ENVIRONMENTAL QUALITY OF WILMINGTON AND
NEW HANOVER COUNTY WATERSHEDS, 2022

by

Michael A. Mallin, Matthew R. McIver and
Nicholas D. Picha

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University of North Carolina Wilmington
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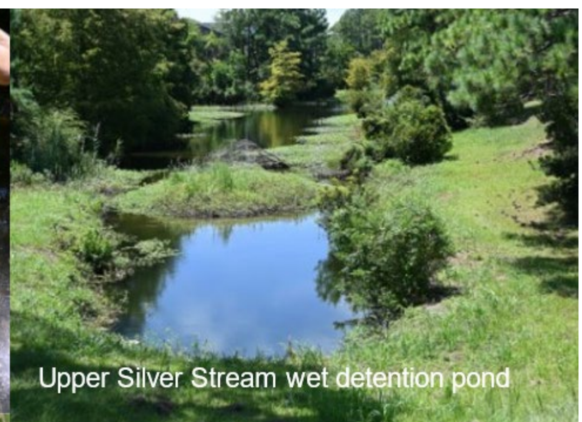
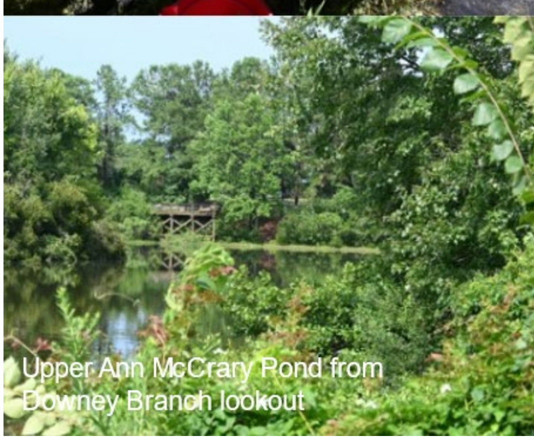
Sediment sampling upper Burnt Mill Creek


Upper Silver Stream wet detention pond


Upper Ann McCrary Pond from Downey Branch lookout


Pervious pavement in UNCW student parking lot

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Executive Summary

This report represents results of Year 25 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The 2022 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 2022. 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 are currently being sampled. Note that several months in summer and early fall were not sampled due to late receipt of funds from the city. From funding sourced by the NC Attorney General's office we were able to sample sediments in 20 wet detention ponds in Wilmington; presented within are data from ponds that drain into Barnards Creek, Greenfield Lake and Hewletts Creek.

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 2022 four samples were collected at two upper creek sites near Carriage Hills close to a wet detention pond (CHP-U and CHP-D). Turbidity was low, dissolved oxygen was fair, but both stations suffered from high fecal coliform counts. One major algal bloom occurred at CHP-D. Sediment samples taken in Carriage Hills Pond indicated that both metals and polycyclic aromatic hydrocarbons (PAHs) were low and not a problem.

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 four times in 2022.

High turbidity and suspended solids in 2022 were not problematic. Dissolved oxygen was stressed (< 5.0 mg/L) on several occasions at the two upper sites BC-RD and BC-CA, but DO was in good shape at the other two stations. Nitrate and especially total phosphorus concentrations were elevated in BC-RD compared with the other sites on Wrightsville Avenue. Both BC-RD and BC-CA had large algal blooms in February 2022. Other than that, algal blooms were not a problem at the other sites. Fecal coliform bacteria counts were moderate at the lower two sites but excessive at BC-RD and BC-CA, which had geometric mean counts of 375 and 282 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 2022, on

five occasions. Fecal coliform conditions were rated Poor at the lowermost station BMC-PP at Princess Place and 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 all three sampling sites.

We note that nitrate significantly declined during passage through the detention pond, but dissolved oxygen and pH increased, as well as turbidity, TSS and total phosphorus. A major algal bloom occurred at all three stations May 2022. 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 phosphorus, indicating non-point pollution sources continue to pollute the lower creek.

Sediment samples at Ann McCrary Pond: the sediment data for AP-1, the upstream-most inflow to Ann McCrary Pond and Downey Branch (AP-DB), which drains suburban neighborhoods into the eastern side of Ann McCrary Pond showed that sediment metals were not at toxic levels. However, some of the PAHs (total PAHs, benzo(a)pyrene, pyrene and chrysene) were at potentially toxic concentrations. The third major input is AP-RA, the inflow at Rosemont Avenue, nearest the dam. Here the sediments presented a potentially toxic environment, with several metals (copper, lead and zinc) at potentially toxic concentrations, and almost all the sediment PAHs of concern at this location were high, at levels, where harmful effects on aquatic organisms are likely to occur.

<u>Futch Creek</u> – 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 2022. New Hanover County employed a consulting firm to sample this creek and data may be requested from the County.

<u>Greenfield Lake</u> – This lake drains a watershed of 2,465 acres, covered by about 37% impervious surface area with a population of about 10,630. In the past this urban lake has suffered from low dissolved oxygen, algal blooms, periodic fish kills and high fecal bacteria counts. The lake was sampled at three tributary stream sites and three in-lake sites on 8 occasions. Of the tributaries of Greenfield Lake, Squash Branch (GL-SQB, near Lake Branch Drive), Jumping Run Branch at 17th Street and Jumping Run Branch at Lakeshore Dr., only 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 2022 a massive summer-fall blue-green algal bloom of *Anabaena* began in early May Summer sampling did not occur since funding was not present, but when sampling resumed in fall the blooms continued in October and November. 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 2022. In 2022 all three tributary stations exceeded the fecal coliform State standard on >55% 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 restoration planning funds for 2020-2022 and UNCW has competed sampling in support of future nutrient reduction efforts on Jumping Run Branch. Data show the Willard Street Wetland, between Willard St., 15th St. and 16th 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. Plans for restoration have been completed by River Watch, NCSU and Moffat & Nichol.

Silver Stream sediment metals concentrations were not problematic. However, several important PAHs were very high, indicating poor sediment quality for aquatic life in this tributary pond/stream.

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 2022 the creek was sampled at four tidal sites on six occasions.

Low dissolved oxygen was not measured in Hewletts Creek in 2022. Turbidity was low and did not exceed the state standard, and no major algal blooms occurred. Fecal coliform bacteria counts were excessive at MB-PGR, but low at the other sites; note that the geometric mean of fecal bacteria counts at HC-3 was not over the state shellfishing standard. Sediment metals and PAHs were low in Municipal Golf Course Pond 1, which drains into the middle branch of Hewletts Creek upstream of MB-PGR.

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, is normally sampled by UNCW under the auspices of the Lower Cape Fear River Program (LCFRP). However, due to ongoing bridge construction at our sampling site no data were collected for 2022.

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 2022.

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 2022 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 (19 sites sampled for fecal coliforms) showed 21% to be in Good condition, 16% in Fair condition and 63**%** in Poor condition. Dissolved oxygen conditions (measured at the surface) system-wide (19 sites) showed 53% of the sites were in Good condition, 31% were in Fair condition, and 16% were in Poor condition. For algal bloom presence, measured as chlorophyll *a*, 47% of the 19 stations sampled were rated as Good, 37% as Fair and 16% 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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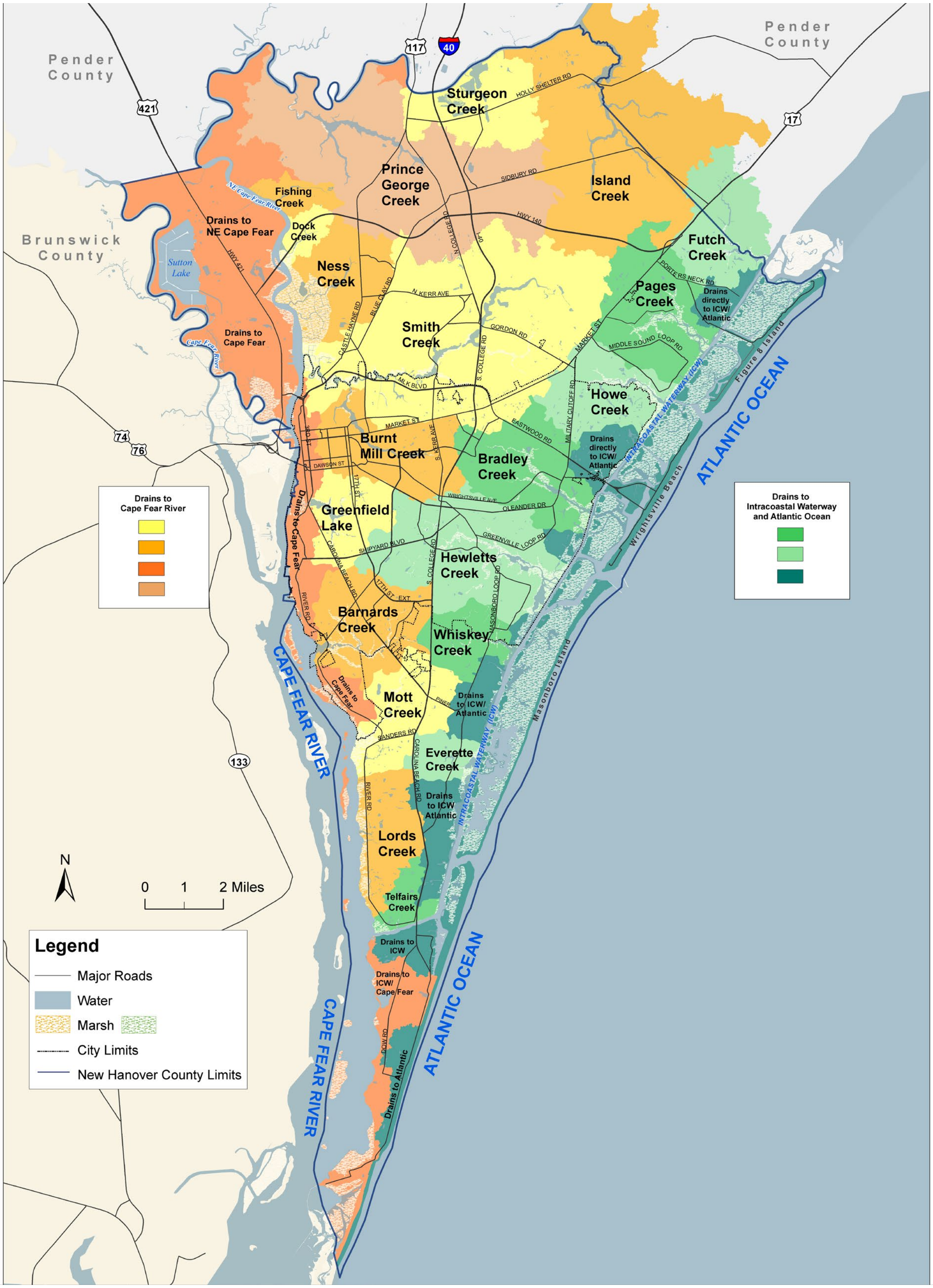


Plate 1. Wilmington and New Hanover County watersheds 2014 map by Wilmington Stormwater Services. Station coordinates are in Appendix C.

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 25 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 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 at two locations in 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 four to eight occasions at 20 locations within the Wilmington City watersheds between January and December 2022. A station on Smith Creek that was normally sampled as part of the Lower Cape Fear River Program and reported here was not sampled due to access issues. 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).

In summer and fall 2022 the sediments of 20 wet detention ponds within the City of Wilmington were collected and scanned for key metals and PAHs. Collection were made by sampling the upper 5 cm of sediments with plastic tubes, mixing several samples together in a bowl, then using the composite for analyses (see cover photo). Samples were frozen and sent to a state-certified laboratory for analyses of various metals and polycyclic aromatic hydrocarbons (PAHs).

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.

The 2022 data (Table 2.1) show minor dissolved oxygen issues, but low turbidity and low total suspended solids (TSS). Nutrients were generally low; there was one major and one minor algal bloom at CHP-D, and both sites exceeded the state fecal coliform standard 50% of samples collected.

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, 2022 as mean (standard deviation) / range, inorganic N/P ratios as mean / median, fecal coliform bacteria presented as geometric mean / range, n = 4 samples collected.

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) 1-2	3 (1) 2-3
TSS (mg/L)	2.0 (1.4) 1.3-4.0	4.2 (2.6) 1.3-7.0
DO (mg/L)	6.6 (1.6) 4.6-8.6	6.6 (1.8) 4.7-8.9
Nitrate (mg/L)	0.030 (0.020) 0.010-0.050	0.030 (0.010) 0.010-0.030
Ammonium (mg/L)	0.050 (0.050) 0.010-0.120	0.050 (0.020) 0.030-0.080
TN (mg/L)	0.690 (0.350) 0.050-1.220	0.820 (0.390) 0.041-1.24
Orthophosphate (mg/L)	0.010 (0.010) 0.010-0.020	0.010 (0.010) 0.010-0.020
TP (mg/L)	0.080 (0.080) 0.010-0.200	0.070 (0.040) 0.010-0.110
N/P inorganic	11 11	12 12
Chlorophyll *a* (µg/L)	6 (9) 1-19	21 (23) 2-49
Fecal col. (CFU/100 mL)	210 50-210	143 77-143

Sediment Metals and PAH Sampling Scan 2022

As noted in the Methods, in summer and fall 2022 the sediments of 20 wet detention ponds within the City of Wilmington were collected and scanned for key metals and PAHs. Collection were made by sampling the upper 5 cm of sediments with plastic tubes, mixing several samples together in a bowl, then using the composite for analyses (see cover photo). Samples were frozen and sent to a state-certified laboratory for analyses of various metals and polycyclic aromatic hydrocarbons (PAHs).

Academic researchers (MacDonald et al. 2000) devised a set of guideline for potential sediment toxicity in which harmful effects of aquatic life are likely to occur, based on experiment and/or epidemiological data. Sediment concentrations below the TEC (see Table 2.2 below) are concentrations where negative impacts are unlikely to occur, and that is how we assess our data.

Table 2.2. Sediment quality guidelines for freshwater for selected metals and organic pollutant concentrations potentially harmful to aquatic life (adapted from MacDonald et al. 2000). TEC = threshold effect concentration, below which harmful effects on aquatic communities are unlikely to be observed. PEC = probable effect concentration, above which harmful effects are likely to be observed.

Pollutant	TEC	PEC
Metal (mg/kg dry wt.)		
Arsenic (As)	9.79	33.0
Cadmium (Cd)	0.99	4.98
Chromium (Cr)	43.4	111.0
Copper (Cu)	31.6	149.0
Lead (Pb)	35.8	128.0
Mercury (Hg)	0.18	1.06
Nickel (Ni)	22.7	48.6
Zinc (Zn)	121.0	459.0
Total PAHs (µg/kg dry wt.)	1,610.0	22,800.0
Anthracene	57.2	845.0
Benzo(a)pyrene	150.0	1,450.0
Chrysene	166.0	1,290.0
Fluoranthene	423.0	2,230.0
Pyrene	195.0	1,520.0

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds with a fused ring structure. PAHs with two to five rings are of considerable environmental concern. They are compounds of crude and refined petroleum products and coal and are also produced by incomplete combustion of organic materials (US EPA 2000). They are characteristic of urban runoff as they derive from tire wear, automobile oil and exhaust particles, and leaching of asphalt roads. Other sources include domestic and industrial waste discharge, atmospheric deposition, and spilled fossil fuels. They are carcinogenic to humans, and bioconcentrate in aquatic animals. In these organisms they form carcinogenic and mutagenic intermediaries and cause tumors in fish (US EPA 2000). The set of 20 ponds included Carriage Hill Pond in the Barnard's Creek basin, and three inflow areas to Ann McCrary Pond in the Burnt Mill Creek basin (see Chapter 4), and Municipal Golf Course Pond 1 (Chapter 7).

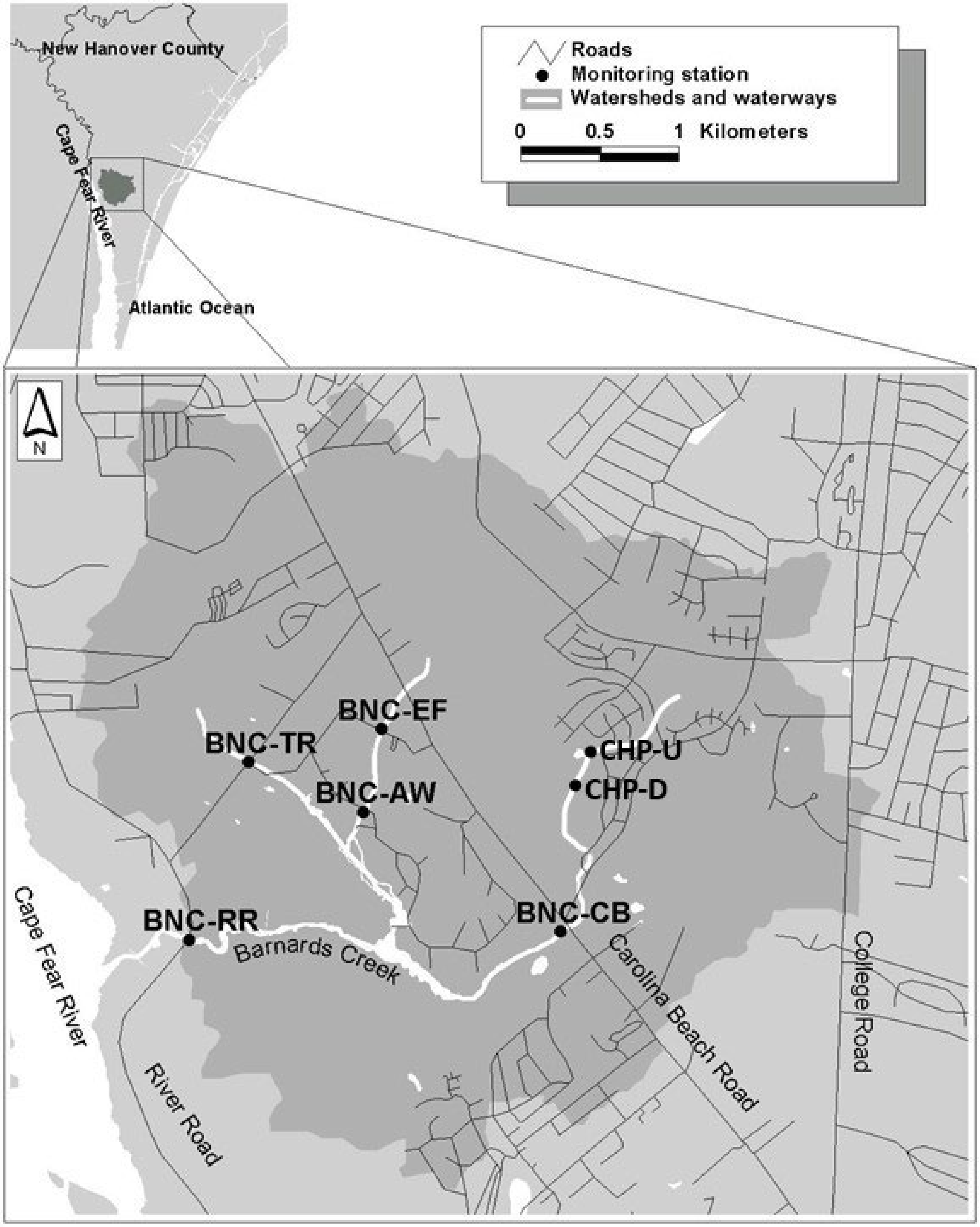
The sediment data for Carriage Hills Pond (Table 2.3) shows that many of the metals and PAHs of concern were either below the detection limit or at concentrations below either the TEC or PEC. Thus, this suburban wet detention pond is not considered to have toxic sediments.

Table 2.3. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Carriage Hills Pond, Barnards Creek watershed, 2022. Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur, and italicized concentrations are near potentially harmful levels (see Table 2.2 for more detail).

Parameter	Carriage Hills Pond
	Dry wt., ppm = µg/g = mg/kg
Arsenic	<2.11
Cadmium	<1.05
Chromium	3.02
Copper	4.97
Lead	3.06
Mercury	<0.026
Nickel	<1.05
Zinc	12.3
	Dry wt., ppb = ng/g = µg/kg
Total PAH	296
Anthracene	<206
Benzo(a)pyrene	<206
Pyrene	<206
Fluoranthene	<206
Chrysene	<206

BDL = below detection limit

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 New Hanover 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 another site, BC-RD on Racine Drive (see cover photo) was added in July 2021 as stream restoration activities are planned for this upper branch (also called Clear Run) and more background data are needed. The drainage area for BC-RD is approximately 90% impervious surface coverage. Thus, there were four samples collected at most sites in 2022; note that stream restoration activities commenced in late 2022 in the BC-CA area, so only three samples were taken there. Restoration work continued into 2023.

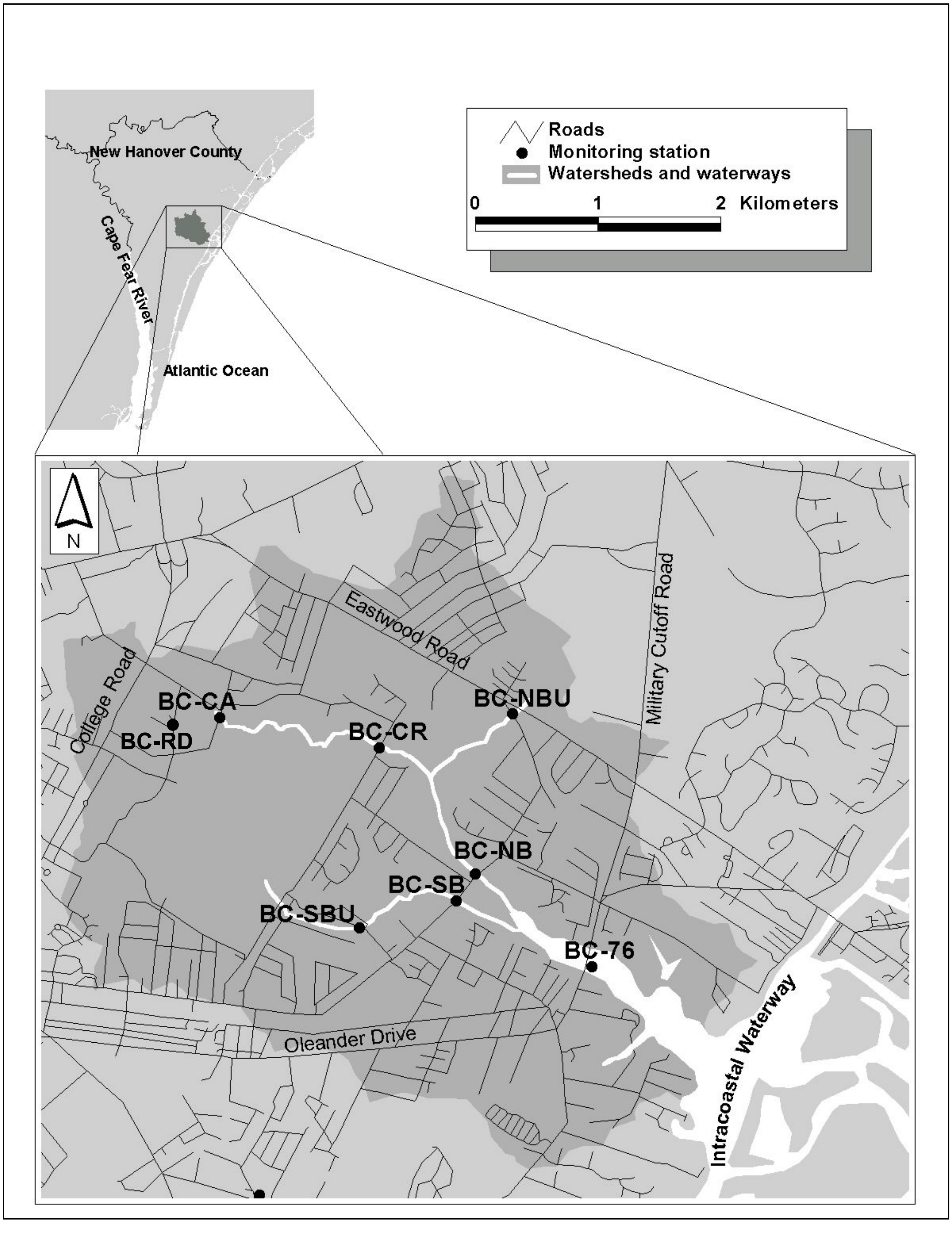
Turbidity was not a problem during 2022; the standard of 25 NTU was not exceeded (Table 3.1). There are no NC ambient standards for total suspended solids (TSS), but UNCW considers 25 mg/L high for the Coastal Plain. As such, TSS did not exceed 21 mg/L in our 2022 samples. Dissolved oxygen was below standard (< 5.0 mg/L) once at BC-RD and twice at BC-CA, but the other two sites had no DO issues.

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 except BC-CA (Table 3.1). Orthophosphate concentrations were low in general at all the sites. Algal blooms occurred at BC-RD and BC-CA in February 2022, but no blooms occurred at the other locations downstream. Median nitrogen to phosphorus ratios at BC-NB and BC-SB were 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 high at BC-RD and BC-CA, with geometric means of 375 and 282 CFU/100 mL, respectively, and maxima of 5,500 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, 2022. Data as mean (SD) / range, N/P ratio as mean/median, fecal coliform bacteria as geometric mean / range, n = 4 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	29.6 (7.7) 18.2-35.6	23.5 (11.7) 7.3-34.4
DO (mg/L)	6.3 (1.3) 4.4-7.3	6.2 (2.7) 4.4-9.3	7.6 (1.6) 5.8-9.4	7.9 (1.7) 5.4-9.0
Turbidity (NTU)	3 (1) 3-4	6 (2) 4-8	2 (2) 1-4	2 (2) 1-5
TSS (mg/L)	3.1 (0.9) 1.8-3.7	7.0 (5.3) 3.7-13.2	13.9 (5.3) 8.4-20.8	11.7 (3.8) 7.1-15.7
Nitrate (mg/L)	0.03 (020) 0.01-0.06	0.08 (0.06) 0.01-0.13	0.01 (0.00) 0.01-0.01	0.01 (0.00) 0.01-0.01
Ammonium (mg/L)	0.44 (0.24) 0.24-0.76	0.13 (013) 0.01-0.27	0.41 (0.27) 0.13-0.72	0.23 (0.21) 0.01-0.43
TN (mg/L)	1.33 (0.34) 0.95-1.62	0.81 (0.28) 0.57-1.12	0.76 (0.13) 0.62-0.93	0.66 (0.23) 0.45-0.88
Orthophosphate (mg/L)	0.04 (0.01) 0.03-0.06	0.03 (0.01) 0.02-0.04	0.02 (0.01) 0.01-0.02	0.02 (0.01) 0.01-0.03
TP (mg/L)	0.11 (0.05) 0.07-0.18	0.10 (0.08) 0.04-0.19	0.07 (0.08) 0.01-0.18	0.04 (0.05) 0.01-0.11
N/P	26 27	20 18	73 81	50 51
Chlorophyll *a* (µg/L)	25 (36) 3-78	42 (69) 2-121	4 (2) 2-7	6 (5) 2-13
Fecal coliforms (CFU/100 mL)	375 73-5,500	282 64-591	24 3-165	133 59-455

Figure 3.1. Bradley Creek watershed and sampling sites.



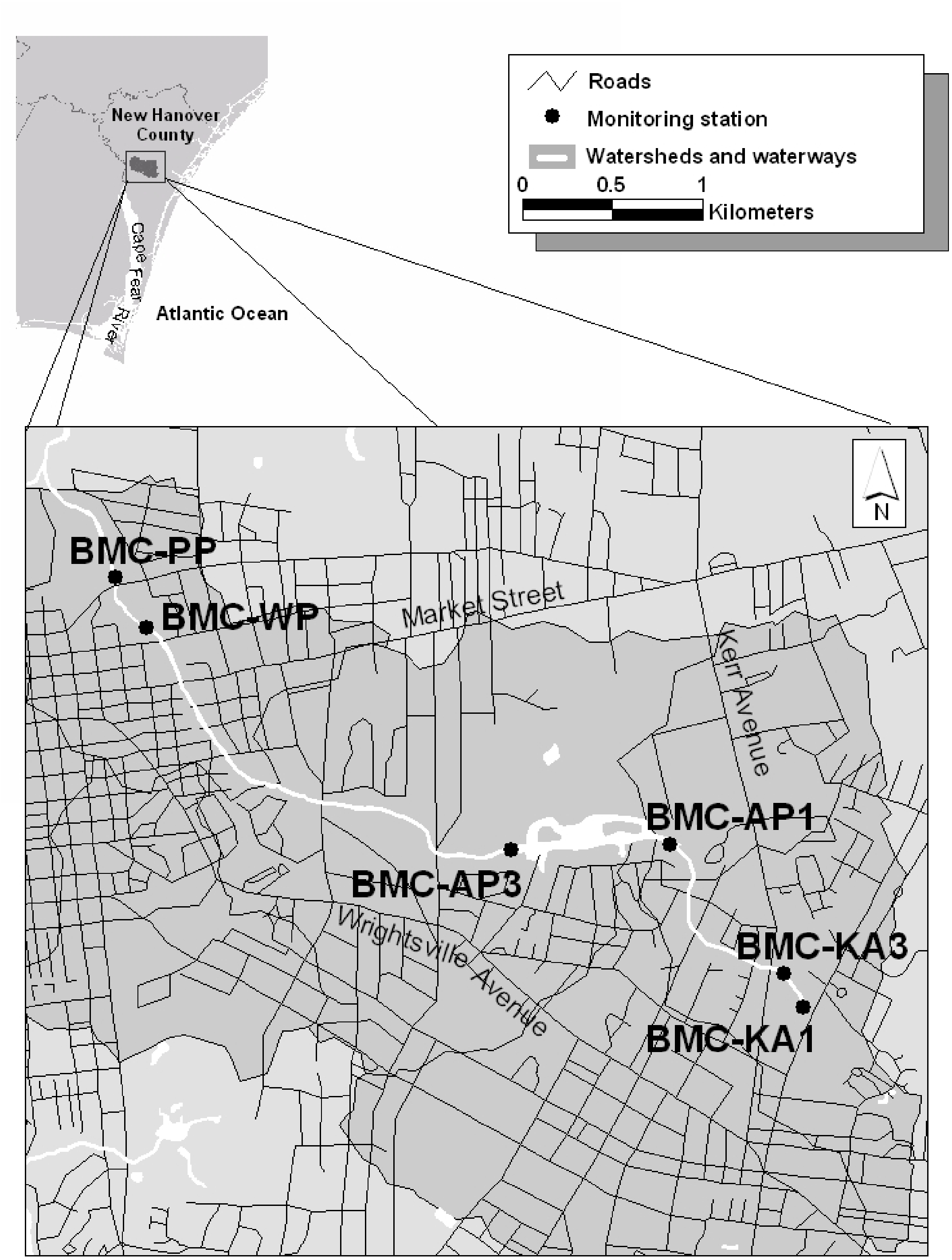
4.0 Burnt Mill Creek

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.

<u>Sampling Sites</u>: During 2022 samples were collected on five 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 five occasions in 2022. Dissolved oxygen concentrations were within standard on all sampling occasions at BMC-AP1 and BMC-AP3. DO and pH both showed a significant ($p < 0.05$) increase 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 2022 sampling, but on average there was a significant increase through the pond. Total suspended solids concentrations were relatively low on most sampling occasions in 2022, but there was a significant increase through the pond on average (Table 4.1). Fecal coliform concentrations at both Ann McCrary Pond stations were slightly elevated, exceeding the state standard 40% of the time sampled (Table 4.1). There was no significant ($p < 0.05$) reduction in fecal coliform counts during passage through the regional detention pond (Table 4.1). There was one major algal bloom at both BMC-AP1 and BMC-AP3 in May, ranging from 96-321 µg/L chlorophyll *a*, and the May 2022 algal bloom spread throughout Ann McCrary Pond and contained several potentially harmful cyanobacterial taxa. There was no significant difference in chlorophyll a between AP1 and AP3. Regarding nutrients, there was a significant decrease in nitrate concentrations through the pond, but a significant increase in TP between AP1 and AP3 (Table 4.1).

Lower Burnt Mill Creek: The Princess Place location (BMC-PP) was the only lower creek station sampled in 2022. One parameter that is key to aquatic life health is dissolved oxygen. Dissolved oxygen at BMC-PP was above standard (< 4.0 mg/L) on all five 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 2022 there was one major algal bloom of 78 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).

In waters where the inorganic 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. At AP-1, mean and median N/P rations were quite high, 44 and 33, but after passage though the pond N/P ratios dropped to 19 and 12, respectively (near the Redfield Ratio), indicating that the algae and macrophytes in the pond took up more N relative to P. Ratios increased downstream at BMC-PP to 25 and 16, respectively along with increases in nutrients, especially N.

Important from a public health perspective are fecal coliform bacteria counts. All three stations had geometric means exceeding the State standard for human contact waters (200 CFU/100 mL) on two occasions in our 2022 samples. Fecal coliform counts were greater than the State standard on 40% of sampling occasions at BMC-PP, BMC-AP1 and BMC-AP3. Whereas geometric mean fecal coliform counts at BMC-AP3 were 34 CFU/100 mL, counts then increased along the passage to the Princess Place location (geometric mean 121 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, 2022

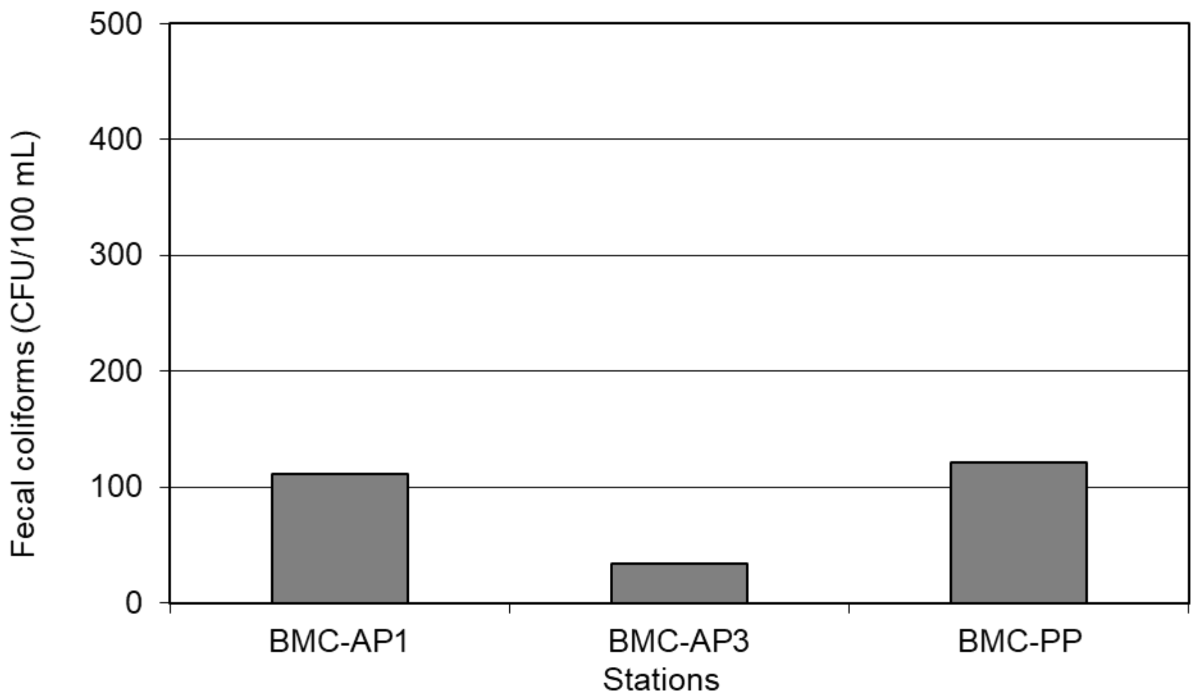


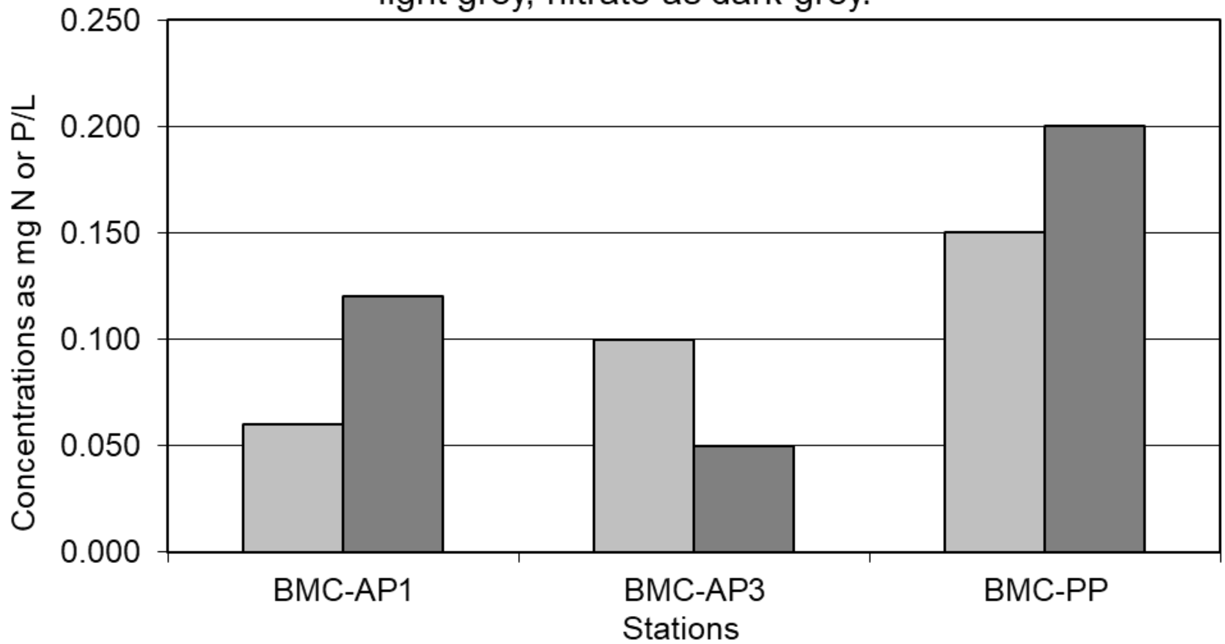
Table 4.1. Water quality data in Burnt Mill Creek, 2022, as mean (standard deviation)/range. Fecal coliforms as geometric mean; N/P as mean/median, n = 5 samples collected.

Parameter	BMC-AP1	BMC-AP3	BMC-PP
DO (mg/L)	7.4 (2.1) 5.4-10.4	10.9 (1.3)* 9.5-12.5	7.3 (2.6) 5.4-11.7
Cond. (μS/cm)	258 (33) 216-303	209 (67) 134-278	1,298 (1,916) 278-4,699
pH	7.1 (0.2) 6.9-7.4	8.0 (0.8)* 7.3-9.1	7.3 (0.3) 7.1-7.8
Turbidity (NTU)	2 (1) 1-4	10 (5)* 6-18	4 (3) 2-9
TSS (mg/L)	1.3 (0.0) 1.3-1.3	9.1 (4.5)* 4.7-16.0	4.4 (3.0) 1.3-8.8
Nitrate (mg/L)	0.120 (0.080) 0.040-0.220	0.050 (0.060)** 0.010-0.150	0.200 (0.110) 0.060-0.330
Ammonium (mg/L)	0.080 (0.090) 0.010-0.220	0.050 (0.050) 0.010-0.130	0.070 (0.060) 0.010-0.140
TN (mg/L)	0.560 (0.170) 0.330-0.770	0.650 (0.240) 0.300-0.930	0.770 (0.120) 0.630-0.880
OrthoPhos. (mg/L)	0.010 (0.000) 0.010-0.020	0.010 (0.010) 0.010-0.030	0.030 (0.010) 0.010-0.020
TP (mg/L)	0.060 (0.060) 0.010-0.160	0.100 (0.070)* 0.060-0.230	0.150 (0.110) 0.070-0.330
N/P molar ratio	44 33	19 12	25 16
Chlor. *a* (μg/L)	68 (142) 2-321	33 (36) 7-96	23 (31) 6-78
FC (CFU/100 mL)	111 14-240	34 3-319	121 41-410

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

To summarize, in some years Burnt Mill Creek has had problems with low dissolved oxygen (hypoxia) at the Princess Place station BMC-PP, but in 2022 all samples were above standard. One major algal bloom occurred in May 2022 at BMC-PP (78 µg/L chlorophyll *a*; also in May major blooms occurred at BMC-AP1 (321 µg/L) and BMC-AP3 (96 µg/L). The N/P ratios in the lower creek indicate that inputs of phosphorus were likely to stimulate algal bloom formation in 2022, 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.

Figure 4.3. Average orthophosphate and nitrate concentrations by station for Burnt Mill Creek, 2022; TP as light grey, nitrate as dark grey.



Sediment Sampling at Ann McCrary Pond

The sediment data for AP-1, the upstream-most inflow to Ann McCrary Pond (Table 4.3) shows that most of the metals and PAHs of concern were either below the detection limit or at concentrations below either the TEC or PEC. Pyrene showed a concentration of 220 ug/kg, which placed it into the TEC category. Downey Branch (AP-DB) drains suburban neighborhoods into the eastern side of Ann McCrary Pond. Sediment metals were not at toxic levels. However, some of the PAHs (total PAHs, benzo(a)pyrene, pyrene and chrysene) were at potentially toxic concentrations, exceeding the TEC but below the PEC (Table 4.3). Notably, the researchers here observed a number of turtles foraging in the waters. The third major input is AP-RA, the inflow at Rosemont Avenue, nearest the dam. Here the sediments presented a potentially toxic environment, with several metals (copper, lead and zinc) exceeding the TEC but below the PEC. However, almost all the sediment PAHs of concern at this location were high, above the PEC, where harmful effects on aquatic organisms are likely to occur.

Table 4.3. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in tributaries feeding Ann McCrary Pond in the Burnt Mill Creek watershed, 2022. Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur, and italicized concentrations are near potentially harmful levels (see Table 2.2 for more detail).

Parameter	AP-1	AP-DB (Downy Branch)	AP-RA
		Dry wt., ppm = µg/g = mg/kg	
Arsenic	<1.61	1.56	4.44
Cadmium	<0.807	<0.721	<1.38
Chromium	<0.807	1.29	17.5
Copper	<0.807	1.59	*40.2*
Lead	1.38	3.12	*58.2*
Mercury	<0.022	<0.022	0.0730
Nickel	<0.807	<0.721	7.51
Zinc	5.37	8.72	*232.0*
		Dry wt., ppb = ng/g = µg/kg	
Total PAH	789	*2,410*	**35,700**
Anthracene	<166	<186	*366*
Benzo(a)pyrene	<166	*309*	**2,590**
Pyrene	*220*	*558*	**5,990**
Fluoranthene	287	<587	**6,980**
Chrysene	<166	*299*	**3,050**

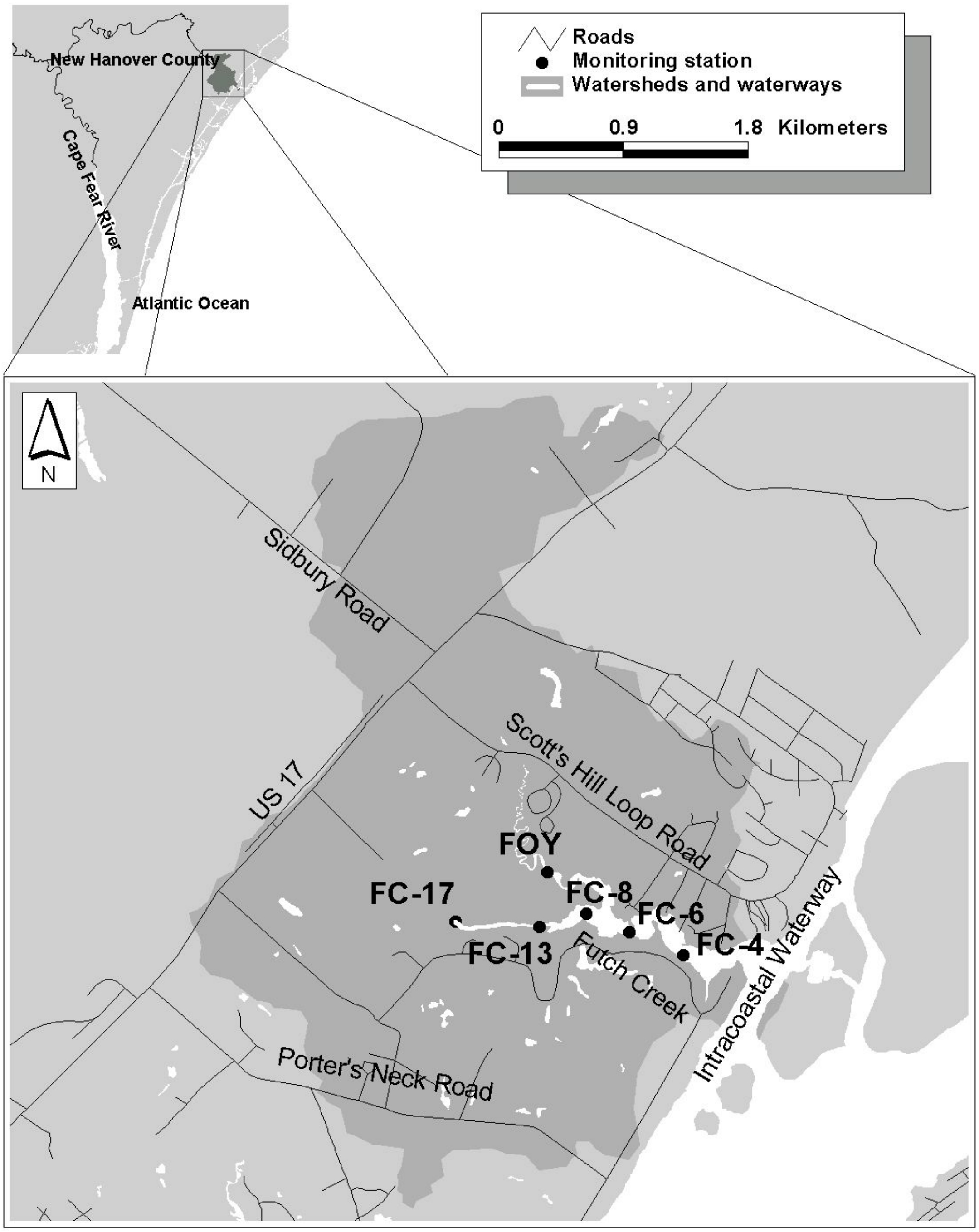
BDL = below detection limit

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 8 occasions in 2022 (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 all sampling occasions (Table 6.1; Appendix B). Station GL-JRB (Jumping Run Branch) had substandard DO on one sampling occasion, as did JRB-17. 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 likewise low at the stream stations (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 November at GL-SQB and GL-JRB with blooms of 56 and 40 µg/L, respectively. The geometric mean fecal coliform bacteria counts for 2022 exceeded the state standard at all three tributary stations (Table 6.1), and the fecal coliform standard was exceeded on >50% of sampling dates at all three stations.

Table 6.1. Mean and (standard deviation) / range of selected field water quality parameters in tributary stations of Greenfield Lake, 2022. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 8 samples collected.

Parameter	JRB-17	GL-JRB	GL-SQB (formerly GL-LB)
DO (mg/L)	7.1 (1.2) 4.8-9.0	6.6 (2.0) 4.1-10.8	3.4 (1.1) 1.8-4.9
Turbidity (NTU)	3 (2) 1-6	3 (1) 1-4	3 (1) 1-4
TSS (mg/L)	2.8 (1.1) 1.3-3.9	3.8 (2.2) 1.3-8.1	3.0 (2.9) 1.3-8.2
Nitrate (mg/L)	0.16 (0.06) 0.11-0.30	0.17 (0.14) 0.01-0.44	0.28 (0.18) 0.08-0.61
Ammon. (mg/L)	0.11 (0.04) 0.06-0.16	0.13 (0.19) 0.01-0.60	0.27 (0.39) 0.01-1.14
TN (mg/L)	0.90 (0.22) 0.56-1.17	0.84 (0.36) 0.48-1.41	1.14 (0.42) 0.65-1.93
Ortho-P. (mg/L)	0.03 (0.01) 0.02-0.05	0.03 (0.01) 0.02-0.04	0.01 (0.04) 0.02-0.06
TP (mg/L)	0.09 (0.08) 0.01-0.26	0.08 (0.06) 0.03-0.22	0.25 (0.21) 0.03-0.62
Inorganic N/P ratio	27 28	24 19	35 22
Chlor. *a* (µg/L)	15 (21) 1-56	14 (12) 3-40	14 (12) 2-32
FC (CFU/100 mL)	386 160-3,000	237 28-2,250	297 86-1,200

Three in-lake stations were sampled on 8 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-P and once at GL-YD in 2022 (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 May of 31 mg/L at GL-YD, concurrent with an algal bloom of 150 µg/L as chlorophyll *a*.

In-lake fecal coliform concentrations exceeded the standard three times at GL2340, twice GL-YD and once at GL-P.

Concentrations of all inorganic nutrients in-lake were mixed with highest nitrate at the upstream station GL-2340, but highest TN and TP at the lower stations where the highest algal biomass was (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 Greenfield Lake at GL-2340 can likely be limited at times by P due to the higher N at that upper lake location, but ratios at GL-YD and GL-P were low, indicating that algae 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).

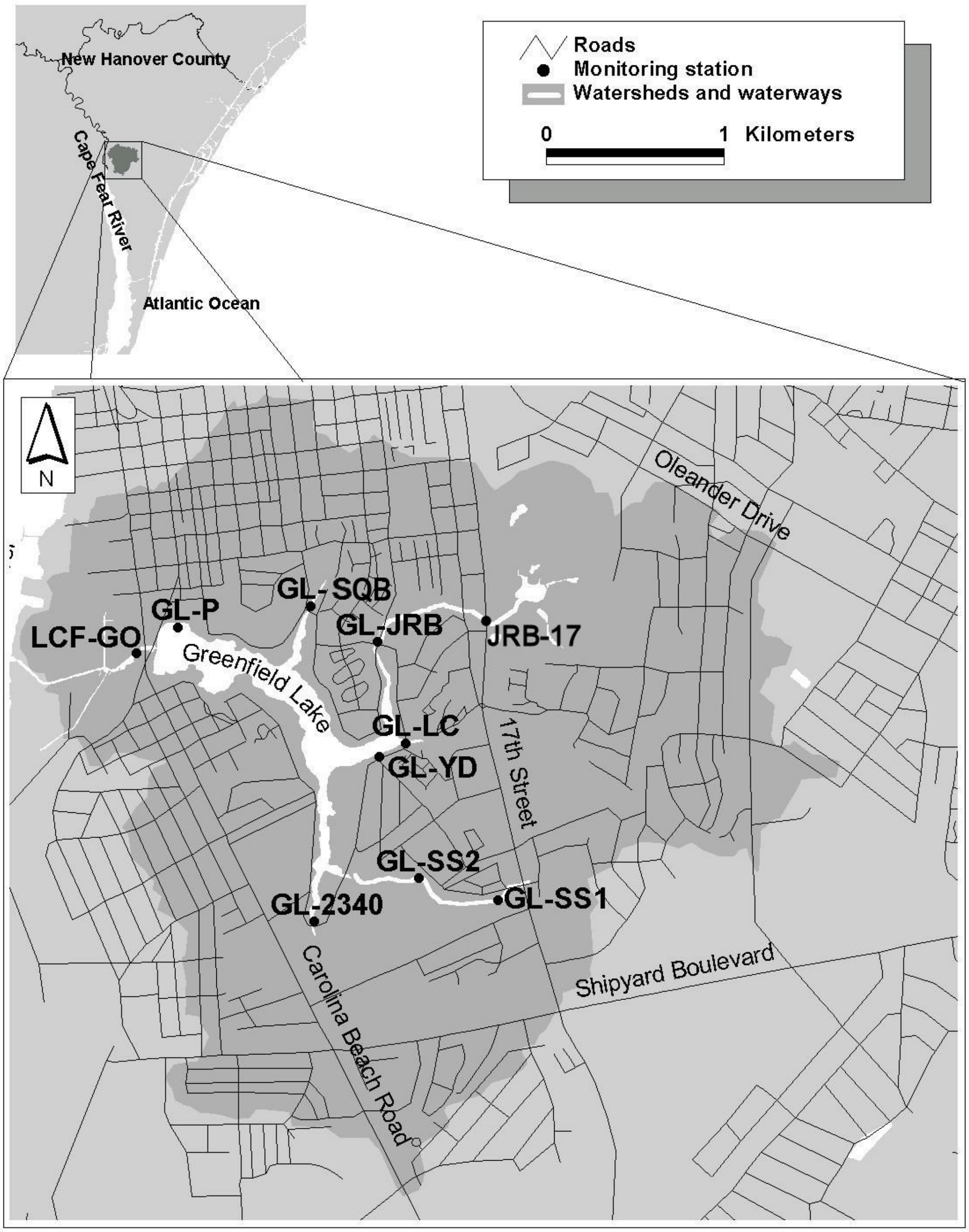
Phytoplankton blooms are problematic in Greenfield Lake (Table 6.2), and usually consist of green or blue-green algal species, or both together. These blooms have occurred during all seasons; in 2022 an extensive bloom of the blue-green *Anabaena spiroides* was sampled in May and June (then sampling was forced to cease until new funding arrived) and bloom conditions were again found in October and November. As such, three blooms exceeding the North Carolina water quality standard of 40 µg/L of chlorophyll *a* were sampled at both GL-YD and GL-P, but none at GL-2340. For the year 2022, chlorophyll *a* exceeded the state standard on 25% of occasions sampled. The North Carolina Division of Environmental Quality placed this lake on the 303(d) list in 2014 for high chlorophyll. Biochemical oxygen demand (BOD5) for 2022 was elevated at GL-YD and GL-P in summer-fall (Table 6.1) with a maximum of 20 mg/L in at GL-P. 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; Iraola et al. 2022).

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 2022. 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. Sediment PAH concentrations are currently high in Silver Stream, one of the input streams to this lake (see below).

Table 6.2. Mean and (standard deviation) / range of selected field water quality parameters in lacustrine stations of Greenfield Lake, 2022. Fecal coliforms (FC) given as geometric mean, N/P ratio as mean / median; n = 8 samples collected.

Parameter	GL-2340	GL-YD	GL-P
DO (mg/L)	5.4 (1.1) 4.1-6.9	9.4 (3.5) 5.4-17.1	10.7 (3.6) 4.6-16.1
Turbidity (NTU)	2 (1) 0-3	4 (4) 0-12	3 (3) 0-9
TSS (mg/L)	2.0 (1.4) 1.3-5.0	7.2 (9.9) 1.3-30.8	6.3 (7.3) 1.3-17.5
Nitrate (mg/L)	0.24 (0.15) 0.01-0.41	0.04 (0.05) 0.01-0.16	0.03 (0.04) 0.01-0.13
Ammonium (mg/L)	0.04 (0.02) 0.01-0.07	0.09 (0.12) 0.01-0.37	0.11 (0.18) 0.01-0.55
TN (mg/L)	0.92 (0.39) 0.50-1.60	0.98 (0.54) 0.44-2.10	1.21 (1.11) 0.46-3.71
Orthophosphate (mg/L)	0.03 (0.01) 0.01-0.04	0.03 (0.02) 0.01-0.07	0.10 (0.14) 0.02-0.41
TP (mg/L)	0.11 (0.08) 0.03-0.25	0.14 (0.10) 0.03-0.29	0.19 (0.20) 0.03-0.62
N/P molar ratio	32 26	13 11	6 5
Fec. col. (CFU/100 mL)	111 10-546	24 3-637	11 3-410
Chlor. *a* (μg/L)	6 (6) 2-18	46 (51) 3-150	69 (78) 1-191
BOD5	2.0 (0.0) 2.0-2.0	3.6 (3.1) 2.0-10.0	5.9 (6.9) 2.0-20.0

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. The results (Iraola et al. 2022) showed that nutrient concentrations and loads were consistently higher in Jumping Run Branch (GL-JRB) and Squash Branch (GL-SQB; also known as GL-LB). 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 and the SurgiCare Pond along 17th St., with cooperation from the owners (Fig. 6.3). The coalition is currently seeking additional funding to complete the restoration work.

Figure 6.2. Greenfield Lake feeder stream stations sampled at various times; note that GL-SQB is also known as GL-LB, and GL-CBB is also known as GL-LC.

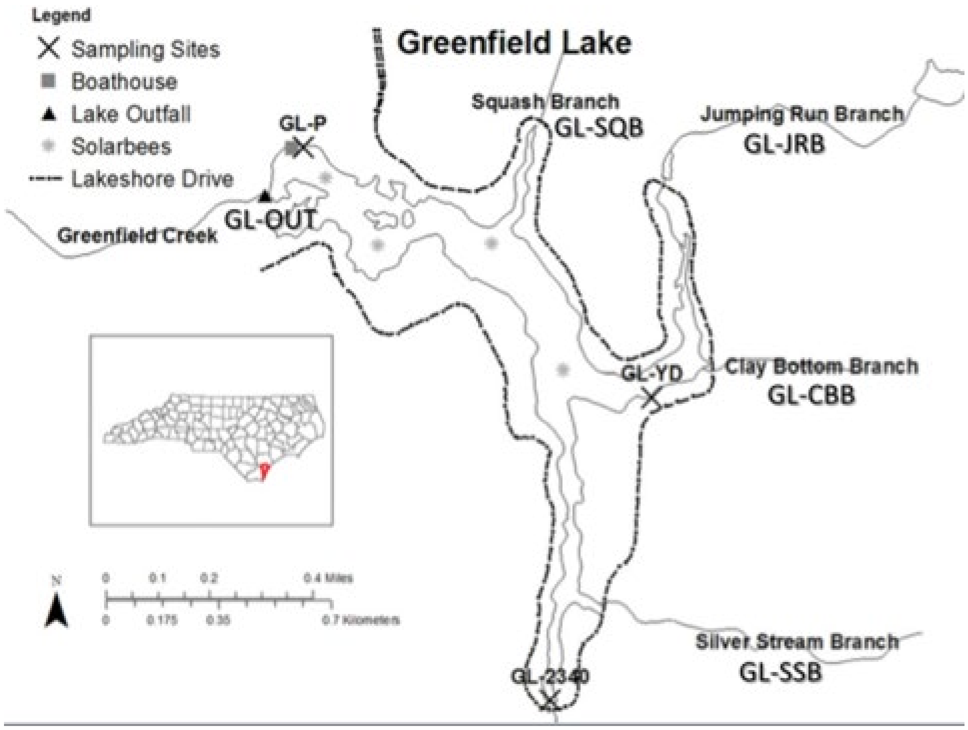


Figure 6.3. SurgiCare Pond on 17th St., drains to Jumping Run Branch, sampled by UNCW in forebay and outfall.

SurgiCare Pond Sampling Efforts

Denitrification in SurgiCare pond

Denitrification is a key means of removal of inorganic nitrogen from eutrophying streams, rivers and lakes. UNCW graduate student Nick Picha has measured this microbially based process at 9 wet detention ponds in Wilmington in 2021-2022. As part of this, sediment cores were taken from the inflow and outflow sites of SurgiCare Pond (9 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.

Denitrification rates in SurgiCare Pond (Fig. 6.4) showed a spatial pattern. Rates in the incoming area, or forebay, were 3X that of the sediments near the outfall.

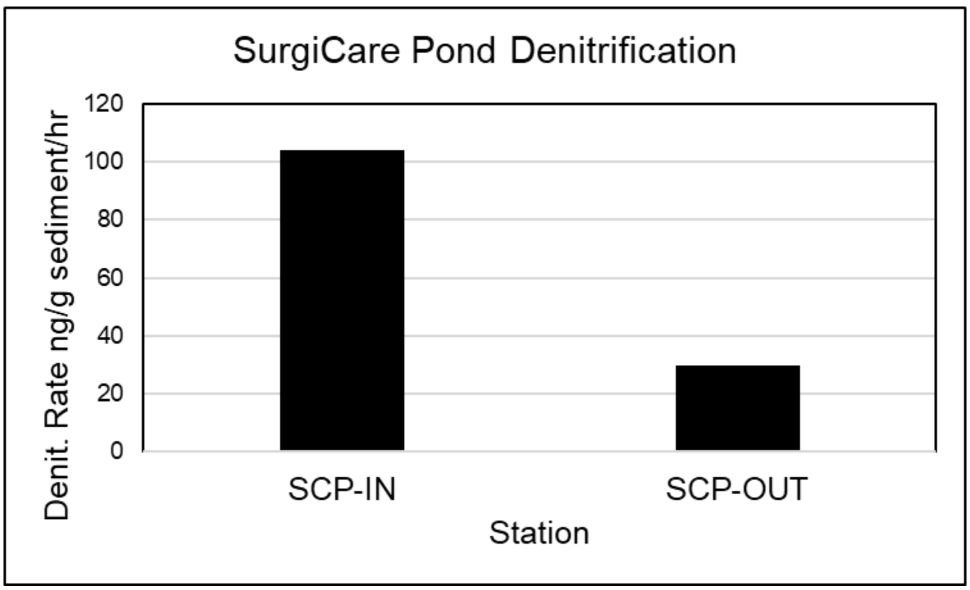


Figure 6.4. Denitrification rates in SurgiCare Pond, 2021-2022 (n = 10 months).

Sediment Metals and PAH Sampling

Sediment metals and PAHs were sampled in upper Silver Stream regional wet detention pond (see cover photo). This pond drains a portion of Greenfield Lake watershed, and collects runoff from a large commercial area, including roads and parking lots. The sediment data for Silver Stream 1 (Table 6.3) shows that many of the metals of concern were either below the detection limit or at concentrations below either the TEC or PEC. However, the PAHs were a different story, with all PAHs of concern exceeding the PEC, or at levels likely harmful to aquatic life.

Table 6.3. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Silver Stream 1, a regional wet detention pond that enters Greenfield Lake, 2022. Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur, and italicized concentrations are near potentially harmful levels (see Table 2.2 for more detail).

Parameter	Silver Stream 1
	Dry wt., ppm = µg/g = mg/kg
Arsenic	<1.41
Cadmium	<0.704
Chromium	2.22
Copper	4.33
Lead	2.72
Mercury	<0.019
Nickel	0.912
Zinc	22.4
	Dry wt., ppb = ng/g = µg/kg
Total PAH	**94,800**
Anthracene	**1,130**
Benzo(a)pyrene	**4,820**
Pyrene	**18,200**
Fluoranthene	**22,500**
Chrysene	**6,770**

BDL = below detection limit

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: Good-Fair
Problematic pollutants: occasional high fecal bacteria, minor algal bloom issues

Hewletts Creek was sampled four 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 (Table 7.2). Dissolved oxygen was within standard on all sampling occasions.

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 moderately high at most locations except MB-PGR. Total nitrogen was low to moderate at all sites. Orthophosphate concentrations were low, and total phosphorus concentrations ranged from low to moderate. 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) showed that no major blooms occurred during the sampling runs; MB-PGR had one minor bloom of 32 µg/L chlorophyll *a* in October 2022. 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, NB-GLR or HC-3, but exceeded standard three times at MB-PGR. The geometric mean of fecal bacteria counts at HC-3 was 4 CFU/100 mL, well below the shellfishing standard of 14 CFU/100 mL.

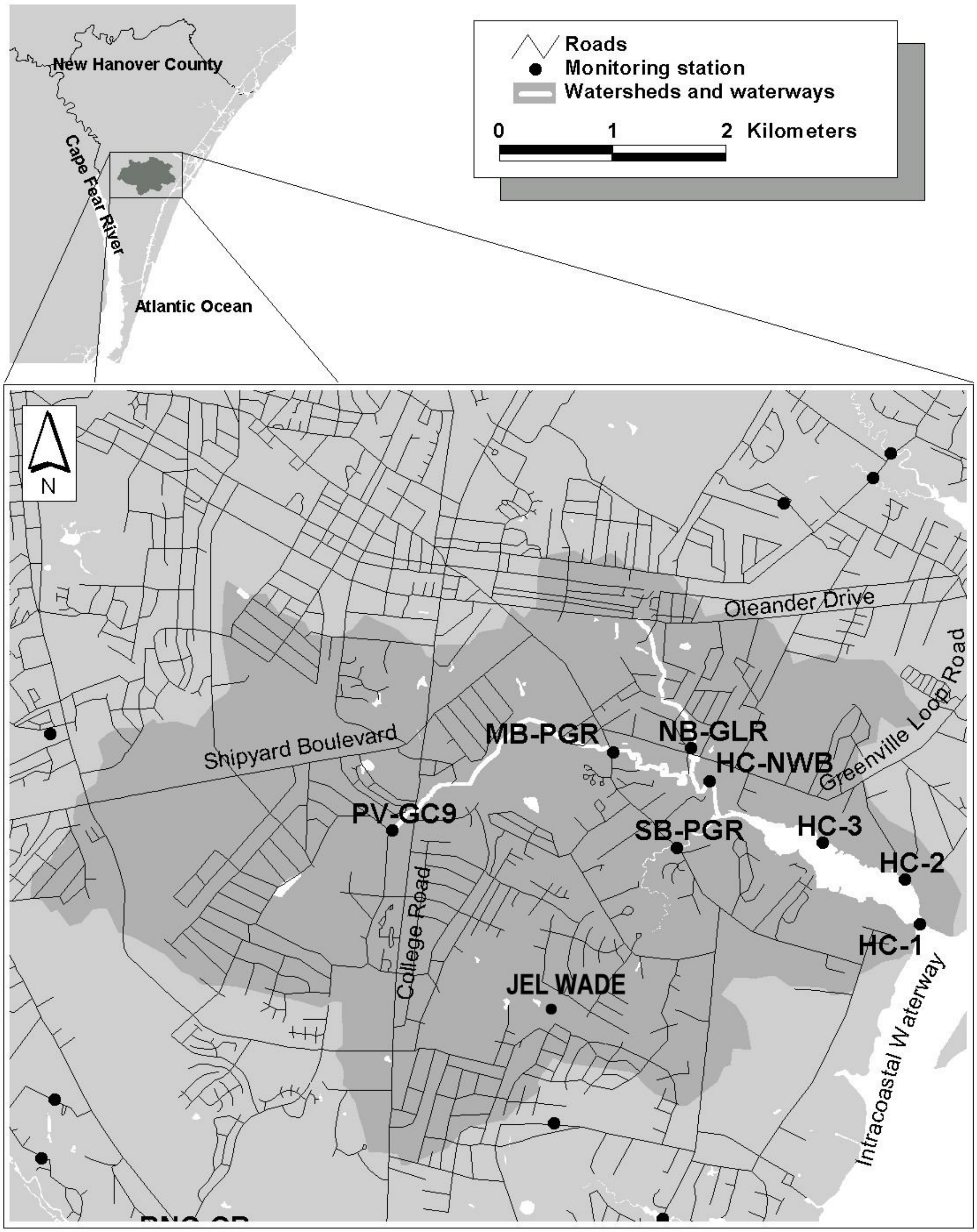


Figure 7.1. Hewletts Creek watershed.

Table 7.1. Selected water quality parameters at stations in Hewletts Creek watershed, 2022, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, n = 4 samples collected.

Parameter	SB-PGR	MB-PGR	NB-GLR	HC-3
Salinity (ppt)	32.2 (4.6) 21.4-36.7	7.1 (7.7) 0.1-17.4	25.1 (8.0) 14.5-32.5	35.4 (1.4) 33.8-37.0
Turbidity (NTU)	2 (2) 0-4	2 (1) 1-2	2 (1) 1-3	2 (1) 0-3
TSS (mg/L)	14.3 (3.7) 9.7-18.1	5.5 (4.8) 1.3-9.9	10.8 (9.0) 1.3-22.9	13.3 (4.0) 10.5-19.1
DO (mg/L)	7.5 (1.4) 5.4-9.0	7.4 (1.6) 5.1-8.5	7.7 (1.5) 5.7-9.2	8.0 (1.1) 6.6-9.2
Nitrate (mg/L)	0.01 (0.00) 0.01-0.01	0.12 (0.10) 0.01-0.25	0.01 (0.00) 0.01-0.01	0.01 (0.00) 0.01-0.01
Ammonium (mg/L)	0.35 (0.24) 0.01-0.53	0.05 (0.03) 0.01-0.07	0.28 (0.20) 0.09-0.52	0.37 (0.16) 0.18-0.56
TN (mg/L)	0.60 (0.16) 0.46-0.74	0.65 (0.44) 0.22-1.26	0.62 (0.29) 0.41-1.05	0.74 (0.16) 0.50-0.88
Orthophosphate (mg/L)	0.02 (0.01) 0.01-0.02	0.02(0.01) 0.01-0.03	0.02 (0.01) 0.01-0.02	0.02 (0.01) 0.01-0.02
TP (mg/L)	0.22 (0.23) 0.01-0.46	0.07 (0.05) 0.01-0.14	0.27 (0.43) 0.01-0.92	0.04 (0.03) 0.01-0.80
Mean N/P ratio Median	55 49	23 25	57 50	67 60
Chlor *a* (µg/L)	4 (2) 2-7	10 (15) 1-32	9 (8) 2-21	4 (3) 1-7
Fecal coliforms (CFU/100 mL)	36 6-200	105 28-1,350	128 41-280	5 1-13

Sediment Sampling

Sediment sampling was performed in the final wet detention pond of Municipal Golf Course (which we named Muni Golf Course Pond 1). Outfall from this pond enters the middle branch of Hewletts Creek, upstream of Station MB-PGR. Nutrients from course fertilization are assumed to be the reason why the waters at MB-PGR consistently have the highest nitrate concentrations of the three main branches of Hewletts Creek.

The sediment data for Municipal Golf Course Pond 1 (Table 7.2) shows that the metals and PAHs of concern were either below the detection limit or at concentrations below either the TEC or PEC. Thus, this golf course wet detention pond is not considered to have toxic sediments at least for the parameters we sampled (note we did not assess herbicide or pesticide levels).

Table 7.2. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Municipal Golf Course Pond 1, Hewletts Creek watershed, 2022. Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur, and italicized concentrations are near potentially harmful levels (see Table 2.2 for more detail).

Parameter	Muni Golf Course Pond 1
	Dry wt., ppm = µg/g = mg/kg
Arsenic	<1.12
Cadmium	<0.559
Chromium	0.628
Copper	14.5
Lead	1.69
Mercury	<0.024
Nickel	<0.559
Zinc	3.50
	Dry wt., ppb = ng/g = µg/kg
Total PAH	180
Anthracene	<180
Benzo(a)pyrene	<180
Pyrene	<180
Fluoranthene	<180
Chrysene	<180

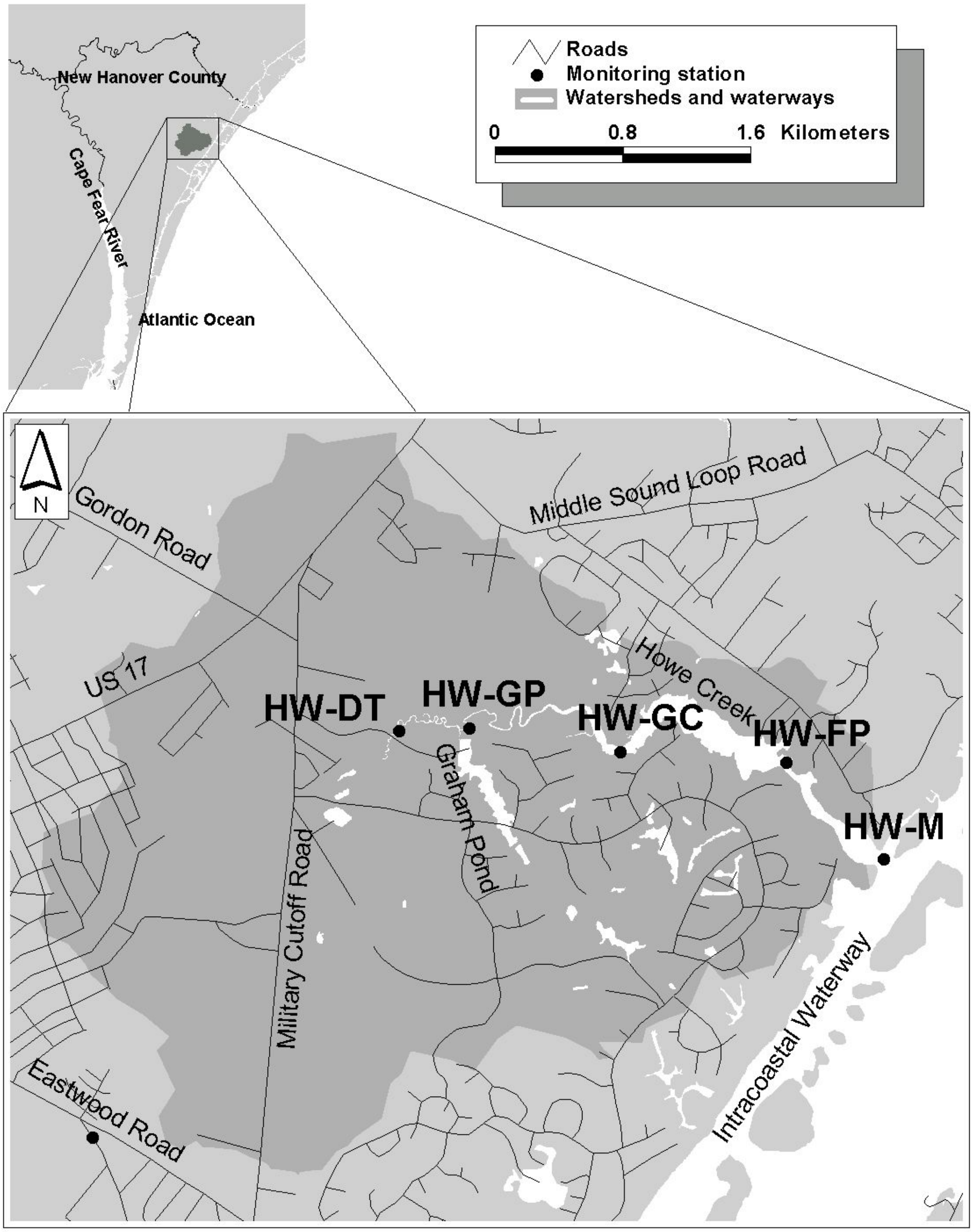
BDL = below detection limit

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.

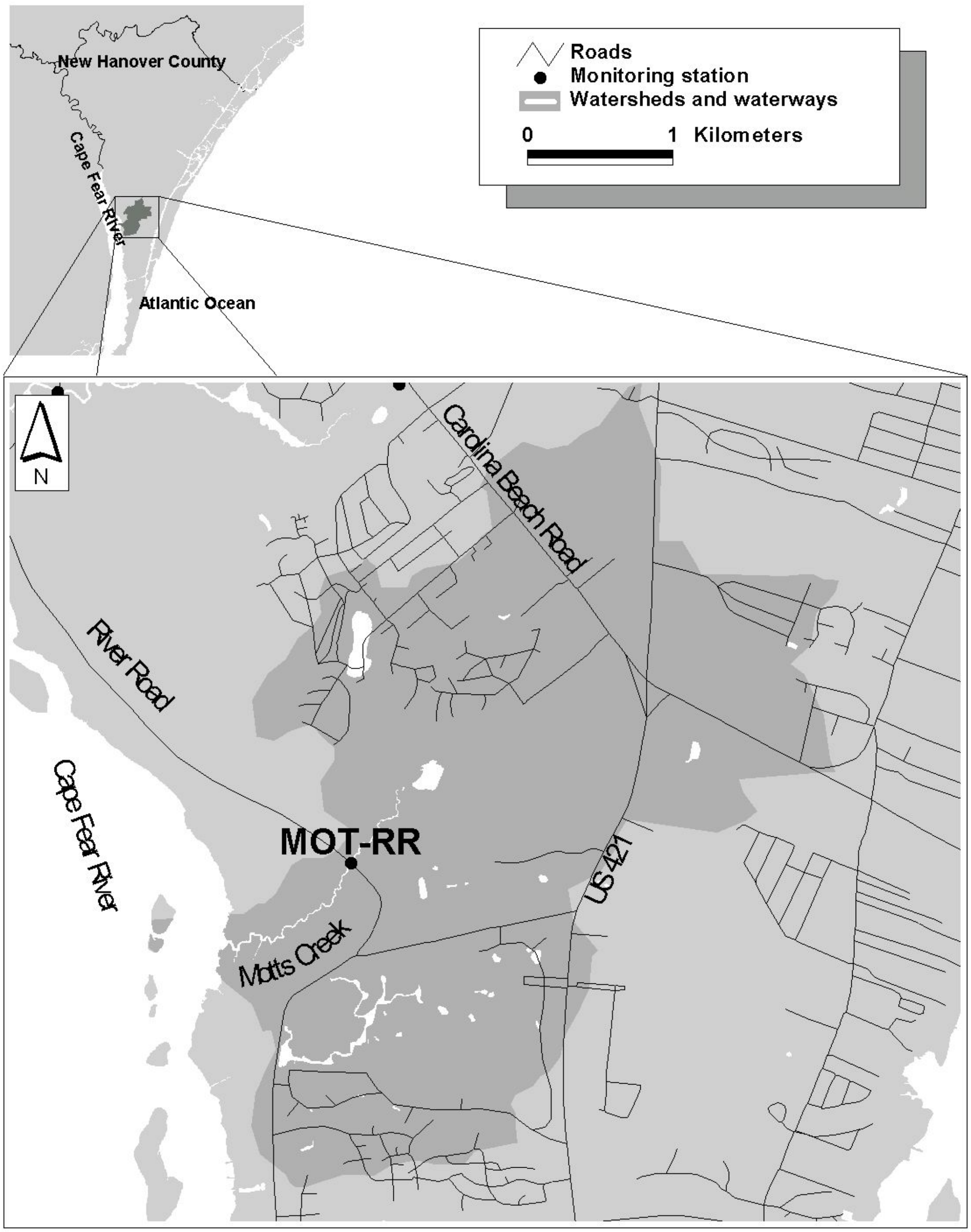


9.0 Motts Creek

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

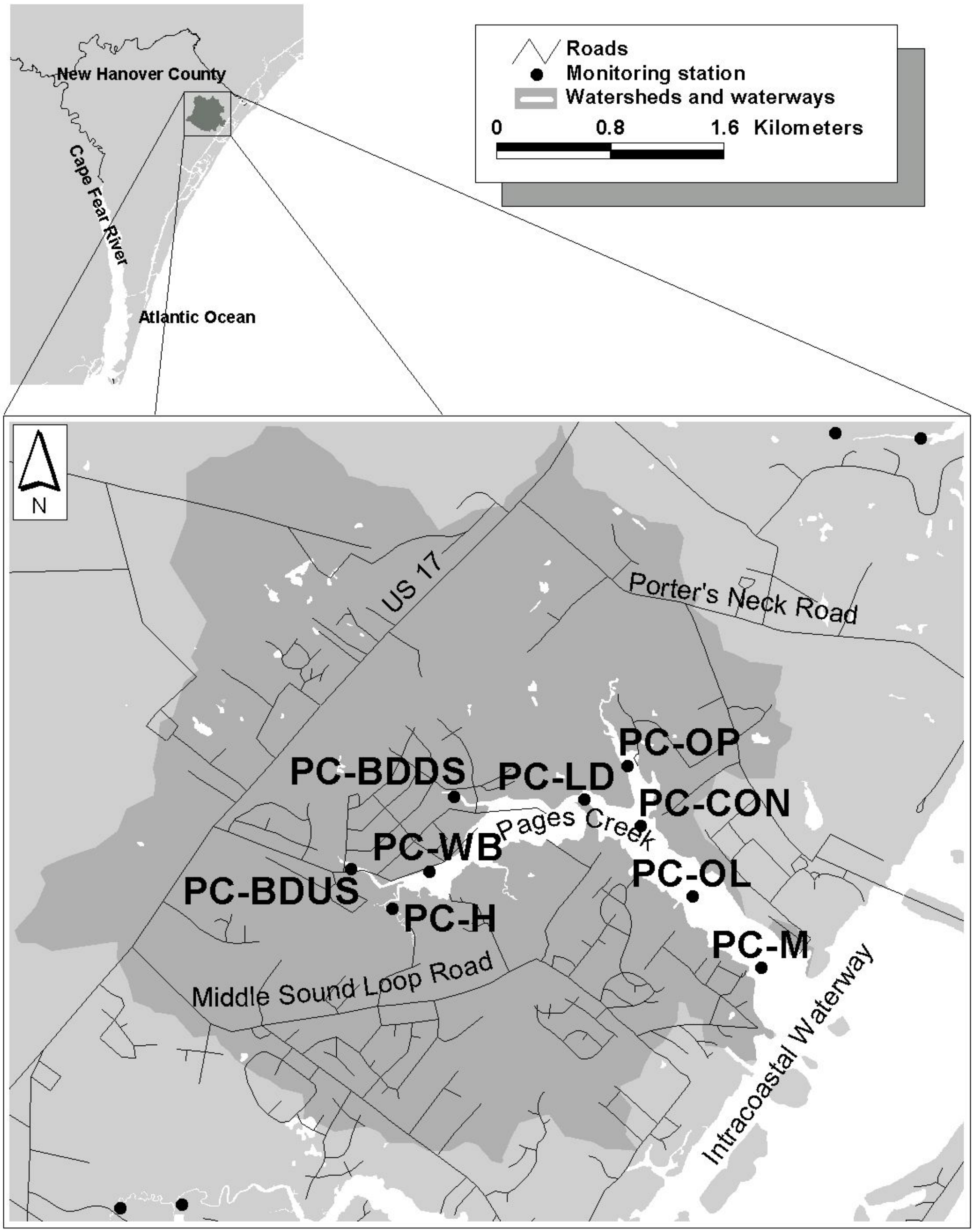


10.0 Pages Creek

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.

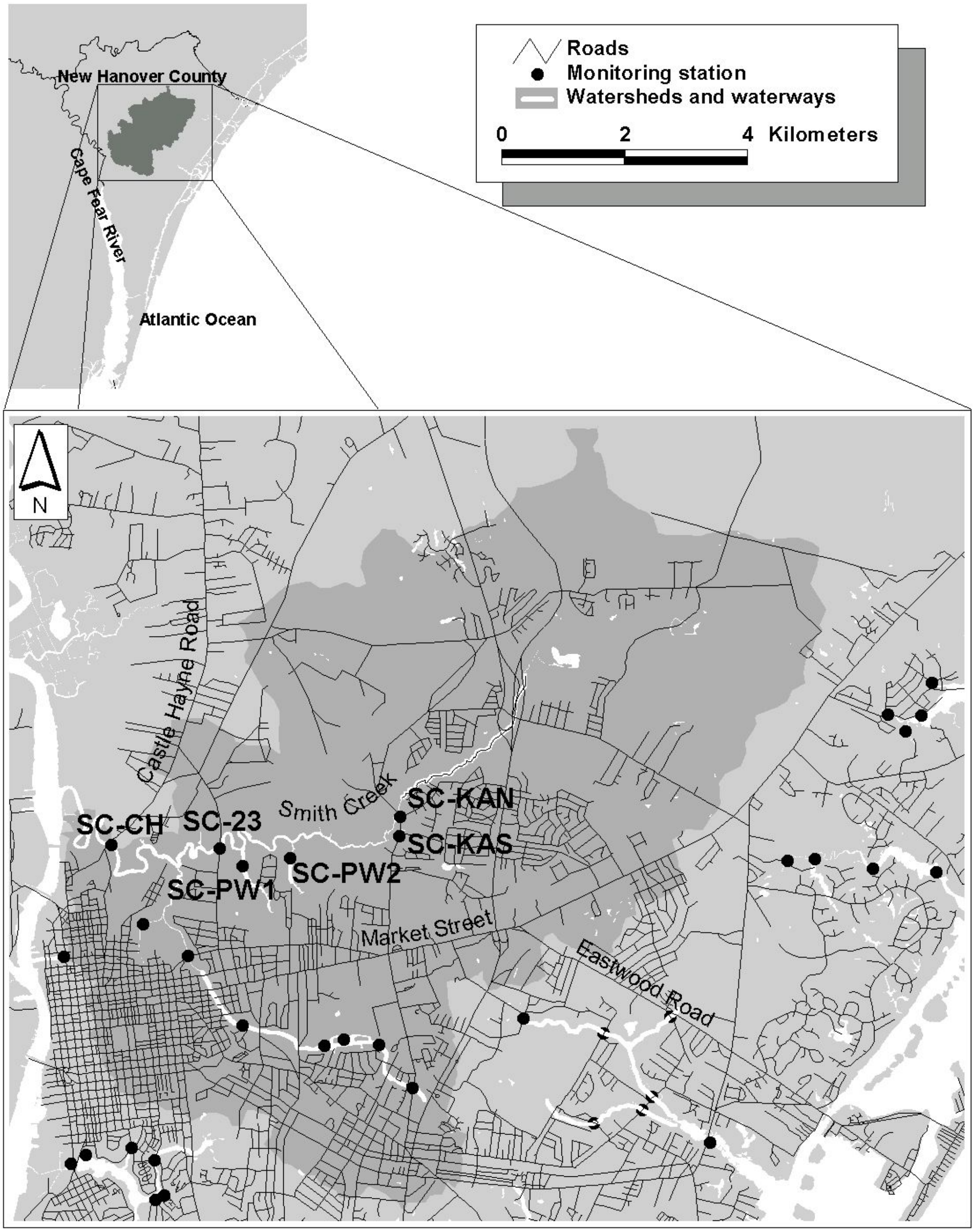


11.0 Smith Creek

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 2022 no samples were collected as bridge construction was ongoing all year at the sampling station.

Figure 11.1 Smith Creek watershed

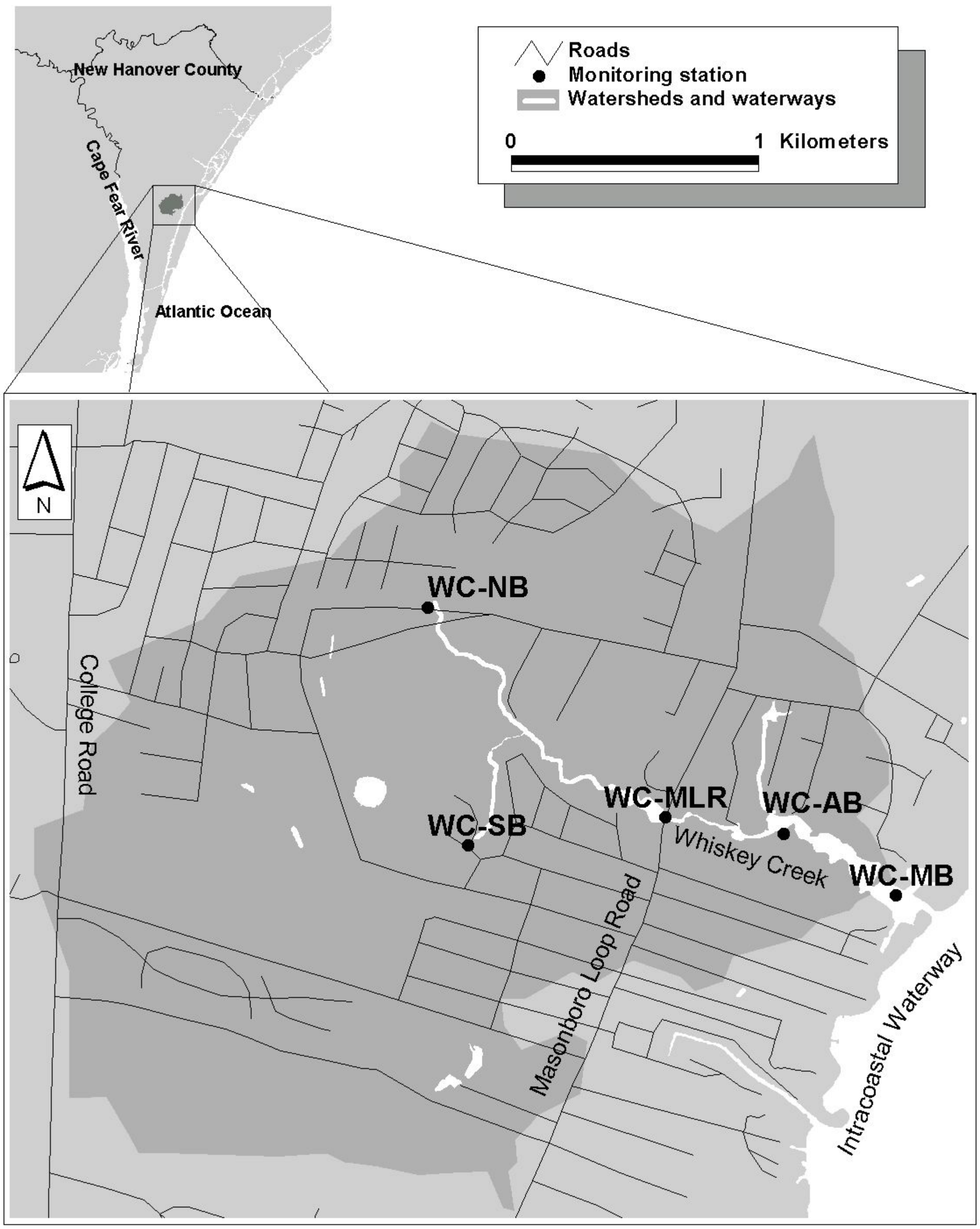


12.0 Whiskey Creek

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 streams), 25 NTU (lakes and reservoirs)
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 2022, where available, for chlorophyll *a*, dissolved oxygen, turbidity, and fecal coliform bacteria (human contact standard) based in part on North Carolina state chemical standards for freshwater or tidal saltwater.

G (good quality) – state standard exceeded in ≤ 10% of the measurements
F (fair quality) – state standard exceeded in 11-25% of the measurements
P (poor quality) – state standard exceeded in >25% of the measurements

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

NS – not sampled due to ongoing bridge construction at the sampling site.

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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