represents results of Year 24 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The 2021 program involved 6 watersheds and 20 sampling stations. In this summary we first present brief water quality overviews for each watershed from data collected between January and December 2021. As part of a change in priorities, sampling at Barnards, Howe, Motts and Whiskey Creek were suspended for the time being to emphasize upper Bradley Creek and the Greenfield Lake watershed, both of which are scheduled for restoration measures; also two new sites in Barnards Creek upstream in Carriage Hills were sampled.

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. In October 2021 sampling was initiated at two upper creek sites near Carriage Hills close to a wet detention pond (CHP-U and CHP-D). Early data show some potential dissolved oxygen and fecal bacteria issues, but we caution that is only based on three samples.

Bradley Creek – Bradley Creek drains a watershed of 4,583 acres, including much of the UNCW campus, into the Atlantic Intracoastal Waterway (AICW – Plate 1). The watershed contains about 27.8% impervious surface coverage, with a population of about 16,470. The uppermost site, BC-RD, is on upper Clear Run at Racine Dr., and subsequently drains downstream to BC-CA, Clear Run at College Acres. The two lower sites currently sampled are BC-NB, Bradley Creek north branch at Wrightsville Ave., and BC-SB, Bradley Creek south branch at Wrightsville Ave.). The sites were sampled six times in 2021.

High turbidity and suspended solids in 2021 were not problematic. Dissolved oxygen was stressed (< 5.0 mg/L) on most occasions at the two upper sites BC-RD and BC-CA. Nitrate and especially total phosphorus concentrations were elevated in Clear Run compared with the lower two sites on Wrightsville Avenue. Except for BC-RD, our Bradley Creek stations did not host significant algal blooms during the 2021 sampling trips. Fecal coliform bacteria counts were moderate at the lower two sites but particularly excessive at BC-RD and BC-CA, which had geometric mean counts of 823 and 750 CFU/100 mL, compared with the NC standard for safe waters of 200 CFU/100 mL.

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 2021, on six occasions. Fecal coliform conditions were rated Poor in at the lowermost station BMC-PP at Princess Place and Fair in the upper two sites BMC-AP1 above and BMC-AP3 below Anne McCrary Pond, the regional wet detention pond on Randall Parkway. Dissolved oxygen concentrations were Good in the two upper stations and Poor in the remaining lower creek site.

We note that fecal coliform counts significantly declined during passage through the detention pond. Several algal blooms occurred in the pond and one major bloom occurred at BMC-PP in May 2021. Several water quality parameters showed an increase in pollutant levels along the creek from the outfall from the detention pond to the downstream Princess Place sampling station, including fecal coliform bacteria, nitrogen and phosphate, 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 2021. 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 three tributary stream sites and three in-lake sites on 11 occasions. Of the tributaries of Greenfield Lake, Squash Branch (GL-SQB, near Lake Branch Drive), Jumping Run Branch at 17^{th} Street and Jumping Run Branch at Lakeshore Dr.,GL-SQB suffered from low dissolved oxygen problems, as did GL-2340 in the main lake.

Algal blooms are chronically problematic in Greenfield Lake and have occurred during all seasons. In 2021 a massive summer-fall blue-green algal bloom of *Anabaena* occurred. In August this organism, combined with Microcystis aeruginosa produced measurable toxicity. Previously published studies found 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, and high BOD occurred congruent with the blooms in 2021. In 2021 all three tributary stations exceeded the fecal coliform State standard on >45% of occasions sampled and rated Poor; the in-lake stations were in Fair condition for fecal bacteria except for GL-2340, rated Poor.

Greenfield Lake is currently on the NC 303(d) list for impaired waters due to excessive algal blooms. The thesis work of former UNCW graduate student Nick Iraola assessed the five main inflowing tributaries to the lake to demonstrate 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 the engineering firm Moffat & Nichol) were awarded funds for 2020-2022 and UNCW has been sampling in support of future nutrient reduction efforts on Jumping Run Branch. Data show the Willard Street Wetland, between Willard St., 15^{th} St. and 16^{th} St. receives high nutrient and very high fecal coliform loads from inflowing drains, and elevated concentrations of those pollutants make it out of the wetland into Jumping Run Branch. An analysis of sediment phosphorus loads found elevated concentrations in Jumping Run Branch both upstream and downstream of the golf course. The engineering team is currently completing strategies to restore the wetland to reduce the pollutant load, and the City is planning to take action on those strategies.

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 2021 the creek was sampled at four tidal sites on six occasions.

Only minor incidents of low dissolved oxygen occurred in Hewletts Creek in 2021. Turbidity was low and did not exceed the state standard, and no major algal blooms occurred. Fecal coliform bacteria counts were elevated somewhat at MB-PGR and NB-GLR, but no sites had a geometric mean that exceeded 200 CFU/100 mL; and the geometric mean of fecal bacteria counts at HC-3 was not over 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. Due to resource re-allocation, sampling was suspended here in 2020.

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%. Due to Covid-19 and resource re-allocation, sampling was suspended here in 2020.

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 2008-2021. 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 (Plate 1). 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 only one of 8 occasions in our 2021 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 2021 sampling, although nitrate increased considerably over 2020. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on only one of 8 sampling occasions in 2021 for a Fair rating.

Whiskey Creek – Whiskey Creek is the southernmost large tidal creek in New Hanover County that drains into the AICW (Plate 1). It has a watershed of 2,078 acres, a population of about 8,000, and is covered by approximately 25.1% impervious surface area. Due to resource re-allocation, sampling was suspended here for 2021.

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 2021 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 (20 sites sampled for fecal coliforms) showed 10% to be in Good condition, 45% in Fair condition and 45**%** in Poor condition. Dissolved oxygen conditions (measured at the surface) system-wide (20 sites) showed 40% of the sites were in Good condition, 30% were in Fair condition, and 30% were in Poor condition. For algal bloom presence, measured as chlorophyll *a*, 65% of the 20 stations sampled were rated as Good, 20% as Fair and 15% as Poor. For turbidity, 100% of sites were Good. It is important to note that the water bodies with the worst water quality in the system also have the most developed watersheds with the highest impervious surface coverage; Burnt Mill Creek – 39% impervious coverage; Greenfield Lake – 37% impervious coverage; Bradley Creek – 28% impervious coverage.

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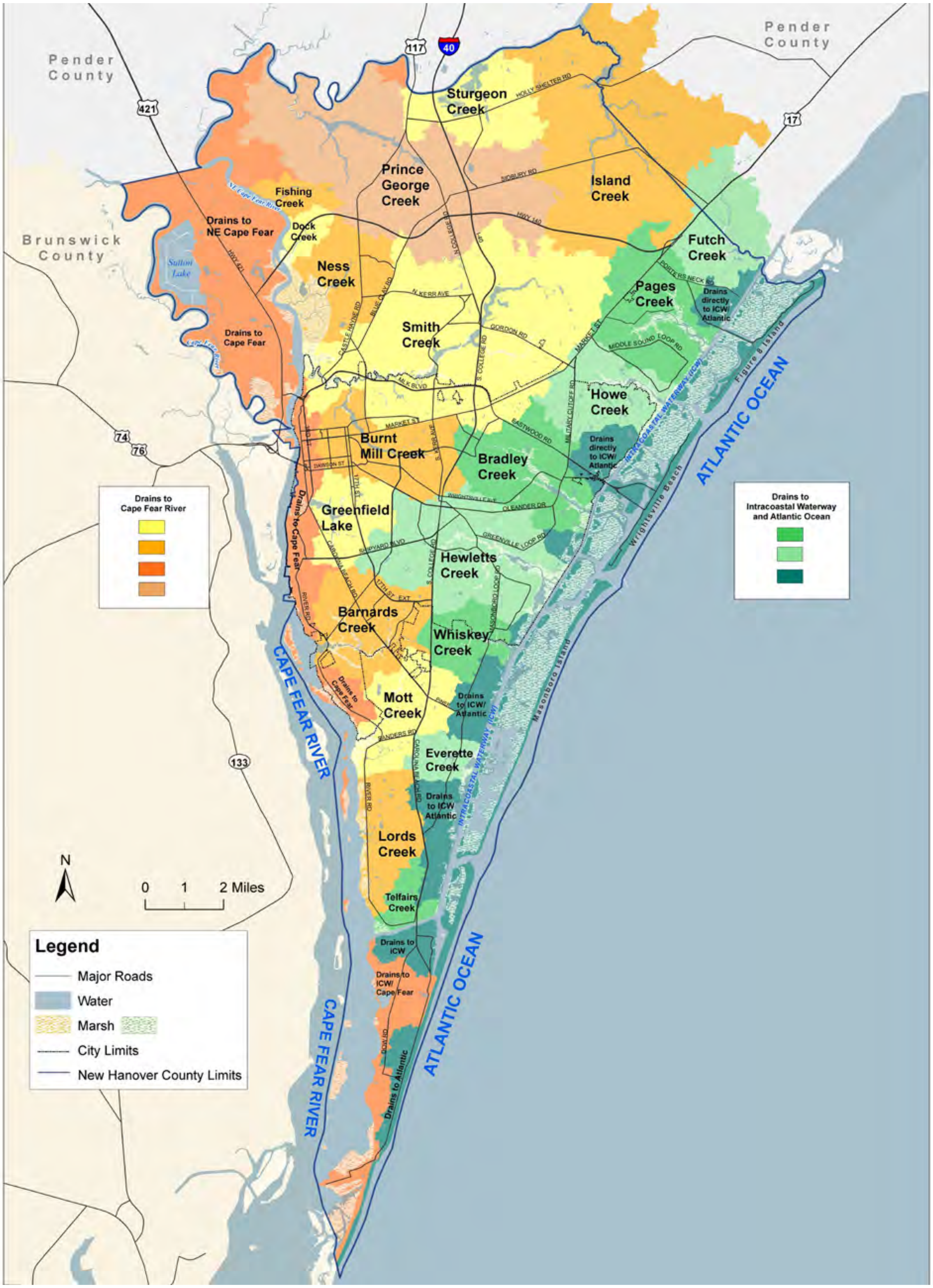


Plate 1. Wilmington and New Hanover County watersheds 2014 map by Wilmington Stormwater Services. Station coordinates are in Appendix C.

1.0 Introduction

In 1993 scientists from the Aquatic Ecology Laboratory at the UNC Wilmington Center for Marine Science Research began studying five tidal creeks in New Hanover County. This project, funded by New Hanover County, the Northeast New Hanover Conservancy, and UNCW, yielded a comprehensive report detailing important findings from 1993-1997, and produced a set of management recommendations for improving creek water quality (Mallin et al. 1998). Data from that report were later published in the peer-reviewed literature (Mallin et al. 2000) 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. Also, certain sites were analyzed for sediment heavy metals concentrations (EPA Priority Pollutants). In the past 24 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 2021, with current funding by the City of Wilmington, the U.S. Fish & Wildlife Service and the NCDEQ 319 Program. In 2020 sampling at lower Barnards and Motts Creeks, Howe Creek and Whiskey Creek were suspended to emphasize upper Bradley Creek and the Greenfield Lake watershed, both of which are scheduled for restoration measures; in fall 2021 sampling of upper Barnard's Creek near Carriage Hills wet detention pond was initiated.

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 three to eleven occasions at 19 locations within the Wilmington City watersheds between January and December 2021. In addition, one station on Smith Creek was also sampled during 8 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 or Pro DSS Multiparameter Water Quality sonde linked to a YSI EXO or Pro DSS display unit. Individual probes within the instrument measured water temperature, pH, dissolved oxygen, turbidity, salinity, and conductivity. The YSI 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 to 24 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

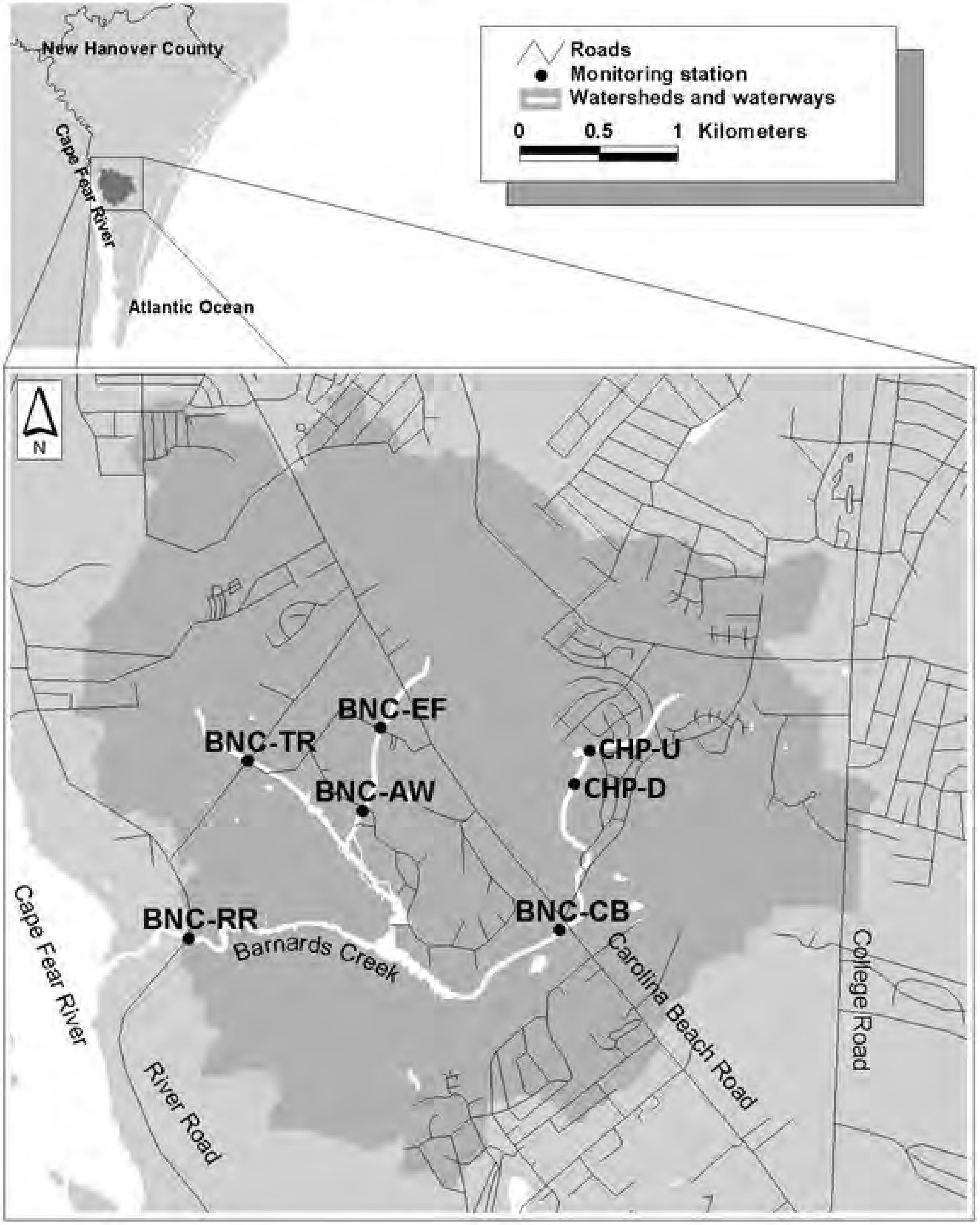
Lower Barnard's Creek drains single family and multifamily housing upstream of Carolina Beach Rd. in the St. Andrews Dr. area and along Independence Boulevard near the Cape Fear River. Another major housing development (River Lights) is well under construction between Barnards and Motts Creeks. This 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. In 2020 sampling of this creek was suspended due to Covid-19 and resource re-allotment. In October 2021 the City commenced funding UNCW to sample two locations on upper Barnards Creek adjacent to Carriage Hills wet detention pond, CHP-U and CHP-D.

Early data (Table 2.1) show some potential dissolved oxygen and fecal bacteria issues, but we caution that is only based on three samples. There were no algal blooms, and nutrients, turbidity and suspended solids were low.

Table 7.1. Selected water quality parameters at sites upstream (CHP-U) and downstream (CHP-D) of Carriage Hills wet pond in upper Barnards Creek, 2021 as mean (standard deviation) / range, inorganic N/P ratios as mean / median, fecal coliform bacteria presented as geometric mean / range, n = 3 samples collected October - December.

Parameter	CHP-U	CHP-D
Salinity (ppt)	0.1 (0) 0.1-0.1	0.1 (0) 0.1- 0.1
Turbidity (NTU)	2 (1) 1-3	5 (3) 3-9
TSS (mg/L)	1.2 (0.0) 1.2-1.2	6.6 (6.6) 1.2-13.9
DO (mg/L)	5.6 (1.5) 4.4-7.3	5.8 (0.2) 5.7-6.1
Nitrate (mg/L)	0.040 (0.060) 0.010-0.110	0.060 (0.060) 0.010-0.120
Ammonium (mg/L)	0.050 (0.050) 0.010-0.100	0.070 (0.050) 0.040-0.130
TN (mg/L)	0.046 (0.047) 0.110-0.840	0.042 (0.028) 0.120-0.670
Orthophosphate (mg/L)	0.020 (0.020) 0.010-0.040	0.020 (0.010) 0.010-0.020
TP (mg/L)	0.120 (0.040) 0.090-0.170	0.060 (0.040) 0.020-0.100
N/P inorganic	9 11	17 18
Chlorophyll *a* (μg/L)	0 (1) 0-1	6 (2) 4-8
Fecal col. (CFU/100 mL)	227 164-410	140 44-591

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

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 has been massive redevelopment of the former Duck Haven property bordering Eastwood Road and development across Eastwood Road; which drains 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) have been sampled in previous years, both fresh and brackish (Fig. 3.1), and a new site, BC-RD on Racine Drive (see cover photo) was added in July as stream restoration activities are planned for this upper branch (also called Clear Run) and more background data are needed. Thus, there were six samples collected at all sites in 2021. The drainage area for BC-RD is approximately 90% impervious surface coverage.

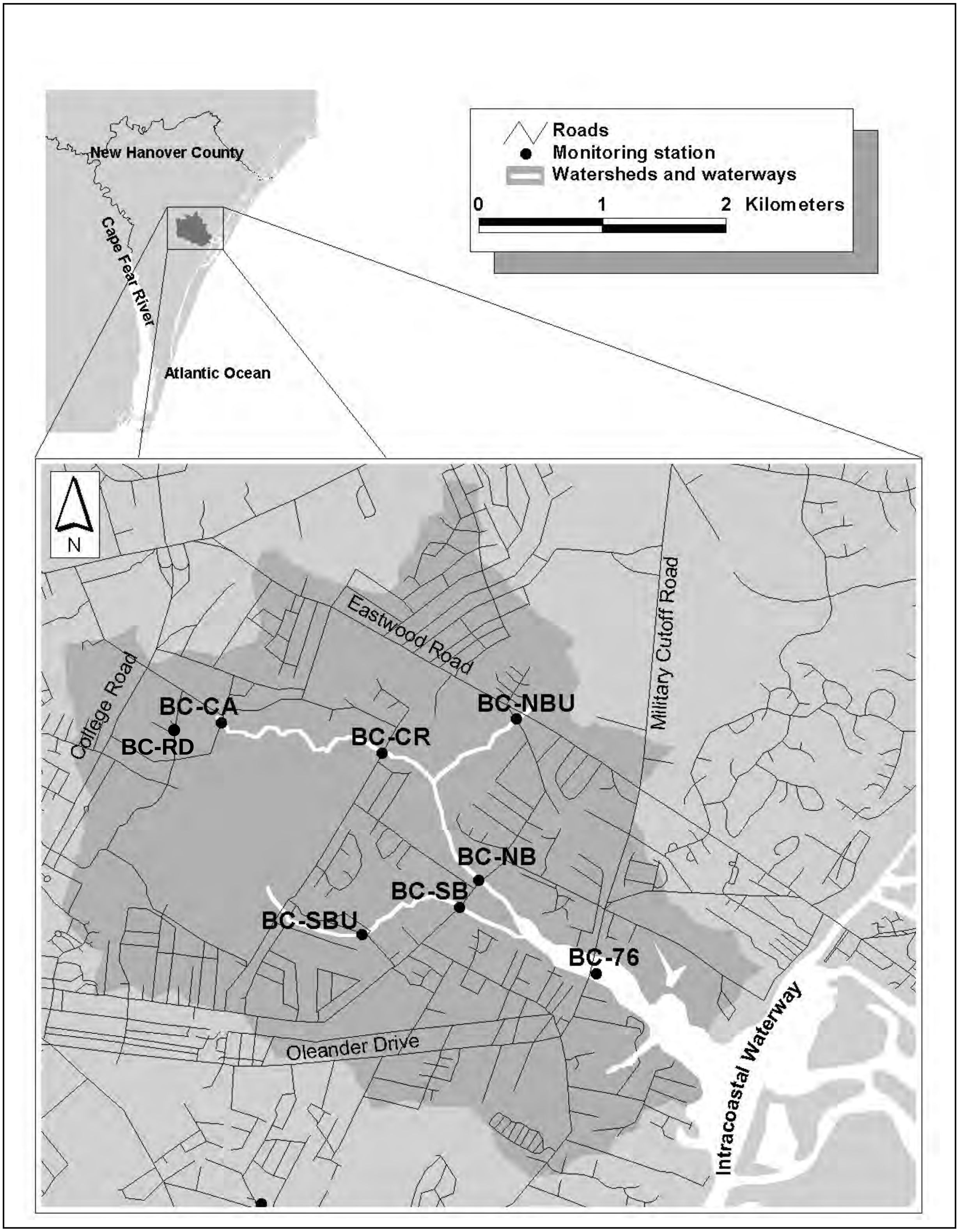
Turbidity was not a problem during 2021; the standard of 25 NTU was not exceeded (Table 3.1). There are no NC ambient standards for total suspended solids (TSS), but UNCW considers 25 mg/L high for the Coastal Plain. As such, TSS exceeded that number twice at BC-SB. Dissolved oxygen was below standard (< 5.0 mg/L) on 50% of the time at BC-RD and 67% of the time at BC-CA, and once each at the other two sites.

Nitrate concentrations were low to moderate at all sites, but ammonium was elevated above 0.300 µg-N/L on several occasions at all sites (Table 3.1). Orthophosphate concentrations were low in general at all the sites. Our Bradley Creek stations did not host algal blooms during the sampling trips in 2021 except for station BC-RD. Median nitrogen to phosphorus ratios at BC-NB and BC-SB were moderately high; as orthophosphate was low but ammonium was unusually high. Fecal coliform bacteria counts were moderate at the two stations on Wrightsville Avenue (Table 3.1) but counts were very high at BC-RD and BC-CA, with geometric means of 823 and 750 CFU/100 mL, respectively, and maxima of 30,000 CFU/100 mL at BC-RD compared with the NC standard of 200 CFU/100 mL for freshwater safety. Note that upper Clear Run receives considerable drainage from across College Road (Fig. 3.1) where there are large parking lots and high (>90%) impervious surface coverage. There is also a considerable amount of dog feces lying on the ground near BC-RD between the nearest apartment parking lot and the creek.

Table 3.1. Water quality parameter concentrations at Bradley Creek sampling stations, 2021. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 6 samples collected.

Station	BC-RD	BC-CA	BC-NB	BC-SB
Salinity (ppt)	0.1 (0.0) 0.1-0.1	0.1 (0.0) 0.1-0.1	30.9 (5.1) 21.6-34.5	21.5 (11.1) 5.9-31.4
DO (mg/L)	5.0 (2.0) 3.2-7.6	4.4 (2.6) 1.4-7.4	6.9 (1.9) 3.9-8.8	6.9 (1.9) 3.7-9.1
Turbidity (NTU)	4 (4) 0-10	2 (2) 0-3	2 (2) 0-5	3 (1) 1-4
TSS (mg/L)	6.8 (6.9) 1.2-20.0	5.3 (3.2) 1.2-9.8	12.6 (3.1) 10.0-18.2	16.6 (8.6) 9.9-28.7
Nitrate (mg/L)	0.08 (012) 0.1-0.30	0.05 (0.04) 0.01-0.11	0.01 (0.00) 0.01-0.01	0.02 (0.02) 0.01-0.05
Ammonium (mg/L)	0.31 (0.25) 0.10-0.73	0.16 (0.16) 0.01-0.48	0.28 (0.20) 0.01-0.51	0.21 (0.23) 0.01-0.62
TN (mg/L)	1.28 (0.75) 0.30-2.06	0.91 (0.80) 0.05-2.39	0.71 (0.48) 0.33-1.64	0.77 (0.60) 0.05-1.84
Orthophosphate (mg/L)	0.04 (0.03) 0.01-0.09	0.03 (0.02) 0.01-0.06	0.02 (0.02) 0.01-0.05	0.02 (0.01) 0.01-0.03
TP (mg/L)	0.29 (0.16) 0.07-0.44	0.16 (0.11) 0.06-0.31	0.10 (0.09) 0.01-0.24	0.13 (0.14) 0.01-0.41
N/P	25 23	16 15	49 43	45 27
Chlorophyll *a* (µg/L)	19 (22) 2-62	9 (3) 6-13	3 (3) 1-7	4 (4) 1-12
Fecal coliforms (CFU/100 mL)	823 10-30,000	750 55-12,000	33 5-620	128 41-237

Figure 3.1. Bradley Creek watershed and sampling sites.



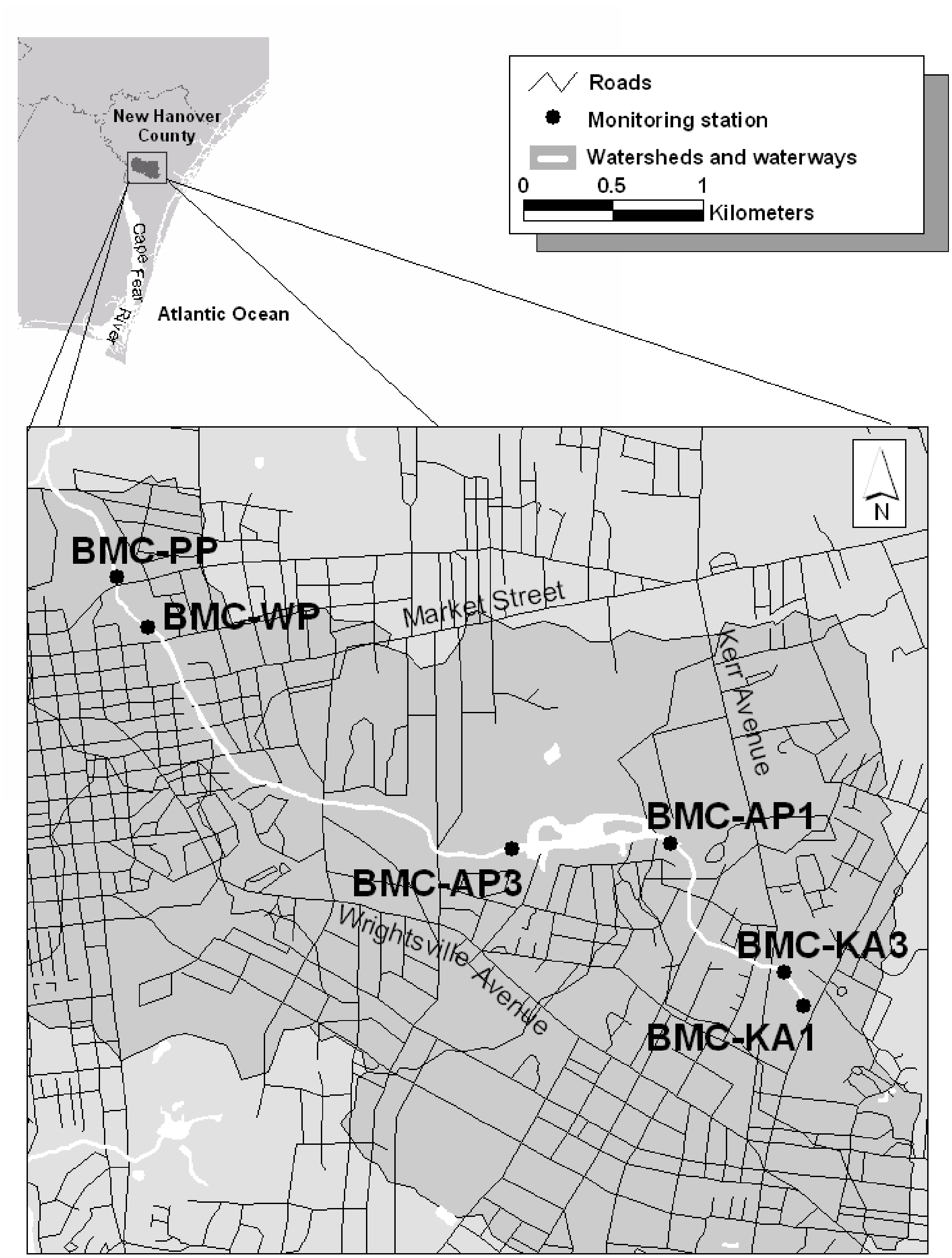
4.0 Burnt Mill Creek

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), water hyacinth overgrowths in 2021

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 (some of these taxa are invasive). 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; 2009b; 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. We note that in 2021 there was a large nuisance growth of water hyacinth *Eichhornia crassipes* that completely blocked the creek (see front cover photograph).

Sampling Sites: During 2021 samples were collected on six 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 six occasions in 2021. Dissolved oxygen concentrations were within standard on all sampling occasions at BMC-AP1 and BMC-AP3. Neither DO nor pH showed a significant ($p < 0.05$) change between the pond inflow and the outflow (Table 4.1). The NC standard for turbidity in freshwater is 50 NTU; there were no exceedences of this value during our 2021 sampling, but on average there was a significant increase through the pond. Total suspended solids concentrations were relatively low on most sampling occasions in 2021 except for a high reading of 80 mg/L at AP3 in December, and there was no significant change through the pond on average (Table 4.1). Fecal coliform concentrations at both Ann McCrary Pond stations were moderate, exceeding the state standard 17% of the time sampled (Table 4.1). There was a significant ($p < 0.05$) reduction in fecal coliform counts during passage through the regional detention pond (Table 4.1). There were two major and two minor algal blooms at BMC-AP3, ranging from 22-182 µg/L chlorophyll *a*, and chlorophyll *a* exiting the pond was significantly higher than entering the pond ($p < 0.05$). One of the blooms at BMC-AP3 contained potentially harmful cyanobacterial taxa. There were no statistically significant changes in nutrient concentrations between entering and exiting the pond (Table 4.1).

Lower Burnt Mill Creek: The Princess Place location (BMC-PP) was the only lower creek station sampled in 2021. One parameter that is key to aquatic life health is dissolved oxygen. Dissolved oxygen at BMC-PP was substandard (< 4.0 mg/L) on three of six 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 2021 there was one major algal bloom of 91 µg/L chlorophyll a at Station BMC-PP. 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 AP-3, just below the pond outfall were 18.8, almost the Redfield Ratio of 16, while AP-1 upstream had ratios considerably higher (>24). BMC-PP mean and median ratios were mixed with a mean of 27 and median of 17. In waters where the N/P ratio is well below 16 (the Redfield Ratio for algal nutrient composition; Hecky and Kilham 1988) 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. None of the three stations had geometric means exceeding the State standard for human contact waters (200 CFU/100 mL) in our 2021 samples. Fecal coliform counts were greater than the State standard on 33% of sampling occasions at BMC-PP, and 17% at BMC-AP1 and BMC-AP3. Whereas geometric mean fecal coliform counts at BMC-AP3 were 18 CFU/100 mL, counts then increased along the passage to the Princess Place location (geometric mean 169 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, 2021

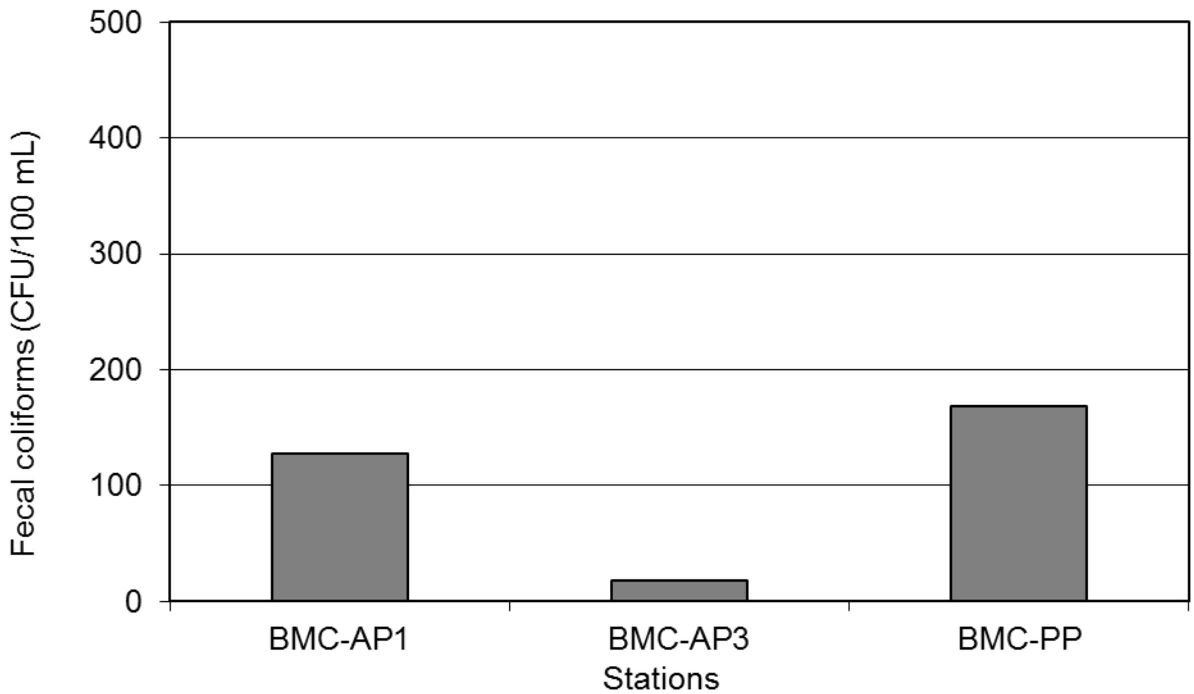
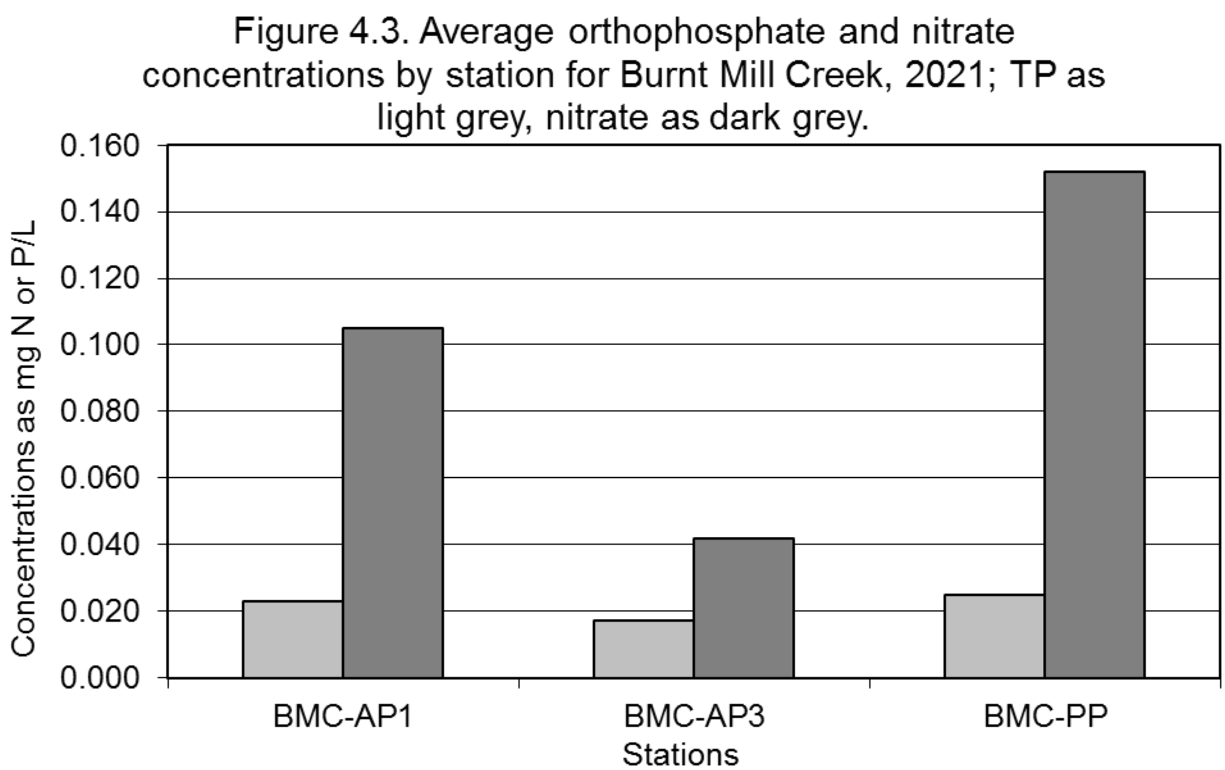


Table 4.1. Water quality data in Burnt Mill Creek, 2021, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as mean/median, n = 6 samples collected.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	8.8 (2.3) 6.7-13.0	10.1 (1.3) 8.6-12.3	5.3 (1.6) 3.7-7.2
Cond. (μS/cm)	263 (27) 215-293	239 (64) 117-303	508 (414) 266-1,348
pH	7.1 (0.3) 6.8-7.5	7.7 (0.3)** 7.3-8.3	7.3 (0.2) 7.2-7.7
Turbidity (NTU)	3 (2) 0-6	7 (2)* 6-11	2 (1) 1-3
TSS (mg/L)	3.2 (2.4) 1.2-7.8	20.2 (29.4) 4.8-80.0	3.5 (3.0) 1.2-9.3
Nitrate (mg/L)	0.105 (0.095) 0.010-0.220	0.042 (0.055) 0.010-0.040	0.152 (0.150) 0.010-0.330
Ammonium (mg/L)	0.085 (0.060) 0.010-0.180	0.060 (0.046) 0.010-0.110	0.080 (0.037) 0.050-0.150
TN (mg/L)	0.952 (0.854) 0.340-2.350	0.958 (0.825) 0.360-2.590	0.768 (0.305) 0.460-1.200
OrthoPhos. (mg/L)	0.023 (0.023) 0.010-0.070	0.017 (0.008) 0.010-0.030	0.025 (0.010) 0.010-0.040
TP (mg/L)	0.085 (0.088) 0.030-0.250	0.095 (0050) 0.040-0.150	0.090 (0.051) 0.050-0.160
N/P molar ratio	24.8 28.2	18.8 18.8	27.3 17.7
Chlor. *a* (μg/L)	12 (16) 1-44	51 (65)* 13-182	19 (35) 3-91
FC (CFU/100 mL)	128 44-773	18* 3-295	169 41-864

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

To summarize, in some years including 2021, Burnt Mill Creek has had problems with low dissolved oxygen (hypoxia) at the Princess Place station BMC-PP. One major algal bloom occurred in 2021 at BMC-PP (91 µg/L chlorophyll *a* in May; also in May a major bloom occurred at BMC-AP3). The N/P ratios in the lower creek indicate that inputs of phosphorus were likely to stimulate algal bloom formation in 2021, but such ratios have differed in previous years. It is notable that nutrient concentrations increased 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 BMC-PP and occasionally at the upper sites. 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 previously 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.

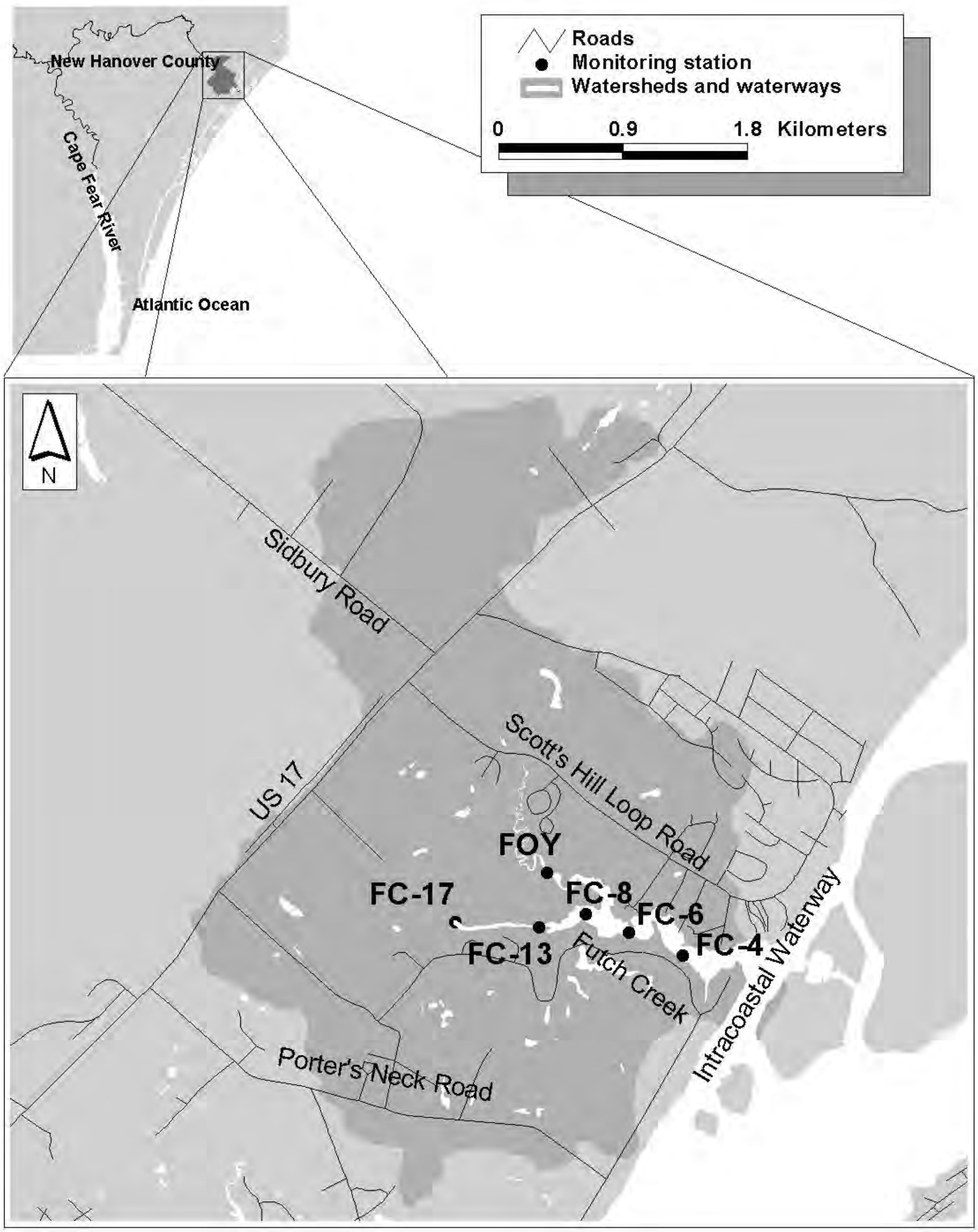


5.0 Futch Creek

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 following 2007. 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,low dissolved oxygen, and nutrient loading in tributaries, high BOD and algal blooms in main lake, sediments contaminated with metals and PAHs

Three stations on tributaries to Greenfield Lake were sampled for a full suite of physical, chemical and biological parameters on 11 occasions in 2021 (Table 6.1, Fig. 6.1). Some tributary stream sites suffered from low dissolved oxygen (DO), as GL-SQB (Squash Branch, formerly called GL-LB) showed DO concentrations below the state standard (DO < 5.0 mg/L) on 73% of sampling occasions (Table 6.1; Appendix B). Station GL-JRB (Jumping Run Branch) had substandard DO on two sampling occasions. Turbidity concentrations were generally low in the tributary stations, with no violations of the freshwater standard of 50 NTU (Table 6.1). Suspended solids were elevated in JRB-SQB (198 mg/L) in October (Table 6.1).

Nitrate, ammonium and TN concentrations were highest at GL-SQB with JRB-17 and GL-JRB also elevated (Table 6.1). Highest phosphorus concentrations occurred at GL-SQB, followed by GL-JRB. 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. The chlorophyll *a* concentration was high in October at GL-SQB with a bloom of 58 µg/L, there was concurrent high TSS, TN and TP. The high biomass was associated with a large summer-fall algal bloom of the nitrogen-fixing cyanobacterium (blue-green alga) *Anabaena*; as well as a dense duckweed *Lemna* bloom in GL-SQB (see front cover photo). The geometric mean fecal coliform bacteria counts for 2021 exceeded the state standard at all three tributary stations (Table 6.1). The fecal coliform standard was exceeded on 10 dates at GL-SQB, six dates at JRB-17 and five sampling dates at GL-JRB.

Table 6.1. Mean and (standard deviation) / range of selected field water quality parameters in tributary stations of Greenfield Lake, 2021. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 11 samples collected.

Parameter	JRB-17	GL-JRB	GL-SQB (formerly GL-LB)
DO (mg/L)	7.3 (1.2) 5.9-9.0	6.2 (1.4) 4.4-8.6	3.8 (1.5) 1.8-6.3
Turbidity (NTU)	5 (4) 1-14	4 (3) 1-9	3 (2) 1.8
TSS (mg/L)	4.5 (4.0) 1.2-13.5	7.4 (5.8) 1.2-19.2	22.2 (58.4) 1.2-198.0
Nitrate (mg/L)	0.16 (0.12) 0.01-0.35	0.21 (0.20) 0.01-0.52	0.26 (0.26) 0.01-0.67
Ammon. (mg/L)	0.13 (0.05) 0.04-0.22	0.07 (0.03) 0.01-0.12	0.17 (0.06) 0.06-0.30
TN (mg/L)	1.03 (0.28) 0.55-1.61	1.03 (0.33) 0.57-1.51	1.45 (1.20) 0.58-4.28
Ortho-P. (mg/L)	0.02 (0.01) 0.01-0.04	0.03 (0.03) 0.01-0.11	0.03 (0.01) 0.01-0.05
TP (mg/L)	0.16 (0.14) 0.05-0.51	0.21 (0.20) 0.01-0.60	0.37 (0.53) 0.05-1.80
Inorganic N/P ratio	30.4 24.4	21.6 15.5	38.7 28.8
Chlor. *a* (µg/L)	7 (6) 2-18	6 (6) 2-19	8 (17) 1-58
FC (CFU/100 mL)	400 46-2,500	287 55-3,400	567 110-4,200

Three in-lake stations were sampled on 11 occasions (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 (< 5.0 mg/L) occurred three times at GL-YD and Once at GL-P in 2021 (see also Section 6.1). Turbidity was at or below the state standard on all sampling occasions. There was a peak in suspended solids in September of 21 mg/L at GL-YD, concurrent with an algal bloom of 98 µg/L as chlorophyll *a*. In-lake fecal coliform concentrations exceeded the standard six times at GL2340 and twice each at GL-YD and GL-P.

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 did not display consistent patterns in 2021. 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 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, although P can stimulate blooms at GL-2340 at times (Mallin et al. 1999; 2016).

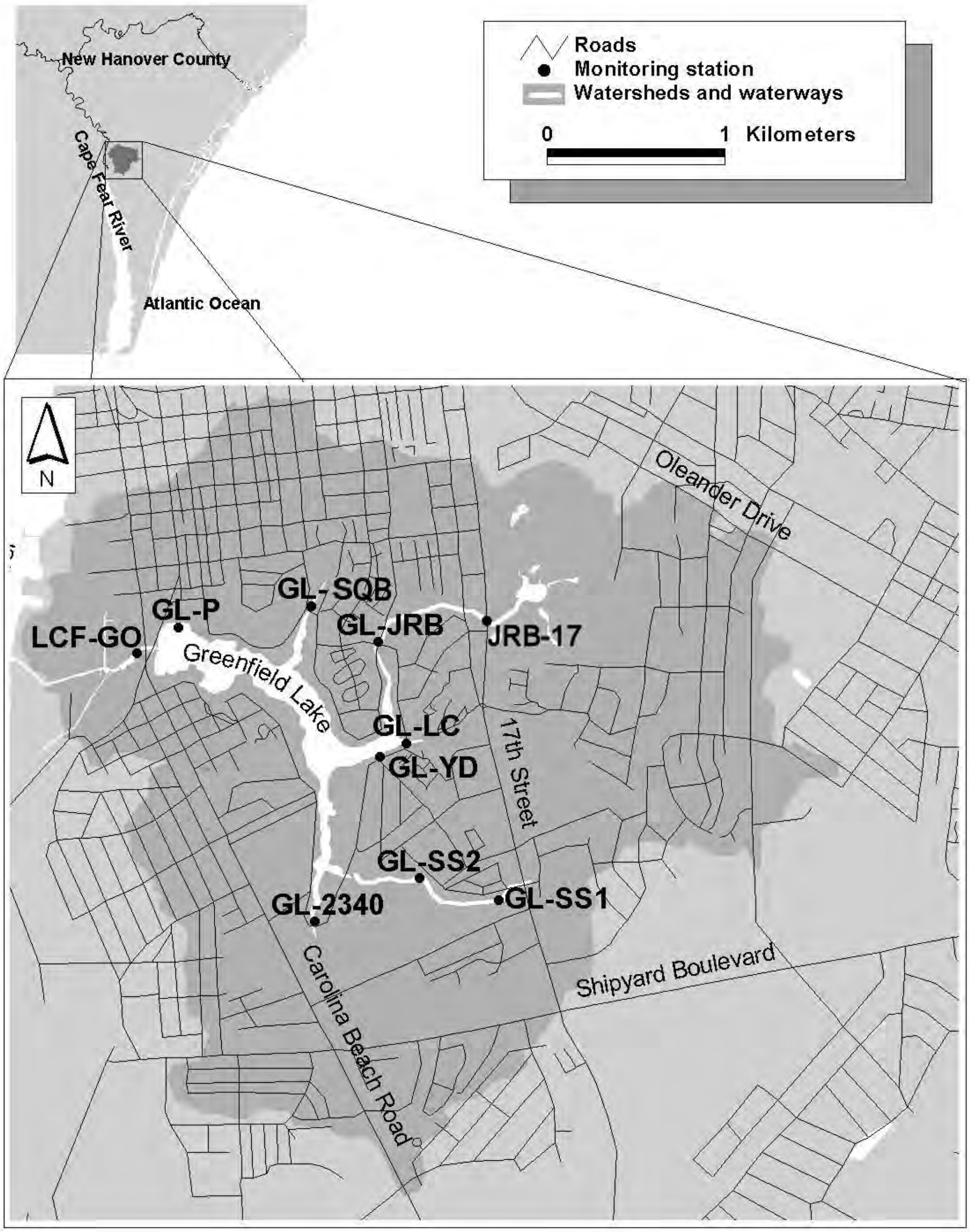
Phytoplankton blooms are problematic in Greenfield Lake (Table 6.2), and usually consist of green or blue-green algal species, or both together. These blooms have occurred during all seasons; in 2021 an extensive bloom of the blue-green *Anabaena spiroides* began in August and lasted until December. As such, four blooms exceeding the North Carolina water quality standard of 40 μg/L of chlorophyll *a* occurred at GL-YD, two blooms at GL-2340, and five blooms at GL-P with the largest bloom (135 μg/L) occurring at GL-P in October. It is notable that in August a bloom of *Microcystis* and *Anabaena* contained toxins. 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. Biochemical oxygen demand (BOD5) for 2021 was elevated at various times (Table 6.1) with a maximum of 10 mg/L in January at GL-YD. 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 chlorophyll *a* concentrations within this lake put it in the eutrophic (highly enriched) category for 2021. 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, 2021. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 11 samples collected.

Parameter	GL-2340	GL-YD	GL-P
DO (mg/L)	5.9 (1.7) 3.6-9.9	8.4 (1.2) 6.4-10.8	8.6 (2.1) 3.7-11.7
Turbidity (NTU)	2 (2) 0-6	2 (2) 0-5	2 (2) 0-6
TSS (mg/L)	3.6 (3.0) 1.2-8.0	5.9 (5.5) 1.2-21.0	5.2 (3.8) 1.2-13.8
Nitrate (mg/L)	0.19 (0.18) 0.01-0.41	0.06 (0.07) 0.01-0.26	0.03 (0.06) 0.01-0.21
Ammonium (mg/L)	0.05 (0.03) 0.01-0.12	0.03 (0.03) 0.01-0.10	0.05 (0.05) 0.01-0.16
TN (mg/L)	0.87 (0.31) 0.41-1.34	0.85 (0.25) 0.47-1.30	0.89 (0.34) 0.46-1.52
Orthophosphate (mg/L)	0.03 (0.03) 0.01-0.10	0.02 (0.02) 0.01-0.09	0.04 (0.03) 0.01-0.10
TP (mg/L)	0.22 (0.34) 0.01-1.20	0.23 (0.25) 0.01-0.77	0.15 (0.13) 0.01-0.494
N/P molar ratio	24.0 12.2	11.7 4.4	6.0 2.2
Fec. col. (CFU/100 mL)	154 25-637	41 3-740	36 3-773
Chlor. *a* (μg/L)	21 (29) 1-84	40 (34) 3-98	44 (37) 6-135
BOD5	2.5 (1.6) 1.0-5.0	3.8 (2.7) 1.0-10.0	3.8 (2.2) 1.0-9.0

Figure 6.1. Greenfield Lake watershed.

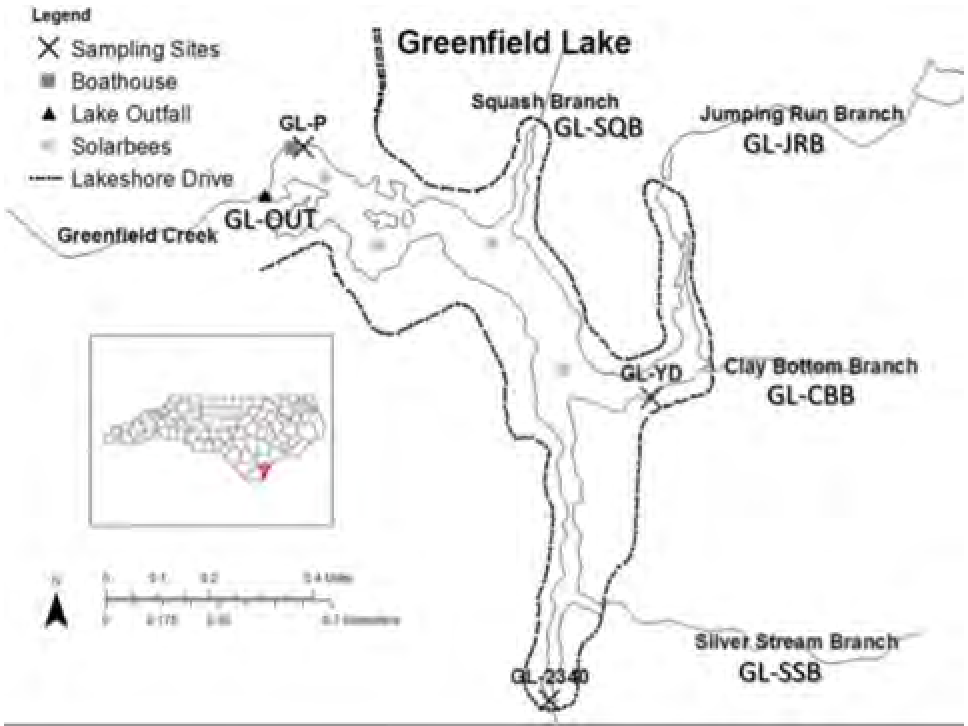


Continuing Efforts to Restore Water Quality in Greenfield Lake

Greenfield Lake has long suffered from eutrophication and beginning in 2005 several steps were taken by the City of Wilmington to restore viability to the lake. These steps included additions of grass carp to control (by grazing) the overabundant aquatic macrophytes, and installation of four SolarBee water circulation systems (SB10000v12 units) 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. 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. None of the above efforts were designed to reduce nutrient loading, however.

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 (Fig. 6.2) that feed Greenfield Lake (Iraola et al. 2022). 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). Nutrient load to Greenfield Lake is computed by multiplying nutrient concentration and stream discharge 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) received 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. The specific areas targeted for restoration work were the City-owned Willard Street Wetland, between Willard St., 15th St., and 16th St. (Fig. 6.3) and the SurgiCare Pond along 17th St., with cooperation from the owners (Fig. 6.4).

Willard Street Wet Pond/Wetland is bordered by 15th Street, 16th Street, and Willard St. and flows into the Jumping Run Branch Tributary of Greenfield Lake

Figure 6.3. Willard St. Wetland and sampling sites, along Jumping Run Branch tributary of Greenfield Lake.

Figure 6.4. SurgiCare Pond on Rt. 17, drains to Jumping Run Branch, sampled by UNCW in forebay and outfall.

Willard Street Wetland and SurgiCare Pond Sampling Efforts

Willard Street Wetland (Fig. 6.3) was sampled at the inflow from 15th St. (WSW-15), the inflow near 16th St. (WSW-16), midway through the pond near a causeway (WSW-MID) and at the outflow from the wetland to Jumping Run Branch (WSW-OUT). SurgiCare Pond (Fig. 6.4) was sampled in the forebay entering SurgiCare Pond (SCP-IN) and were its discharge leaves the pond (SCP-OUT). Water quality sampling efforts were completed for Willard Street Wetland and SurgiCare Pond spring and summer 2020 and again in summer and fall 2021. 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). Water samples were collected for ammonium, nitrate, total nitrogen, orthophosphate, total phosphorus, total suspended solids (TSS) and fecal coliform bacteria. Samples were placed on ice and transported back to the laboratory at the Center for Marine Sciences for processing and analysis. TSS samples were analyzed using Method SM 2540D. Fecal coliform bacteria were analyzed using Method 9222D MF (APHA 2005).

Sediment phosphorus samples were collected at collected in Jumping Run Branch just upstream of the normal UNCW water sampling station at JRB-17. Sediment samples were also collected at two sites upstream of the golf course as upper Jumping Run Branch was exiting a suburban area and just prior to entering the golf course. On-site, triplicate 5-cm cores were taken at each site with a 2.5 cm diameter clear PVC corer, placed into 50-mL centrifuge tubes and kept on ice until delivery at the laboratory, where they were dried at 50 °C until analysis. Dried sediment samples were mixed thoroughly, a subsample was weighed (to 0.0001 g), and the subsample was extracted using 10 mL of the Mehlich III reagent (to quantify ‘bioavailable’ P, Mehlich, 1984), then reacted with 1 additional mL of the P mixed reagent (Parsons et al., 1984, ‘the molybdenum blue’ mixed reagent, prepared fresh) for 24 hrs. Samples were then centrifuged to create clear supernatant and we measured absorbance of the supernatant vs. duplicate true blank samples (everything except the sediment) at 885 nm on a Fisherbrand AccuSkan GO model spectrophotometer (Thermo Fisher Scientific, MA). Dried sediment subsamples were then ashed at 450 ^oC for 24 hours, then a weighed amount (to 0.0001 g) was extracted and reacted as above. The sediments generally had a high organic content (~43% on average, as weight loss on ignition, WLOI). Samples were then centrifuged to create clear supernatants and we measured absorbance of the supernatant vs. duplicate true blank samples (everything except the sediment) at 885 nm on a Fisherbrand AccuSkan GO model spectrophotometer (Thermo Fisher Scientific, MA). Absorbance values were converted to µM, multiplied by 31 to convert to µg P, then expressed as µg P per gram ashed sediment, then converted to µg P per gram of dried sediment using WLOI values for each sample. The average of the duplicate samples was used for site sediment P concentrations. Total P values are reported in Table 3; the difference between total P and ‘bioavailable’ P corresponds to organic P.

Data Highlights

Water Quality

Samples were collected during both wet and dry periods. Dry periods were defined as no noticeable rain the previous five days, and wet periods were defined as having at least one half inch of rain fallen within the previous 24 hours. The rainfall data used were that collected at the Port of Wilmington by the NC State Port Authority (available from the Weather Underground and State Climate Office of North Carolina).

Water quality data are presented in Table 6.3 as average and median data for dry periods (n = 5) and wet periods (n = 8) for several key parameters: turbidity, TSS, ammonium, nitrate, TN and TP (Table 6.3). Note that fecal coliform bacteria are presented as the geometric mean.

Turbidity was generally low at most sites (Table 6.3). This is likely because the coastal soils in the Wilmington area have generally low concentrations of clays (the lightest portions of the soil compositions); clays tend to stay suspended in the water longest and contribute to turbidity. However there were a few incidents of elevated turbidity during wet period samples, particularly in July and December. The SurgiCare forebay maintained higher turbidity than the outfall area, and WSW-16 had somewhat higher turbidity than the other WSW sites.

Total suspended solids (TSS) ranged from low to very high (Table 6.3). In the Willard Street wetland WSW-15 maintained higher TSS than all other sites, in both wet and dry periods. Wet period sites had generally higher TSS than dry period at all sites. The highest sample was 1,667 mg/L at WSW-15 in the June 8 rainy period. As with turbidity, the SurgiCare forebay maintained considerably higher TSS than the outfall.

Fecal coliform bacteria were at low to moderate concentrations coming into SurgiCare Pond, but low exiting the pond. Fecal coliform concentrations were very high at WSW-15, particularly during wet periods, but quite low at WSW-16. Samples were generally high in the middle pond and at time unacceptably high at the wetland outfall to Jumping Run. It is possible that some of the high counts that occurred there (91,000 CFU/100 mL on June 8 and 52,000 CFU/100 mL on June 12, 33,000 CFU/mL on July 17 and 25,500 on July 1) may be reflective of a sewer leak upstream and should be investigated as such. Ammonium was generally low at all sites except for WSW-16, where it was 2-4X higher than the other sites. Nitrate was low in upper and lower Sugicare Pond; moderate at WSW-15 and quite high at WSW-16, doubling that of WSW-15. Nitrate concentrations decreased somewhat through the wetland but were still elevated at the wetland outfall. TN concentrations showed a pattern similar to nitrate. TP concentrations were clearly reduced in passage through SurgiCare Pond, but TN and DIN concentrations were not. In the Willard Street Wetland there was no apparent decrease in TP concentrations passing through the wetland (Table 3).

Rainfall impacts were variable regarding the samples, and somewhat unexpected. Turbidity was generally higher on rain sampling days compared with dry periods (Table 3) as were TSS samples, with the exception of SCP-IN. Fecal coliform bacteria samples were in general far higher during rain event sampling compared with dry periods, with WSW-15 rain periods geometric means of 6,794 CFU/100 mL (Table 3). However, most nutrient showed little difference between rain and dry periods. At some sites nitrate and TN showed higher concentrations in dry periods compared with wet – we can speculate that these nutrients may have been diluted by rainfall (particularly in WSW-16, the inflow that drains the golf course).

Table 6.3. Water quality data for selected parameters, pre-construction sampling in the Jumping Run Branch watershed, 2020-21, wet periods v dry periods (as averages and medians, geometric means for fecal coliforms, 8 wet samples, and 5 dry samples).

Site	SCP-IN	SCP-OUT	WSW-15	WSW-16	WSW-MID	WSW-OUT
Turbidity (NTU)						
wet mean	3.3	1.1	9.7	13.3	5.3	6.4
wet median	2.5	1.0	5.0	6.0	3.0	2.0
dry mean	3.8	1.6	5.5	5.4	3.8	1.8
dry median	2.0	2.0	6.0	4.0	3.0	2.0
TSS (mg/L)						
wet mean	4.2	2.2	282.8	14.4	5.6	4.3
wet median	4.1	2.0	31.2	3.3	3.3	3.3
dry mean	17.7	2.2	11.3	4.1	2.6	0.6
dry median	4.9	1.6	5.8	2.2	1.1	0.2
Fecal coliform bacteria (CFU/100 mL)						
Wet geomean	381	46	6,794	308	1,378	1,229
Dry geomean	21	6	626	115	261	607
Ammonium (mg-N/L)						
wet mean	0.032	0.040	0.027	0.130	0.071	0.060
wet median	0.037	0.030	0.027	0.135	0.069	0.054
dry mean	0.034	0.066	0.029	0.150	0.093	0.049
dry median	0.006	0.064	0.028	0.154	0.106	0.048
Nitrate (mg-N/L)						
wet mean	0.042	0.075	0.335	0.698	0.421	0.332
wet median	0.025	0.027	0.382	0.720	0.421	0.330
dry mean	0.011	0.015	0.487	1.095	0.742	0.530
dry median	0.010	0.003	0.461	0.927	0.678	0.454
TN (mg-N/L)						
wet mean	0.309	0.218	0.500	0.957	0.703	0.571

wet median	0.226	0.195	0.493	0.902	0.690	0.540
dry mean	0.524	0.425	0.787	1.765	1.345	0.963
dry median	0.494	0.469	0.780	1.667	1.314	0.931
TP (mg-P/L)						
wet mean	0.060	0.025	0.043	0.053	0.057	0.053
wet median	0.054	0.022	0.040	0.050	0.050	0.050
dry mean	0.049	0.021	0.092	0.035	0.057	0.055
dry median	0.041	0.020	0.051	0.029	0.052	0.045

Sediment Phosphorus Concentrations

Sediment sampling for phosphorus (P) was performed in July 2021 to assess the potential impacts of the Cape Fear Country Club golf course on Jumping Run Branch P concentrations. Samples were collected upstream of the golf course in a creek channel accessed from Gillette Drive. Downstream of the golf course we sampled Jumping Run Branch just upstream of the SurgiCare Pond outfall, a location near the JRB-17 water quality station. Sediment cores were collected in triplicate and assessed for P using methods reported earlier. At the JRB-17 there was unusually high variability. Upstream of the golf course it is clear that there are significant sources of P influencing the creek sediment P concentrations. More sampling is planned to investigate this further.

Table 6.4. July 2021 sediment phosphorus concentrations in Jumping Run Branch, as µg P/g sediment.

Site	average	standard deviation	range
Gillette 1	259.4	38.3	221.5-298.2
Gillette 2	103.0	30.7	81.4-138.1
JRB-17	200.1	314.1	16.0-562.8

Additional sediment samples were collected in February 2022 to expand the spatial coverage of sediment P analyses. Sampling sites included the JRB channel just below the bridge at Lakeshore Drive (JRB-LD), the JRB channel just below the Willard Street wetland outfall (JRB-WSW), the JRB channel upstream of 16th Street (JRB-16) and the JRB channel upstream of 17th Street (JRB-17). Values are shown in Table 6.5.

Table 6.5. February 2022 sediment phosphorus concentrations in Jumping Run Branch, as µg P/g sediment.

Site	average	standard deviation	range
JRB-LD	437	57	383-496
JRB-WSW	1,921	500	1,405-2,405
JRB-16	2,023	1,224	861-3,302
JRB-17	2,016	743	1,491-2,541

These values are generally much higher than values obtained in the July sampling shown in Table 6.4, but the difference is more likely a function of season than location. Phosphorus is a primary plant nutrient, and nutrient uptake, especially by aquatic macrophyte vegetation, is likely much higher in the summer months than in winter, leaving more phosphorus to accumulate in sediments. Another noteworthy pattern is the lower sediment P values in the most downstream sampling location – JRB-LD, which lies downstream of a wide, shallow portion of JRB just above the Lakeshore Drive bridge and where aquatic plant growth was observed despite winter conditions. These data indicate that JRB can be a potentially significant source of P to Greenfield Lake, but that P management by aquatic plants (in moderation) may be an effective remedy.

<u>Denitrification in the Willard St. Wetland and SurgiCare pond</u>

Denitrification is a key means of removal of inorganic nitrogen from eutrophying streams, rivers and lakes. Thus, this microbially based process was measured at several locations in the Jumping Run Branch watershed. Sediment cores were taken from three sites in the Willard Street Wetland (3 occasions) and the inflow and outflow sites of SurgiCare Pond (7 occasions). These cores were subsampled in the lab and our procedure for measuring denitrification followed a modified Long, et al. (2013) methodology, incubating sediments with a $^{15}NO_3$ tracer to acquire denitrification rates for each pond in summer 2021 – spring 2022.

Denitrification rates in the Willard Street Wetland showed a special pattern (Fig. 6.5). Rates were lowest at the 15th Street inflow, but about 2X higher at the 16th street inflow, then highest at the outfall of the wetland into Jumping run Branch (those samples were taken just below the discharge of the pipe into the creek. Samples were taken in July, October and December, but did not display any consistent seasonal pattern.

Denitrification rates in SurgiCare Pond (Fig. 6.6) also showed a spatial pattern. Rates in the incoming area, or forebay, were 3X that of the sediments near the outfall.

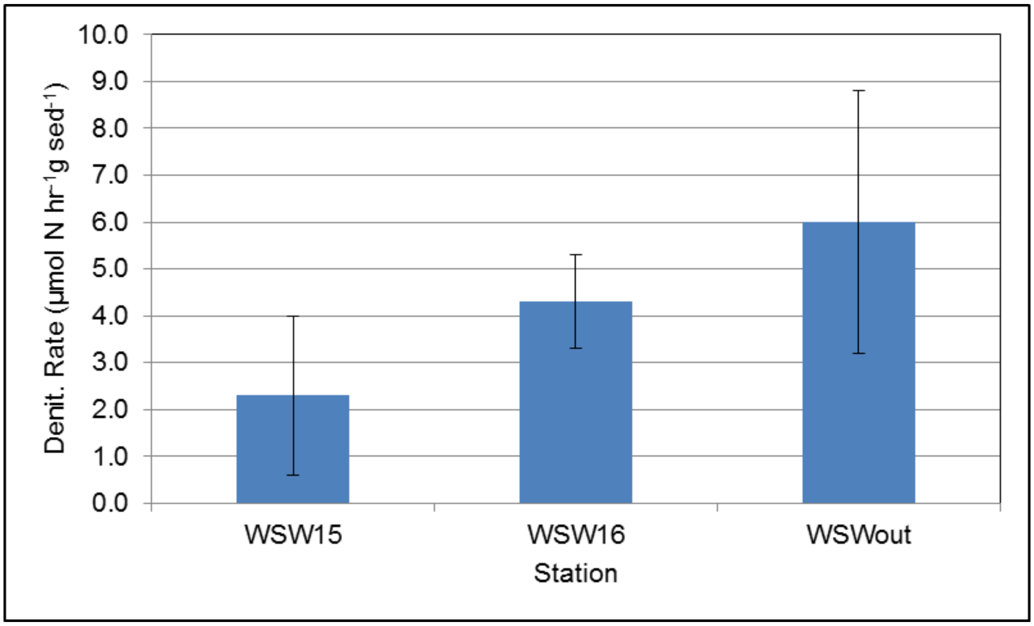


Figure 6.5. Denitrification rates in Willard Street Wetland, 2021 (n = 3 months).

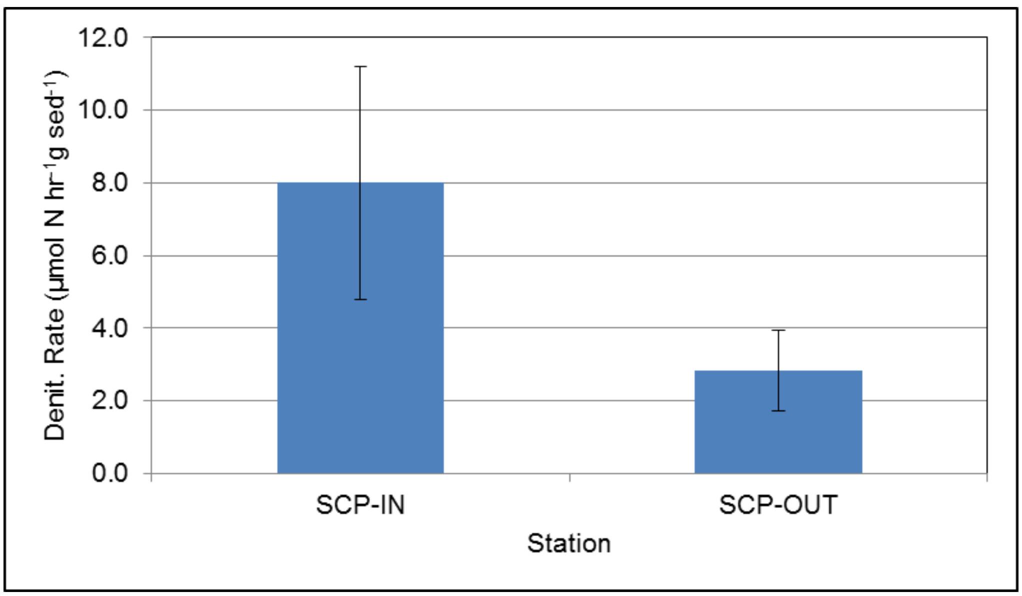


Figure 6.6. Denitrification rates in SurgiCare Pond, 2021-2022 (n = 7 months).

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: occasional 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) - 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. TSS levels were below 25 mg/L at all times sampled except at NB-GLR in May (28 mg/L) and November (54 mg/L) (Table 7.2). Dissolved oxygen was within standard on all sampling occasions except at SB-PGR (4.4) and NB-GLR (3.5) in May.

Nitrate concentrations were low at all sites except MB-PGR (Table 7.1) which receives inputs from the Wilmington Municipal Golf Course (Fig. 7.1; Mallin and Wheeler 2000). Ammonium concentrations were generally low to moderate in most locations but rather high at HC-3 in the estuary; several oyster reefs are present there and the ammonium may be a waste product from oyster excretion. Total nitrogen was low to moderate at all sites. Orthophosphate concentrations were low to moderate, as were total phosphorus concentrations. Mean N/P ratios were high in most sites including HC-3, due to elevated ammonium, indicating that at times P can stimulate algal growth at any of these sites. The chlorophyll *a* data (Tables 7.1 and 7.2) showed that no major blooms occurred during the sampling runs; SB-PGR had one minor bloom of 21 µg/L chlorophyll *a* in May 2021. 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 did not exceed the State standard at SB-PGR and HC-3, and only exceeded standard once each at NB-GLR and MB-PGR. The geometric mean of fecal bacteria counts at HC-3 was 5 CFU/100 mL, well below the shellfishing standard of 14 CFU/100 mL.

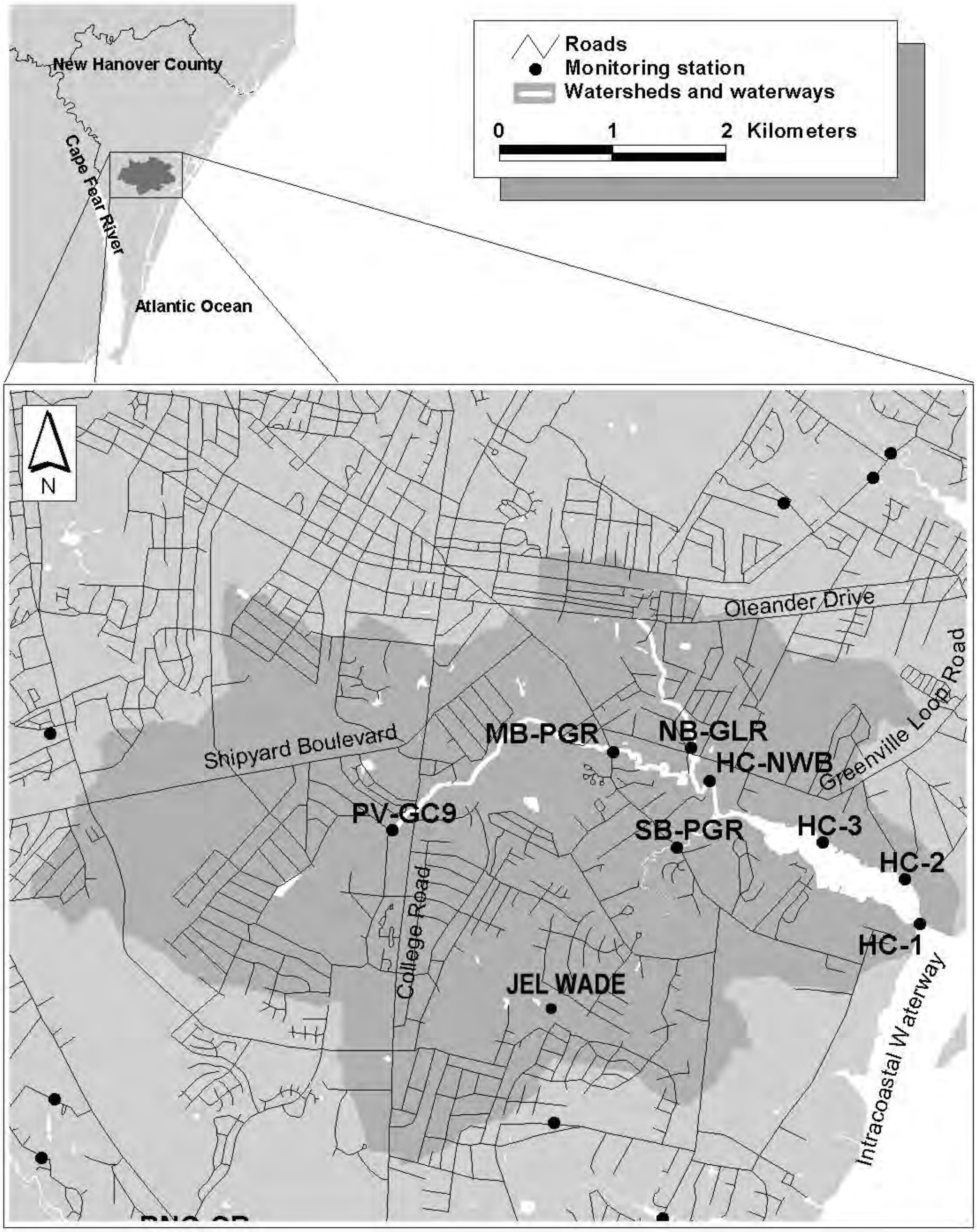


Figure 7.1. Hewletts Creek watershed.

Table 7.1. Selected water quality parameters at stations in Hewletts Creek watershed, 2021, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 6 samples collected.

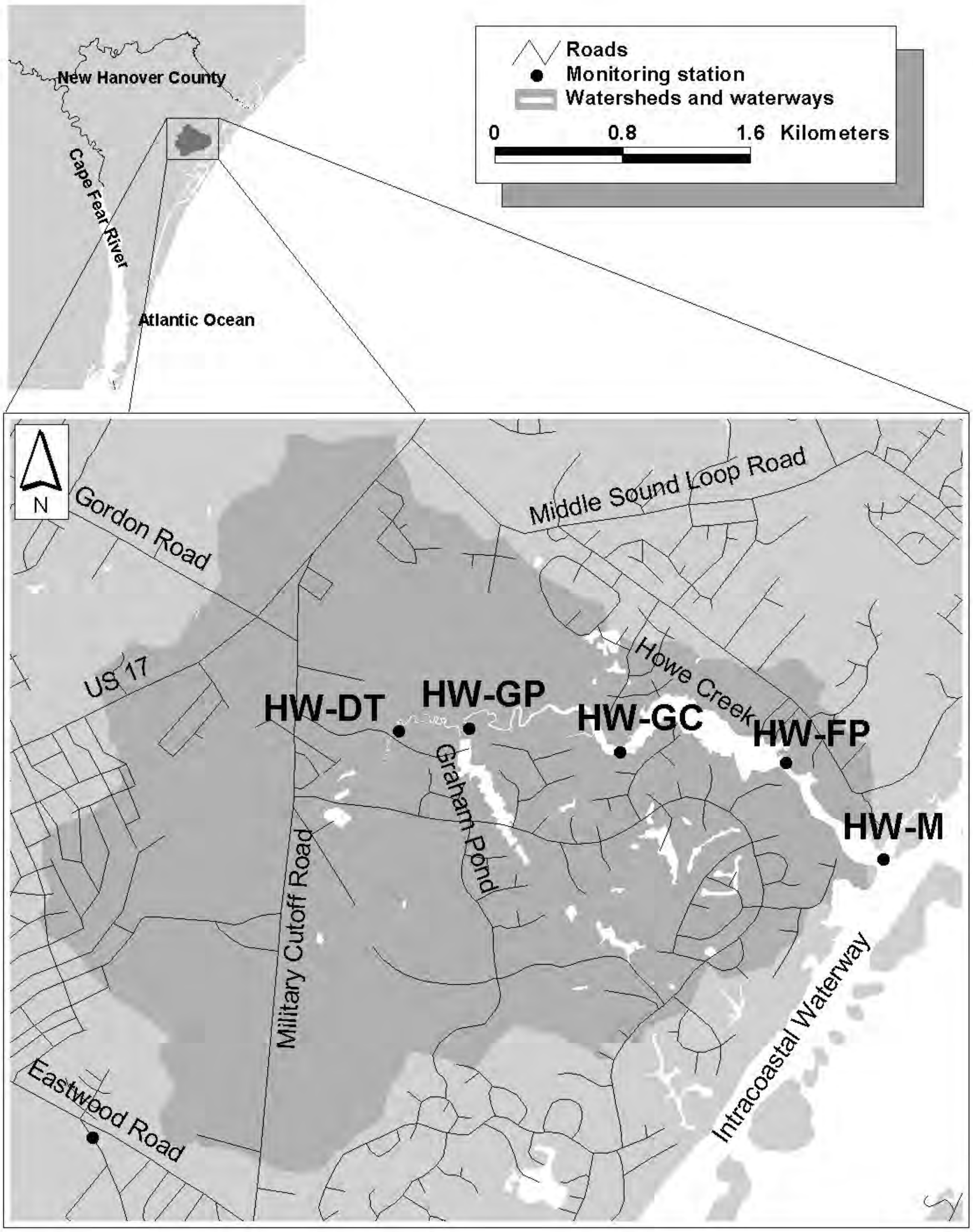
Parameter	SB-PGR	MB-PGR	NB-GLR	HC-3
Salinity (ppt)	31.9 (5.6) 21.4-36.7	4.2 (7.6) 0.1-19.5	23.4 (10.9) 4.3-31.5	34.9 (3.0) 29.5-38.6
Turbidity (NTU)	2 (1) 1-3	1 (1) 0-2	2 (1) 1-3	2 (1) 0-3
TSS (mg/L)	10.7 (4.3) 3.4-15.5	5.6 (7.8) 1.2-21.2	21.1 (13.5) 8.4-54.0	17.0 (12.0) 9.4-34.0
DO (mg/L)	7.0 (1.6) 4.4-8.7	7.3 (1.0) 6.0-8.7	6.7 (1.9) 3.5-8.8	7.5 (1.4) 5.4-9.1
Nitrate (mg/L)	0.02 (0.03) 0.01-0.09	0.15 (0.18) 0.01-0.38	0.05 (0.06) 0.01-0.16	0.01 (0.00) 0.01-0.01
Ammonium (mg/L)	0.25 (0.23) 0.01-0.54	0.07 (0.07) 0.01-0.16	0.13 (0.20) 0.01-0.51	0.26 (0.16) 0.01-0.48
TN (mg/L)	0.92 (0.60) 0.43-1.91	0.65 (0.29) 0.38-1.03	0.84 (0.60) 0.29-1.99	0.70 (0.29) 0.41-1.18
Orthophosphate (mg/L)	0.04 (0.03) 0.01-0.09	0.02(0.01) 0.01-0.03	0.02 (0.01) 0.01-0.03	0.02 (0.02) 0.01-0.05
TP (mg/L)	0.15 (0.07) 0.06-0.21	0.12 (0.13) 0.01-0.34	0.14 (0.11) 0.02-0.28	0.10 (0.11) 0.01-0.30
Mean N/P ratio Median	32.2 32.9	33.6 19.9	34.8 12.4	39.6 22.3
Chlor *a* (µg/L)	5 (8) 1-21	2 (1) 1-2	4 (2) 2-8	2 (2) 1-5
Fecal coliforms (CFU/100 mL)	36 6-200	105 28-1,350	128 41-280	5 1-13

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 drains a 3,516 acre watershed into the ICW (Fig. 8.1). Two to five stations have been sampled in this creek in various years. Due to resource re-allocation, sampling was suspended for the time being in 2020.

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

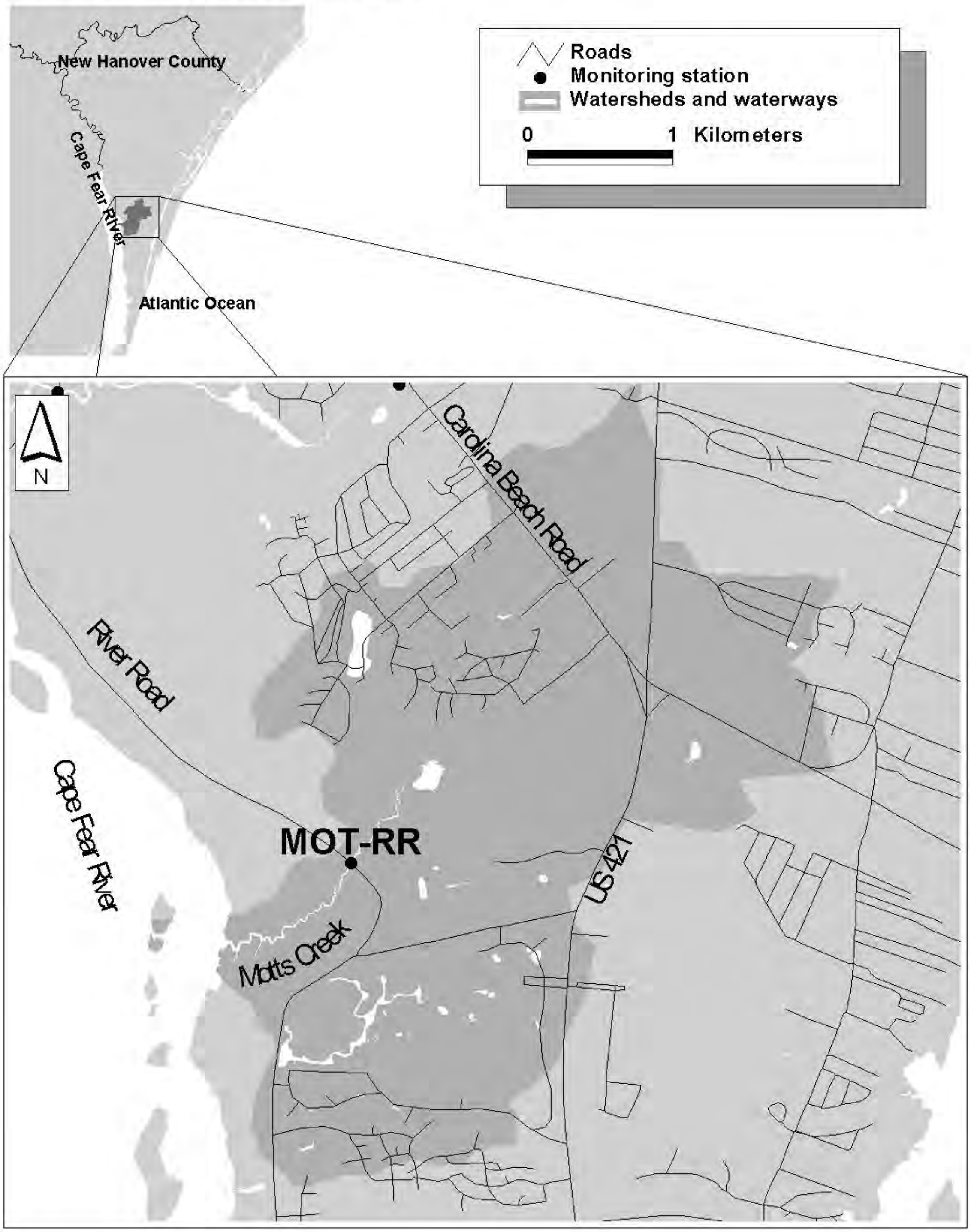


9.0 Motts Creek

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. Due to resource re-assignment, sampling is currently suspended on this creek.

Figure 9.1 Motts Creeks watershed

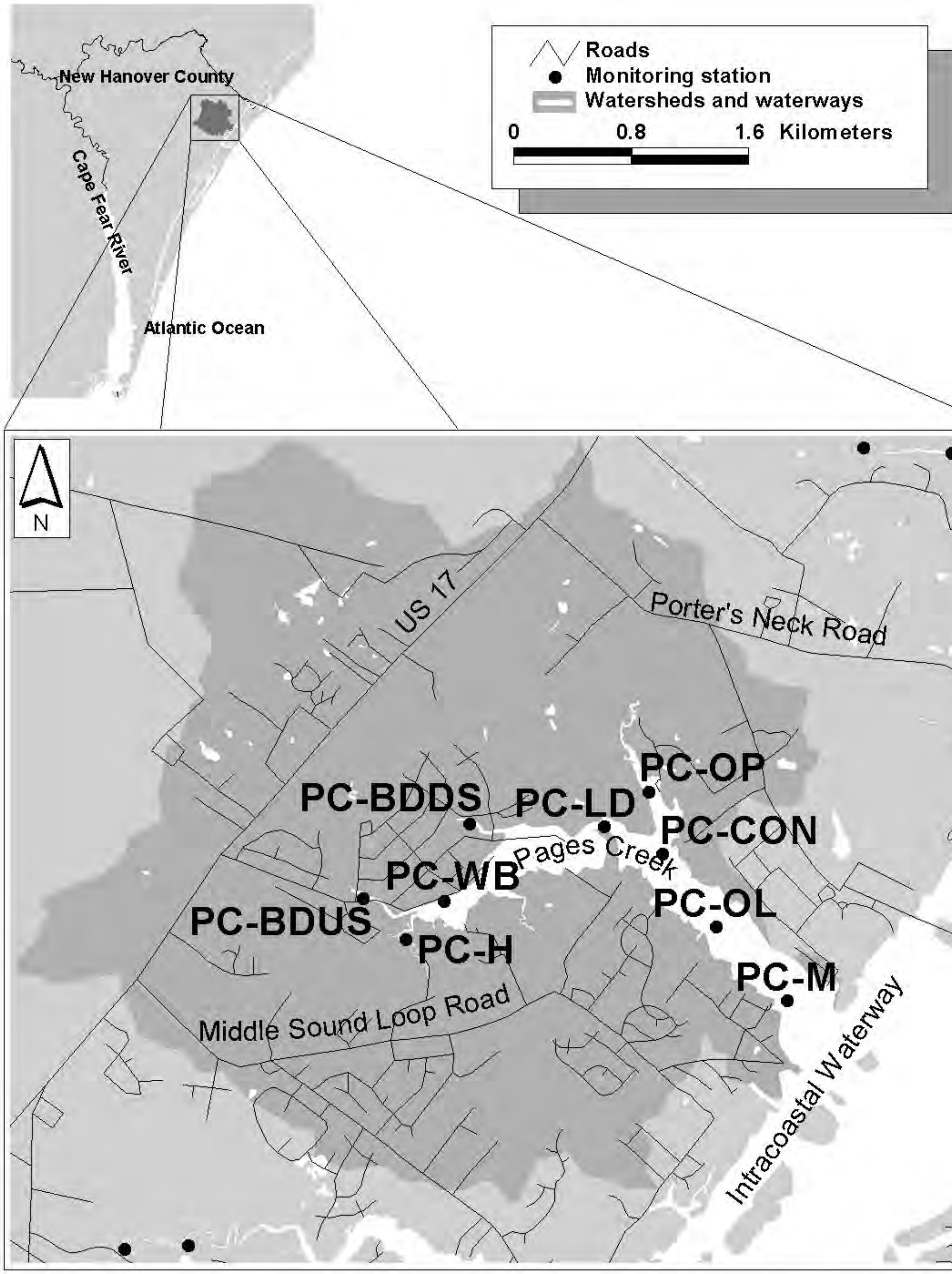


10.0 Pages Creek

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 since 2007 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: Good to Fair
Problematic pollutants: occasional turbidity, low dissolved oxygen and 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 normally 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). Note that in 2021 only eight samples were collected due to ongoing bridge repair and access issues.

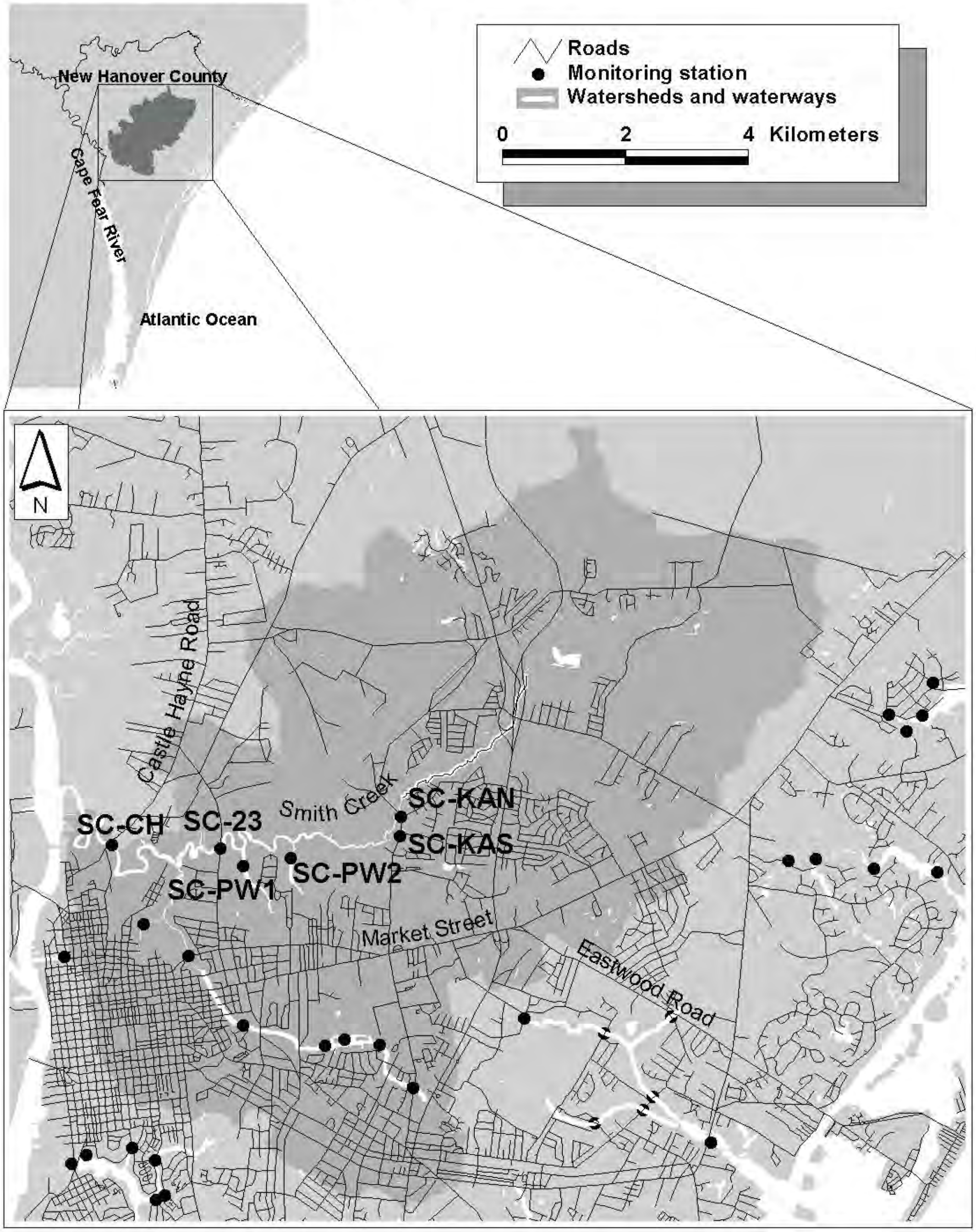
The dissolved oxygen standard for Smith Creek, which is rated as C Sw waters, is 4.0 mg/L, and was violated on one occasion in our 2021 samples for a Fair rating. The North Carolina turbidity standard for estuarine waters (25 NTU) was not exceeded in our 2021 samples, and TSS concentrations were not excessive.

Ammonium was low in 2021 (Table 11.1), although nitrate in this creek was relatively high compared to other tidal creeks; if fact nitrate in 2021 approximately doubled from 2020. Total nitrogen also considerably increased over 2020; however total phosphorus was quite low in 2021. There were no major algal blooms in 2021. Fecal coliform bacterial concentrations exceeded 200 CFU/100 mL on only one of eight sampling occasions at SC-CH in 2021, for a Fair rating (Table 11.1).

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range, 2021, n = 8 samples collected.

Parameter	SC-CH	
	Mean (SD)	Range
Salinity (ppt)	1.9 (3.1)	0.0-7.0
Dissolved oxygen (mg/L)	6.9 (2.0)	3.9-9.8
Turbidity (NTU)	7 (3)	4-13
TSS (mg/L)	9.1 (5.2)	4.2-19.6
Ammonium (mg/L)	0.035 (0.027)	0.010-0.080
Nitrate (mg/l)	0.484 (0.239)	0.140-0.800
Total nitrogen (mg/L)	1.311 (0.365)	0810-1.770
Total phosphorus (mg/L)	0.129 (0.078)	0.050-0.320
Chlorophyll *a* (µg/L)	7.0 (6.0)	2-18
Fecal col. /100 mL (geomean / range)	73	23-1,200

Figure 11.1 Smith Creek watershed

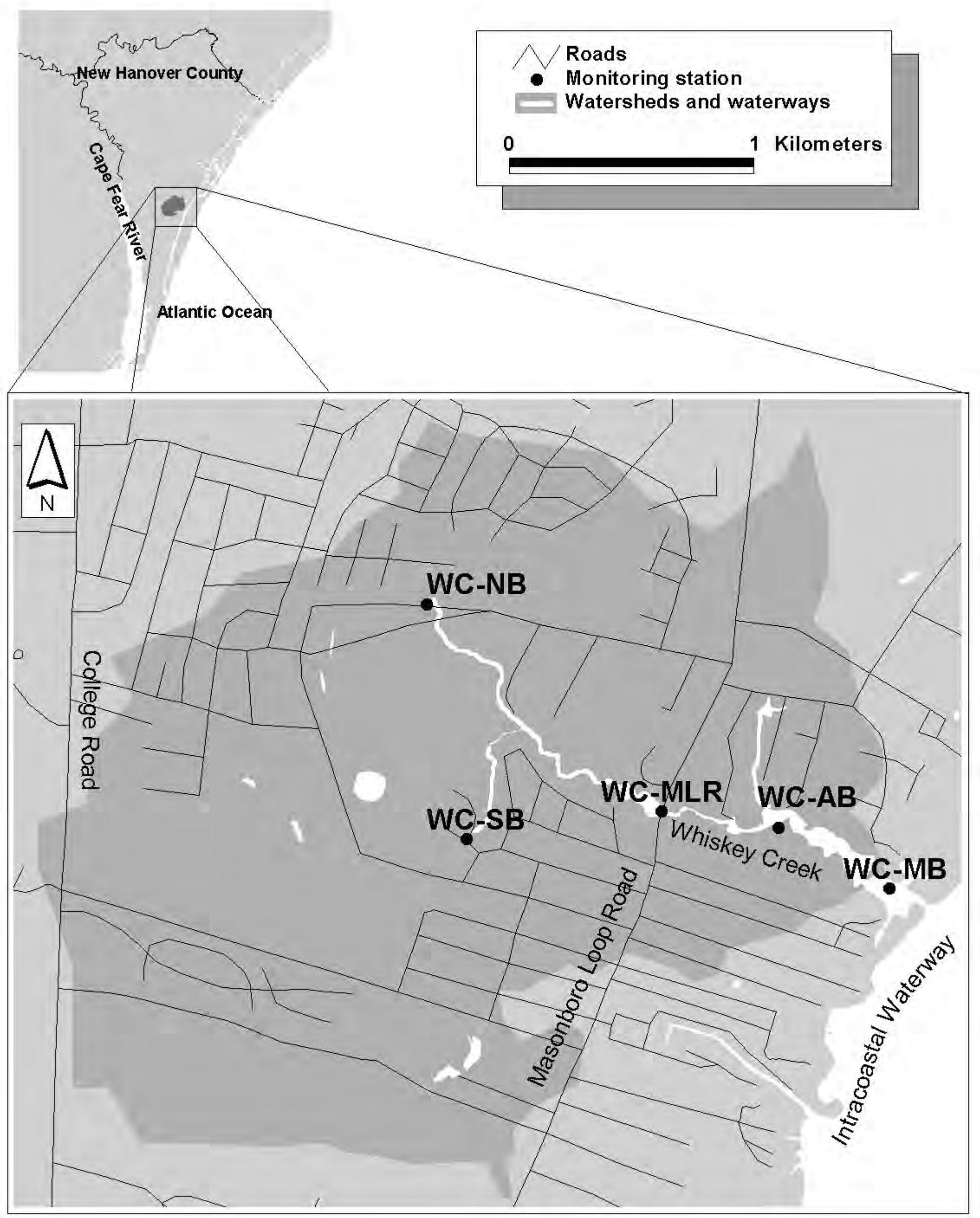


12.0 Whiskey Creek

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). Due to resource reassignment, sampling is currently suspended on this creek.

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 2021, 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 $\leq$ 10% of the measurements
F (fair quality) – state standard exceeded in 11-25% of the measurements
P (poor quality) – state standard exceeded in >25% of the measurements

Watershed	Station	Chlor *a*	DO	Turbidity	Fecal coliforms
Bradley Creek	BC-RD	F	P	G	P
	BC-CA	G	P	G	P
	BC-SB	G	F	G	P
	BC-NB	G	F	G	F
Barnards Creek	CHP-U	G	P	G	P
	CHP-D	G	G	G	P
Burnt Mill Creek	BMC-AP1	F	G	G	F
	BMC-AP3	P	G	G	F
	BMC-PP	F	P	G	P
Greenfield Lake	JRB-17	G	G	G	P
	GL-JRB	G	F	G	P
	GL-SQB	G	P	G	P
	GL-2340	F	P	G	P
	GL-YD	P	G	G	F
	GL-P	P	G	G	F
Hewletts Creek	NB-GLR	G	F	G	F
	MB-PGR	G	G	G	F
	SB-PGR	G	F	G	F
	HC-3	G	G	G	G
Smith Creek	SC-CH	G	F	G	F

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

Watershed	Station	GPS coordinates	
Barnard's Creek	BNC-RR	N 34.15867	W 77.93784
	CHP-U	N 34.1682	W 77.9102
	CHP-D	N 34.1680	W 77.9102
Bradley Creek	BC-RD	N 34.23249	W 77.87071
	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-RD	98.5	90.0%
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-SQB	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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