

Goose and Crooked Creeks Local Watershed Plan

Watershed Assessment Report – Phase II

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Ecosystem Enhancement Program

TETRA TECH

CCOG Centralina Council of Governments

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Executive Summary

The Goose Creek and Crooked Creek watersheds are located in Mecklenburg and Union counties in the southern piedmont region of North Carolina. Stream reaches in Goose Creek and Crooked Creek are listed as impaired or impacted on the 2010 303(d) list due to habitat degradation, turbidity and fecal coliform. (NCDENR, 2012) The Goose Creek watershed supports a population of the Carolina heelsplitter (*Lasmigona decorata*), which is listed as endangered at the federal level and critically endangered at the state level. Phase I of the Goose Creek and Crooked Creek Local Watershed Planning (LWP) process focused on characterizing the watersheds, and concluded in 2009.

Phase II of the NCEEP Goose Creek and Crooked Creek LWP process – focus on watershed assessment – began in April 2010. The goals of Phase II of the LWP was to determine the functional integrity of streams and other aquatic systems in the watershed; identify the key stressors and their sources impacting water quality, habitat, and hydrology and determine where they are focused and identify key assets in the watershed.

The success of all phases of this LWP is rooted in the active interest and continuing participation of a variety of different stakeholders. The stakeholder process was designed to involve several distinct groups, including Project Administration Team (PAT), the Watershed Technical Team (WTT), and community stakeholders. The WTT, which consists of up to 40 key and active stakeholders in these watersheds that broadly represent several organizations and interests, has emerged as the primary engagement group over the course of LWP Phases I & II. During Phase II, the WTT convened four (4) times from July 2010 – August 2011; once at the Centralina COG office and the remainder at the Indian Trail Civic Building.

Developing Goose Creek and Crooked Creek LWP Goals & Objectives was one of the main tasks taken on by the WTT during the Goal Setting Phase of Phase II. LWP Goals & Objectives were vetted and then adopted at the March 2011 WTT meeting. The adopted, overarching Goals for the LWP are as follows:

> **GOAL 1:** Restore, protect, and enhance watershed functions such as hydrology, water quality, and aquatic and terrestrial habitat
> **GOAL 2:** To minimize impacts on water quality, aquatic and terrestrial habitat, and hydrology in the watershed by supporting balanced, sustainable, and diverse land use and development, in accordance with existing and future policies
> **GOAL 3:** Build partnerships and involve stakeholders in the protection and restoration of the watersheds

During the development of Phase II of this LWP many partners collaborated to collect and analyze various types of data throughout these watersheds. Partners include NC Division of Water Quality (NCDWQ) Watershed Assessment Team, NC DWQ Biological Assessment Unit, US Fish and Wildlife Service, and NC Department of Transportation Biological Surveys Group. The data that was collected includes but is not limited to habitat, benthic macroinvertebrate and fish community assessments, physical and chemical water quality parameters, channel stability assessments and watershed modeling outputs.

The Phase I Preliminary Findings memo discussed the linkages between the major stressors, sources, impacts, and functional deficits (see Table 12) and hypothesized that sediment and increased peak

flows/runoff volumes are the most important and pervasive stressors to watershed function in the Goose Creek and Crooked Creek watersheds. The following were hypothesized as secondary stressors: bacteria, oxygen demanding substances/nutrients, and toxicity-related pollutants (i.e., ammonia, copper, and pesticides) (Tetra Tech, 2008a; Centralina, 2009). The results of the Phase II assessments generally support the presence of the proposed stressors in the Phase I preliminary findings memo developed by Tetra Tech.

Key stressors identified through this Phase II work support the Phase I findings that peak flow/runoff and sediment are significant to these watersheds. Therefore management strategies presented in the Phase III Watershed Management Plan (WMP) will focus on control and reduction of these impacts. In addition, consideration will be given to additional stressors including oxygen demanding substances/nutrients, bacteria and copper. Management strategies will be presented and discussed in the Phase III Watershed Management Plan (WMP).

Section 1 Introduction

1.1 LWP Background

The Goose and Crooked Creeks watershed, located in Mecklenburg and Union Counties, are approximately 42 and 53 mi^2, respectively. These watersheds encompass eleven (11) local government jurisdictions including: the Village of Lake Park, the Towns of Fairview, Hemby Bridge, Indian Trail, Matthews, Mint Hill, Stallings, Unionville, the City of Monroe, and Union and Mecklenburg Counties. All streams in the watershed are classified as C surface waters, in which aquatic life propagation/protection and secondary recreation are designated as the best uses. Stream reaches in Goose Creek and Crooked Creek are listed as impaired on the 2010 303(d) list due to ecological/ biological integrity, turbidity and fecal coliform. (Tetra Tech, 2008a)(NCDENR, 2012)

The Goose Creek watershed supports a population of the Carolina heelsplitter (*Lasmigona decorata*), which is listed as endangered at the federal level and critically endangered at the state level (WRC, 2005). The population is known to exist along two creeks within the planning area, Goose and Duck Creek, and is one of nine surviving populations of the species within its known range. Historically, the species populated portions of the Catawba, Pee Dee, Savannah, and Saluda river basins (EMC, 2007). In 2002, USFWS designated specific stream reaches as critical habitat for the Carolina heelsplitter along Goose and Duck creeks. Goose and Crooked creeks also support sensitive mussel species other than the Carolina heelsplitter including Carolina creekshell, Atlantic pigtoe, Savannah lilliput, Creeper, Notched rainbow and Eastern creekshell. The Carolina heelsplitter has not been observed in Crooked Creek, but four sensitive mussel species, including state endangered species and federal species of concern, have been observed within this watershed. (Tetra Tech, 2008a)

During Phase I, Tetra Tech developed a Land Use/Land Cover (LULC) dataset for these watersheds (described in Appendix A). The resultant GIS coverage represents the improved and updated LULC coverage for the Goose Creek and Crooked Creek watersheds. Table 1 shows the percentages of existing land use within reporting categories for the Goose Creek and Crooked Creek watersheds.

When the two watersheds are compared, both have similar percentages of developed land, but the Crooked Creek watershed has a slightly higher percentage of high density development, particularly in commercial land uses. Crooked Creek also has a higher percentage of agricultural land while Goose Creek has a higher percentage of natural area (forest, wetland, etc.). Much of the development in both watersheds has occurred in the headwaters, and much of the agricultural and forested land exists in the lower reaches. (Tetra Tech, 2008a)

Table 1. Percent (%) Existing Land Use/Land Cover within Goose and Crooked Creeks Watersheds

Watershed	Acres	Barren Land/Developed, Open Space	Commercial/Industrial/Transportation	Multi-Family Residential	Residential, High Density	Residential, Medium Density	Residential, Low Density	Residential, Very Low Density	Pasture/Agricultural Lands	Forest/Shrub/Scrub	Wetland	Water
		Percent (%)										
Goose Creek	27,040	0.5	4.1	0.0	0.0	0.9	4.0	4.4	36.8	47.0	1.8	0.4
Crooked Creek	32,173	0.5	7.4	0.0	0.0	1.8	4.6	4.2	46.1	32.4	2.5	0.4
Both Watersheds	59,213	0.5	5.9	0.0	0.0	1.4	4.4	4.3	41.9	39.0	2.2	0.4

Tetra Tech, 2008a

1.1.1 Phase II Stakeholder Involvement

The long-term success of this local watershed plan is rooted in the active interest and continuing participation of a variety of different stakeholders. The stakeholder process was designed to involve several distinct groups. In general these were the Project Administration Team (PAT), Watershed Technical Team (WTT), and Community Stakeholders. The WTT, which consists of up to 40 key and active individuals in these watersheds that broadly represent several organizations and interests, has emerged as the primary engagement group. Stakeholders have had opportunities to be involved through meetings, phone calls, emails, and the LWP's website (www.gooseandcrooked.org *or* www.gooseandcrooked.net).

Project Administration Team

The PAT continues to provide an arena within which lead project partners can coordinate with each other on logistics and contract management issues throughout the course of the LWP. In addition, this team has been responsible for overall decision-making and guiding the activities of Phase II of this watershed plan as well as ensuring ongoing coordination with the complementary NC Division of Water Quality funded 319 Grant titled "Rocky River Watershed Improvement Projects." The PAT is comprised of representatives from Centralina COG, NC Division of Water Quality, NC Ecosystem Enhancement Program (NCEEP), and Tetra Tech, and has convened six (6) times beginning in spring 2008.

Watershed Technical Team

The WTT has emerged from the existing base of individuals and organizations that have met through related watershed processes and initiatives in the past. Through PAT contacts and input NCEEP identified critical organizations, key individuals and groups were contacted that represent strategic and specialized knowledge related to the watershed. The WTT has served in a steering capacity for Phase II of this plan. This team of experts has provided guidance, accuracy checks, and feedback on LWP Goals and Objectives, watershed modeling and analysis activities, regulatory and institutional measure reviews, and site and related significant information based on local area knowledge. Furthermore, members of the WTT have provided input on how future phases of the LWP could be carried out.

The WTT is comprised of invited representatives from the eleven (11) jurisdictions within the watershed area (Mecklenburg County; Union County; Fairview; Hemby Bridge; Indian Trail; Lake Park; Matthews; Mint Hill; Monroe; Stallings and Unionville). In addition, representatives from other organizations have included, but are not limited to: Catawba Land Conservancy, Natural Resources Conservation Service, Soil & Water Conservation District representatives, NC Cooperative Extension Service, NC Wildlife Resources Commission and the US Fish and Wildlife Service, water quality consultants/engineers, and the NC Division of Water Quality. Over the course of Phase II, the WTT has emerged as an active consortium of experts and community stakeholders. Additional individuals and organizations with local area knowledge and interests will continue to be welcome members of the WTT as the LWP process seeks long term engagement and ownership of watershed activities, especially after NCEEP has completed its formal involvement in the area.

Phase II Activities

During Phase II of the LWP, the WTT convened four (4) times; once at the Centralina COG office and the remainder at the Town of Indian Trail Civic Center. Meeting dates and an outline of topics are in Table 2 below.

Table 2. Watershed Technical Team Meeting Dates and Purpose

WTT Meeting Date	Purpose
July 20, 2010	Phase II kickoff, convey LWP process to date and going forward, overview of watersheds, initiate Goals & Objectives discussion, discuss project timeline
December 15, 2010	Overview of regulatory and institutional measures assessment, Goals & Objectives input, water quality overview, and stream and wetland work updates
March 29, 2011	Field site visits to two (2) locations in the watersheds that illustrate preservation and mitigation activities being conducted by project partners, update of regulatory and institutional measures assessment, review of water quality model being conducted in coordination with

	319 funds
August 3, 2011	Presentation of sub-watershed prioritization findings, roadmap, input, and guidance on LWP Phase III, Goose Creek Site Specific Water Quality Management Plan, NCDWQ monitoring data

1.2 Goals and Objectives of the Local Watershed Plan

Developing the Goose and Crooked Creeks Local Watershed Plan Goals and Objectives was one of the main tasks during the Goal Setting Phase of Phase II. These Goals and Objectives will be focused on and addressed largely in the Phase III Watershed Management Plan. See Appendix B for more details regarding the development of these LWP Goals and Objectives. The Goals and Objectives were vetted during and between (via email) Watershed Technical Team (WTT) meetings 1-3:

I. July 20, 2010 – WTT Phase II Meeting #1
II. December 15, 2010 – WTT Phase II Meeting #2
III. March 29, 2011 – *Adopted.* WTT Phase II Meeting #3

Goose Creek and Crooked Creek Local Watershed Plan
LWP Goals and Objectives
Adopted March 29, 2011

GOAL 1:

Restore, protect, and enhance watershed functions such as hydrology, water quality, and aquatic and terrestrial habitat

OBJECTIVES 1:

a) Restore, expand, support, and protect beneficial watershed functions and uses including:
   - Protect flood plain function
   - Terrestrial & aquatic habitat
     i. Environmentally sensitive and critical lands
        1. Undeveloped natural areas
        2. Natural area connectivity
     ii. Native vegetation
     iii. Native aquatic biology
     iv. In-stream habitat
   - Recreation
   - Wetland hydrology

b) Design and construct projects to restore, maintain, and enhance:
   - Stream banks
   - Riparian areas
   - Wildlife habitat areas
   - In-stream habitat
   - Riparian buffers

- Wetlands

c) Minimize impacts of stormwater runoff and erosion on stream hydrology to promote stable stream morphology and protect aquatic habitat and native tree species
d) Minimize impacts on water quality by pathogens, nutrients, and other pollutants in stormwater runoff
e) Cooperate with property owners and permitting agencies to detect and eliminate illicit discharges, sanitary sewer overflows, and malfunctioning septic systems to protect human health, enhance water quality and aquatic habitat
f) Address impacts to stream water quality due to livestock access to streams
g) Address pollutant(s) of concern for state approved Total Maximum Daily Loads and water quality improvement plans

GOAL 2:

To minimize impacts on water quality, aquatic and terrestrial habitat, and hydrology in the watershed by supporting balanced, sustainable, and diverse land use and development, in accordance with existing and future policies

OBJECTIVES 2:

a) Promote site planning, design, construction and maintenance strategies to maintain or restore hydrology and water quality of the property
b) Identify strategies that strive to maximize effectiveness, minimize cost, and minimize impacts on businesses and residents where possible
c) Identify restoration and protection strategies that complement comprehensive plans and policies and provide multiple benefits such as recreation and protection of critical lands
d) Design and construct infrastructure projects (e.g., water/sewer lines, energy transmission lines, etc.) in manner that minimizes impacts on watershed functions (i.e., water quality, habitat, and hydrology)
e) Promote design and construct new developments, recreation areas, etc. in manner that minimizes impacts on watershed functions, including minimizing impervious areas

GOAL 3:

Build partnerships and involve stakeholders in the protection and restoration of the watersheds

OBJECTIVES 3:

a) Increase education, awareness, and stewardship within the watershed, including encouraging policy makers to develop policies that support a healthy watershed
b) Identify and recruit stakeholders and partners in protecting, maintaining, and restoring watersheds in Mecklenburg and Union counties
c) Report progress toward protection and restoration through monitoring and assessment
d) Identify funding for implementation
e) Seek adoption or endorsement of the local watershed plan by each local jurisdiction within the watersheds

1.3 Summary of Phase I Findings and Recommendations

The preliminary findings for the Goose Creek and Crooked Creek watersheds, which was developed by Tetra Tech and is entitled "*Goose Creek and Crooked Creek LWP Phase I Preliminary Findings*", provided

a review of the existing data and assessments, field reconnaissance conducted in July 2008, other scoping analyses, and the development of conceptual models describing the linkages between sources, stressors, and impacts.

The Phase I hypothesis was that the primary stressors in both watershed are increased peak flows and runoff volumes, sediment, and bacteria. Oxygen demanding substances and toxic substances were thought to be secondary stressors. The preliminary assessment suggested that sediment and increased peak flows/runoff volumes are the most important and pervasive stressors to watershed function. These stressors, resulting primarily from the lack of historical pre- and post-construction stormwater control, have resulted in impairments to aquatic habitat in both watersheds. (Tetra Tech, 2008a; Centralina, 2009)

1.4 Goals and Objectives of Phase II Watershed Assessment

The Phase I report identified the following key questions for further assessment in Phases II and III:

· Where have the greatest impacts (for each stressor) occurred, or where are they likely to occur in the future?
· What management opportunities can address the stressors in the priority areas?
· Which management opportunities are the most cost-effective and feasible?
· How should the watershed management plan and recommended opportunities be implemented?
· In addition to NCEEP, who are the potential stakeholders that can help implement the LWP?

Additional goals of the Phase II watershed assessment are to:

- determine the functional integrity of streams and other aquatic systems in the watershed;
- identify the key stressors and their sources impacting water quality, habitat, and hydrology and determine where they are focused;
- and identify key assets in the watershed

Section 2 Methods

During the development of Phase II of this LWP many partners collaborated to collect and analyze various types of data throughout these watersheds. Partners include NCDWQ Watershed Assessment Team, NCDWQ Biological Assessment Unit, United States Fish and Wildlife Service, and Department of Transportation Biological Surveys Group. The data that was collected includes but is not limited to habitat, benthic macroinvertebrate and fish community assessments, physical and chemical water quality parameters, channel stability assessments and watershed modeling outputs. The following section details the methodologies associated with this data collection.

2.1 Biological and Habitat Data

Benthic macroinvertebrate and fish community assessment methods are reported in two memos: "*EEP Baseline Macroinvertebrate Monitoring in the Goose and Crooked Creek Drainages*" (NCDWQ, 2009) and "*Summary of May 2010 Fish Collections in the Goose and Crooked Creek Watersheds"* (NCDOT, 2011), in

Appendix C and D respectively. Benthic macroinvertebrates were sampled at seven sites in 2009 according to NCDWQ's Standard Qualitative method, identified, and analyzed with standard benthic metrics. Fish were surveyed at eight sites in 2010 using DOT's Biological Surveys Group's fish collection protocols.

Habitat was assessed by NCDWQ and/or NCEEP staff at all fish and benthic macroinvertebrate sites using NCDWQ's habitat evaluation forms, and methods are described in "*EEP Baseline Macroinvertebrate Monitoring in the Goose and Crooked Creek Drainages*" (NCDWQ, 2009), in Appendix C. Habitat was assessed using the same protocols by Tetra Tech at 28 sites during Phase I stream assessments and another 28 sites during Phase II stream assessments (Appendix H). (Tetra Tech, 2008a & Tetra Tech, 2010)

2.2 Water Column Data

Physical and chemical monitoring methods are reported in "*Water Quality Integrated Analysis Report for the Goose and Crooked Creek Local Watershed Plan*" (NCDWQ, 2011a), in Appendix E.

NCDWQ assessed physical and chemical water quality parameters at ten stations throughout the Goose and Crooked Creeks watershed and at one site on Barnes Creek, which served as a reference site, between August 2009 and June 2010. Parameters assessed include those taken via field meter, including dissolved oxygen, pH, specific conductance, and temperature, and those analyzed in a laboratory, including nutrients (nitrite-nitrate, total Kjeldahl nitrogen, total phosphorus, and ammonia), total suspended solids, turbidity, fecal coliform bacteria, and copper. Both baseflows and stormflows were sampled.

In order to provide data to assess copper toxicity through the Biotic Ligand Model, NCDWQ sampled five sites in the Goose Creek watershed four times under a range of flow conditions and analyzed for dissolved organic carbon, total alkalinity, and copper and a number of anions and cations in filtered and unfiltered samples. This work is reported in "*Copper Concentrations in Goose Creek, Union County, NC: Data Collection for Use with the Biotic Ligand Model for Copper Toxicity*" (NCDWQ, 2011b), in Appendix F.

2.2.1 Biotic Ligand Model

Among the water quality concerns identified in Goose Creek over the past 15 years is total copper in surface waters at concentrations exceeding the State's water quality action level of 7 µg/L (parts per billion) (NCDENR, 2007). Biotic ligand models have been developed to enable mechanistic modeling of copper bioavailability and acute toxicity as a function of metal speciation and the protective effects of competing cations. This model was included as an assessment for the Goose Creek watershed because of the potential for elevated copper levels, particularly total copper, to impact the Carolina heelsplitter mussel. There is some uncertainty in how much of the total copper exists in a form that would be readily bioavailable and toxic (Ward et al. 2007), particularly to mussels that have been a focus of natural

resource management in Goose Creek. A goal of this assessment was to determine if additional management strategies need to be considered based on the instream copper concentrations present.

Significance of current copper data

Data collected by NCDWQ (2011b) were evaluated with BLM Windows Interface, Version 2.2.3 (HydroQual Inc., 2007) in Water Quality Criteria Calculation mode. This use of the model takes input data on water temperature, pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity to tailor the EPA acute and chronic water quality criteria for protection of aquatic life to local water chemistry conditions. The modeled-predicted criteria are then compared to dissolved copper concentrations measured at the same time as the DOC, alkalinity, pH, cations, and anions used in the BLM.

Adequacy of existing data

To evaluate the adequacy of the 2009-2010 Goose Creek water chemistry database which populates the BLM, summary statistics for NCDWQ's sampling of Goose Creek were calculated to compare to historical data (when available) and to support a sensitivity analyses of the water quality variables' influence on BLM outputs. For the sensitivity analyses, medians (50th percentile values) for each BLM input parameter were used to model an "average" BLM application for the creek. Twenty successive model runs were then performed which changed one parameter at a time (water temperature, pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity) to its maximum then minimum to determine the influence of each variable on model output.

Because dissolved copper measurements during substantial storm flows were not part of the 2009-2010 dataset, historic copper data for the creek at SR 1524 was applied to the BLM (Steven Mill Road, station ID Q8360000) which was retrieved from STORET. Those data are all total copper and the BLM evaluates the significance of dissolved copper. A dissolved fraction was estimated for the historic total copper concentrations by using the ratio of dissolved to total copper from the 2009-2010 dataset which included both measures (NCDWQ, 2011b). For the 11 measures of both forms of copper which exceeded method detection limits, 0.8 was the median fraction of total copper represented by the dissolved fraction (range = 0.6 to 1.0). Using median values for most parameters (for the variables with minimal influence on the BLM) and median and low values (10th percentile) for DOC and pH that drive the BLM's site-specific derivation of safe copper values, the estimated dissolved copper concentrations from the historic dataset were evaluated.

2.3 Channel Data

Channel assessment methods are reported in the "*Goose Creek & Crooked Creek LWP Phase II-III Stream Restoration Planning*" technical memo produced by Tetra Tech, in Appendix H. (Tetra Tech, 2010) This section includes excerpts from this report.

During Phase I, the team conducted an assessment to document existing conditions of reaches and to identify gaps in knowledge. Building on that preliminary watershed characterization, the objective of the Phase II field assessment was to identify and prioritize stream enhancement and restoration

opportunities. The Phase II assessment consisted of a more comprehensive survey that includes a geomorphic assessment, a Stream Habitat Evaluation (SHE) (NCDENR, 2001), supporting field observations (e.g., evidence of beavers, migration barriers, debris dams, floodplain disconnection, livestock access), and reach management information (e.g., reach accessibility, constraints, and restoration type). Parameters collected during the geomorphic assessment were used to calculate a Bank Erosion Hazard Index (BEHI) (Rosgen, 2001b) and stream stability index, and to classify the reaches according to stages of the Channel Evolution Model (Simon, 1989). Sketches of stream plan forms and cross sections were also collected.

Employing the BEHI requires collecting field data used to generate six parameters. The measured and/or calculated values for the first five parameters are converted to index scores ranging from 0 to 10 and the total is summed (Table 3). The total score may be adjusted using the sixth parameter – bank materials – which is based on whether the materials are more highly or less highly erodible. The six parameters include: (1) Banktop Height to Bankfull Height Ratio, (2) Rooting Depth to Bank Height Ratio, (3) Rooting Density, (4) Bank Angle, (5) Surface Protection, and (6) Bank Materials. The risk of streambank erosion for field assessed stream reaches was categorized using thresholds provided in Table 3. Visual examples of the three classes identified in the study area are presented in Figure 7 through Figure 9 of the Tetra Tech Stream Restoration Planning Technical Memo available in Appendix H.

Table 3. BEHI Index Scores and Risk Rating Categories (Rosgen, 2001a)

Adjective Hazard or Risk Rating Categories		Bank Height/ Bankfull Height	Root Depth/ Bank Height	Root Density %	Bank Angle (Degrees)	Surface Protection %	Totals
VERY LOW	Value	1.0-1.1	1.0-0.9	100-80	0-21	100-80	
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	5-9.5
LOW	Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55	
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	10-19.5
MODERATE	Value	1.2-1.5	0.49-0.3	54-30	61-80	54-30	
	Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	20-29.5
HIGH	Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15	
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	30-39.5
VERY HIGH	Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10	
	Index	8.0-9.0	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	40-45
EXTREME	Value	>2.8	<0.05	<5	>119	<10	
	Index	10	10	10	10	10	46-50

The bank height to bankfull ratio indicates the degree of channel incision. Ideally, the bankfull height coincides with the top of the streambank, such that the height ratio is one. If this ratio exceeds a certain critical threshold, determined by the geotechnical properties of the streambank soils, the streambanks will become unstable and will begin to fail by mass wasting. The conversion of the degree of channel incision (Rosgen, 2001b), as quantified through the bank height ratio to a qualitative rating of channel stability, is shown in Table 4.

Table 4. Conversion of Bank Height to Bankfull Ratio to Stability Ratings (Rosgen, 2001b)

Bank Height to Bankfull Ratio	Stability Rating
1.0 – 1.05	Stable (low risk of degradation)
1.06 – 1.3	Moderately Stable
1.3 – 1.5	Unstable (high risk of degradation)
Greater than 1.5	Highly Unstable

The Channel Evolution Model (CEM) is a conceptual model that has been used widely to classify stream reaches in the field, for a wide variety of flow regimes and regions throughout the country. The six channel form stages developed for this model represent different points in a time series. This is often in response to upstream drainage area development and/or changes in land use and land cover. While this conceptual model does not represent all forms a stream reach may be found in during its evolution through time, it can serve as a proxy for the degree of stream ecosystem degradation in impacted watersheds. The CEM is used for this purpose in the Goose Creek and Crooked Creek watersheds.

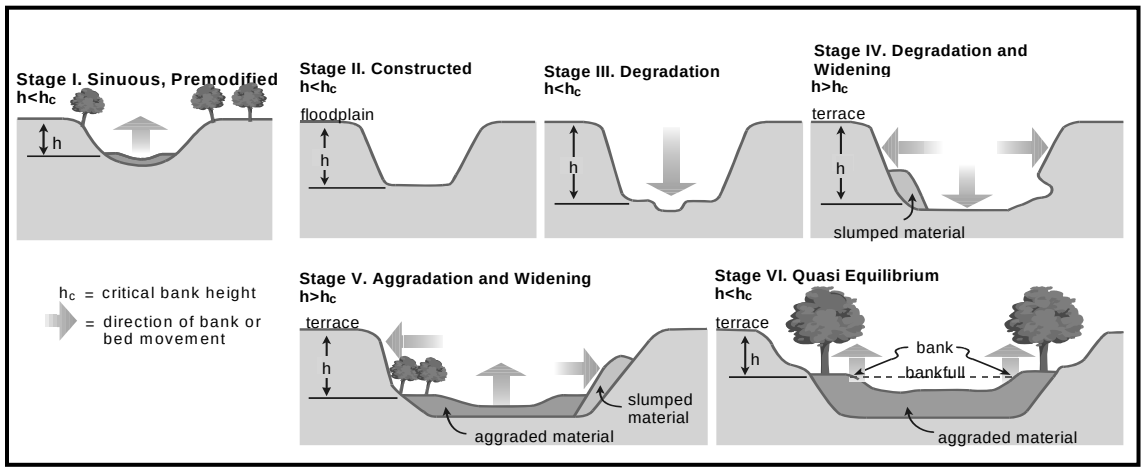


Figure 1. Channel Evolution Model

In order to begin a preliminary prioritization of potential projects, information on channel and riparian area condition collected in the field was used to begin the development of management

recommendations for each stream reach. Each recommendation was site specific and took into account constraints on the ground. Costs and benefits were estimated for sites with higher level management recommendations (e.g., restoration, enhancement). The resulting cost-effectiveness information is combined with additional information such as amount of forested riparian area, number of adjacent landowners and proximity to utilities, to support project prioritization and selection.

2.4 Watershed Modeling Data

In January 2009, Centralina Council of Governments and Tetra Tech submitted a 319 Grant application to conduct modeling work in the Goose and Crooked Creeks planning area to supplement the Phase II/III efforts. Grant funding was awarded to this project and the work began in spring 2010. Tetra Tech developed a technical memo summarizing this effort and the findings entitled "*Revised Goose Creek and Crooked Creek LWP Model Scenario Summary"* (Tetra Tech, 2012b) can be found in Appendix I. This section includes excerpts from this technical memo.

The EPA-approved Loading Simulation Program C++ (LSPC) model was selected for the Goose Creek and Crooked Creek watersheds (http://www.epa.gov/athens/wwqtsc/html/lspc.html). LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land, as well as a stream fate and transport model (Tetra Tech, 2009). LSPC model configuration for the Goose Creek and Crooked Creek watersheds relied on a variety of local data sources. The data included detailed elevation data, meteorological time series of rainfall and evapotranspiration, point source discharges, land cover/land use, soils, existing HEC models, field data from detailed stream surveys, and stream monitoring from several sources.

Sediment and increased peak flows/runoff volumes are considered the most important and pervasive stressors to watershed function in the Goose Creek and Crooked Creek watersheds (Tetra Tech, 2008a). These stressors, resulting primarily from the lack of historical pre- and post-construction stormwater control, have resulted in impairments to aquatic habitat in both watersheds. Nutrient loading is also important as an indicator and surrogate for the remaining stressors of oxygen-demanding substances, bacteria, and toxic pollutants. To address the parameters of concern, the LSPC model was configured to simulate the following:

- Continuous hydrology
- Sediment, including upland loading, in-stream transport, and bed and bank behavior
- Nutrients (as total phosphorus and total nitrogen), including upland loading and in-stream reduction and transport

The model simulation spans January 1, 1999 through May 31, 2010. The time period reflects the availability of data needed to calibrate the model and use it in a decision support role. LSPC was configured to simulate the Goose Creek and Crooked Creek watersheds as a series of hydrologically connected subbasins. The spatial subdivision of the watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors. Each subbasin

was modeled as a defined land area draining to a single stream, with land area made up of model Hydrologic Response Units (HRUs). Output from LSPC is for the most downstream point of each subbasin. The model simulates continuous hydrology from the land surface HRUs, including runoff, interflow, groundwater, and the pollutants carried by each. Flow and pollutants become inputs to the streams in the model, represented as a series of interconnected "reaches." The reach simulation incorporates additional processes affecting pollutant fate and transport, including deposition or erosion in the bed, nutrient uptake, and bank erosion. The model also simulates the influence of stormwater best management practices (BMPs) on hydrology and pollutant reduction. Calibration data included flow measurements from U.S. Geological Survey (USGS) gages, water quality monitoring data from several different entities, and field data from stream surveys.

Development of Scenarios

Tetra Tech developed a framework for the stressor-based prioritization of subwatersheds based directly on the Goose Creek and Crooked Creek LWP goals adopted by the Watershed Technical Team. The goals provide general statements regarding the desired outcomes for the watershed plan, and the objectives identify actions to take to achieve the goals. Goals 1 and 2 are most relevant to the stressor based analysis:

- Goal 1: Restore, protect, and enhance watershed functions such as hydrology, water quality, and aquatic and terrestrial habitat.

- Goal 2: To minimize impacts on water quality, aquatic and terrestrial habitat, and hydrology in the watershed by supporting balanced, sustainable, and diverse land use and development, in accordance with existing and future policies.

Goal 1 generally seeks to protect or improve existing watershed functions, while Goal 2 seeks to address future impacts to watershed functions. The LSPC scenarios address Goals 1 and 2 respectively by providing targeting performance measures for current conditions in the watersheds (Existing Baseline) and anticipated conditions in the future (Future Baseline). The performance measures were tied into the scoring system discussed in the Stressor-Based Subwatershed Prioritization (Appendix I) (Tetra Tech, 2012a).

LSPC does not explicitly represent the spatial location of land cover beyond the subbasin scale. By extension, stormwater BMP locations and specific drainage areas are also not spatially explicit, but rather are lumped on a subbasin scale. LSPC accounts for BMP treatment using stage-storage-discharge relationships and pollutant reduction processes scaled to the total acreage of treated land area. Runoff from land area designated for treatment is routed to the scaled BMP, and is released to the reach (via outflow) or to subbasin groundwater (via infiltration). The BMP simulation occurs on a continuous basis.

Existing Baseline

Existing Baseline scenario land covers were developed from the following sources:

- The National Land Cover Dataset (NLCD) from 2001, which is based on interpretation of multi-seasonal Landsat satellite images into 30-meter grid cells. The land use/land cover and impervious surface data products were both utilized.

- Local cadastral (parcel) data, which provided land use classification in developed areas (a weak point for NLCD).
- Building footprints, planimetric impervious surfaces, and roadways to represent the majority of impervious surface; NLCD impervious data were used to supplement impervious surface classification.
- Forest cover data from the U.S. Forest Service (USFS)/DOI LANDFIRE Existing Vegetation Cover dataset.

The developed *land uses* were split into pervious and impervious *land covers* via post-processing calculations. Pervious land areas were then further divided into Hydrologic Soil Group B and C subcategories.

Location and influence of existing stormwater BMPs were estimated to reflect conditions during and prior to the year 2007. Exact location and treatment area data were not readily available in an electronic format from local municipalities for existing BMPs, so treatment areas were defined based on parcel year-built data. Stormwater requirements through 2007 reflect primarily peak flow control, typically specified as reducing post-development peak flows to pre-development levels for a set of design storm events (e.g., the 2-year 24-hour event and the 10-year 24-hour event). Only about 400 developed acres of land were estimated to be treated by peak-control BMPs, spread between Mint Hill/Matthews (subject to Mecklenburg County peak-control regulations since 1979), and Indian Trail/Stallings (local requirements beginning circa 2005). Pollutant removal was not explicitly included since peak control devices release stored water quickly; however, some removal was allowed to occur via minimal infiltration within the basins.

Future Baseline

For the Future Baseline model scenario, land use was based on 2030 future conditions projected by Michael Baker Engineering for the Monroe Bypass (MB) study (Michael Baker Engineering, 2010). The MB study land use data could not be used directly in LSPC, since different land use classes were utilized compared to the Existing Baseline land use. In addition, the MB study provided semi-spatial land use assignment for both current and future 2030 conditions, making a direct change-analysis to Existing Baseline land use unusable. Instead, the increase in development area and type was calculated for MB existing versus future land use, separately within each LSPC subbasin. A translation methodology was developed for relating MB study existing land use to LSPC existing land use, and the *change* in MB study existing to future land use was applied within each subbasin, using the same translation methods, to estimate equivalent growth for the Tetra Tech land use classes. Undeveloped land covers were reduced within each subbasin, according to relative proportions of both land cover and HSG.

There are several new or modified stormwater management regulations for new development throughout the two watersheds, originating from both state and local authorities. Many of the regulated areas overlap, so the most stringent requirement was assumed. Pertinent details are summarized below:

- Goose Creek Site Specific Water Quality Management Plan – applies to all areas in the Goose Creek watershed, enforced by NC DENR outside of municipalities that have adopted it to their stormwater ordinances. Applies to any project affecting one or more acres that increases impervious area (no threshold). Provides water quality detention and treatment (85 percent TSS load reduction required) for increase in runoff volume between pre-developed and post-developed conditions for the 1-year 24-hour storm. Also provide peak control for the 1-year 24-hour storm matching pre-developed peak flow. In addition, the stormwater management measures are required to promote infiltration for the purpose of maintaining stream baseflow; though no specific performance criteria are provided for infiltration volume.
- Phase II – applies to all of Union County. Currently enforced by NC DENR outside of municipalities listed in the following. For development densities greater than 24 percent impervious area, the runoff from the first inch of rainfall must be detained and treated for water quality (85 percent TSS load reduction required), and peak flow control for the 1-year 24-hour storm to match predevelopment conditions.
- In addition to Phase II requirements, Indian Trail and Stallings adopted the Goose Creek Rule water quality volume and treatment requirements within their entire jurisdictional boundaries which extend beyond the Goose Creek watershed. However, a density threshold was included in the Crooked Creek watershed, so the rules apply only to development greater than 24 percent impervious area. In addition, there is a requirement to match pre-developed peak flows for the 2-year, 10-year, 25-year, 50-year, and 100-year storm events, invoked at 24 percent impervious area in the Crooked Creek watershed and 10 percent impervious area in the Goose Creek watershed.
- In addition to Phase II requirements, Mint Hill adopted the Goose Creek Rule within the Goose Creek watershed. Mint Hill also requires peak matching to pre-developed conditions for a range of storms from the 2-year storm through the 10-year storm.
- In addition to adopting Phase II, Matthews requires peak matching to pre-developed conditions for the 10-year and 25-year storm events. In the Crooked Creek watershed, for developments exceeding 10 percent impervious area, Matthews requires 24 hour minimum detention for the 1- year storm event, and also that stormwater management facilities reduce total phosphorus loading by 70 percent.
- In addition to Phase II, Monroe requires peak matching to pre-developed conditions for non-residential development creating a new impervious footprint exceeding 20,000 ft^2, applicable to the 2-year and 10-year storm events. Exemptions are provided for existing impervious surface, and for sites that discharge to the 100-year floodplain.

There are also stream-buffer protection requirements included in the regulations. The Monroe Bypass study took all of these into account and explicitly excluded buffered lands from their future land use projection.

The Future BMPs selected represented likely candidates given their utility in meeting multiple, layered regulations. All meet the 85 percent TSS load reduction requirement. Three general BMP applications were chosen: wet ponds meeting minimum stormwater requirements (Phase II), bioretention in rural

areas meeting more stringent requirements (Goose Creek Rule), and wet ponds in urban areas meeting more stringent requirements (Indian Trail and Stallings).

Measures Developed to Support Scoring Framework

Listed by stressor category, the following indicators were selected for model output:

- **Hydrology:** Percent increase in the time duration of bankfull events compared to undisturbed (forest) conditions based on hourly simulated flow. The bankfull event was defined as the 1.44 year return interval storm event for rural areas in the NC piedmont (Doll et al., 2002). Many researchers have investigated the role of increased duration of near-bankfull events due to urbanization and the risk of increased scour and bank erosion (MacRae, 1992; MacRae, 1993; Bledsoe and Watson, 2001).

- **Sediment:** Upland Sediment (tons/acre/year) and Streambank and Bed Sediment (tons/mile/year) based on simulated loading occurring within subwatershed boundaries.

- **Oxygen Demanding Substances/Nutrients:** Total nitrogen (TN; lbs/acre/year) and total phosphorus (TP; lbs/acre/year) based on simulated loading from within subwatershed boundaries.

- **Bacteria** and **Toxicity-related Pollutants:** considered qualitatively.

  The simulation of bacteria and toxicity-related pollutants was beyond the scope of the watershed modeling, so adjustments to the subwatershed priorities were made based on a qualitative assessment of potential bacteria or toxicity-related pollutant loading.

The selected indicators highlight management gaps and opportunities to achieve LWP goals through watershed improvement. The areas with the greatest impacts are likely to exist where extreme stormwater flows and volumes and high pollutant loading are occurring or will occur in the future. Since the watershed modeling reflects much of the data and knowledge gathered to date in support of the LWP, the model output provides the best available measure of stressor levels. Another advantage of the watershed model is that it provides output across all subwatersheds throughout an extended continuous period (e.g., annually or seasonally) as opposed to monitoring, which is limited to data at sampling locations reflecting only a few discrete points in time and space.

2.5 Wetland Assessment Data

Wetland assessment methods are reported in the "*Goose Creek and Crooked Creek LWP Phase II-III Wetland Mitigation Planning*" technical memo produced by Tetra Tech, in Appendix J. (Tetra Tech, 2012c) This section includes excerpts from this report.

Since sediment and increased peak flows/runoff volumes are considered the most important and pervasive stressors to watershed function in the Goose Creek and Crooked Creek watersheds (Tetra Tech, 2008a) and there are additional stressors including pollutant loading from urban and agricultural sources to consider as well, riparian wetlands restoration or enhancement is particularly important as it

would address these stressors by reducing the velocity and volume of stormwater runoff and stream flows that are hydrologically connected to the restoration site. As part of Phases II-III, wetlands mitigation opportunity identification and prioritization was a collaborative effort between NCEEP and Tetra Tech. NCEEP identified the candidate wetlands for restoration projects and conducted initial landowner outreach and field verification, and Tetra Tech developed a prioritization using NCEEP's results and available watershed data.

NCEEP identified candidate wetlands mitigation opportunities based on presence of hydric soils and national wetland inventory (NWI) GIS layers and if aerial photographs were indicative of land alteration, such as ditching. Following this identification, NCEEP developed an initial viability rating based on available information and GIS data. The factors in this rating were:

- Presence of hydric soils and/or NWI layer
    - Sites that did not exhibit hydric soils but where associated with an isolated NWI layer were considered but not ranked as highly viable.
- Number of landowners
    - NCEEP prefers to identify sites with three landowners or fewer. Those sites with three or more landowners received a lower prioritization.
- Ease of access for construction/monitoring/stewardship
    - Mitigation sites should have a logical ingress/egress for construction, monitoring, and stewardship purposes. Sites that appeared on aerial photography as potentially difficult to access received a lower prioritization.
- Evidence of land alteration
    - For sites identified for potential restoration/enhancement activities, the search included, but was not limited to, sites that exhibit ditching in areas of hydric soils/NWI layers, straightening of adjacent streams, land clearing activities and lack of stream buffer.
- Presence of utility or other structural constraints
    - Sites that exhibit obvious impacts from utility easements, structures, and other infrastructure received a lower prioritization.
- Opportunity area available for wetlands mitigation
    - NCEEP prefers to identify sites where a large wetland area is available on the smallest number of parcels however for this assessment smaller isolated wetlands were not excluded due to the need to identify non-riparian wetlands.

The criteria used to rate the sites is explained in more detail in Appendix J.

Tetra Tech's Phase II-III recommendations memorandum (Tetra Tech, 2008b) was used as a foundation for discussing criteria for the wetlands mitigation prioritization. The following steps summarize the recommended approach for Phase II of the project:

- Select management strategies that address watershed functional deficits and associated stressors identified in the detailed assessment.
- Protect high quality resources from future degradation.
- Consider both local and contributing drainage area conditions to ensure successful restoration.

- Identify cost-effective opportunities for restoration and retrofit.
- Consider implementation timeframes where a variety of stressors are at play.
- Consider NCEEP criteria associated with mitigation.

As a guide to following the recommended Phase II-III approach, Tetra Tech developed the following overarching goal for the wetland mitigation prioritization:

- Prioritize sites that would provide the greatest potential benefit related to watershed stressors and are feasible and cost-effective.

The wetlands prioritization was focused on the direct benefits provided by each site with some consideration of how the sites would support other management activities. With the above goal and objectives in mind, data were selected that would measure how well a wetland mitigation opportunity would provide functional benefits, feasibility, and mitigation value. Tetra Tech prioritized riparian and non-riparian wetlands separately and selected "major focus indicators" on which to base the prioritization. The following identifies the major focus indicators and how they are related to benefits, feasibility and mitigation value. Appendix J provides more detail on these assessments including specific scoring criteria.

Benefits

Tetra Tech selected five major focus indicators to measure the relative benefit provided by each wetland mitigation opportunity:

1) Provides potential water quality/hydrology benefits to hydrologically connected waters

This indicator provides a measure of the quality and quantity of water that would potentially flow into the wetland (using impervious surface and disturbed land cover) as well as the status of waters receiving flow from the wetland (using supporting or impaired stream status). This information provides an estimate of the potential water quality and hydrologic benefits of each wetland in its surrounding landscape.

Tetra Tech analyzed functional benefits relating to water quality and hydrology for each wetland mitigation opportunity on a drainage area basis. Assessment at this level accounted for each site's position within the greater landscape. Four supporting indicators were used to assess functional benefits.

A. The percent of cumulative drainage area as impervious surface
B. The percent of cumulative drainage area as forest/wetland/shrub
C. The cumulative drainage area in acres
D. The 303(d) stream status downstream from each site

Although these supporting indicators are related to other functions, such as habitat, they were chosen to provide measures of water quality and hydrologic function benefits.

2) Supports a stream restoration opportunity

Riparian and non-riparian wetland mitigation opportunities were evaluated based on their proximity to stream restoration opportunities identified during Phase II-III of the LWP (Tetra Tech, 2010). Any sites located within a 500-foot distance from either side of the stream were considered as supporting a stream restoration opportunity. This buffer distance was selected because a majority of the riparian sites were within 500 feet of the stream and riparian sites are expected to have potential for a connection to an adjacent stream channel.

3) Supports or is supported by a BMP opportunity

Based on a visual inspection of the orientation between BMP locations and sites, it was apparent that no candidate wetland mitigation sites were located directly upstream or downstream from a BMP opportunity. Further assessment was performed by creating a 500-foot buffer around each BMP location to identify mitigation sites that may not have been hydrologically connected to BMPs, but were near BMP locations. The 500-foot buffer distance was chosen to remain consistent with the analysis of stream restoration opportunities.

4) Supports existing wildlife habitat or endangered/threatened species

Two supporting indicators were selected to assess how each wetland mitigation opportunity would support existing wildlife habitat or endangered/threatened species.

A. The site's adjacency to publicly-owned protected natural areas
B. The proximity of each site to a NC Natural Heritage Element Occurrence (NHEO)

To determine a site's adjacency to protected natural areas, Tetra Tech used the protected natural areas layer generated during Phase 1 of the LWP (Tetra Tech, 2008a), which includes protected areas reported by Mecklenburg County, Union County, the Town of Mint Hill, and the NC Wildlife Resource Commission. The parcels containing each of the sites were identified by NCEEP and, based on visual inspection, any site located in a parcel that was adjacent to one of the protected natural areas was classified as a "yes."

Although restored wetlands are expected to provide habitat benefits to terrestrial species, the effect on aquatic species is likely to be more pronounced and was determined to represent a priority for the LWP, specifically for sensitive mussel species. To indicate priority relating to support of aquatic Natural Heritage Element Occurrences, all extant aquatic NHEO's within the Goose Creek and Crooked Creek watersheds were selected, which included both fish and mussel species, and created a 2,000-foot buffer along streams for all NHEO locations. The 2,000-foot buffer distance was selected because sites within this distance were thought to provide a greater benefit to sensitive aquatic species, and it appeared that most sites were either within 2,000 feet or significantly farther away from the NHEOs and this threshold represented a natural break in the locations.

5) Future availability is affected by development pressure

Several data layers were compiled in GIS to determine each site's proximity to existing or future development. Existing development was defined by the NC Statewide Municipal Boundary data layer. This layer was developed by the NC Department of Transportation's GIS Unit; it includes boundaries for

all NC incorporated cities and towns and was last updated in March of 2009. Future development was defined by data layers obtained from the Centralina Council of Governments (N. Bennett, CCOG, personal communication to P. Cada, June 2010) which included future land use boundaries for Stallings, Indian Trail, Monroe, Mint Hill, and Unionville. The to-be constructed Monroe Bypass was also included in this analysis. The bypass right-of-way (ROW) data layer was obtained from the NC Turnpike Authority and the PBS & J Corporation (C. Shumate, NCTA, and C. Gibilaro, PBS & J, personal communication to P. Cada, August 2010).

Sites were classified into one of five potential priority categories. The priorities reflect that development is more likely to occur within existing municipal boundaries compared to future municipal boundaries. Development is also more likely to occur within or near future municipal boundaries compared to areas outside and farther away. Development considered here is not specific to density or amount of imperviousness, but simply the potential of a site to be impacted by any type of development. Areas near the Monroe Bypass were also given priority to account for increased development pressure near the future roadway. The categories are listed below in order of importance with the first category of highest priority relating to development pressure:

A. Within existing municipal boundaries (existing)
B. Within 10,000 feet of Monroe Bypass and within future municipal boundaries but outside of existing municipal boundaries (future; <10,000)
C. Within future municipal boundaries, but outside of existing municipal boundaries and greater than 10,000 feet from Monroe Bypass (future)
D. Less than 2,000 feet from future municipal boundaries (<2,000)
E. Greater than 2,000 feet from future municipal boundaries (>2,000)

The 2,000-foot and 10,000-foot distances were selected based on natural breaks in the data and allowed for effective separation of sites for evaluation. For further information on the evaluation see Appendix J.

Feasibility

Tetra Tech identified two major focus indicators to measure the feasibility of constructing each site within the Goose Creek and Crooked Creek watersheds.

1) Constraints related to landowners
2) Constraints related to existing utilities and obstacles for access

All of the sites included in this analysis are located on private land. In general, less restricted wetland projects are coupled with fewer landowners and landowners that are willing to cooperate with the needs of the wetland project.

Aside from constraints related to landowners, additional constraints for wetland projects arise from the presence of utility easements or restricted access to the site. Access to a site could be limited for a number of reasons including the surrounding land use or natural landscape features.

1) Constraints – Landowners

Based on records from the site identification process, sites were classified by the number of owners and each site was classified into one of four potential categories for landowner willingness ordered from highest to lowest priority:

A. Landowners allowed NCEEP access to their property (yes)

B. A potential willingness from the landowner is evident and NCEEP was allowed access to the sites after harvesting was completed (potential)

C. Willingness is unknown because contact was not yet attempted by NCEEP or NCEEP had not yet received a response from the landowner (unknown)

D. Landowners denied NCEEP access to their property (no)

2) Constraints – Utilities/Access

The presence of utilities was assessed based on visual inspection in GIS using a multitude of utility data layers. Within Mecklenburg County, the location of stormwater infrastructure and outfalls, wastewater infrastructure, and utility ROWs were inspected. Within Union County, the location of stormwater infrastructure was inspected; other utility layers were not available. The presence of utilities on each site was additionally inspected using aerial imagery.

Access constraints were reported for sites by NCEEP during the site identification process. For sites where access constraints were noted as difficult or moderately difficult to access, that site was classified as a "yes." If a site had no indication of access constraints, it received a "no."

For further information on the feasibility evaluation see Appendix J.

Mitigation Value

The mitigation value of a project is the amount of mitigation credit NCEEP receives from the regulatory agencies for implementing a watershed project multiplied by the NCEEP In-Lieu Fee Program fee schedule for a particular mitigation type (for fees see http://portal.ncdenr.org/web/eep/mitigation-applicants). The fee includes all program costs (e.g., watershed planning, project development and construction, monitoring, maintenance, administration, overhead) per credit. Individual projects may cost less or more than the fee schedule to implement based on many factors (e.g. land cost, site constraints, construction cost, etc.) and therefore mitigation value is not a measure of construction cost or cost efficiency. However, approximate mitigation values of projects are an important consideration for mitigation providers in project selection.

Another important consideration is cost efficiency which includes all the costs to implement a watershed project, the mitigation value of the project, and the carrying cost of a project. In areas where mitigation demand is high, and therefore credits will be consumed more quickly, credits developed in addition to current needs will be consumed quickly, the carrying cost will be low, and, as a result, larger projects are usually more cost-effective. In areas where mitigation demand is low and credits are consumed more slowly, carrying costs are higher and larger projects may not be as cost-effective.

For each site, the wetland opportunity acres available were estimated in terms of restoration, enhancement, and preservation. These estimates were based on a review of available GIS data, including NWI and hydric soils. The actual opportunity area is uncertain, and these estimates may change once NCEEP has the opportunity to visit the sites.

To estimate potential Wetland Mitigation Units (WMUs), Tetra Tech applied the approximate opportunity areas to the current mitigation ratios used by NCEEP. The standard ratios of mitigation acres to impact acres are: 1:1 for restoration, 2:1 for enhancement, and 5:1 for preservation (R. Hoffman, NCEEP, personal communication to H. Fisher, November 2010). These ratios generally represent the amount of mitigation provided, but the actual credit award may vary based on site conditions

Cost estimates were developed for reference purposes but were not included in the formal prioritization since this Cataloging Unit is expected to continue to have high mitigation demand and therefore the cost estimates represent the same trends as the WMU estimates (i.e., larger sites are preferred to smaller sites due to cost-effectiveness). The in-lieu fees, at the time of this analysis, for wetland impacts were $62,210 per acre for riparian and $44,883 for non-riparian wetlands in High Fee Cataloging Units, including 03040105, where this LWP is located (Appendix A of Tetra Tech, 2012c). These fees represent the average cost per acre for wetlands restoration in High Fee Cataloging Units. To estimate the cost for each potential watershed project, the wetland acres were divided by the mitigation ratios (1:1 for restoration, 2:1 for enhancement and 5:1 for preservation) and then multiplied by the fee schedule.

Prioritization

Using the data described above, a scoring system was developed to prioritize wetland mitigation opportunities based on functional benefits, feasibility, and mitigation value. Scoring methods and results are discussed in the following sections.

Scoring Methods

Data resulting from GIS analyses and collected by NCEEP during the site identification process were used to prioritize sites by assigning scores to each site based on scoring thresholds or breaks within the data. Two forms of data were generally recorded; either continuous data (e.g., cumulative drainage area) or categorical data (e.g., supports a stream restoration opportunity). For continuous data, scoring thresholds were set using equal intervals or obvious natural breaks within the data. Equal intervals were calculated as quartiles, which are statistical ranges that divide the data into four sets, each representing 25 percent of the range. When the continuous data for a supporting indicator was not divided into quartiles, it was divided into 2, 3, or 4 groups using obvious natural breaks, or spaces in the data where values are clustered. For supporting indicators with categorical data, Tetra Tech established qualitative categories or predefined categories for scoring thresholds. The scoring criteria are listed in Appendix J, organized by category and major focus indicator. If scoring criteria depended on the metrics data, different criteria were used for riparian versus non-riparian sites, as indicated in Appendix J.

Scores ranged from 1 to 10, with a score of 10 assigned to characteristics of highest priority (Appendix J). When more than one supporting indicator was identified for a major focus indicator, the scores for each supporting indicator were averaged to calculate a composite score for the major focus indicator (e.g.,

scores for landowner willingness and number of landowners were averaged to calculate the score for the constraints associated with landowners). As a result, each wetland had one score for each of the major focus indicators. Overall composite scores were then calculated for each site by averaging scores across the major focus indicators to ensure each indicator received equal weight in the overall composite score.

Section 3 Results

3.1 Biological and Habitat Data

Benthic macroinvertebrate and fish community monitoring results are reported in two memos: "*EEP Baseline Macroinvertebrate Monitoring in the Goose and Crooked Creek Drainages*" (NCDWQ, 2009) and "*Summary of May 2010 Fish Collections in the Goose and Crooked Creek Watersheds*" (NCDOT, 2011), Appendix C and Appendix D respectively. Taxa lists, water quality and habitat data, community metrics, maps, and extensive interpretation are presented in those documents. The following section provides a brief summary of key results and an expanded discussion of habitat quality at the sample sites.

Benthic Macroinvertebrate Communities

In July 2009, NCDWQ biologists sampled benthic macroinvertebrate communities at six sites in the Goose and Crooked Creeks watersheds and at one reference site (Barnes Creek) outside of the watershed (Figure 2, Table 5). All sites in the study watershed were rated Fair or Poor, while Barnes Creek was rated Good. All sites were sampled previously (in 1998, 2000, or 2006), and no sites showed improvement in bioclassification ratings.

North Fork Crooked Creek at SR 1514 (site #9) had the most impacted benthic community of all sites, likely impacted by a combination of water quality, habitat, and stormwater scour. This site is downstream of Crooked Creek WWTP #2, a major WWTP with the largest discharge of all WWTPs in the watershed. The benthic macroinvertebrate community on lower Crooked Creek (SR 1547, site #13 (reference Figure 2 below)) indicated water quality problems including low dissolved oxygen; the site is downstream of three wastewater treatment plants (WWTPs), including Crooked Creek WWTP #2.

Four sites were sampled on Goose Creek, with the most upstream site at SR 1524 (#33) indicating the least water quality impacts of the Goose Creek sites. In comparison, the next downstream site on Goose Creek (SR 1525, #28) indicated the worst water quality of all Goose Creek sites; this site is downstream of two minor WWTPs. The two downstream sites (at US 601 [#23] and SR 1547 [#19]) on Goose Creek also demonstrate water quality impacts from WWTPs and non-point sources, although habitat was excellent at both sites.

Benthic communities in the watershed are impacted by a mix of factors, including WWTP inputs, non-point source pollutants, stormflow scour, sedimentation, and periodic toxicity. In 2009, benthic communities may have still been recovering from severe drought conditions in 2007 and 2008. Not only was drought a possible long-term stressor for benthic communities, it can also lead to higher

concentrations of pollutants from WWTPs and non-point sources. In addition, low flows were observed at a number of sites in the study watershed at the time of sampling.

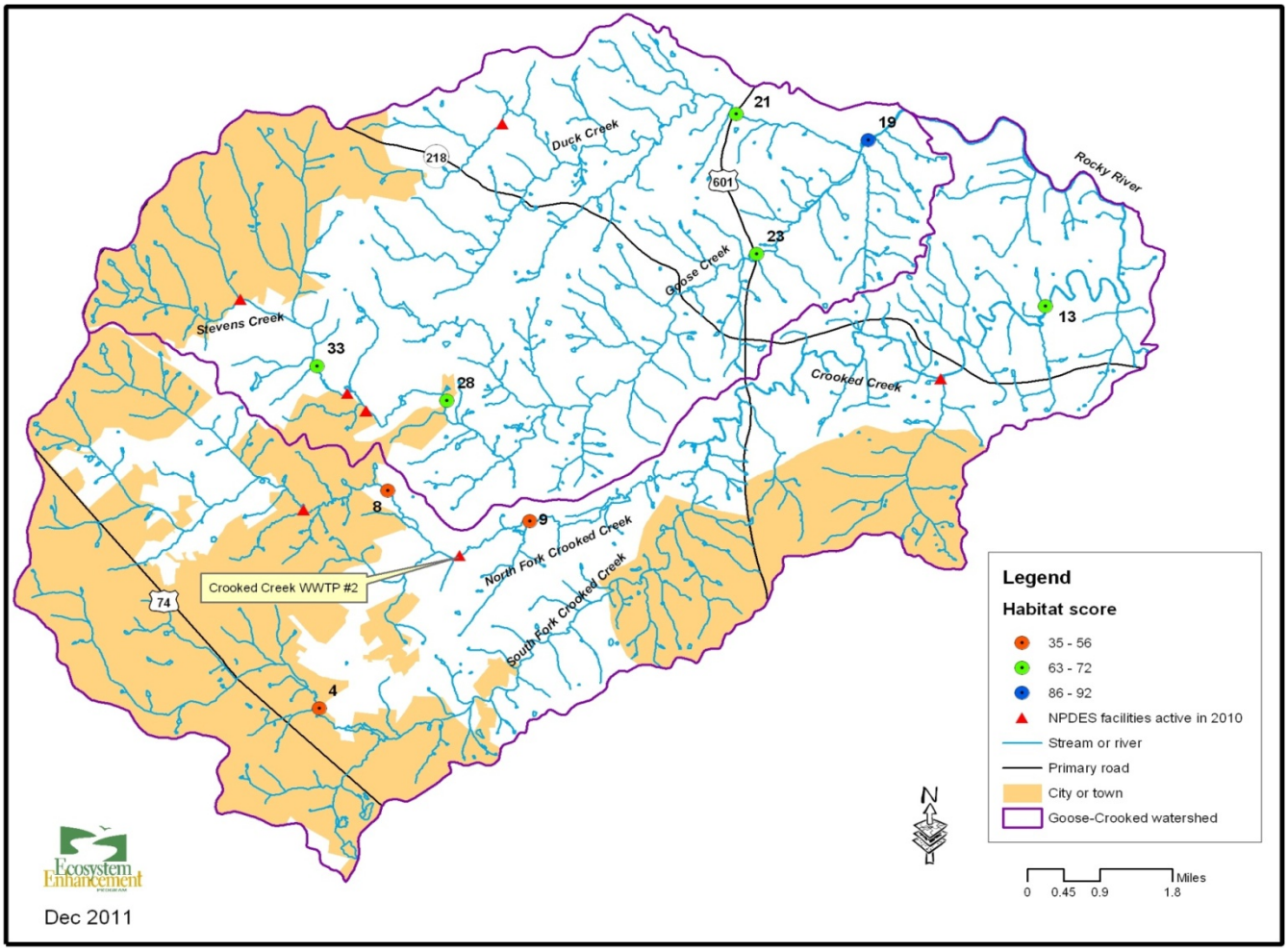


Figure 2. Biological monitoring sites and associated habitat score

Fish Communities

In May 2010, DOT, NCDWQ, and NCEEP biologists monitored fish communities at eight sites in the Goose and Crooked Creeks watershed (included in Figure 2 and Table 5). All four of the Crooked Creek watershed sites were sampled previously by NCDWQ in 1995 or 2006. In 2006, the Crooked Creek site (#13) was rated Good; in 1995, the lower North Fork Crooked Creek site (#9) was rated Good-Fair, and the upper South Fork Crooked Creek site (#4) was rated Good-Fair above and Fair below a WWTP that is now off-line. The fish communities found in 2010 at these sites were similar to those monitored in the past.

Two sites on North Fork Crooked Creek (SR 1520 [#8] and SR 1514 [#9]) bracketed the Crooked Creek WWTP #2. The most notable difference was an increase in the percent of tolerant fish individuals from

39% above to 62% below the WWTP. There were also decreases in the number of fish individuals and species collected below the WWTP.

The fish communities in the Goose and Crooked Creeks Watershed were impacted by low flow conditions. Many sites had low or no flow; only fish species that are tolerant to periodic low dissolved oxygen and isolated pools can survive in such conditions. The most downstream Crooked and Goose Creek sites were the only sites with all three darter species found in the watershed; this may be linked to larger watershed size at these sites and more constant and higher flows.

Poor in-stream habitat at all sites on North Fork Crooked Creek and South Fork Crooked Creek likely impacted the fish communities at these sites.

Like the benthic macroinvertebrate community, the fish community in this watershed is likely impacted by a suite of stressors, including WWTP inputs, non-point source water quality issues, poor habitat at some sites, and low flows.

Habitat Assessment at Biological Sampling Sites

Habitat assessments were performed for each of the ten fish and benthic macroinvertebrate monitoring sites. Overall habitat scores ranged from 92 out of a possible 100 points at Barnes Creek to 35/100 at South Fork Crooked Creek at SR 1515 (Table 5). There was considerable variability in habitat quality within the Goose and Crooked Creeks watershed, with notable differences in bottom inorganic substrate (proportion of bedrock, boulder, cobble, gravel, sand, and silt), quality of pool and riffle habitats, and in-stream habitat. One common deficiency among many sites was a lack of available root mat and undercut bank habitats; many of these were isolated above water. This isolation may be due to the low flows in these Slate Belt streams, but downcutting due to stormwater impacts may exacerbate this impact.

Goose Creek

Overall habitat scores for Goose Creek were moderate to high, increasing from upstream to downstream, with the uppermost site at SR 1524 (site #33) at 65 and the lowest site at SR 1547 (site #19) at 86, the highest scoring site in the watershed. All Goose Creek sites had abundant rock habitat, with a mix of larger substrates. However, there was still considerable sand+silt at these sites compared to the reference site on Barnes Creek, with values ranging from 35-45%. The Goose Creek site at SR 1525 (#28) had a higher degree of embeddedness than other sites (40-80%). Riffle habitats were infrequent and poor at SR 1525 (sites #33) and at US 601 (site #23).

Despite the wide and healthy riparian zones of each site, leafpacks were rare at all sites but the lowest Goose Creek site.

Duck Creek

The overall habitat score for Duck Creek (site #) was moderate at 63. As at the middle Goose Creek site #28, it had abundant rock habitat, but its riffles were highly embedded (40-80%). Both pools and riffles were infrequent and of poor quality. Leafpacks were rare, as at most sites in the watershed.

Crooked Creek

The lowest overall habitat scores occurred in the upper reaches of North and South Fork Crooked Creeks, with total scores ranging from 35 to 56. These sites were similar in many ways. In-stream habitat was low (8 of 20 possible points), with both rocks and leafpacks rare. Bottom substrate was low as well (2-3 of 15 possible points), with sand+silt consisting of 80-90% of the inorganic substrate. Riffle habitats were infrequent and poor (0-3 of 16 possible points).

These sites drain the most developed portion of the watershed, with the cumulative imperviousness of their drainages ranging from 14% at North Fork Crooked Creek at SR 1514 (site #9) to 15% at North Fork Crooked Creek at SR 1520 (site #8) to 24% at the South Fork Crooked Creek (site #4) (Tetra Tech, 2008a). The site with the highest cumulative imperviousness (site #4) was also that with the lowest overall habitat score, no pools, and a highly modified (straightened) channel.

Crooked Creek at SR 1547 (site #13), on the other hand, had much better habitat, with an overall habitat score of 71. This site was similar to many Goose Creek sites, with abundant rocks, moderate embeddedness (20-40%), and an intact riparian zone. It had no pools, and infrequent and poor riffles. It had the lowest amount of sand+silt (10%) of all study sites.

Additional Habitat Assessments

Tetra Tech performed habitat assessments at numerous reaches in the study watershed in their Phase I and Phase II stream assessments. These data are reported in the following documents: "*Goose Creek and Crooked Creek LWP Phase I Preliminary Findings*" (Tetra Tech, 2008a) and "*Goose Creek and Crooked Creek LWP Phase II-III Stream Restoration Planning*" (Tetra Tech, 2010).

Tetra Tech found generally better quality habitat in the Goose and Duck Creek watersheds, and poorer habitat in the Crooked Creek watershed as well as generally better scores downstream. Common habitat deficiencies were poor riffle quality and high degrees of embeddedness and/or sedimentation. (See Appendix H Figure 21) These findings are generally consistent with the previously discussed habitat data.

Table 5. NC DWQ Habitat Scores for the Goose and Crooked Creek watershed*										
Site #	33	28	23	19	21	4	8	9	13	ref
Stream	Goose	Goose	Goose	Goose	Duck	S Fk Crooked	N Fk Crooked	N Fk Crooked	Crooked	Barnes
Location	SR 1524	SR 1525	US 601	SR 1547	US 601	SR 1515	SR 1520	SR 1514	SR 1547	SR 1303
Biological Community Monitored	fish, benthos	fish, benthos	fish, benthos	benthos	fish	fish	fish	fish, benthos	fish, benthos	benthos
Parameter (Max. Score)										
Channel Modification (5)	4	4	5	5	5	2	4	4	5	5
Instream Habitat (20)	12	12	14	16	15	8	8	8	18	20
-Rocks	abundant	abundant	abundant	abundant	abundant	rare	rare	rare	abundant	abundant
-Leafpacks**	rare	rare	rare	common	rare	rare	rare	rare	rare	common
-Snags & logs	rare	rare	common	common	common	common	abundant	abundant	common	rare
Undercut banks/rootmats	common/rare	rare	common	rare	common/rare	common	rare	rare	common/rare	abundant
Bottom Substrate (15)	12	5	11	12	6	2	3	3	12	15
-Embeddedness	20-40%	40-80%	20-40%	20-40%	40-80%	-	-	-	20-40%	<20%
-Dominant substrate type	gravel, cobble, boulder	bedrock, silt, sand	gravel, cobble	gravel, cobble, boulder	gravel, cobble	sand, silt	sand	sand	gravel, cobble, boulder	gravel, cobble, boulder
Pool Variety (10)	4	6	8	10	4	6	8	10	0	10
Riffle Habitat (16)	3	10	3	14	3	0	3	3	3	15
Bank Stability and Veg. (14)	11	12	11	9	10	8	10	7	13	12
Light Penetration (10)	10	10	10	10	10	7	10	7	10	7
Riparian Veg. Zone Width (10)	9	9	10	10	10	2	10	7	10	8
Total Score (100)	**65**	**68**	**72**	**86**	**63**	**35**	**56**	**49**	**71**	**92**
Substrate Composition (~ %)										
Bedrock	10	30	15	0	20	0	0	Trace	0	10
Boulder	10	10	10	20	15	5	Trace	Trace	20	30
Cobble	20	10	20	20	25	5	Trace	Trace	40	30
Gravel	15	15	20	20	10	10	10	10	30	15
Sand	40	25	25	20	20	60	80	80	10	10
Silt	5	10	10	20	10	20	10	10	0	5
Sand+Silt	45	35	35	40	30	80	90	90	10	15
*Scores from most recent evaluations are included here. All site scores are from the 2010 fish community study from except those for										
site #19 and "ref" (reference site), which are from the 2009 benthic community study.										
**For site #19 and "ref", this accounts for both sticks and leafpacks; for all other sites, it accounts for leafpacks only.										

3.2 Water Column Data

Physical and chemical monitoring results are reported in *"Water Quality Integrated Analysis Report for the Goose and Crooked Creek Local Watershed Plan*" (Appendix E) (NCDWQ, 2011a). The objectives of this study were (1) to provide water quality data to Centralina COG and Tetra Tech for application in a water quality simulation model and (2) to characterize general water quality in the watershed. NCDWQ assessed physical and chemical water quality parameters at ten stations throughout the Goose and Crooked Creeks watershed and at one site on Barnes Creek, which served as a reference site, between August 2009 and June 2010. The following section briefly summarizes key findings from this study. See Figure 3 below for locations of stations and Appendix E for further details, including Table 1 with descriptions of monitoring locations.

Low dissolved oxygen concentrations (<4 mg/L) occurred frequently and were associated with low flows and warmer water temperatures. Most of these observations were collected in North Fork Crooked Creek and South Fork Crooked Creek.

The highest median nutrient (nitrite-nitrate and total phosphorus) concentrations and specific conductance values were found on North Fork Crooked Creek at SR 1514 (#9) and Crooked Creek at SR 1547 (#13), both below the Crooked Creek WWTP #2. A median nitrite-nitrate value of 12.0 mg/L and median value of 1.8 mg/L of total phosphorus was found at North Fork Crooked Creek at SR 1514 (#9), just downstream of the plant. Other sites below WWTPs, including North Fork Crooked Creek at SR 1520 (#8) and Goose Creek at SR 1525 (#28) also had high nutrient and specific conductance values.

Although copper has been a concern in the past, sampling during the current study found few concentrations above the state action level of 7 ug/L; those samples above 7 ug/L were all at the North Fork Crooked Creek site at SR 1514 (#9).

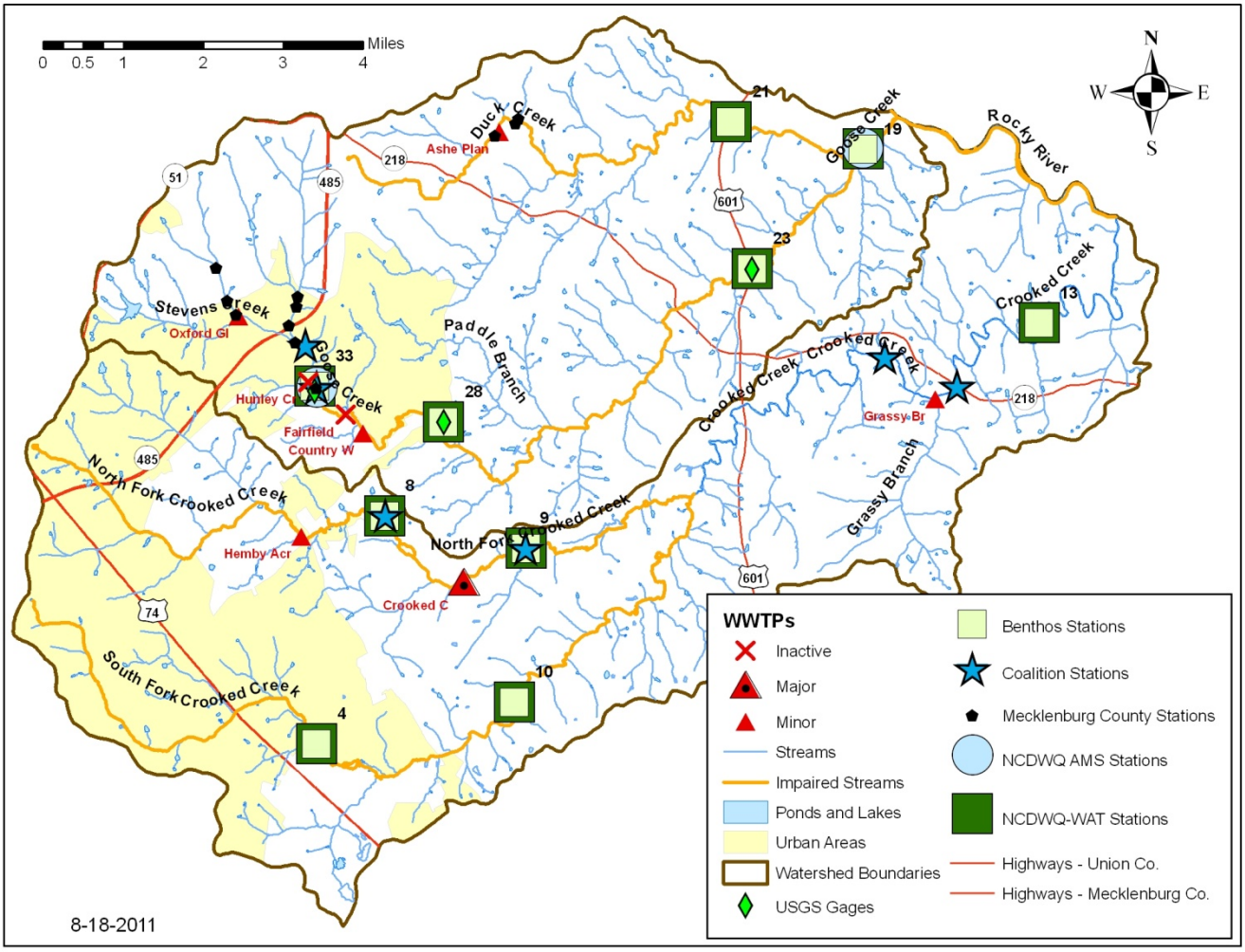


Figure 3. Locations of NCDWQ-WAT, AMS, and Coalition water quality monitoring stations and NCDWQ-BAU benthic macro-invertebrate monitoring stations.

3.2.1 Biotic Ligand Model

USFWS staff determined the likelihood of copper toxicity to mussels with the Biotic Ligand Model; the results of this work are reported in "*Evaluation of Copper Concentrations in Goose Creek with regard to Conservation of Freshwater Mussels*", found in Appendix G. (USFWS, 2011) Thefollowing includes excerpts which summarize the report findings. :

The USFWS conducted an evaluation of copper as a limiting factor for the endangered Carolina heelsplitter (*Lasmigona decorata*), a freshwater mussel, in Goose Creek, Mecklenburg and Union Counties, North Carolina. The study revealed that the copper data for Goose Creek do not exceed biotic ligand model (BLM)-derived water quality criteria for the protection of aquatic life. These data, if representative of the system, indicate copper is not currently of toxicological concern. Stream pH is well-characterized in this watershed and the recent data are consistent with historic data and therefore are

determined to be adequate. There are few data for DOC so this parameter should be considered in future monitoring efforts.

Estimation of historical dissolved copper concentrations (by applying the 0.8 dissolved fraction multiplier to historic data for total copper) indicated few exceedences of the BLM criteria and the few exceedences that were indicated appear to be associated with higher flows when total suspended solids and turbidity are also elevated, and it is reasonable to expect that a high fraction of copper bound to sediment (which is of lesser toxicological concern than the dissolved copper) would be present. The review of the historic data is likely conservative (protective) with regard to evaluating effects on aquatic life. It is recommended that attention continues to be paid to redressing stormwater run-off of sediment, bank instability, and flashy flows (all of which are documented concerns in the watershed). Nonpoint source controls of sediment would also further reduce copper loadings. No special management strategies or controls would be needed to address copper based these findings.

3.3 Channel Data

As detailed in the Tetra Tech technical memo titled "*Goose Creek & Crooked Creek LWP Phase II-III Stream Restoration Planning*" (Tetra Tech, 2010)(Appendix H), the more rigorous field assessment of stream reaches throughout the Goose Creek and Crooked Creek watersheds revealed widespread stream channel impacts. Most reaches evaluated in the current study had a moderate-to-high risk of bank erosion, with characteristics similar to highly unstable channels. This indicates that some reaches may be actively unstable or could become unstable if peak flows and runoff volumes were to increase. The following includes excerpts from this memo.

Evidence of undercutting, incision to bed rock, and widening of stream channels was observed. In many reaches incision has disconnected streams from the floodplain. Mass wasting of streambanks was also observed in both watersheds, which results in streambanks failing and large quantities of sediment entering the stream.

A compilation of key indices collected in the Phase II assessment is provided below (Table 6). There was some correlation between indices. Sites with low BEHI were either categorized as CEM stage 1 or 2, were stable (or moderately stable) and had an average habitat score of 79 (habitat scores ranged from low of 14 to high of 95). Those sites found to have a high BEHI were all highly unstable and produced an average habitat score of 51 and were categorized as CEM stages 3 through 5. The moderate BEHI category, which made up 60 percent of sites, showed greater variability in CEM, stability rating, and habitat score (average of 59). See Appendix H (Stream Restoration Planning technical memo) for more detailed information on watershed-wide BEHI results and risk to channel stability due to incision. The CEM results across the watersheds from Phase II are illustrated below in Figure 4.

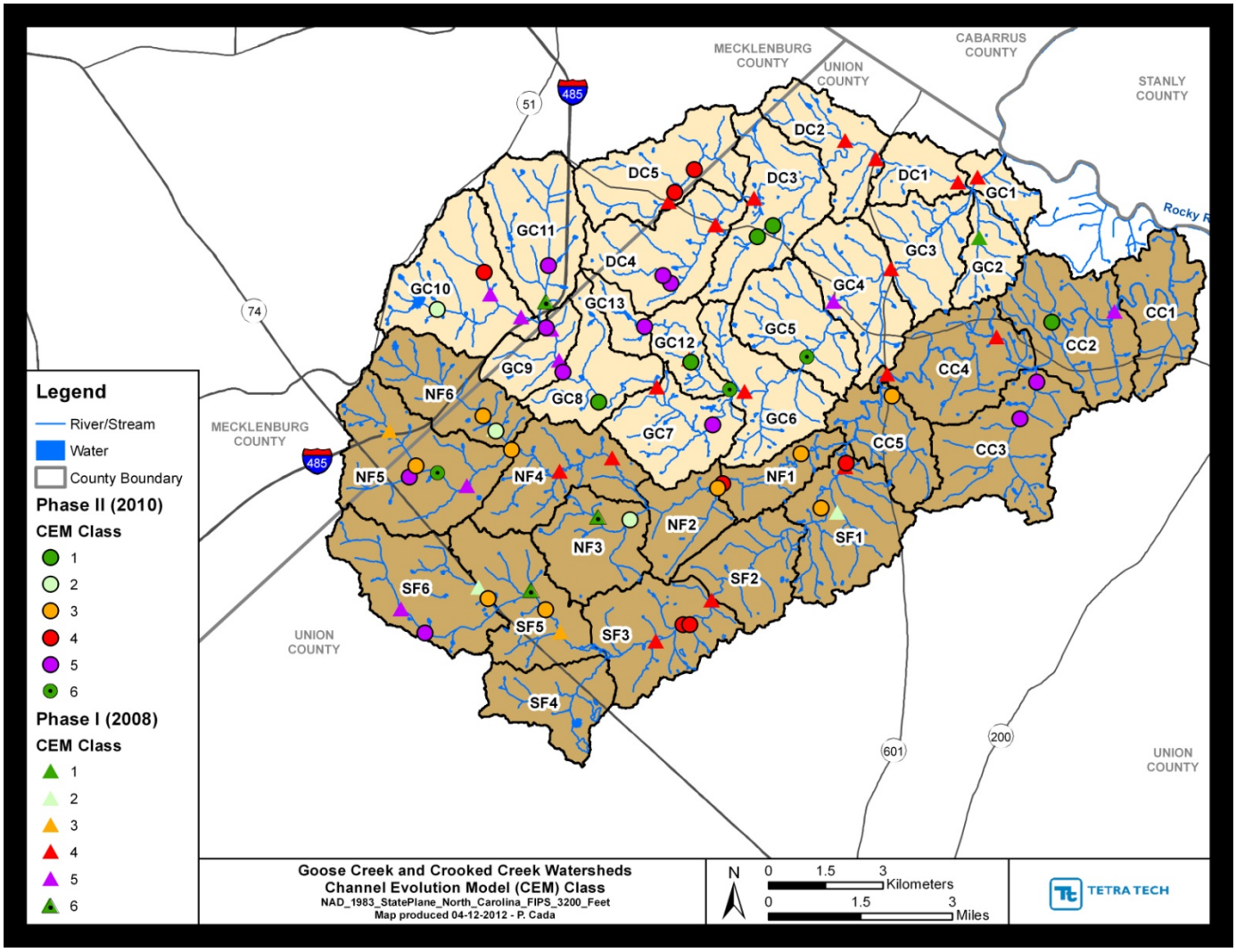


Figure 4. Channel Evolution Model Class Results for Reaches in the Goose and Crooked Creeks Watershed

Table 6. Summary Key Assessment Indices

Watershed	Site ID*	BEHI Category	Stability Rating	Habitat Score	CEM Category
Goose	1	Moderate	Highly Unstable	74	2
Goose	2	High	Highly Unstable	66	4
Goose	4	Moderate	Highly Unstable	58	5
Goose	5	High	Highly Unstable	61	5
Goose	6	Moderate	Highly Unstable	73	5
Goose	7	Low	Stable	93	1
Goose	25	Moderate	Highly Unstable	46	6
Goose	29	High	Highly Unstable	51	5
Goose	30	Low	Moderately Stable	74	1
Goose	31	Moderate	Unstable	70	6
Goose	32	Low	Stable	84	1
Goose	33	Low	Stable	84	1
Goose	34	Moderate	Highly Unstable	87	5
Goose	35	Moderate	Highly Unstable	87	5
Goose	36	Moderate	Highly Unstable	83	4
Goose	37	Moderate	Highly Unstable	87	4
Goose	38	Moderate	Highly Unstable	76	5
Crooked	3	Moderate	Highly Unstable	29	5
Crooked	8	Moderate	Highly Unstable	30	3
Crooked	9	Moderate	Stable	40	2
Crooked	10	High	Highly Unstable	46	3
Crooked	11	Moderate	Highly Unstable	51	3
Crooked	12	Moderate	Highly Unstable	64	6
Crooked	13	Moderate	Highly Unstable	19	3

Watershed	Site ID*	BEHI Category	Stability Rating	Habitat Score	CEM Category
Crooked	14	Moderate	Highly Unstable	46	5
Crooked	15	Moderate	Highly Unstable	49	3
Crooked	16	High	Highly Unstable	50	4
Crooked	17	High	Highly Unstable	54	4
Crooked	18	Low	Moderately Stable	41	2
Crooked	19	High	Highly Unstable	71	4
Crooked	20	High	Highly Unstable	14	3
Crooked	21	Low	Stable	95	1
Crooked	22	Moderate	Moderately Stable	70	5
Crooked	23	Moderate	Moderately Stable	70	5
Crooked	24	High	Highly Unstable	58	3
Crooked	26	Moderate	Highly Unstable	55	3
Crooked	27	High	Highly Unstable	42	4
Crooked	28	Moderate	Highly Unstable	33	3

* Site IDs are different from those in biological and physical/chemical monitoring sections. See Figure 6 in Appendix H for site locations.

This information provided the basis for preliminary management recommendations which are provided in Figure 5 and Table 7 and Table 8 (below). Based on the information collected, all reaches were considered feasible for some degree of management. During plan implementation, more detailed, site-specific feasibility assessments and contact with landowners will be required. See Appendix H for additional information, including details on restoration categories and cost-effectiveness. These recommendations will be further discussed and refined in the Watershed Management Plan.

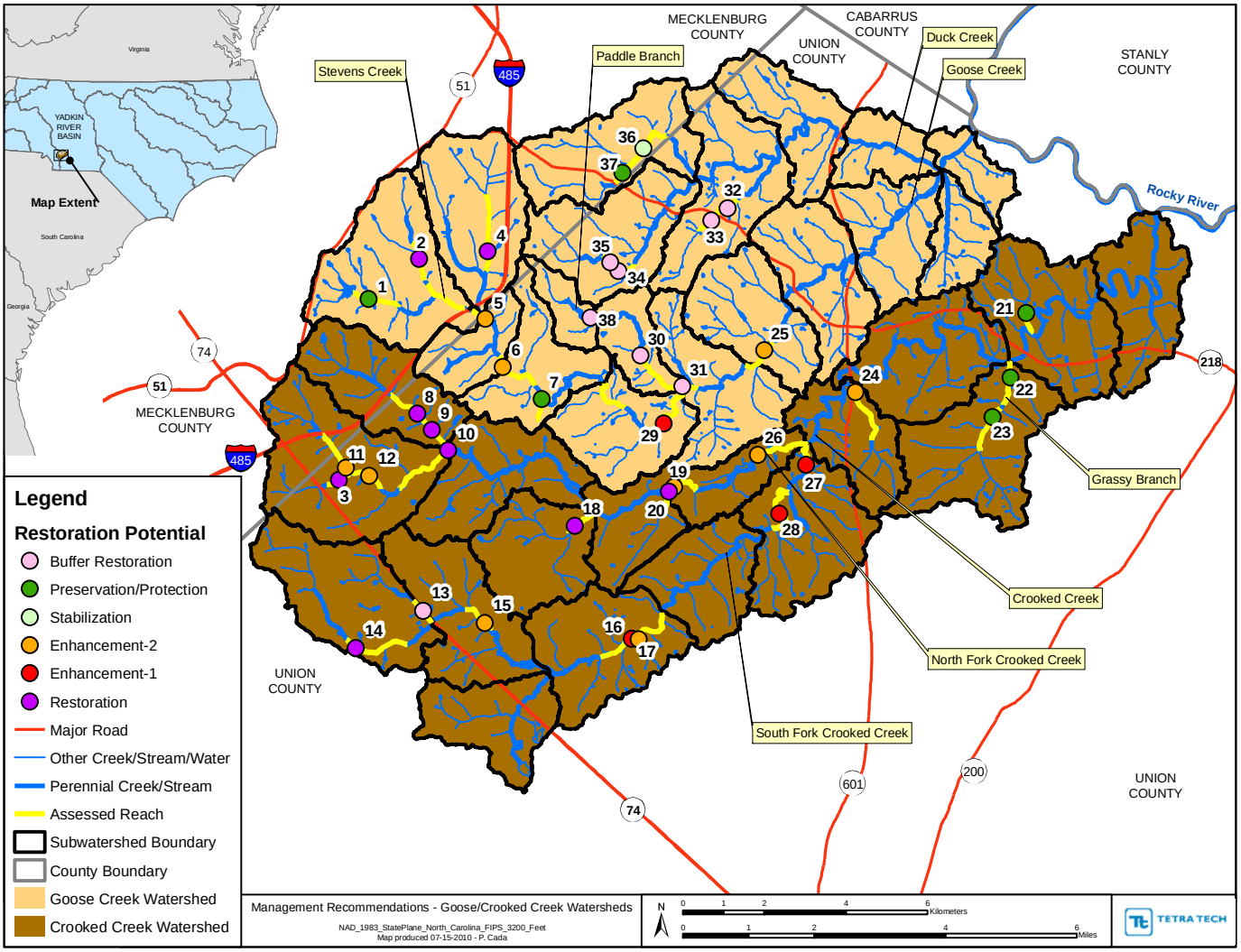


Figure 5. Recommended (Primary) Management Strategies for Selected Reaches

Table 7. Reach Accessibility and Management Recommendation Results – Goose Creek Watershed

Site ID	Reach Accessibility	Management Recommendation (Primary)	Management Recommendation (Secondary)
1	Fair	Preservation/Protection	--
2	Good	Restoration	--
4	Good	Restoration	--
5	Good	Enhancement-2	--
6	Good to Fair	Enhancement-2	--
7	Difficult	Preservation/Protection	--
25	Fair	Enhancement-2	Buffer Restoration
29	Fair	Enhancement-1	--
30	Fair	Buffer Restoration	--
31	Fair to Difficult	Buffer Restoration	--
32	Fair	Buffer Restoration	--
33	Fair	Buffer Restoration	--
34	Fair	Buffer Restoration	--
35	Fair to Difficult	Buffer Restoration	Preservation/Protection
36	Fair	Stabilization	Buffer Restoration
37	Fair	Preservation/Protection	--
38	Good to Fair	Buffer Restoration	--

Table 8. Reach Accessibility and Management Recommendation Results – Crooked Creek Watershed

Site ID	Reach Accessibility	Management Recommendation (Primary)	Management Recommendation (Secondary)
3	Good to Fair	Restoration	--
8	Good	Restoration	--
9	Good	Restoration	--
10	Good to Fair	Restoration	--
11	Good	Enhancement-2	--
12	Good	Enhancement-2	Enhancement-1 or Restoration
13	Good	Buffer Restoration	Enhancement-2 or Restoration
14	Good to Fair	Restoration	Buffer Restoration
15	Fair	Enhancement-2	--
16	Good to Fair	Enhancement-1	--
17	Good to Fair	Enhancement-2	--
18	Fair	Restoration	--
19	Good to Fair	Enhancement-2	--
20	Good	Restoration	--

Site ID	Reach Accessibility	Management Recommendation (Primary)	Management Recommendation (Secondary)
21	Difficult	Preservation/Protection	--
22	Good to Fair	Preservation/Protection	--
23	Good to Fair	Preservation/Protection	--
24	Fair	Enhancement-2	--
26	Good to Fair	Enhancement-2	--
27	Fair	Enhancement-1	--
28	Good to Fair	Enhancement-1	--

3.4 Watershed Modeling Data

Tetra Tech has developed a technical memo summarizing the watershed modeling effort and the findings entitled "*Revised Goose Creek and Crooked Creek LWP Model Scenario Summary*" (Tetra Tech, 2012b) can be found in Appendix I. The following includes excerpts from this technical memo.

The modeling work conducted for this LWP was developed for several purposes. It allowed for resources awarded through the 319 Grant Program to be utilized in conjunction with resources the State of North of Carolina was already investing in these watersheds through NCEEP, resulting in a more thorough and robust watershed analysis for all interested parties. More specifically, the findings will produce a better understanding of the hydrology and pollutant loading processes within these watersheds, it allows for the examination of finer scale questions, enables us to forecast future development effects, and target and prioritize management strategies more efficiently and effectively.

The graphical summary results are grouped separately by Goose Creek and Crooked Creek, which are both split further into *Upper* and *Lower* designations. Upper sections of both watersheds tend to correspond to more urbanized/developed areas, while the Lower sections are more rural and agricultural. The distinctions are helpful for understanding trends in the results. Figure 6 below identifies the subwatershed groupings. Additionally, the results are presented as Existing Baseline, Future Baseline and Future No BMPs. Future Baseline conditions are based on 2030 future projections from analyses done for the Monroe Bypass study (Michael Baker Engineering, 2010) and includes several new or modified stormwater management regulations and the associated BMPs that would most likely be utilized. Future No BMPs represents a scenario where these BMPs would not be implemented. Results are summarized in Figure 7 through Figure 11 and are provided in more detail in Appendix I.

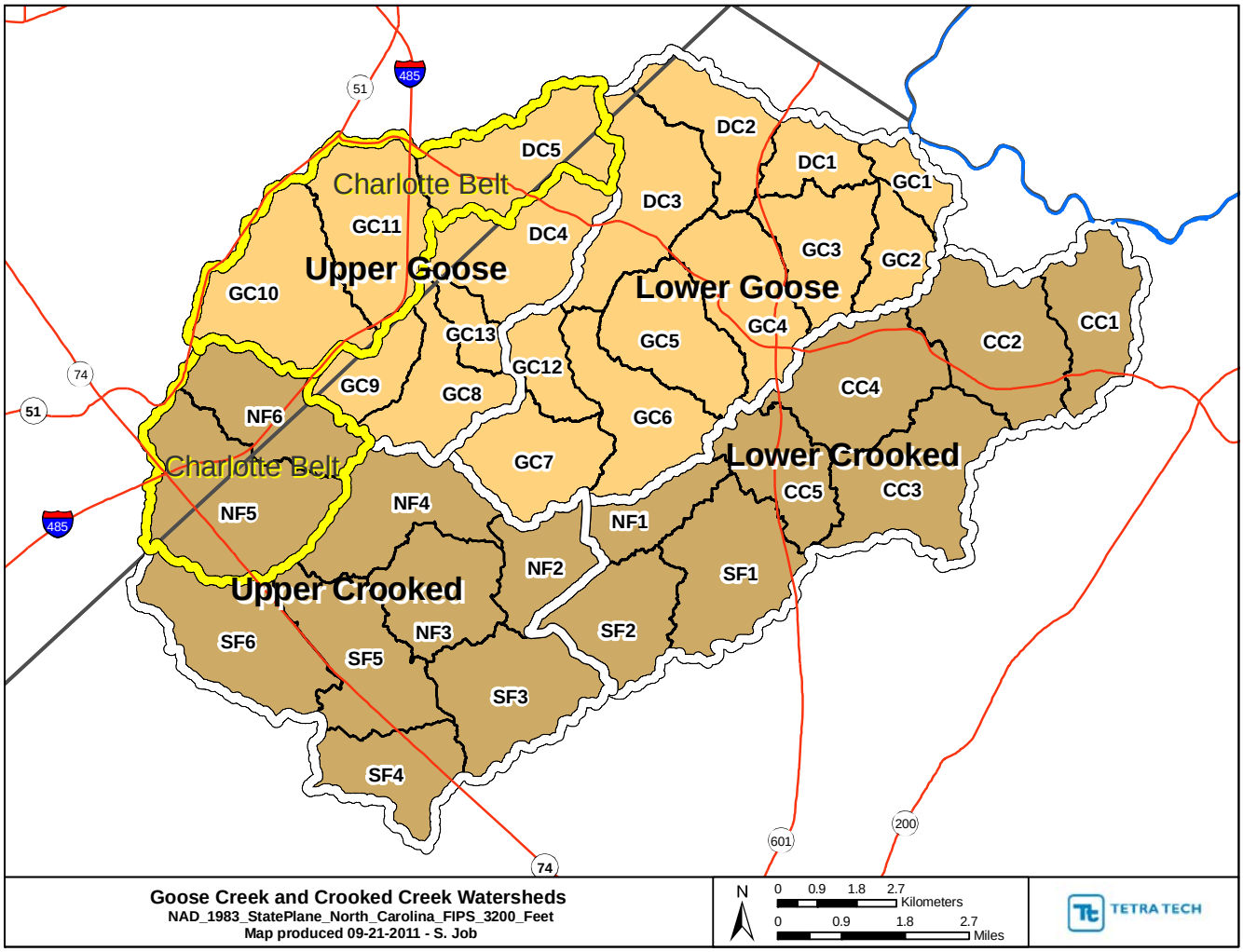


Figure 6. Location Map for Subbasin IDs and Reporting Zones

Hydrologic Response

For percent increase in bankfull time duration, two additional subgroups were added – Upper Goose non-Charlotte Belt, and Upper Crooked non-Charlotte Belt (Figure 6). The Charlotte Belt geological zone is associated with the westernmost subbasins, largely within Mecklenburg County. Charlotte Belt soils are fairly impermeable, but the Slate Belt soils in the remainder of both watersheds are highly impermeable even in an undeveloped state. For the very largest storm events which contribute to this measure, undeveloped forested Slate Belt soils react with runoff rates somewhat analogous to impervious surfaces. The Charlotte Belt soils differ for large storm event runoff due to higher infiltration rates – the jump from forested to developed conditions creates a significantly larger increase in the duration of bankfull events.

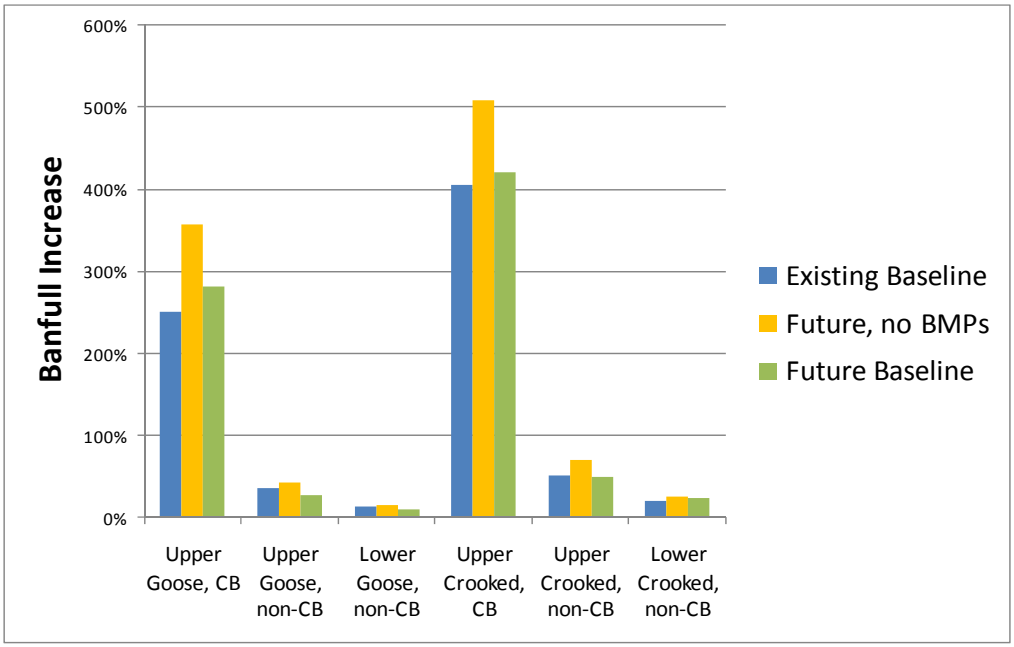


Figure 7. Scenario Results for Percent Increase in Bankfull Time Duration (CB=Charlotte Belt)

While the magnitude difference is large between the zones, it does not necessarily mean there is little risk of channel geomorphologic change in the Slate Belt areas. Streams adjust to local conditions, and an alteration in peak flow and duration still may translate to increased risk of channel erosion. A relative comparison of the results shows that new development increases bankfull event duration across the board, more so in areas with larger increases in impervious surfaces. However, the stormwater management requirements appear to be effective at mitigating the risk and managing increased volume. The Bed+Bank Sediment Erosion measure shows a similar trend (Figure 8); unmitigated runoff from new development increases bed and bank erosion, but stormwater management requirements mitigate the increase by holding back the increase in erosive flows.

Sediment

Upland sediment loading and bed+bank erosion are not directly comparable since upland loading is areal (per acre) while bed+bank erosion are linear (per mile) and confined to the streams. When the rates are scaled back to loads, the Existing Baseline scenario indicates that about 31,800 and 47,500 tons of sediment are washed from upland areas to streams in Goose and Crooked creeks respectively, while an additional 43,500 and 56,800 tons are eroded from the banks and the beds from Goose and Crooked creeks respectively. Upland sediment does contribute to modeled aggradation in the stream (in a few reaches), so the total load leaving the two watersheds is slightly lower than the sum of the two contributions.

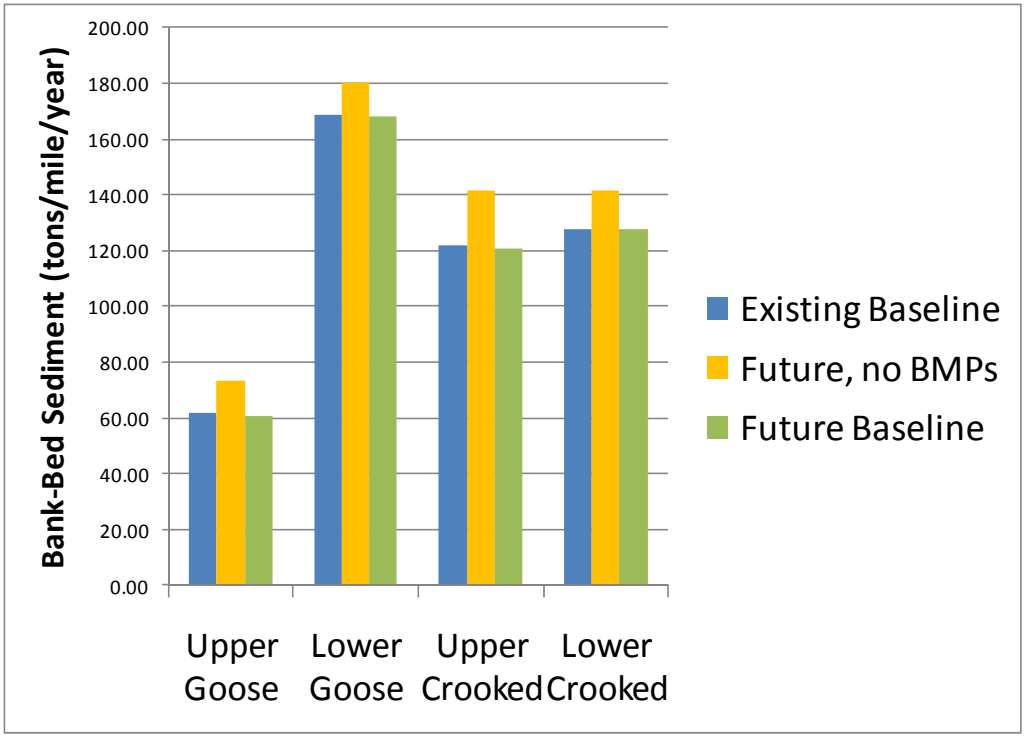


Figure 8. **Scenario Results for Bed+Bank Sediment Erosion**

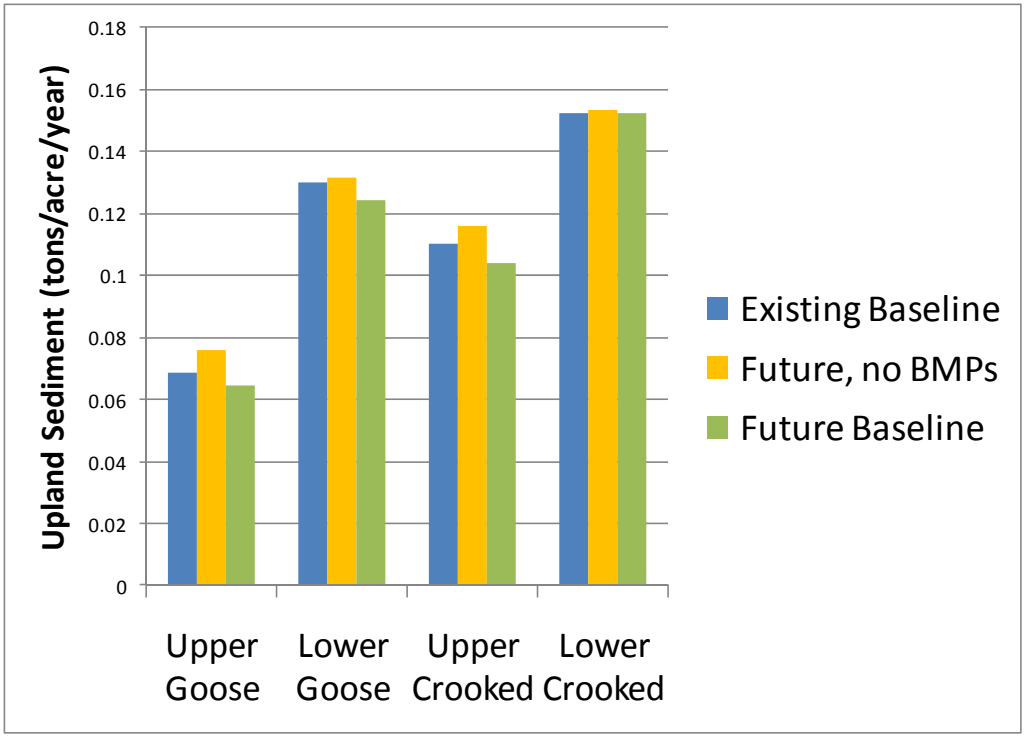


Figure 9. **Scenario Results for Annual Upland TSS Loading Rates**

Nutrients

The Annual Upland Loading Rate measures show some trends that might not be expected; new development does not necessarily raise overall loading much, even if treatment BMPs are not used. This outcome is due chiefly to relatively high loading rates originating from agricultural land; when development with low or medium housing densities replaces agricultural land, overall rates may decrease. BMPs provide an additional reduction in loading rates.

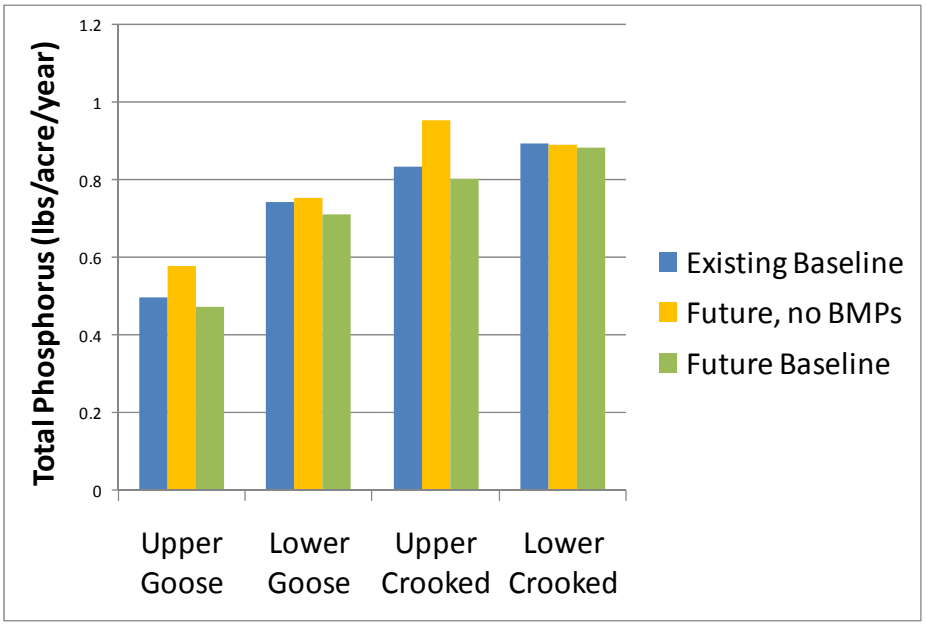


Figure 10. Scenario Results for Annual Upland TP Loading Rates

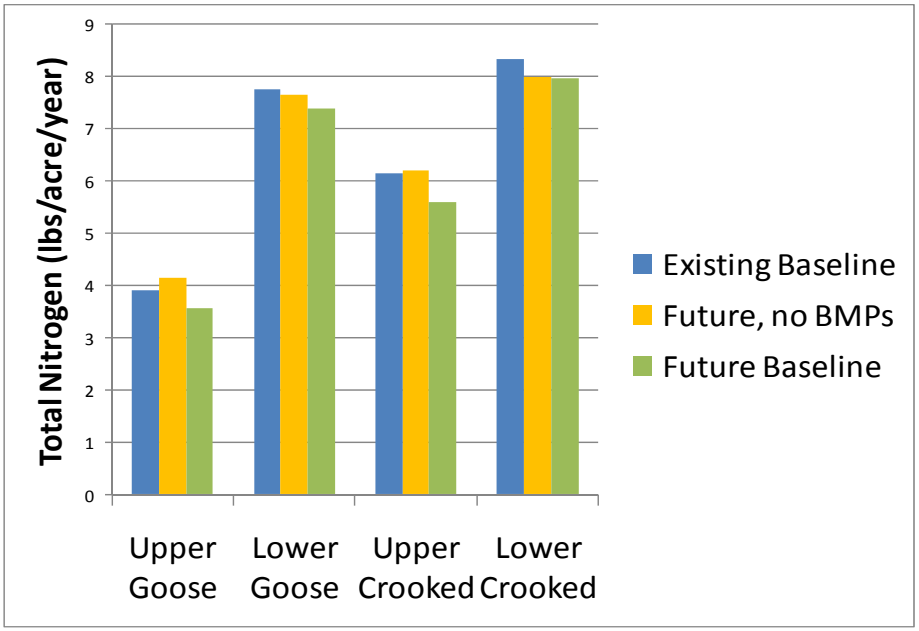


Figure 11. Scenario Results for Annual Upland TN Loading Rates

These findings are largely incorporated into the determination of priority subwatersheds within this planning area as well as the identification of appropriate management strategies for stressors within these watersheds.

3.5 Wetland Assessment Data

Wetland assessment results are presented in their entirety in Tetra Tech's technical memo titled "*Goose Creek and Crooked Creek LWP Phase II-III Wetland Mitigation Planning*" included as Appendix J. (Tetra Tech, 2012c)This section includes excerpts from this memo.

As previously discussed, riparian wetlands restoration or enhancement would address pertinent watershed stressors for Goose and Crooked Creeks by reducing the velocity and volume of stormwater runoff and stream flows that are hydrologically connected to the restoration site. The type of wetlands enhancement provided would determine to what extent these stressors are addressed, but enhancement activities such as planting or minor improvements in hydrologic storage would slow runoff which would encourage settling within the enhanced wetland, leading to reduced turbidity and TSS in streams. Beyond enhancement, wetlands restoration could provide a much greater increase in these functions. Riparian wetlands enhancement or restoration may help reduce nutrients and other pollutants in these flows as well. In addition, enhancing or restoring wetland habitat would support the protection or restoration of critical aquatic habitat for sensitive mussel species through ecological pathways, like enhanced food web interactions and improved habitat through reduction in sediment loading, control of storm flows, and regulation of temperature through shading, among other benefits. Protection of sensitive mussel species is a key consideration for the LWP. Wetlands preservation would protect the water quality, hydrology, and habitat functions provided by existing wetlands. Non-riparian wetlands mitigation would restore or preserve the unique ecological functions of non-riparian wetlands, including habitat for rare, threatened, and endangered species.

Thirty-two sites were evaluated between the two watersheds (23 riparian and 9 non-riparian), which represent the initial sites identified through GIS and additional sites identified after the field verification. The following presents the results of these 32 opportunities by focus area indicators and then by overall prioritization of these identified sites as identified in Tetra Tech's Wetland Mitigation Planning memo.

Benefits

As stated in Section 2.5, Tetra Tech selected five major focus indicators to measure the relative benefit provided by each wetland mitigation opportunity. Results for each indicator are provided below.

1) Provides potential water quality/hydrology benefits to hydrologically connected waters

Table 9 presents the results of the water quality/hydrology evaluation of the identified sites. See Appendix J for additional information regarding the results of this assessment.

Table 9. Water Quality/Hydrology Metric Values for the Wetland Mitigation Opportunity Sites

Wetland ID	Water Quality/Hydrology			
	Cumulative Drainage Area (acres)	% of Cumulative Drainage Area as Impervious Surface	% of Cumulative Drainage Area as Forest/Wetland/Shrub	Stream Status - drains to a 303d impaired stream
Riparian				
1	2,911	18	22	yes
3	13,600	7	43	yes
4	1,766	22	22	yes
5	4,430	23	17	yes
6	8,583	17	23	yes
8	13	0	1	yes
9	24,730	12	28	yes
10	30,308	10	29	yes
11	4,899	15	28	yes
13	9,562	14	30	yes
14	22,599	13	27	yes
15	10,922	14	24	yes
16	25,746	12	28	yes
17	24,316	12	28	yes
18	15,954	7	40	yes
19	4,435	5	55	yes
20	8,765	9	47	yes
21	8,423	9	47	yes
22	8,306	4	54	yes
23	1,879	21	32	yes
25	13	7	0	no
29	375	6	60	no

Wetland ID	Water Quality/Hydrology			
	Cumulative Drainage Area (acres)	% of Cumulative Drainage Area as Impervious Surface	% of Cumulative Drainage Area as Forest/Wetland/Shrub	Stream Status - drains to a 303d impaired stream
32	941	8	42	no
Non-Riparian				
2	5	2	1	NA
12	48	3	88	NA
17	5	12	28	NA
24	27	0	22	NA
26	48	1	52	NA
27	25	0	81	NA
28	21	2	20	NA
30	12	10	20	NA
31	8	1	4	NA

2) Supports a stream restoration opportunity

Six riparian sites intersected the 500-foot stream buffer along potential stream restoration reaches, while 17 sites did not, and all non-riparian sites were found outside of the 500-foot stream buffer (Table 10).

3) Supports or is supported by a BMP opportunity

As a result of this analysis, no wetland mitigation sites were found within the 500-foot buffer zone of BMPs; therefore, it was concluded that zero candidate wetland mitigation sites either support or are supported by a BMP opportunity (Table 10).

4) Supports existing wildlife habitat or endangered/threatened species

Twenty riparian sites and four non-riparian sites were found to intersect the NHEO buffer, while eight sites were located outside of this buffer (Table 10).

5) Future availability is affected by development pressure

Eighteen riparian sites and eight non-riparian sites were found to be located within existing municipal boundaries, one site was less than 2,000 feet from future municipal boundaries, one site was greater than 2,000 feet from future municipal boundaries, and four sites were within 10,000 feet of the Monroe Bypass and outside of existing municipal boundaries (all four sites were within future municipal

boundaries (Table 10). No sites were found within future municipal boundaries (category 3) that were farther than 10,000 feet from the Monroe Bypass ROW. Table 10 below presents the findings from the above indicators.

Table 10. Wetland Focus Indicator Benefit-Related Metrics

Wetland ID	Supports a Stream Restoration Opportunity	Supports or is Supported by a BMP Opportunity	Supports Existing Wildlife Habitat or Endangered/Threatened Species		Future Availability based on Development Pressure
			Adjacent Public Natural Area	Near Aquatic NHEO	
Riparian					
1	yes	no	no	yes	1) existing
3	no	no	yes	yes	1) existing
4	yes	no	no	yes	1) existing
5	no	no	no	yes	1) existing
6	no	no	no	yes	2) future; <10,000
8	no	no	no	yes	1) existing
9	no	no	no	yes	1) existing
10	no	no	no	yes	5) >2,000
11	no	no	no	no	2) future; <10,000
13	yes	no	no	no	2) future; <10,000
14	no	no	no	yes	1) existing
15	yes	no	no	yes	1) existing
16	no	no	no	yes	1) existing
17	no	no	no	yes	1) existing
18	no	no	yes	yes	1) existing
19	no	no	no	yes	1) existing
20	yes	no	no	yes	4) <2,000
21	no	no	no	yes	1) existing
22	no	no	no	yes	1) existing
23	no	no	no	yes	1) existing

Wetland ID	Supports a Stream Restoration Opportunity	Supports or is Supported by a BMP Opportunity	Supports Existing Wildlife Habitat or Endangered/Threatened Species		Future Availability based on Development Pressure
			Adjacent Public Natural Area	Near Aquatic NHEO	
25	no	no	no	yes	1) existing
29	no	no	yes	no	1) existing
32	yes	no	no	yes	1) existing
Non-Riparian					
2	no	no	no	yes	2) future; <10,000
12	no	no	no	no	1) existing
17	no	no	no	yes	1) existing
24	no	no	no	no	1) existing
26	no	no	no	no	1) existing
27	no	no	no	no	1) existing
28	no	no	no	yes	1) existing
30	no	no	no	no	1) existing
31	no	no	no	yes	1) existing

Feasibility

Tetra Tech identified two major focus indicators to measure the feasibility of constructing each site within the Goose Creek and Crooked Creek watersheds. The following presents the results from the assessment of these indicators.

1) Constraints related to landowners

Of the 32 sites analyzed, landowner willingness for 21 sites was unknown (a majority of these landowners had been contacted by NCEEP, but had not yet responded), four sites were classified as having the potential for landowner willingness, four sites resided on properties where landowners denied access to NCEEP, and three sites were located on properties where landowners were willing to cooperate with NCEEP and future wetland projects (in these counts, site 17 was counted as two sites, once for the riparian and once for the non-riparian portion) . The number of landowners for riparian sites ranged from 1 to 25 landowners, with an average of approximately four landowners per site. Two non-riparian sites had two owners, while seven non-riparian sites had a single owner.

2) Constraints related to existing utilities and obstacles for access

In all, 19 riparian sites were classified as having unconstrained access while the remaining four sites had constrained access and five non-riparian sites were classified as having unconstrained access while four sites had constrained access.

For additional information regarding this assessment see Table 3 in Appendix J.

Mitigation Value

Cost estimates ranged widely from $4,000 to $1.9 million, with a mean of $340,000. See Table 11 below for costs of these sites. As presented in Section 2.5, to estimate the cost for each potential project, the wetland acres were divided by the mitigation ratios and then multiplied by the fee schedule. Additional information is available in Appendix J.

Table 11. Mitigation Value Metrics

Wetland ID	Mitigation Type	WMUs	Cost
Riparian			
1	enhancement/preservation	2.4	$149,000
3	restoration/enhancement	18.5	$1,151,000
4	preservation	1.8	$112,000
5	preservation	5.8	$361,000
6	preservation	2.8	$174,000
8	enhancement/preservation	5.1	$317,000
9	restoration/enhancement	5.5	$342,000
10	preservation	8.4	$523,000
11	preservation	4.8	$299,000
13	preservation	1.8	$112,000
14	preservation	11.5	$715,000
15	restoration/enhancement	2.5	$156,000
16	preservation	4.0	$249,000
17	restoration	30.0	$1,866,000
18	preservation	6.0	$373,000
19	restoration	11.0	$684,000

Wetland ID	Mitigation Type	WMUs	Cost
20	preservation	6.0	$373,000
21	enhancement/preservation	1.6	$96,000
22	enhancement/preservation	5.5	$342,000
23	preservation	4.4	$274,000
25	restoration	20.0	$1,244,000
29	restoration	3.0	$187,000
32	enhancement	5.0	$311,000
Non-Riparian			
2	restoration/enhancement	4.0	$180,000
12	preservation	1.4	$63,000
17	enhancement	0.2	$7,000
24	enhancement/preservation	0.4	$18,000
26	enhancement	0.1	$4,000
27	preservation	0.1	$4,000
28	restoration	0.8	$36,000
30	restoration	0.7	$31,000
31	restoration	0.3	$13,000

Prioritization

Total riparian wetland scores ranged from 4.2 to 7.1, with an average score of 5.9. Of the 23 riparian sites prioritized, 11 of the sites had overall composite scores greater than 6.0. Based on these results, the three riparian sites of highest priority were sites 15, 17, and 3 with scores of 7.1, 7.0, and 7.0, respectively. Total non-riparian wetland scores ranged from 3.3 to 5.8, with an average score of 4.8. Of the nine non-riparian sites prioritized, site 2 was the highest scoring site having a score of 5.8. Site locations and total scores for riparian and non-riparian sites are displayed in Figure 12 and Figure 13. The higher priority sites appear to be spread evenly throughout the watershed, and neither high nor low priority sites are concentrated in a particular location. See Appendix J for additional information including the scores for each individual site.

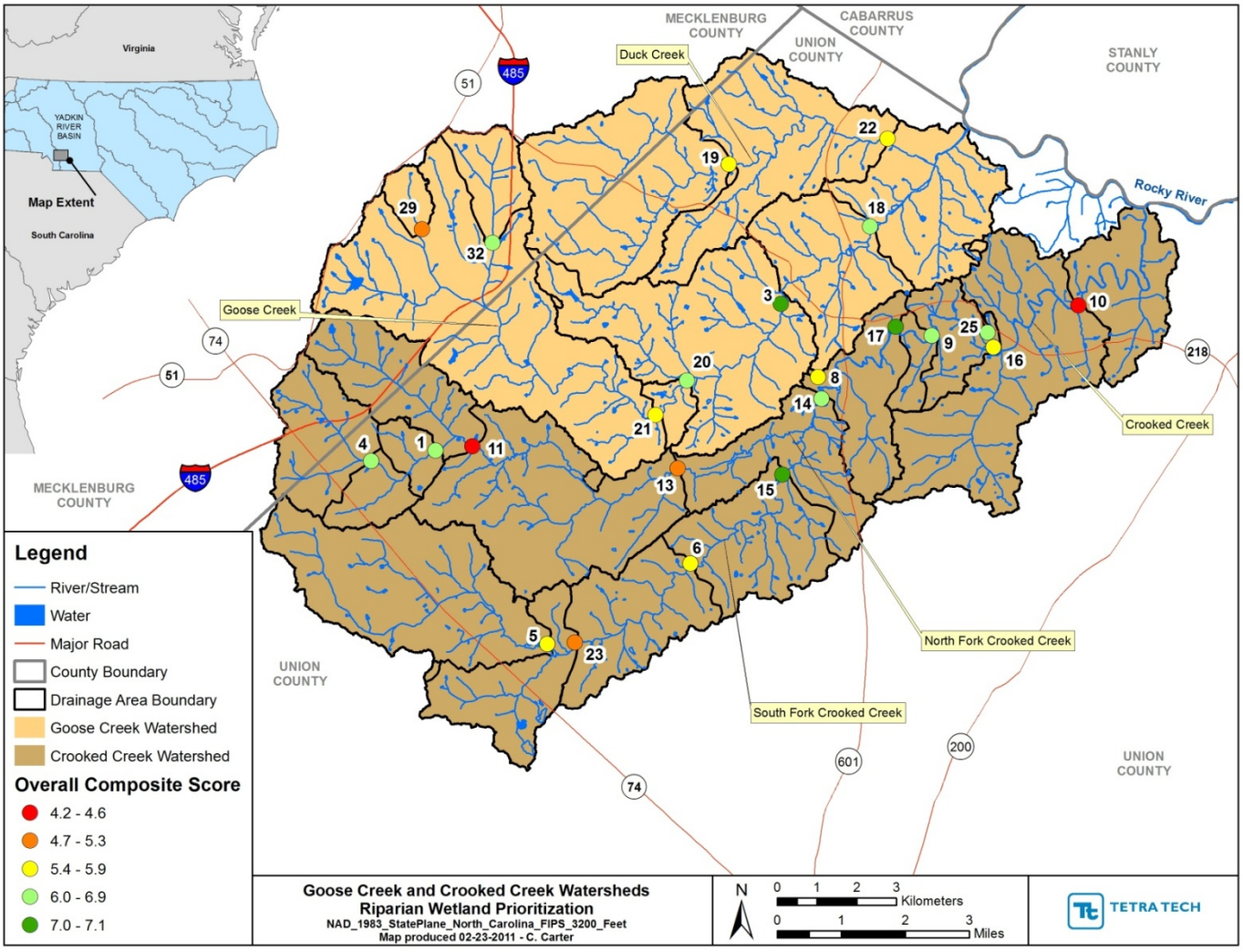


Figure 12. Potential Riparian Wetland Mitigation Sites Varying by Overall Composite Score

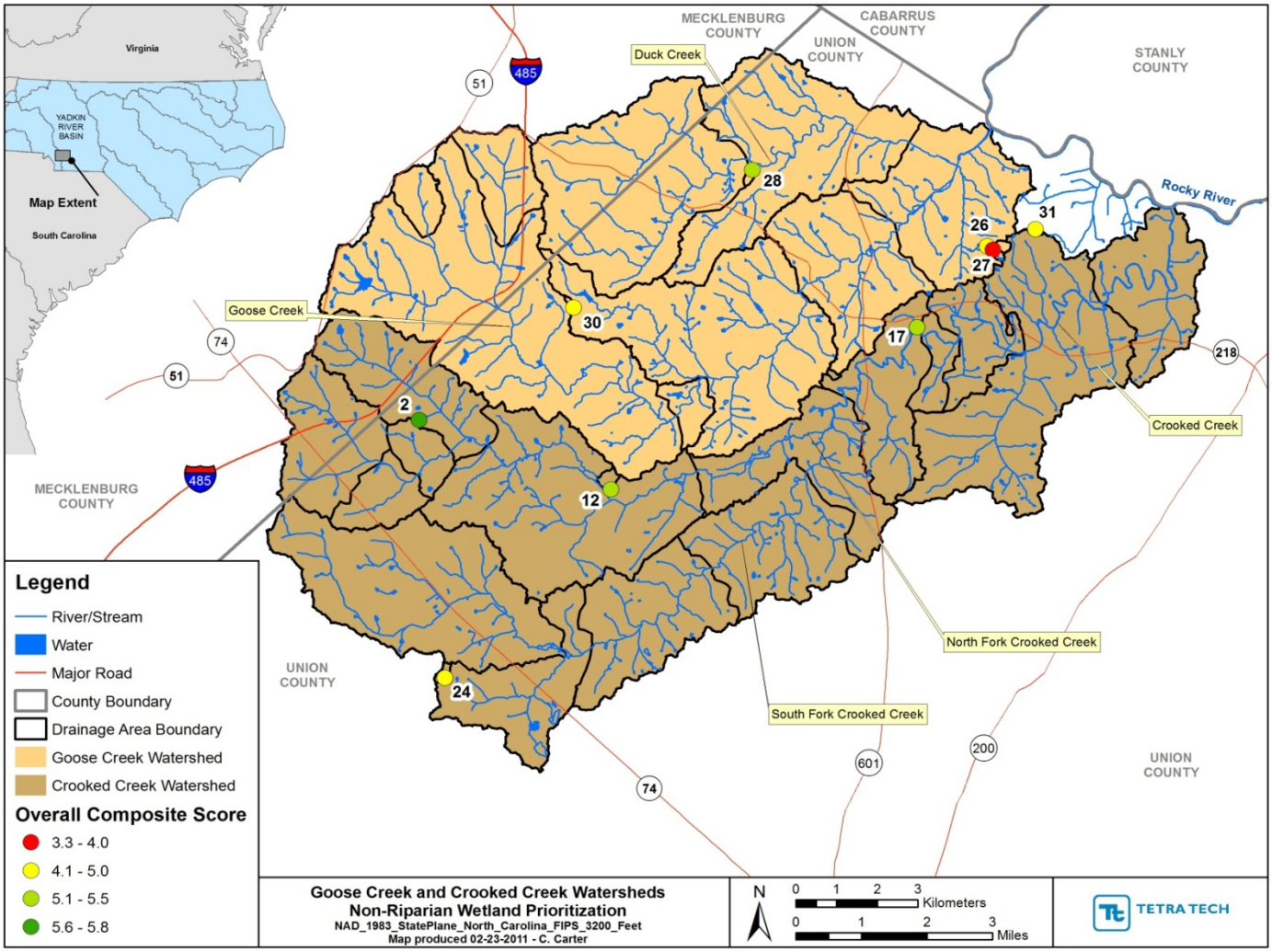


Figure 13. Potential Non-riparian Wetland Mitigation Sites Varying by Overall Composite Score

The wetlands prioritization provides a tool for comparing benefits, feasibility, and mitigation value across the 32 wetland mitigation opportunities identified by NCEEP. To assess whether the composite scores adequately reflected the overall goal of the analysis, Tetra Tech reviewed the characteristics of the three top riparian and the top non-riparian scoring sites (15, 17, 3, and 2) (Appendix J, Table 5). All four sites appeared to provide promising opportunities. For additional information on these sites see Appendix J.

Section 4 Stressors and Sources

The Phase I preliminary findings report discussed the linkages between the major stressors, sources, impacts, and functional deficits (Table 12) and hypothesized that sediment and increased peak flows/runoff volumes are the most important and pervasive stressors to watershed function in the Goose Creek and Crooked Creek watersheds . The following were hypothesized as secondary stressors: bacteria, oxygen demanding substances/nutrients, and toxicity-related pollutants (i.e., ammonia,

copper, and pesticides). (Tetra Tech, 2008a; Centralina, 2009) The results of the Phase II assessments generally support the presence of the proposed stressors in the Phase I preliminary findings report developed by Tetra Tech and are discussed below by proposed stressor.

Increased Peak Flows and Runoff Volumes: During the continued monitoring events within these watersheds evidence of impacts from increased peak flows and runoff volumes has been present.

All Crooked and Goose Creek macroinvertebrate monitoring stations within this study received Poor or Fair bioclassifications indicating continued impaired water quality in the catchment. The macroinvertebrate data suggests that potentially the most important factor continuing to affect these streams is rapid expansive urbanization of the Goose and Crooked Creeks headwaters. Habitat quality increases and impervious surfaces decrease as you move downstream in both watersheds suggesting that controlling these impacts in the headwaters is important. Commercial/Industrial and residential land use in headwaters leads to more impervious surface and ultimately, to a modified hydrologic regime. Stormwater runoff over impervious surfaces with reduced riparian buffers may lead to the rapid movement of water downstream increasing scour, erosion, and sediment input. North Fork Crooked Creek at SR 1514 is a stream reach that suffers from severe erosion, lack of course substrate, and narrow/patchy riparian zones and may be an example of this altered hydrologic flow. Virtually no course substrate was observed at this site potentially due to high flows through the channel during storm events. (NCDWQ, 2009)

The discussion on the findings from habitat assessments further supports the presence of this stressor specifically with the notation that one common deficiency among many sites was a lack of available root mat and undercut bank habitats; many of these were isolated above water. This isolation may be due to the low flows in these Slate Belt streams, but downcutting due to stormwater impacts may exacerbate this impact.

Assessments conducted to evaluate stream conditions revealed that evidence of undercutting, incision to bed rock, and widening of stream channels was observed. In many reaches incision has disconnected streams from the floodplain. Mass wasting of streambanks was also observed in both watersheds, which results in streambanks failing and large quantities of sediment entering the stream. Most reaches evaluated in the current study have a moderate-to-high risk of bank erosion, with characteristics similar to highly unstable channels. This indicates that some reaches may be actively unstable or could become unstable if peak flows and runoff volumes were to increase. With high degrees of imperviousness upstream and agricultural impacts resulting in problems such as reduced or lack of riparian buffer happening downstream, management of runoff and peak flows is important throughout these watersheds. HEC-RAS was used to simulate channel velocities within these watersheds and highlighted reach segments with cross-sections having an average velocity above the 85th percentile ranking and also reaches where two consecutive cross-sections exceeded the 85th percentile (Appendix H, Figure 3 and Figure 4). Through this process high velocity reaches were identified throughout the planning area further suggesting these impacts are resulting from both urbanization in the headwaters, with watersheds of 7.8%-24.6% impervious, and also agricultural practices in the lower portions of the watersheds, with Pasture/Agricultural Lands typically being the dominate land use. (Tetra Tech, 2010)

The transition within both of these watersheds from urban upstream to rural and agricultural downstream mean that it will be important to consider a variety of strategies to reduce and manage runoff and peak flows. It is likely that the headwaters will warrant stormwater management practices in addition to stream and wetland projects and consideration of stabilizing features such as existing riparian buffer, and possibly buffer restoration projects, will be important in the lower portions.

Sediment: The modeling work conducted by Tetra Tech was developed considering sediment impacts to be a major stressor in these watersheds therefore findings from this work are particularly useful when determining the extent of related impacts. The Bed+Bank Sediment Erosion measure from this report shows a trend; unmitigated runoff from new development increases bed and bank erosion, but it also indicates that stormwater management requirements mitigate the increase by holding back the increase in erosive flows. The findings from the modeling work further indicate that significant amounts of sediment are being contributed through upland wash as well as from streambank erosion in both watersheds while some aggradation is also occurring, again likely resulting from urbanization and imperviousness upstream and agricultural impacts downstream. (Tetra Tech, 2012b)

The habitat assessment report results indicate that all Goose Creek sites had abundant rock habitat, with a mix of larger substrates. However, there was still considerable sand+silt at these sites compared to the reference site on Barnes Creek, with values ranging from 35-45%, indicating large amounts of sediment are being contributed likely either through runoff and/or bank erosion. In addition, Duck Creek riffles were highly embedded (40-80%) and the upper reaches of North and South Fork Crooked Creeks showed that the bottom substrate was sand+silt consisting of 80-90% of the inorganic substrate further suggesting that sediment impacts are significant. (NCDWQ, 2009)

The channel assessment work done by Tetra Tech also provides valuable insight to the assessment of the impacts from sedimentation. As previously indicated, assessments conducted to evaluate stream conditions revealed that evidence of undercutting, incision to bed rock, and widening of stream channels was observed. In many reaches incision has disconnected streams from the floodplain. Mass wasting of streambanks was also observed in both watersheds, which results in streambanks failing and large quantities of sediment entering the stream. Most reaches evaluated in the current study have a moderate-to-high risk of bank erosion, with characteristics similar to highly unstable channels. This indicates that some reaches may be actively unstable or could become unstable if peak flows and runoff volumes were to increase. (Tetra Tech, 2010) Again this suggests impacts from sedimentation are occurring from urban impacts upstream as well as agricultural impacts downstream so management of this stressor throughout the watershed is important.

The NCDWQ WAT Integrated Report showed only one baseflow result from the monitoring stations exceeded the water quality standard for turbidity but most all stormflow results exceeded the water quality standard of 50 NTU. Among the monitoring stations within the LWP area, there are no notable differences in the results for turbidity (NCDWQ, 2011a). This also supports the need for stormwater management practices to be considered and implemented in conjunction with stream and wetland improvement projects.

As previously indicated, the transition within both of these watersheds from urban upstream to rural and agricultural downstream mean that it will be important to consider a variety of strategies to reduce and manage sedimentation.

Oxygen Demanding Substances/Nutrients: Low dissolved oxygen concentrations (<4 mg/L) were sampled frequently and associated with low flows and warmer water temperatures indicating sources like imperviousness, urban runoff and lack of riparian buffers are likely contributors. Most of these observations were collected in North Fork Crooked Creek and South Fork Crooked Creek. The highest median nutrient (nitrite-nitrate and total phosphorus) concentrations and specific conductance values were found on North Fork Crooked Creek and Crooked Creek, both below the Crooked Creek WWTP #2 (NCDWQ, 2011a).

All Crooked and Goose Creek macroinvertebrate monitoring stations within this study received Poor or Fair bioclassifications indicating continued impaired water quality in the catchment. Many factors are potentially contributing to its degraded water quality including point and nonpoint sources. Increases in urban activities near headwater reaches may be leading periodic toxicity and additionally, several permitted Wastewater Treatment Plants (WWTPs) are located upstream from benthic sampling locations likely contributing to more tolerant macroinvertebrate assemblages. The dominating presence of low dissolved oxygen tolerant and high nutrient/organic waste tolerant taxa downstream of these WWTPs indicates they are likely significant sources of this stressor. In addition, there were several sites where it was noted that quality habitat was available however tolerant species were dominant indicating that poor water quality resulting from a variety of sources (both urban and rural) was likely the key stressor (NCDWQ, 2009). It should be noted that the North Carolina Division of Water Quality implemented a Site Specific Water Quality Management Plan (SSWQMP) for the Goose Creek watershed in 2009 and one of the controls included in this rule is for wastewater management; under this SSWQMP no new dischargers or expansions of existing dischargers is allowed as a result. This should prevent future increases of point source contributions of nutrients/oxygen demanding substances to the Goose Creek watershed.

Bacteria: Historically, fecal coliform bacteria counts within Goose Creek have been high resulting in 303(d) listing in 2003 and the development of a Total Maximum Daily Load (TMDL) for this watershed (see: http://portal.ncdenr.org/web/wq/ps/mtu/tmdl/tmdls#yadkin). NCDWQ-WAT did not sample for fecal coliform bacteria within the Goose Creek watershed as part of the LWP monitoring since monitoring by other programs led to a TMDL for fecal coliform bacteria. However, NCDWQ-WAT did sample fecal coliform bacteria as part of its Stormflow Study at two Goose Creek sites as well as at several sites in Crooked Creek (NCDWQ, 2011a). Results of the sampling reveal the continued presence of fecal coliform bacteria over the evaluation level, particularly during stormflow events in 5 of the 8 monitoring sites. The sources for this stressor are likely varied, but may include urban runoff, agricultural impacts (e.g., livestock having access to streams) and WWTP discharges. Though this is a stressor of concern for both watersheds, the TMDL that is in place for Goose Creek should act a control for impacts there though additional measures could also be considered. Future management strategies

developed in the Crooked Creek watershed should take into consideration the controls in place in Goose Creek..

Toxic Substances (Ammonia and Copper): Overall there are no noteworthy patterns to the concentrations for ammonia nitrogen among all the NCDWQ-WAT monitoring stations. The NCDWQ-AMS station near Mint Hill is less than one mile downstream of the Hunley WWTP. Between 1995 and 2006, this WWTP discharged high concentration of ammonia nitrogen. In 2006, wastewater from the Hunley WWTP was directed to another regional WWTP, thus removing the ammonia discharges to Goose Creek. (NCDWQ, 2011a) In addition, the SSWQMP implemented for the Goose Creek watershed includes a control for toxicity under which any contributions of ammonia with the potential to be toxic to the Carolina heelsplitter (*Lasmigona decorata*)mussel must be reduced to levels below the toxicity threshold (0.5mg/L or less of Total Ammonia). Due to the findings from the NCDWQ WAT report and the implementation of the SSWQMP, ammonia is not likely to be considered a significant stressor for this watershed at this time.

Additionally, the Biotic Ligand Model developed by USFWS with support from NCDWQ WAT specifically evaluated potential impacts from dissolved copper as this was indicated as stressor of concern for the Carolina heelsplitter. This report states that the data collected, if representative of the system, indicate copper is not currently of toxicological concern. From a watershed management standpoint, attention to nonpoint source controls of sediment would further reduce copper loadings, but no special attention would be needed to address copper. (USFWS, 2011) Though this does not appear to be a significant stressor within this watershed at this time, further investigation is being considered and could reveal additional concerns. Therefore, copper will likely continue to be considered during the development of management strategies for this watershed.

It will be important to consider the sources identified in Table 12 when watershed management strategies are developed for impacts resulting from these stressors.

Table 12. Linkage Between Stressors, Sources, Impacts and Functional Deficits in the Goose Creek and Crooked Creek Watersheds

Stressor	Source(s)	Impact(s)	Functional Deficit(s)
Increased Peak Flows and Runoff Volumes	Impervious surface, removal of vegetation, direct stormwater discharges	Decreased groundwater recharge and baseflows, channel modification, substrate disturbance; increased velocities, scour	Impaired aquatic habitat, loss of wetland hydrology/ habitat, Impaired aquatic organisms
Sediment	Erosion of construction sites, agricultural land, livestock access to streams, streambank and channel erosion, ATV use	Increased deposited sediment in stream channel, increased turbidity/suspended sediment	Impaired aquatic habitat and aquatic organisms

Stressor	Source(s)	Impact(s)	Functional Deficit(s)
Bacteria	Pets, livestock, wastewater discharges, septic tanks, wildlife	Increased count of pathogens in surface and ground water	Increased risk to human health (and aquatic life)
Oxygen Demanding Substances/ Nutrients	WWTPs; Nutrient loading from urban and agricultural runoff, temperature increase in runoff from impervious surfaces; natural sources; septic systems; direct loading from livestock; other agricultural sources.	Excessive algal growth, depletion of dissolved oxygen	Aquatic organism stress and mortality
Ammonia, Copper, Pesticides (toxicity-related)	Wastewater discharges, runoff from lawns, golf courses, and agricultural land (manure and agrochemicals)	Increased concentration of toxic chemicals	Toxic effects on aquatic organisms

Tetra Tech, 2008a

4.1 Functional Assessment and Identification of Problem Areas

It is necessary to also consider impacts on a small scale in order to gain the best understanding possible of current conditions as well as to identify areas where resources will be most effective in providing benefits and most efficiently used. In addition, an assessment at a scale such as a subwatershed can also help to reveal the level at which these watersheds are functioning. Generally, those watersheds with more assets (i.e., high-quality habitat, forested riparian and floodplain area, stable banks, undisturbed uplands, etc.) and few stressors are classified as high-functioning watersheds. These watersheds are likely to be good candidates for preservation opportunities. Watersheds with impacted streams, wetlands, and floodplains are under increased stress and unable to sustain functions. These lower functioning systems have little high quality habitat to preserve, but are more likely to contain stream and wetland restoration and enhancement opportunities. Watersheds in the middle, functioning-at risk, require a mix of conservation and restoration actions to maintain or improve their functions. The priority for this assessment was to identify problem areas that were in the most need of improvement, or were likely to be considered lower functioning.

To this end, Tetra Tech developed a general framework for the prioritization of subwatersheds within this planning area and then selected indicators, or datasets, that supported this framework and addressed the stressors identified during Phase I. The prioritization effort, entitled "*Goose Creek and Crooked Creek LWP Phase II-III Stressor-Based Subwatershed Prioritization – Revised*", is attached as Appendix K. (Tetra Tech, 2012a) The framework for the stressor-based prioritization was based directly on the Goose Creek and Crooked Creek LWP goals. Goals 1 and 2 are most relevant to the stressor based analysis:

- Goal 1: Restore, protect, and enhance watershed functions such as hydrology, water quality, and aquatic and terrestrial habitat.

- Goal 2: To minimize impacts on water quality, aquatic and terrestrial habitat, and hydrology in the watershed by supporting balanced, sustainable, and diverse land use and development, in accordance with existing and future policies.

Goal 1 generally seeks to protect or improve existing watershed functions, while Goal 2 seeks to address future impacts to watershed functions. To prioritize subwatersheds where management would best meet each of these goals, two scores were calculated for each subwatershed: one for existing conditions and one for future conditions. As part of the scoring, the subwatersheds with the greatest magnitude of stressors were considered the highest priority because addressing these areas would address the most extreme impacts to mussel habitat and other watershed functions.

Tetra Tech then selected indicators that would measure the gaps between existing and future conditions and also indicate opportunities to achieve these goals through watershed improvement. The areas with the greatest impacts are likely to exist where extreme stormwater flows and volumes and high pollutant loading are occurring or will be occurring in the future. Tetra Tech considered the available data gathered and developed for the LWP, including modeling, field-based assessment, and water quality monitoring data to develop the watershed prioritization. Field assessments performed for previous tasks directly contributed to opportunity identification (e.g., stream assessments led to stream enhancement and restoration opportunities). Water quality monitoring and stream assessment data also were used to develop watershed model input and calibration. Since these datasets have already been incorporated in the watershed modeling, the model output provides the best available measure of stressor levels. Another advantage of the watershed model is that it provides output across all subwatersheds throughout an extended continuous period (e.g., annually or seasonally) as opposed to monitoring, which is limited to data at sampling locations reflecting only a few discrete points in time and space. Details on the indicators used in the model can be found in Section X.X.

Subwatershed Scoring

The data used for the scoring was developed as part of the 319 grant-funded watershed modeling developed by Tetra Tech for the Centralina Council of Governments. Loading Simulation Program C++ (LSPC), a continuous simulation watershed hydrology and water quality model, was calibrated and validated using available flow and water quality data. Development of the existing and future baseline scenarios are discussed below. The methodology and results from the modeling work are detailed in Section 2.4 and Section 3.4.

The Goose and Crooked Creeks watersheds were scored separately to provide each watershed a similar number of priority subwatersheds and to ensure protection of the Carolina heelsplitter (*Lasmigona decorata*). For details on the scoring methodology see Appendix K. Figures 13 and 14 below display the results of the stressor-based scoring for existing and future conditions, respectively, and the scoring results for each watershed are detailed in Appendix K. The subwatersheds are shaded according to natural breaks in the overall composite scores. Two tiers of priorities are recommended: Tier I represents primary management needs, and Tier II represents secondary management needs. A yellow border indicates the subwatersheds are recommended as Tier II management priorities under both the existing and future baselines in Figure 14 and Figure15. These subwatersheds exhibit moderate to high

level stressors across the indicators and/or low scores (very high loading) under the TN and TP indicators. Management focused only on the Tier I priority subwatersheds may miss opportunities to improve watershed conditions with management in these additional subwatersheds. The Future Baseline scenario differs from the Existing Baseline scenario by applying areal changes to the land use and land cover, and by the addition of stormwater BMPs for the treatment of new development according to current regulations.

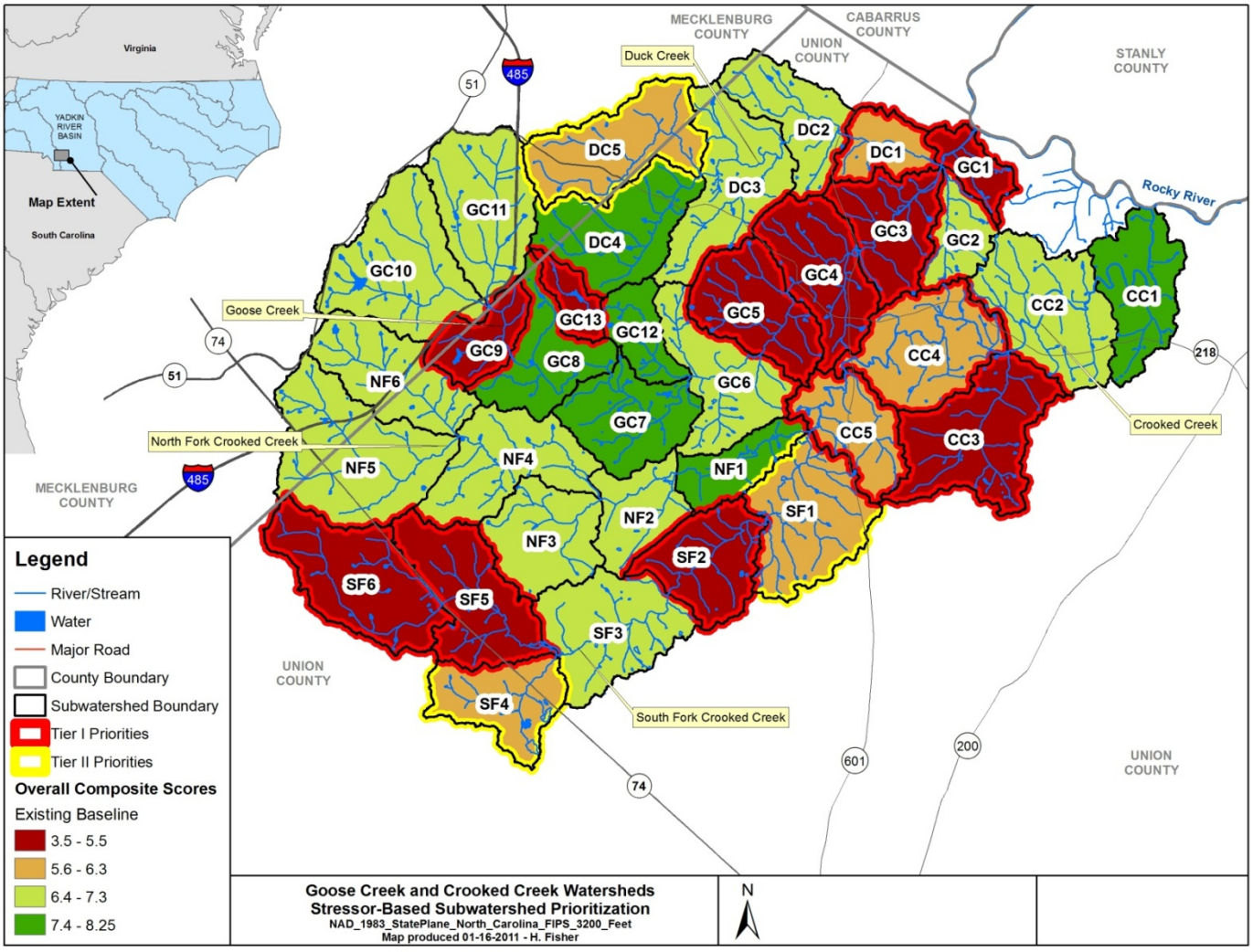


Figure 14. Existing Baseline Subwatershed Scoring Results and Priority Recommendations

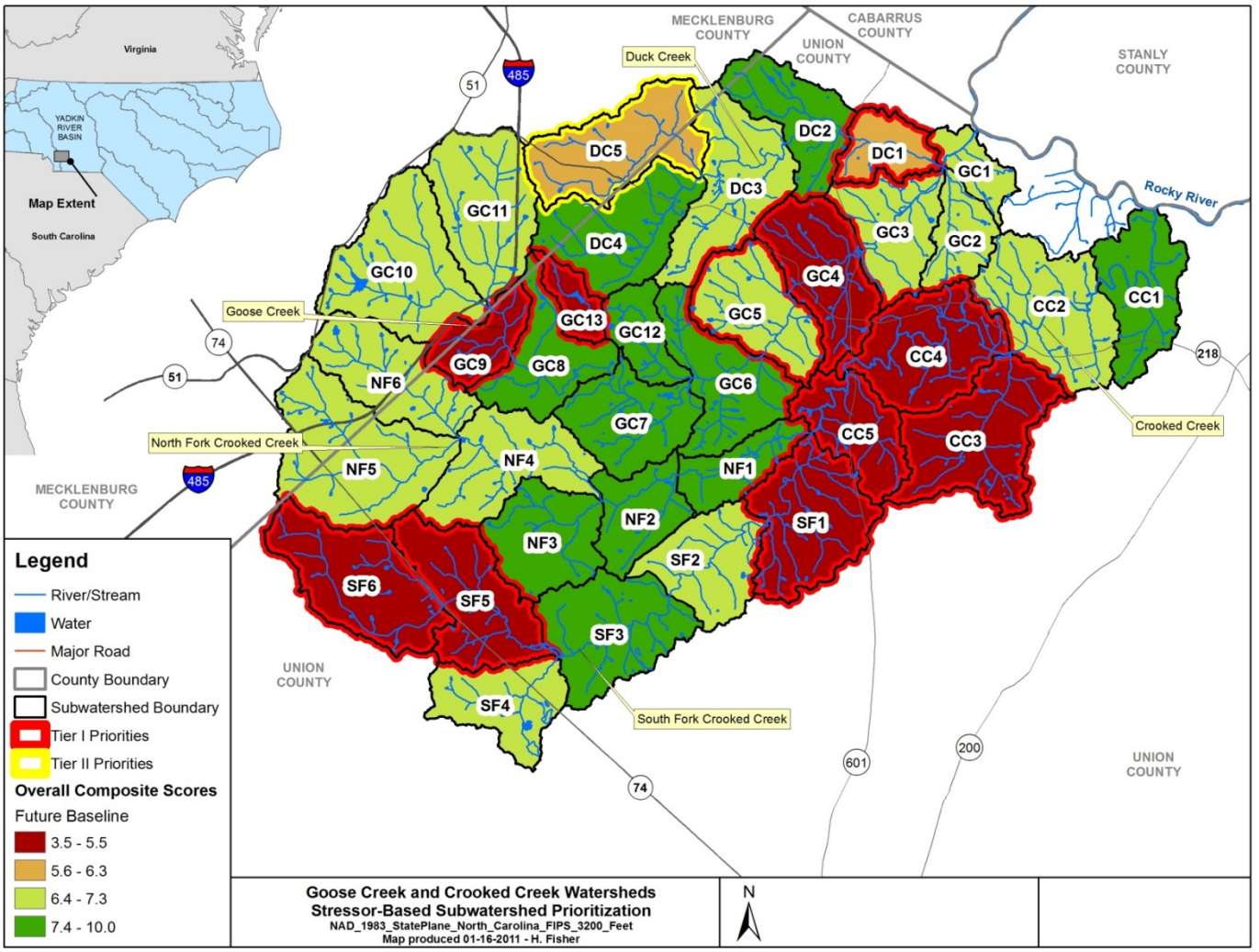


Figure15. Future Baseline Subwatershed Scoring Results and Priority Recommendations

The Tier I and II priority subwatersheds are recommended as tools for selecting the most promising management opportunities for the Goose Creek and Crooked Creek LWP. During the development of the watershed management plan, these priorities will aid in identifying management opportunities that would best address the major stressors and help restore and protect watershed functions.

Section 5 Watershed Assets

An important component of a watershed assessment is identifying watershed assets. Watershed assets are considered twofold for this assessment: 1) as significant natural resources that exist within the watersheds and 2) as beneficial natural resources that exist and provide protection for water quality and habitat for significant resources. The value of beneficial natural resources will vary between watersheds, particularly depending on what key stressors are present. In general, intact riparian buffers, undisturbed or undeveloped land, land already under conservation, high quality habitat, and even proactive landowners and stakeholders are examples of things considered important when

evaluating watershed assets. Preservation of these assets, especially in clusters, is an effective way to protect against the impacts of stressors and support long-term watershed health. The preservation of assets is valuable in the Goose and Crooked Creeks watersheds for many reasons including: the protection of riparian buffers that will aid in the reduction of sediment, runoff/peak flow and nutrient impacts, maintaining existing natural areas that will prevent further impacts from additional disturbed land or imperviousness and ensuring the conservation of habitat that supports the many significant species within these two watersheds including the federally endangered Carolina heelsplitter (*Lasmigona decorata*) found in the Goose Creek watershed.

5.1 Significant Natural Resources

Table 13 below identifies the sensitive native mussel species within Goose and Crooked Creeks watersheds.

Table 13. Sensitive Mussel Species in the Goose Creek and Crooked Creek Watersheds

Scientific Name	Common Name	Watershed(s)	Status
Lasmigona decorata	Carolina heelsplitter	Goose Creek	Endangered – federal and state
Villosa vaughaniana	Carolina creekshell	Goose and Crooked Creeks	Federal species of concern and state endangered
Fusconaia masoni	Atlantic pigtoe	Goose Creek	Federal species of concern and state endangered
Toxolasma pullus	Savannah lilliput	Crooked Creek	Federal species of concern and state endangered
Strophitus undulatus	Creeper	Goose Creek	Threatened - state
Villosa constricta	Notched rainbow	Goose Creek	Special concern -state
Villosa delumbris	Eastern creekshell	Goose and Crooked Creeks	Significantly rare - state

Tetra Tech, 2008a

The North Carolina Natural Heritage Program (NHP) supports conservation of the rarest and the most outstanding elements of the natural diversity of our state. These elements of natural diversity include those plants and animals which are so rare or the natural communities which are so significant that they merit special consideration as land-use decisions are made. According to the NHP, a Significant Natural Heritage Area (SNHA) is an area of land or water identified by the NHP as being important for conservation of the State's biodiversity. SNHAs contain one or more Natural Heritage Elements which are high-quality or rare natural communities, rare species, and special animal habitats (NCDENR, 2012b). There have been several Natural Heritage Element Occurrence (NHEO) observations within these watersheds; many are identified as one of the above mentioned mussel species but there have also been sensitive terrestrial and aquatic plant species observed including Indian Physic (*Gillenia stipulate*), Piedmont Aster (*Eurybia mirabilis*), Schweinitz's Sunflower (*Helianthus schweinitzii*), Smooth Sunflower

(*Helianthus laevigatus*) and Virginia Quillwort (*Isoetes virginica*). In addition to the NHEOs there are some areas within these watersheds that are also identified by the NHP as unique SNHAs. The North Fork Crooked Creek Sunflower site, Goose and Duck Creek Aquatic habitat and also the Crooked Creek Aquatic Habitat which support the various sensitive species are all included as SNHAs.

Goose Creek and its major tributary, Duck Creek also are considered significant by the United States Fish and Wildlife Service (USFWS) because they support the federally endangered Carolina heelsplitter and are designated critical habitat for this species.

5.2 Prioritization of Watershed Assets

The Phase I Preliminary Findings report (Tetra Tech, 2008a; Centralina, 2009) included an assessment of preservation opportunities within these watersheds and serves as the foundation for this section. In addition, the discussion in Section 4 is also useful as it not only identified the areas within these watersheds that are the most impacted but also resulted in identify highly functioning subwatersheds. In order to determine areas to prioritize for preservation, information from these two sources was layered to identify subwatersheds that have fewer impacts from stessors and that also have significant amounts of existing natural areas.

In the Preliminary Findings report land cover data from Southeast Gap Analysis Program (SEGAP) was utilized to show land cover distribution throughout these watersheds. This distribution provides an indication of natural area connectivity within each subwatershed. Natural area includes the following land cover classes: Southern Piedmont Dry Oak-(Pine) Forest – Hardwood Dominant, Southern Piedmont Mesic Forest, Southern Piedmont Dry Oak-(Pine) Forest – Loblolly Pine Dominant, Southern Piedmont Dry Oak-(Pine) Forest – Mixed, Southern Piedmont Small Floodplain and Riparian Forest. Percent natural area cannot fully measure connectivity, but subwatersheds with a high percentage of natural area are likely to contain more connected natural areas (Tetra Tech, 2008a; Centralina, 2009). Table 14 below identifies the percent of natural areas within these watersheds utilizing SEGAP data.

Table 14. Percent of Land in Natural Area and Other General Land Cover by Subwatershed*

Stream Name	SW ID	Total Area of SW (acres)	Developed	Disturbed/ Managed/ Successional	Open Water	Upland Natural Area	Wetland Natural Area	Total Natural Area
Duck Creek	DC1	847	6.1	59.0	0.1	29.9	4.9	34.8
Duck Creek	DC2	1,466	5.5	45.7	0.2	47.0	1.6	48.6
Duck Creek	DC3	2,172	4.0	52.2	0.2	41.0	2.6	43.6
Duck Creek Headwaters	DC4	2,055	16.5	36.2	0.1	45.4	1.8	47.2
Unnamed Trib of Duck Creek	DC5	2,079	13.4	38.7	0.1	45.7	2.1	47.8
Goose Creek	GC1	605	4.8	44.2	0.1	45.6	5.2	50.8
Stevens Creek	GC10	2,577	19.9	40.0	0.8	37.0	2.3	39.3
Goose Creek Headwaters	GC11	2,135	21.6	40.0	0.3	36.2	2.0	38.2
Paddle Branch	GC12	795	13.2	45.7	0.3	38.9	1.9	40.8
Paddle Branch Headwaters	GC13	501	59.7	17.2	0.0	21.9	1.3	23.1
Unnamed Trib of Goose Creek	GC2	857	3.2	55.8	0.2	39.9	0.9	40.8
Goose Creek	GC3	1,527	4.6	55.2	0.0	35.2	4.9	40.1
Goose Creek	GC4	1,826	12.0	63.9	0.1	21.6	2.5	24.1
Goose Creek	GC5	1,750	4.6	72.4	0.4	21.7	0.9	22.6

Stream Name	SW ID	Total Area of SW (acres)	Developed	Disturbed/ Managed/ Successional	Open Water	Upland Natural Area	Wetland Natural Area	Total Natural Area
Goose Creek	GC6	1,810	13.3	42.9	0.1	41.5	2.2	43.8
Goose Creek	GC7	1,645	9.0	33.9	0.2	53.6	3.3	57.0
Goose Creek	GC8	1,502	24.4	18.9	0.0	54.7	2.1	56.7
Goose Creek	GC9	890	77.3	8.1	0.1	14.0	0.4	14.4
Crooked Creek	CC1	1,630	2.5	54.7	0.2	40.0	2.6	42.6
Crooked Creek	CC2	2,351	6.4	56.1	0.1	35.4	1.9	37.3
Grassy Branch	CC3	2,433	4.0	65.8	0.1	28.8	1.2	30.0
Crooked Creek	CC4	2,163	6.1	57.3	0.1	31.8	4.7	36.4
Crooked Creek	CC5	1,393	8.0	59.9	0.1	28.2	3.8	31.9
North Fork Crooked Creek	NF1	947	4.5	56.1	0.1	32.2	7.1	39.3
North Fork Crooked Creek	NF2	1,147	5.4	52.1	0.0	33.3	9.1	42.4
Unnamed Trib of North Fork Crooked Creek	NF3	1,626	29.3	40.0	0.0	27.8	2.9	30.7
North Fork Crooked Creek	NF4	1,968	37.6	25.6	0.1	30.8	5.9	36.7
North Fork Crooked Creek Headwaters	NF5	2,976	46.0	30.2	0.1	22.1	1.6	23.7

Stream Name	SW ID	Total Area of SW (acres)	Developed	Disturbed/ Managed/ Successional	Open Water	Upland Natural Area	Wetland Natural Area	Total Natural Area
Unnamed Trib of North Fork Crooked Creek	NF6	1,785	35.9	38.4	0.3	24.3	1.1	25.4
South Fork Crooked Creek	SF1	2,174	6.4	67.8	0.1	24.2	1.4	25.6
South Fork Crooked Creek	SF2	1,577	5.5	67.6	0.0	24.3	2.6	26.9
South Fork Crooked Creek	SF3	2,141	15.8	52.0	0.1	28.7	3.4	32.1
Unnamed Trib of South Fork Crooked Creek	SF4	1,472	30.3	43.1	0.7	23.5	2.3	25.9
South Fork Crooked Creek	SF5	2,059	50.4	28.8	0.0	18.1	2.6	20.8
South Fork Crooked Creek Headwaters	SF6	2,334	56.5	28.0	0.1	14.0	1.4	15.4

Tetra Tech, 2008a

*The subwatersheds with a minimum of the 40 percent in natural area average for Goose Ck and 31 percent in natural area average for Crooked Ck were considered for prioritization and further evaluation and are highlighted in yellow. Those also identified as priority problem areas in Section 4 there are highlighted in green.

The Goose and Crooked Creeks watersheds were further evaluated separately in order to identify a similar number of opportunities within each watershed and also to allow for the potentially different nature of preservation projects within these watersheds due to additional protections in place for the Goose Creek watershed (15A NCAC 2B .0600-.0609, February 2009).

Goose Creek

As previously mentioned, a set of management rules was adopted in February 2009 to protect water quality and habitat for the Carolina heelsplitter in the Goose Creek watershed. In addition to the benefits identified in Section 4, this rule has land protection measures that include riparian buffer management. The riparian buffer requirements for this watershed are as follows:

- Within the 100-year floodplain, undisturbed riparian buffers are required within 200 feet of water bodies, and
- Outside the 100-year floodplain, undisturbed riparian buffers are required within 100 feet of water bodies.

These requirements apply to perennial streams, intermittent streams, lakes, ponds, and modified natural streams that are depicted on the most recent printed version of the soil survey maps prepared by the Natural Resources Conservation Service or the 1:24,000 scale quadrangle topographic maps prepared by the U.S. Geological Survey (NCDWQ, 2012). The level of protection expected from this SSWQMP is such that it is unlikely that mitigation credit will be awarded for preservation projects within the Goose Creek watershed. However, the value of the natural resources within this watershed and the relatively good condition of the watershed supports preservation as an important component of the watershed assessment. Potential preservation projects may need to be implemented through other means such as through grant funding or using other interested local entities with available funding.

As noted in Table 14 the total natural area ranges from 14 to 57 percent in the Goose Creek watershed with an average of 40 percent. The subwatersheds with a minimum of the 40 percent average were considered for prioritization and further evaluation and are highlighted in yellow in Table 14. When these subwatersheds are compared to the subwatersheds identified as priority problem areas in Section 4 there are three that overlap (highlighted in green). According to the land use/land cover data presented in the Preliminary Findings, DC5 is located in the developing headwaters portion of the Goose Creek watershed with about 20 percent in residential use and another 16 percent in pasture/agricultural use and both GC1 and GC3 contain substantial amounts of pasture/agricultural land with 39 and 48 percent respectively (Tetra Tech, 2008a; Centralina, 2009). Watersheds where a combination of problems and assets exist such as these can benefit greatly from restoration efforts and also have the advantage of building off of the significant existing assets which can provide support to the restoration work through high quality habitat and good water quality. Since these watersheds consist of 40 percent or more of natural area they will remain under consideration for preservation as well as for restoration.

To confirm that these prioritized subwatersheds are appropriate for targeting preservation efforts several additional factors were considered and are presented below in Table 15. In addition to those

subwatersheds identified through existing natural area percentage, another subwatershed was included in the prioritization after evaluating the data included in Table 15. Subwatershed GC10 was added because of the large amount of natural area already under protection, including Mecklenburg County's Stevens Creek Nature Preserve which is 227 acre and is the largest natural area under conservation within the planning area. This additional subwatershed compares closely with the previously identified priorities and the benefit from building upon the existing conservation efforts here makes this a reasonable addition to the preservation priorities for this watershed.

Table 15. Additional Considerations for Preservation Priorities in Goose Creek

Stream Name	SW ID	Total Natural Area (%)	Protected Natural Area (acres)	Average Imperviou s (%)	Existing Riparian Buffer 100ft+ (%)	NHEO (species count)	SNHA (Intersecting)
Duck Creek	DC2	48.6	6	3.6	79.47	3	1
Duck Creek	DC3	43.6	1	2.5	74.43	3	1
Duck Creek Headwaters	DC4	47.2	9	4.7	83.13	3	1
Unnamed Trib of Duck Creek	DC5	47.8	14	4.9	80.3	3	1
Goose Creek	GC1	50.8	10	2.9	75.54	6	1
Unnamed Trib of Goose Creek	GC2	40.8	1	1.8	71.17	4	1
Goose Creek	GC3	40.1	27	2.1	68.33	4	1
Goose Creek	GC6	43.8	1	3.5	66.88	1	1
Goose Creek	GC7	57.0	0	3.8	77.21	6	2
Goose Creek	GC8	56.7	0	8.5	84.85	1	1
Stevens Creek	*GC10*	*39.3*	*243*	*7.8*	*77.95*	*1*	*1*
Paddle Branch	GC12	40.8	0	2.4	67.62	1	1

Tetra Tech, 2008a

Consideration should also be given to the feasibility of implementing effective preservation projects. Factors to consider at the subwatershed scale relating to feasibility include areas with large parcels to encourage implementing more beneficial preservation projects with fewer numbers of landowners and also areas with approved plans for large scale development such as incoming subdivisions which would indicate that protection measures may be needed sooner (before development occurs) or there could

be the possibility of protecting open space within a development. To this end additional data were considered including an assessment of parcels that are 50 acres or more and also where planned subdivisions are expected in the near term (this information was available for Union County only). Large parcels are located within each of the prioritized subwatersheds in Goose Creek and are identified in Figure 16. Figure 17 below from the Preliminary Findings report also identifies the planned subdivisions for Union County and there are several within subwatersheds proposed for prioritization (GC8, DC4, and DC2 with small patches in GC 7 and GC6). A more thorough look at the implications of the planned subdivisions should be included in Phase III where specific preservation projects are identified.

Crooked Creek

As noted in Table 14 the total natural area ranges from 15 to 43 percent in the Crooked Creek watershed with an average of 31 percent. Subwatersheds with a minimum of the 31 percent average were considered for prioritization and further evaluation and are highlighted in yellow in Table 14. When these subwatersheds are compared to the subwatersheds identified as priority problem areas in Section 4 there are two that overlap (highlighted in green). According to the land use/land cover data presented in the Preliminary Findings, CC4 and CC5 contain substantial amounts of pasture/agricultural land with 48 and 54 percent respectively (Tetra Tech, 2008a; Centralina, 2009). Watersheds where a combination of problems and assets exist such as these can benefit greatly from restoration efforts and also have the advantage of building off of the significant existing assets which can provide support to the restoration work through high quality habitat and good water quality. Since these watersheds consist of 31 percent or more of natural area they will remain under consideration for preservation as well as for restoration.

To confirm that these prioritized subwatersheds are appropriate for targeting preservation efforts several additional factors were considered and are presented below in Table 16.

Table 16. Additional Considerations for Preservation Priorities in Crooked Creek

Stream Name	SW ID	Total Natural Area (%)	Protected Natural Area (acres)	Average Impervious (%)	Existing Riparian Buffer (%)	NHEO (Species Count)	SNHA (Intersecting)
Crooked Creek	CC1	42.6	0	1.7	83.19	3	1
Crooked Creek	CC2	37.3	0	3.7	71.55	3	1
Crooked Creek	CC4	36.4	0	3.2	66.54	2	1
Crooked Creek	CC5	31.9	0	2.9	58.63	3	1
North Fork Crooked Creek	NF1	39.3	0	3	65.24	2	1
North Fork Crooked Creek	NF2	42.4	0	5.7	60.94	0	1

North Fork Crooked Creek	NF4	36.7	0	13.1	63.3	2	1
South Fork Crooked Creek	SF3	32.1	0	7.9	57.51	3	1

Tetra Tech, 2008a

Large parcels located within each of the Crooked Creek prioritized subwatersheds are identified in Figure 16. Figure 17 below from the Preliminary Findings report also identifies the planned subdivisions for Union County and there are several within subwatersheds proposed for prioritization (NF4, NF2 and a small patch in CC4). Again, a more thorough look at the implications of the planned subdivisions should be included in Phase III where specific preservation projects are identified.

5.3 Conclusion

The 12 subwatersheds identified as priorities for preservation in the Goose Creek watershed and the 8 subwatersheds identified as priorities for preservation in the Crooked Creek watershed should allow for the focused protection of quality habitat and water quality that supports the sensitive and unique species within them and also prevent further degradation from sources such as imperviousness, construction, stormwater, agriculture and other non-point sources. The subwatersheds identified are often contiguous which will encourage clustering preservation efforts and yet span much of these two watersheds to encompass the wide variety of protection needs within this planning area.

The Phase III Watershed Management Plan and Project Atlas will identify management strategies to address gaps in or improvements to protection measures as identified in the Preliminary Findings report and also identify specific locations within these prioritized subwatersheds to target for preservation projects.

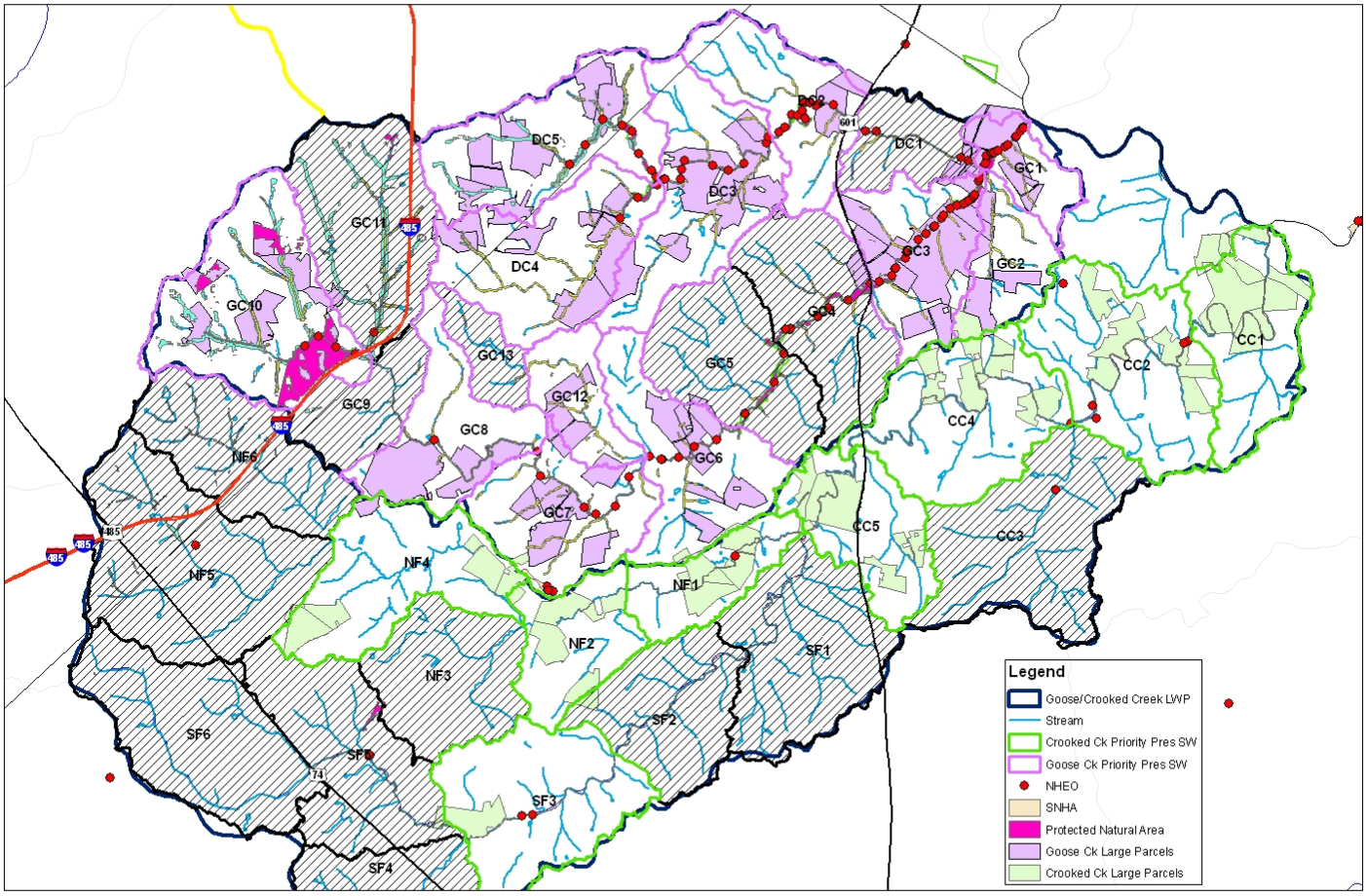


Figure 16. Goose and Crooked Creeks Priority Subwatersheds for Preservation

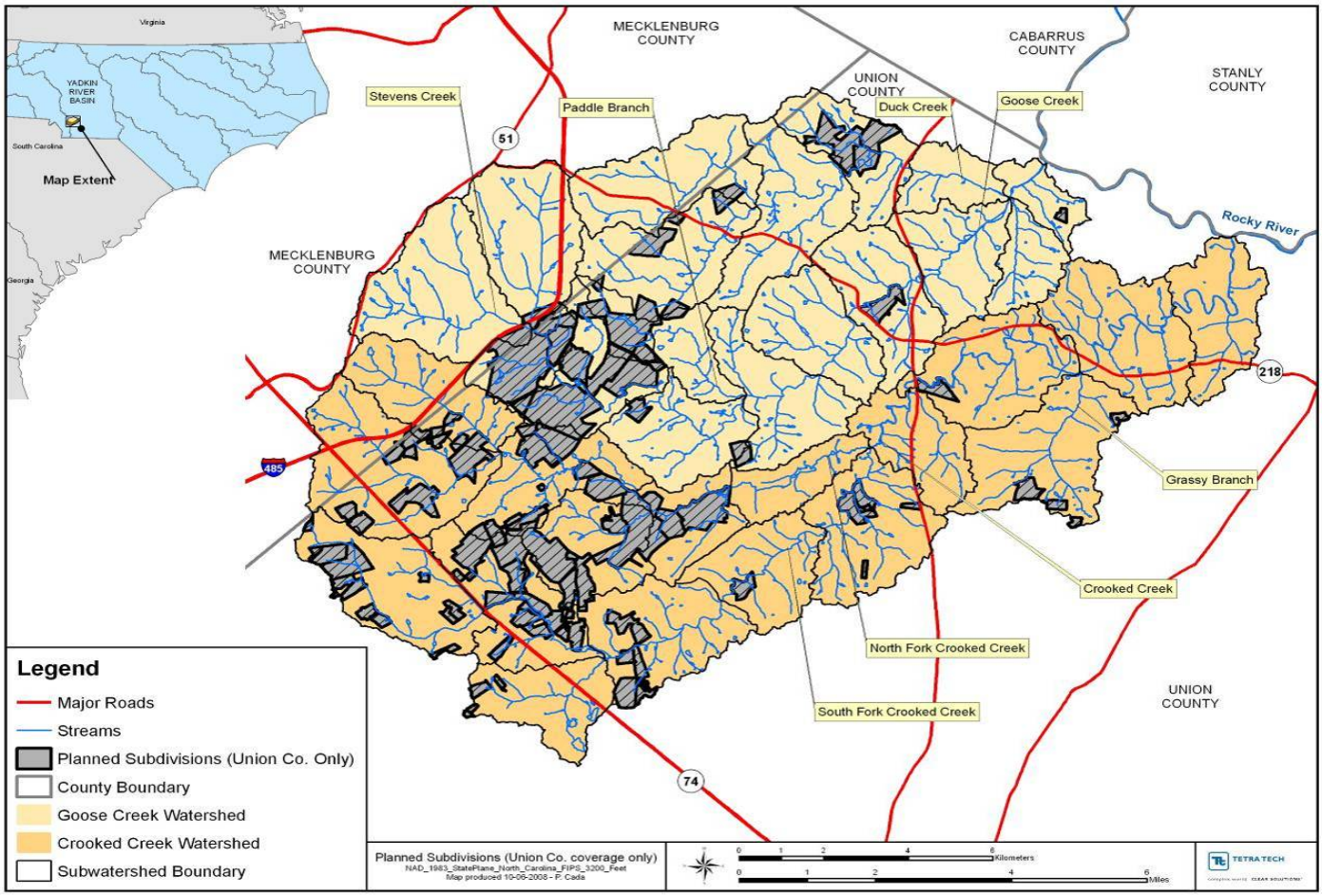


Figure 17. Union County Planned Subdivisions

Section 6 Conclusion/Next Steps

Key stressors identified through this Phase II work support the Phase I findings that peak flow/runoff and sediment are significant to these watersheds. Therefore management strategies presented in the Phase III Watershed Management Plan (WMP) will focus on control and reduction of these impacts. In addition, consideration will be given to additional stressors including oxygen demanding substances/nutrients, bacteria and copper. Management strategies will be presented and discussed in the WMP.

An assessment of the assets within these watersheds identified 12 subwatersheds as priorities for preservation in Goose Creek and 8 subwatersheds as priorities for preservation in Crooked Creek. Both Goose and Crooked Creek watersheds are home to sensitive biological resources however this assessment is particularly important for Goose Creek as this watershed contains a population of the federally endangered Carolina heelsplitter. Findings from this work will support efforts to protect and conserve valuable resources within these watersheds including the maintenance and the repopulation of the Carolina heelsplitter.

Thirty-eight stream restoration, enhancement and preservation sites are currently being proposed for consideration and will be further assessed and detailed in the Phase III Project Atlas. Thirty-two wetland restoration, enhancement and preservation sites are currently being proposed for consideration and will be further assessed and detailed in the Phase III Project Atlas. Fourteen BMPs for stormwater management and agricultural impacts will also be presented and discussed in the Phase III Project Atlas.

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Appendix A:

Development of Existing Land Use/Land Cover Dataset

Appendix A: Development of Existing Land Use and Land Cover Dataset

Methods

The base layer for the existing LULC analysis was a GIS grid coverage (30 m resolution) developed by the Multi-Resolution Land Characteristics Consortium (MLRC) known as the National Land Cover Dataset, or NLCD, for the year 2001, created from satellite imagery taken during years 1999 to 2001. This data source was chosen as the base layer for two primary reasons: there was not a current land use or land cover data set for Union County available at the time these analyses were performed and only land use was available for Mecklenburg County. Land use data often does not provide detailed resolution for undeveloped or vacant properties (e.g., large polygons of vacant land were present in the County's dataset whereas those areas had multiple NLCD LULC classes). Additional GIS coverages including parcels, roads, and waterbodies were used to update the NLCD grid coverage to more fully represent present day conditions and to provide more resolved developed land uses. In order to update the NLCD coverage with these additional data sets the NLCD grid was converted to polygons using the ESRI "raster to polygon" tool (without simplifying). From this point forward ESRI's "intersect" tool was used to update the NLCD polygon coverage.

The first data used to update the NLCD 2001 coverage were the parcel polygon coverages from both Mecklenburg and Union counties with records dating until the end of 2006. Both counties' parcel data sets have an attribute that lists the year that a structure was built on that particular parcel as well as a description of the use of that parcel (e.g., Single Family, Duplex, Mobile Home, Commercial, Warehouse, etc.). All parcels that were built upon (i.e., had a year built date) were classified according to development type, density (based on parcel size), and into broad categories of developed land (see Appendix B, Table B-1 of the Preliminary Findings memo for full classification scheme). The NLCD classes for agricultural and undeveloped land uses were retained. Similar LULC classes were aggregated for reporting purposes (Table 1).

To ensure accuracy of the parcel coverage's use description, a cursory review using 2007 aerial imagery was used to validate or edit the LULC descriptions given to the parcel coverage. For example, all areas were inspected for correct LULC category assignment to ensure that the NLCD LULC classification was appropriate for all "developed" parcels that were greater in size than 5 acres. In cases where a NLCD LULC classification was not appropriate for the entire parcel then that particular parcel was split into multiple polygons that were then re-classified appropriately using the classification scheme.

Table 1. LULC Aggregation Schema and Residential Class Attributes

LULC Description	Aggregated LULC Description
Barren Land/Developed, Open Space	Barren Land/Developed, Open Space
Commercial/Industrial/Transportation	Commercial/Industrial/Transportation
Multi-Family Residential – (Duplexes and Mobile Homes)	Multi-Family Residential
Residential, High Density – (Lots smaller than 0.25 acres)	Residential, High Density
Residential, Low Density – (Lots between 0.25 and 0.5 acres)	Residential, Medium Density
Residential, Medium Density – (Lots between 0.5 and 2 acres)	Residential, Low Density

Residential, Very Low Density – (Lots between 2 and 5 acres)	Residential, Very Low Density
Pasture/Hay	Pasture/Agricultural Lands
Cultivated Crops	
Grassland/Herbaceous	
Deciduous Forest	Forest/Shrub/Scrub
Evergreen Forest	
Mixed Forest	
Shrub/Scrub	
Emergent Herbaceous Wetland	Wetland
Woody Wetland	
Water	Water

Next, the NLCD 2001 coverage was updated with a GIS coverage representing land that has been converted to existing transportation uses (i.e., road surfaces). The polyline coverages that represent roads obtained by Tetra Tech—secondary roads downloaded from the NCDOT GIS data website, and highways from CCOG—were buffered by 5 meters to create polygons which most accurately represent the full widths of road surfaces. The appropriate width to buffer road polylines was determined using the 2007 aerial imagery. All NLCD 2001 areas that were within this new roads polygon coverage were classified as Commercial/Industrial/Transportation LULC.

Finally, a GIS coverage representing waterbodies within the watershed (obtained from DWQ) was used to reclassify any NLCD 2001 LULC classes into the Water LULC class. This was primarily done because the resolution (30-meter grid cells) of the NLCD 2001 did not always accurately capture the shape and size of waterbodies.

Results

The resultant GIS coverage represents the an improved and updated (2007) LULC coverage for the Goose Creek and Crooked Creek watersheds (Figure 5). Table 2 shows the percentages of existing land use within reporting categories for the Goose Creek and Crooked Creek watersheds. Percent existing LULC by reporting subwatershed is provided in Appendix B Table B-2 and Table B-3 of the Preliminary Findings Report.

When the two watersheds are compared, both have similar percentages of developed land, but the Crooked Creek watershed has a slightly higher percentage of high density development, particularly in commercial land uses. Crooked Creek also has a higher percentage of agricultural land while Goose Creek has a higher percentage of natural area (forest, wetland, etc.). Much of the development in both watersheds has occurred in the headwaters, and much of the agricultural and forested land exists in the lower reaches.

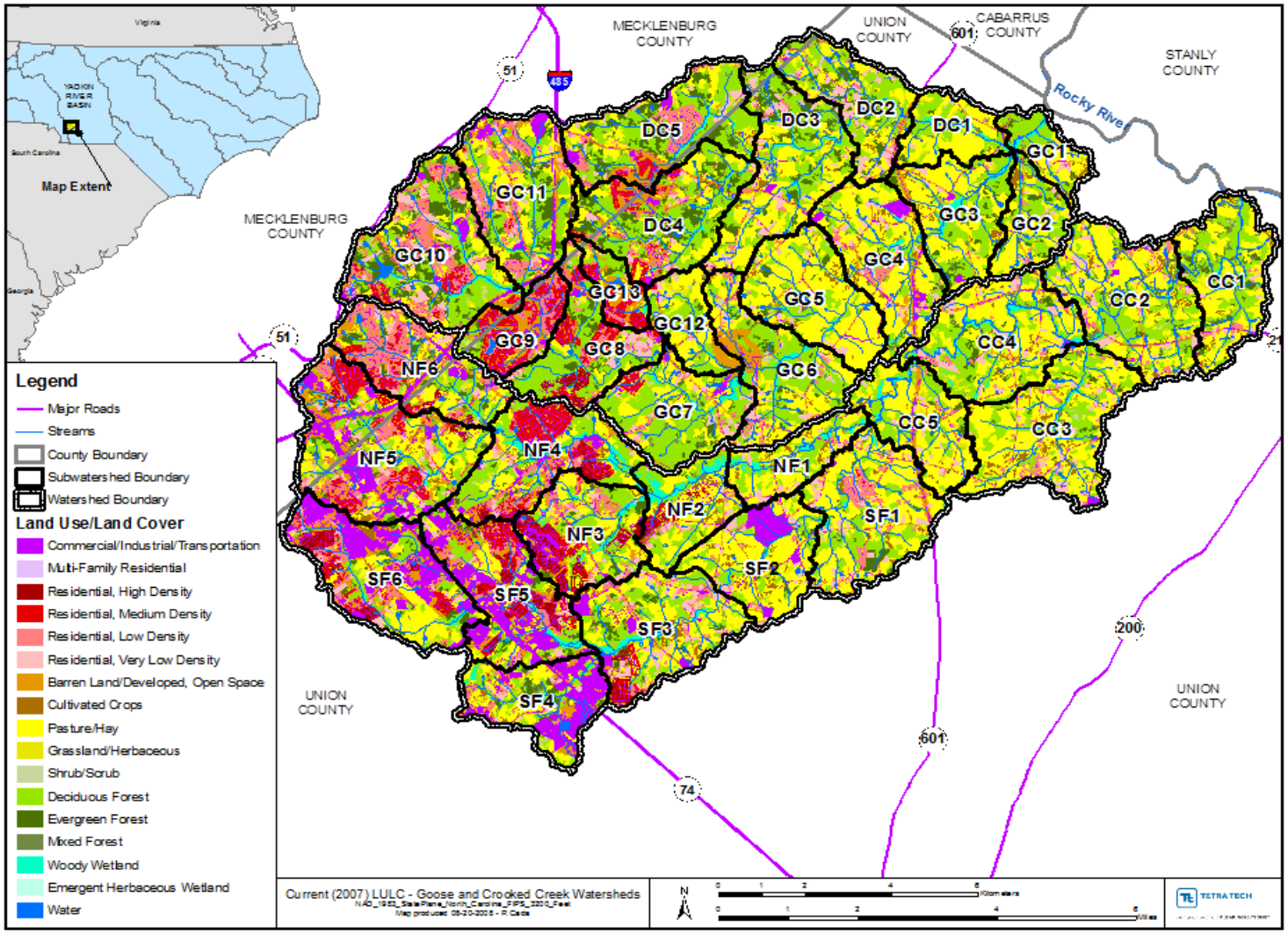


Figure 1. Existing (2007) Land Use/Land Cover for Goose Creek and Crooked Creek Watersheds

Table 2. Percent (%) Existing LULC

Watershed	Acres	Barren Land/Developed, Open Space	Commercial/Industrial/Transportation	Multi-Family Residential	Residential, High Density	Residential, Medium Density	Residential, Low Density	Residential, Very Low Density	Pasture/Agricultural Lands	Forest/Shrub/Scrub	Wetland	Water
		Percent (%)										
Goose Creek	27,040	0.5	4.1	0.0	0.0	0.9	4.0	4.4	36.8	47.0	1.8	0.4
Crooked Creek	32,173	0.5	7.4	0.0	0.0	1.8	4.6	4.2	46.1	32.4	2.5	0.4
Both Watersheds	59,213	0.5	5.9	0.0	0.0	1.4	4.4	4.3	41.9	39.0	2.2	0.4

Appendix B:

LWP Goals and Objectives Development Process

Appendix B: LWP Goals and Objectives Development Process

Developing Goose and Crooked Creek Local Watershed Plan Goals and Objectives was one of the main tasks during the Goal Setting Phase of Phase II. The Goals and Objectives were vetted during and between (via email) Watershed Technical Team (WTT) meetings 1-3:

I. July 20, 2010 – WTT Phase II Meeting #1
II. December 15, 2010 – WTT Phase II Meeting #2
III. March 29, 2011 – *Adopted.* WTT Phase II Meeting #3

The following outlines the WTT group process followed from July 2010 – March 2011 that resulted in the adoption of Local Watershed Plan Goals and Objectives (see below) on March 29, 2011.

Goals & Objectives Process – July 20, 2010, WTT meeting #1

The remainder the meeting was devoted to small group, focused conversation. Jason explained the process and the large group broke into small groups lead by Jana, Robin, Todd, and Jason.

See attached: Focused Conversation Process Handout

Group Process – Focused Conversation:

1) Focus Question: What steps might be taken by this WTT to create our own set of goals and objectives?
2) Time: 60 minutes
3) Purpose: to give the WTT an example framework to help establish goals and objectives. The potential outcome is the development of goals and objectives for our own LWP
4) Context/Consensus: Previously, during Phase I – it was established that:
a. goals and objectives were needed
b. goals and objectives needed to be measurable
c. *linkages were established between stressors-sources-impacts-functional deficits*

The following reflects what was reported out from each small group after the allotted time was up:

WTT Small Group Feedback

Small Group 1

- Table 14 is important – to set goals, must know what's wrong. However, are there larger or different concerns than those in Table 14?
- Major theme: the ability to get public buy-in in this LWP process. Public perception – the heelsplitter is *not* the most important thing. Need to figure out how to re-pitch the project to watershed residents that is *not* about heelsplitter.
- How can we sell the LWP differently to achieve a variety of outcomes beyond water quality? Recreation, fishing, and greenways – things that may be of more interest to the community/of benefit to the public.
- Need community outreach and education, focus groups, and surveys. We need to get out into the community and get on the agendas of other established groups in the watershed – HOAs, Farm Bureau, etc.
- Need the ability to rank projects and possibly prioritize LWP goals and objectives, as it is difficult to address all stressors with available resources
- What can stakeholders contribute?
- They can serve as a reviewing body for established goals and objectives
- They can educate elected officials and groups in the watershed communities
- Reach out to and invite elected officials to stakeholder groups

To do list – before the next WTT meeting:

- Work on getting public buy-in and input to assess community needs.

- Meet with community leaders, organizations, large land owners, etc. to find out what watershed residents think/want/need
- WTT should sell LWP in their own communities by distributing brief survey, etc.
- Staff needs to develop a brief survey (ex. Survey Monkey) for stakeholders/WTT to take to their communities and distribute

Small Group 2

- Restoring and protecting aquatic habitat and organisms – restoration may be easier to "sell"
- Education is a key component – with public and politicians
- Political education – with public bodies collaborating to achieve goals, politicians are more likely to adopt if request comes from public within watershed
- From looking at Morgan & Little example, all but eutrophication apply to Goose and
- Crooked Creek – all other objectives worth consideration
- Low flow hydrology as stressor because it's important to aquatic organisms
- It may be appropriate on broad issues – perhaps beyond the heelsplitter (has too high of a billing – refocus emphasis)

Small Group 3

- Overall, the Morgan & Little objectives seem reasonable
- Morgan & Little objectives seem to lack the socio-economic perspective (human element), also zoning/planning perspectives, and recreational opportunities.
- "Heelsplitter fatigue" may be occurring in the watershed. Recreational opportunities good thing to focus on, not the mussel

To do list – before the next WTT meeting:

- Pull together and distribute an Executive Summary of LWP Phase I
- Have an inquiry as to each individual WTT member's interest – to help hone in on goals and objectives

Small Group 4

- What is the WTT's message? Not mussels, but property protection
- Definitions are important. How does the LWP tie into the SSMP requirements? Other opportunities?
- What are reasonable expectations of the watershed and its inhabitants?
- What are watershed residents connected to?

Goals & Objectives Process – December 15, 2010, WTT meeting #2

Jason explains handouts and offers back ground information. PAT wanted to get WTT votes on the Goals and Objectives. He explains the voting – accept, reject, modify, and the group proceeded with the voting process.

See attached: Voting Results Power Point presentation

Goals and Objectives Process – March 29, 2011, WTT meeting #3

The majority of this meeting was spent was spent making site visits in the watershed. Upon return to the Indian Trail Civic Building, the Project Administration Team (PAT) sought the WTT's endorsement of the Goals and Objectives document, having been through rounds of revisions. At the end of the meeting, the group adopted the Goals and Objectives document (see below).

NC EEP Goose Creek and Crooked Creek Local Watershed Plan
Phases II & III
LWP Goals and Objectives
Adopted March 29, 2011

GOAL 1:

Restore, protect, and enhance watershed functions such as hydrology, water quality, and aquatic and terrestrial habitat

OBJECTIVES 1:

a) Restore, expand, support, and protect beneficial watershed functions and uses including:
    - Protect flood plain function
    - Terrestrial & aquatic habitat
        i. Environmentally sensitive and critical lands
            1. Undeveloped natural areas
            2. Natural area connectivity
        ii. Native vegetation
        iii. Native aquatic biology
        iv. In-stream habitat
    - Recreation
    - Wetland hydrology

b) Design and construct projects to restore, maintain, and enhance:
    - Stream banks
    - Riparian areas
    - Wildlife habitat areas
    - In-stream habitat
    - Riparian buffers
    - Wetlands

c) Minimize impacts of stormwater runoff and erosion on stream hydrology to promote stable stream morphology and protect aquatic habitat and native tree species

d) Minimize impacts on water quality by pathogens, nutrients, and other pollutants in stormwater runoff

e) Cooperate with property owners and permitting agencies to detect and eliminate illicit discharges, sanitary sewer overflows, and malfunctioning septic systems to protect human health, enhance water quality and aquatic habitat

f) Address impacts to stream water quality due to livestock access to streams

g) Address pollutant(s) of concern for state approved Total Maximum Daily Loads and water quality improvement plans

GOAL 2:

To minimize impacts on water quality, aquatic and terrestrial habitat, and hydrology in the watershed by supporting balanced, sustainable, and diverse land use and development, in accordance with existing and future policies

OBJECTIVES 2:

a) Promote site planning, design, construction and maintenance strategies to maintain or restore hydrology and water quality of the property
b) Identify strategies that strive to maximize effectiveness, minimize cost, and minimize impacts on businesses and residents where possible
c) Identify restoration and protection strategies that complement comprehensive plans and policies and provide multiple benefits such as recreation and protection of critical lands
d) Design and construct infrastructure projects (e.g., water/sewer lines, energy transmission lines, etc.) in manner that minimizes impacts on watershed functions (i.e., water quality, habitat, and hydrology)
e) Promote design and construct new developments, recreation areas, etc. in manner that minimizes impacts on watershed functions, including minimizing impervious areas

GOAL 3:

Build partnerships and involve stakeholders in the protection and restoration of the watersheds

OBJECTIVES 3:

a) Increase education, awareness, and stewardship within the watershed, including encouraging policy makers to develop policies that support a healthy watershed
b) Identify and recruit stakeholders and partners in protecting, maintaining, and restoring watersheds in Mecklenburg and Union counties
c) Report progress toward protection and restoration through monitoring and assessment
d) Identify funding for implementation
e) Seek adoption or endorsement of the local watershed plan by each local jurisdiction within the watersheds

Appendix C:

NCEEP Baseline Macroinvertebrate Monitoring in the Goose and Crooked Creek Drainages

Division of Water Quality
Biological Assessment Unit, December 1, 2009

MEMORANDUM

To: Anjie Ackerman (Environmental Planner, Ecosystem Enhancement Program)

Through: Eric Fleek (Acting Biological Assessment Unit Supervisor) EF
and Jay Sauber (Acting Environmental Sciences Section Chief)

From: Victor Holland (Environmental Specialist) VH

Subject: Ecosystem Enhancement Program (EEP) Baseline Macroinvertebrate Monitoring in the Goose and Crooked Creek Drainages (Yadkin Subbasin 12), Union County, July 2009.

EXECUTIVE SUMMARY

In July of 2009, Anjie Ackerman (EEP) requested that the BAU conduct benthic macroinvertebrate sampling at 10 sites within the Goose Creek and Crooked Creek catchments to support the development of a Local Watershed Plan (LWP) and for potential uses in both wetland and stream restoration projects (NCDWQ 2009). Barnes Creek, a tributary to the Uwharrie River in the Yadkin Basin was the Slate Belt Level IV Ecoregion reference stream selected for this study. Four of the 10 selected sampling locations in the Goose and Crooked Creek catchments were not sampled due to lack of sufficient stream flows. As requested, benthic macroinvertebrate sampling was conducted at seven locations during the summer of 2009.

All Crooked and Goose Creek macroinvertebrate monitoring stations within this study received Poor or Fair bioclassifications indicating continued impaired water quality in the catchment.
Many factors are potentially contributing to its degraded water quality including point and nonpoint sources. Increases in urban activities near headwater reaches may be leading to increased erosion, scour, sediment load, and periodic toxicity. Additionally, several permitted Wastewater Treatment Plants (WWTPs) are located upstream from benthic sampling locations likely contributing to more tolerant macroinvertebrate assemblages.

Studies suggest drought conditions in the Slate Belt Level IV Ecoregion continue to affect benthic communities up to one year following recovery (NCDWQ 2004). Severe drought conditions observed in 2007 and 2008 without persistent flows subsequent to the drought may contribute to lack of macroinvertebrate colonization. Fluctuating drought conditions could lead to escalated point and nonpoint source pollution via pollutants remaining in stagnant streams for longer periods and/or accumulated pollutant runoff during storm events. Either of these factors could contribute to inputs of higher pollutant concentrations and the streams ultimate degraded state, especially at headwater sampling locations in the Slate Belt Ecoregion. The attached report details the data collection, analysis, and conclusions.

Division of Water Quality
Biological Assessment Unit
December 1, 2009

Macroinvertebrate Monitoring in Goose and Crooked Creek (Yadkin HUC 03040105), July 2009

INTRODUCTION

Goose Creek and Crooked Creek flow northeasterly into Rocky River. North and South Fork Crooked Creek are tributaries to Crooked Creek and Duck Creek is a tributary to Goose Creek (Figure 1). The Goose Creek catchment has been more comprehensively studied than the Crooked Creek drainage in the last decade due to the presence of the Federally Endangered Carolina heelsplitter (*Lasmigona decorata*). Increased urbanization in the headwaters of Goose and Crooked Creeks is a continuing concern regarding this endangered mussel species and water quality in general. The goal of this study is to determine current water quality status of both the headwaters and downstream segments of Goose and Crooked Creeks. Water chemistry and fecal coliform counts will occur in conjunction with benthic samples (NCDWQ 2009). An additional goal is to identify segments of the streams with potential for further stormwater Best Management Practices (BMPs) and/or stream/wetland restoration efforts.

WATERSHED DESCRIPTION

The Goose and Crooked Creek drainages are located in rapidly developing areas within Mecklenburg and Union counties, NC in the Yadkin River Basin (HUC 03040105). Barnes Creek (HUC 03040103), a tributary to the Uwharrie River, is the reference site sampled in the Yadkin-Pee Dee River Basin. This reference site is located approximately 80 miles southeast of the Goose and Crooked Creek catchments. All macroinvertebrate monitoring stations (Table 3 and Figure 1) are located in the Carolina Slate Belt Level IV Ecoregion (Griffith et al. 2002). This ecoregion extends from southern Virginia to eastern Georgia. It is known to exhibit poorly sustained base flows due to thin soils with low water storage capacities during base-flow periods (Weaver et al. 1998).

Upstream reaches are experiencing rapid urbanization while downstream locations are dominated by rural areas with the presence of some active agriculture. Potential point source stressors include current active NPDES dischargers within these catchments. All active permitted NPDES dischargers upstream from proposed benthic sampling locations (Figure 1) are listed in Table 2. There is only one active major NPDES permitted discharger (discharge > 1 MGD) located within the sampling area. Two active Ambient Monitoring System (AMS) stations are located within the Goose Creek catchment (Table 1 and Figure 1). There are no AMS stations within the Crooked Creek drainage.

Duck Creek, North and South Fork Crooked Creek, Crooked Creek and Goose Creek are all Class C waters from their source to eventual confluence with Rocky River. Duck Creek, North and South Fork Crooked Creek, and Goose Creek are currently listed as impaired on the 303d list for fecal coliform bacteria and biological integrity (benthos). Main-stem Crooked Creek downstream from North and South Fork Crooked Creek is not currently listed as impaired. Causes of impairment are likely due to both nonpoint and point source stressors, including increased urban runoff leading to flow flashiness and scour impacts.

PREVIOUS MONITORING WITHIN THE STUDY AREA

Table 4 shows results of all historic macroinvertebrate sampling locations within the study area. North Fork Crooked Creek has rated Good-Fair or Fair since 1995. South Fork Crooked Creek was only sampled in 1995 when it rated Fair. In 2009 this location was not sampled due to low flow and water levels. Crooked Creek at SR 1547 increased from a Fair to Good-Fair rating

between 1996 and 2001. Duck Creek rated Fair in 1998 and could not be sampled in 2009 due to low flow conditions. Goose Creek at SR 1524 and SR 1525 received Good-Fair and Poor ratings respectively in 1998. From 1996 to 2001 Goose Creek at U.S. 601 was rated Poor based on benthic samples but in 2006 was rated Fair suggesting slightly better water quality. Goose Creek at SR 1547 was rated Fair in 1998 and was not sampled again until 2009. Barnes Creek at SR 1303 is the Slate Belt Ecoregion reference stream selected for this study and has rated either Good or Excellent since 1985.

In 2009, four out of the 10 macroinvertebrate monitoring locations in the Goose and Crooked Creek catchments were not sampled due to lack of sufficient flows including: Duck Creek at U.S. 601, South Fork Crooked Creek at SR 1515 and SR 1367, and North Fork Crooked Creek at SR 1520.

METHODS

Habitat Evaluation

Qualitative habitat and land use data collections were conducted at all sampling locations to assess the presence/absence of in-stream habitat and potential sources of stressors within the catchment. Habitat parameters assessed included: channel modification; relative abundance of in-stream structure; substrate type; presence of riffles/pools; riparian zone width and function, and stability as it relates to erosion and surrounding land use. This evaluation results in a score from 1 to 100. Higher numbers typically reflect increased habitat quality with reduced anthropogenic influence.

Physical-Chemical

Several physicochemical properties are collected at each sampling site. Field measurements include specific conductance, water temperature, pH, and dissolved oxygen using both YSI 85 and Accumet AP 61 meter. Pre and post-meter calibrations were completed daily.

Benthos

In July, 2009 macroinvertebrates were collected from Goose, Crooked, and Barnes Creek (reference) sampling locations (Table 3). The Division of Water Quality's Standard Qualitative (Full Scale) sampling methods were used. Full scale samples are conducted in wadeable streams with drainage areas > 3 mi^2 (NCDWQ 2005). This sampling method consists of 10 separate samples including three sweep-net samples; two kick net samples, one leaf pack, two fine-mesh log and/or rock wash, one sand sample, and visuals of substrates not otherwise easily sampled by previous techniques. Habitats such as riffles, macrophytes, root mats/undercut banks, and detritus deposits are sampled using these techniques. Samples are picked at the site and preserved in ethanol for laboratory analysis. Benthic sampling is performed to obtain an inventory of aquatic fauna at the specific sampling location. Each taxon is classified as Rare (1-2 specimens, denoted by "R" on taxa tables), Common (3-9 specimens, "C"), Abundant (≥ 10 specimens, "A"). Data from each site is entered into a database.

Data Analyses

Several data-analysis summaries (metrics) are used to detect water quality issues. These metrics are based on long-term intensive studies showing that unstressed stream/river systems generally exhibit higher macroinvertebrate diversity and higher proportions of pollution intolerant taxa. On the contrary, relatively higher proportions of pollution tolerant taxa are found in polluted streams and rivers. Diversity of benthic fauna is evaluated using taxa richness defined as the total number of different taxa present (S). Stream communities are evaluated using a biotic index that is generated from the reaction of various taxa to different stressors. This is known as the North Carolina Biotic Index (NCBI or BI) (NCDWQ 2005). These values allow comparisons among sample sites and reference sites. Individual species and associated community biotic

index values are rated on a 0-10 scale. Higher values represent more tolerant taxa and potential stream pollution. Indicator taxa, EPT abundance (EPT N), EPTBI, and S are used to further elucidate between-site differences. All stream stations received bioclassifications based on biocriteria for wadeable streams with drainage areas > 3 mi^2 (Full Scale). There are five possible classifications including: Excellent, Good, Good-Fair, Fair, and Poor. Bioclassifications were generated based on the NCBI, EPTBI, and EPTS thresholds for the Piedmont Ecoregion and Full-Scale macroinvertebrate collection method.

Land Use Analysis

A land use analysis was conducted using Geographic Information Systems (GIS) for the Goose Creek and Crooked Creek catchments. Percentages were calculated from both 2001 and 2007 GIS rasters for Union County, NC to observe spatial and temporal trends among sample sites. The proportions represent land use parameters upstream from each sample site. Land use parameters include: agricultural, barren land, developed (urban), forest, grass, and water bodies. Data from 2007 was obtained from Tetra Tech, Inc.

MONITORING SITES

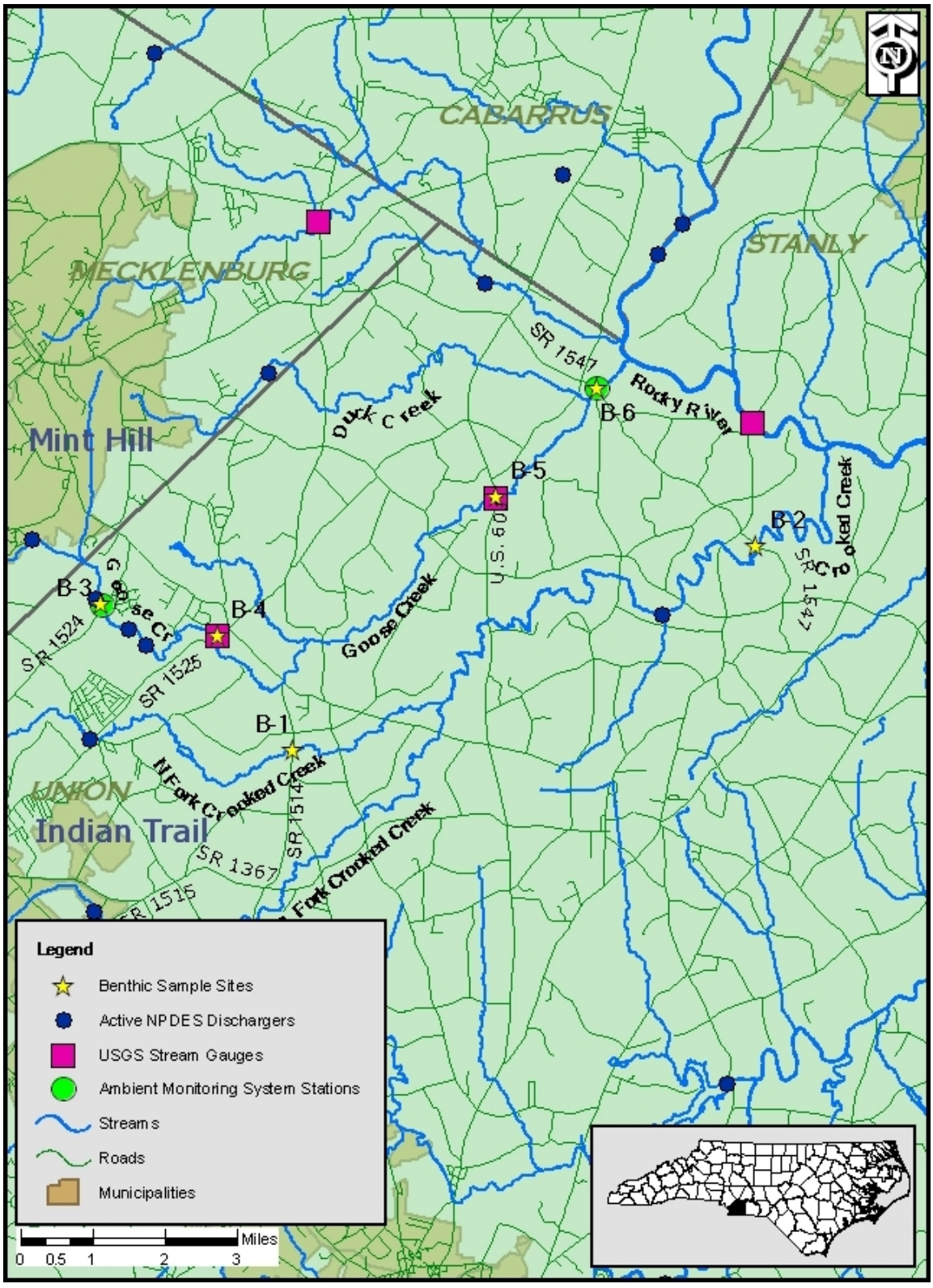


Figure 1. Location of macroinvertebrate monitoring stations (yellow stars) sampled in July, 2009.

Table 1. Active Ambient Monitoring System Stations within the Goose Creek catchment.

Station	Location	Class
Q8360000	Goose Creek at SR 1524	C
Q8374000	Goose Creek at SR 1547	C

Table 2. Permitted active NPDES dischargers located upstream from proposed sampling locations.

Permit	Facility	County	Receiving Water Body	Permitted Flow (MGD)
NC0069841	Crooked Creek WWTP #2	Union	S. Fork Crooked Creek	1.9
NC0035041	Hemby Acres WWTP	Union	N. Fork Crooked Creek	0.3
NC0063584	Oxford Glen WWTP	Mecklenburg	Stevens Creek	0.075
NC0072508	Hunly Creek WWTP	Union	Goose Creek	0.02
NC0034762	Fairfield Plantation WWTP	Union	Goose Creek	0.07
NC0065684	Country Wood WWTP	Union	Goose Creek	0.67
NC0065749	Ashe Plantation WWTP	Mecklenburg	Duck Creek	0.1
NC00685812	Grassy Branch WWTP	Union	Grassy Branch	0.05

Table 3. Macroinvertebrate monitoring stations in the Goose Creek, Crooked Creek, and Barnes Creek catchments, July, 2009.

Stream	N FK CROOKED CR	CROOKED CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	BARNES CR
Site Location	SR 1514	SR 1547	SR 1524	SR 1525	US 601	SR 1547	SR 1303
County	Union	Union	Union	Union	Union	Union	Montgomery
Site ID	QB358	QB344	QB351	QB352	QB355	QB354	QB276
Basin	Yadkin	Yadkin	Yadkin	Yadkin	Yadkin	Yadkin	Yadkin
Subbasin	12	12	12	12	12	12	9
Latitude (º)	35.1024	35.1450	35.1301	35.1250	35.1539	35.1759	35.4396
Longitude (º)	-80.5854	-80.4717	-80.6310	-80.6028	-80.5350	-80.5116	-79.9979
Drainage area (mi²)	15.1	47.3	8.4	11.0	24.1	44.0	23.1
Stream Segment AU	13-17-20-1	13-17-20	13-17-18b	13-17-18b	13-17-18b	13-17-18b	13-2-18-(2.5)
Stream Classification	C	C	C	C	C	C	C
Level 4 Ecoregion	45c	45c	45c	45c	45c	45c	45c
Type of Sample	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale
Map #	B-1	B-2	B-3	B-4	B-5	B-6	

Table 4. Sites previously sampled in the Goose Creek, Crooked Creek, and Barnes Creek catchments.

Waterbody	Location	County	Date	Sample Type	Total EPT Taxa	EPT BI	Total Taxa	BI	Bioclass
N FK CROOKED CR	SR 1514	UNION	9/12/1995	Full Scale	12	5.79	59	6.46	Good-Fair
	SR 1514	UNION	6/27/2000	Full Scale	7	6.79	53	6.98	Fair
N FK CROOKED CR	SR 1520	UNION	6/27/2000	Full Scale	6	6.50	57	7.23	Fair
S FK CROOKED CR	SR 1367	UNION	9/12/1995	Full Scale	8	6.22	42	6.71	Fair
S FK CROOKED CR	SR 1515	UNION	9/13/1995	Full Scale	5	6.83	54	6.89	Fair
CROOKED CR	SR 1547	UNION	8/20/1996	EPT	12	4.93			Fair
	SR 1547	UNION	8/22/2001	Full Scale	18	5.16	68	5.93	Good-Fair
	SR 1547	UNION	8/23/2006	Full Scale	11	5.79	63	6.27	Good-Fair
DUCK CR	US 601	UNION	4/21/1998	Full Scale	14	5.52	64	6.42	Fair
GOOSE CR	SR 1524	UNION	4/22/1998	EPT	16	4.66			Good-Fair
GOOSE CR	SR 1525	UNION	4/21/1998	Full Scale	4	6.95	35	6.95	Poor
GOOSE CR	US 601	UNION	8/20/1996	EPT	2	6.07			Poor
	US 601	UNION	4/21/1998	Full Scale	10	5.88	47	7.37	Poor
	US 601	UNION	8/22/2001	Full Scale	5	5.98	48	7.16	Poor
	US 601	UNION	8/22/2006	Full Scale	11	6.65	67	6.87	Fair
GOOSE CR	SR 1547	UNION	5/1/1998	EPT	11	6.00			Fair
BARNES CR	SR 1303	MONTGOMERY	5/20/1985	Full Scale	36	3.88	100	4.83	Excellent
	SR 1303	MONTGOMERY	8/1/1985	Full Scale	29	3.89	87	4.81	Excellent
	SR 1303	MONTGOMERY	7/8/1987	Full Scale	27	3.79	90	4.93	Good
	SR 1303	MONTGOMERY	7/20/1987	EPT	28	4.05			Excellent
	SR 1303	MONTGOMERY	7/11/1989	Full Scale	24	3.80	83	4.89	Good
	SR 1303	MONTGOMERY	8/7/1996	Full Scale	36	3.41	99	4.46	Excellent
	SR 1303	MONTGOMERY	8/9/2001	Full Scale	40	3.55	108	4.22	Excellent
	SR 1303	MONTGOMERY	9/28/2001	Full Scale	38	3.03	79	4.16	Excellent

RESULTS AND DISCUSSION

North Fork Crooked Creek, SR 1514, Union County



Figure 2. Upstream view of North Fork Crooked Creek at SR 1514, Union County, NC, sampled on July 14, 2009.

Date: July 14, 2009
Drainage area: 15.1 square miles
Qualitative Visible land use (%): 30 forest, 30 residential, 40 fallow fields
Width (m): 5
Depth (m): Avg: 0.2 Max: 0.5
Canopy (% cover): 90, mixed hardwood
Substrate (%): boulder (0), cobble (0), gravel (50), sand (25), silt/fine particulate (25)
Riparian quality: riparian zone intact (>18m)
Instream habitat: Rocks and macrophytes absent. Sticks/leafpacks and snags/logs are common. Undercut banks abundant.
Dissolved Oxygen (mg/L): 5.2
Specific conductance (µmhos/cm): 425
Temperature (°C): 22.5
pH: 7
Habitat Score: 61

North Fork Crooked Creek at SR 1514 had the lowest EPT taxa richness (4) and abundance (EPTN = 31) and highest NCBI (7.09) (Table 5, Appendix 1) compared to all other sampling locations. Tolerant taxa were dominant at this site including: *Hydropsyche betteni* (abundant) and *Cheumatopsyche spp.* (abundant). *Maccaffertium modestum* was absent from this site and abundant at all other sampling sites within this study suggesting a lack of riffle habitat. Low flows were noted at the site in addition to lack of habitat favorable for macroinvertebrate colonization including the absence of cobble riffle substrates and submerged root mats. Additionally, this stream segment is suffering from severe bank erosion leading to increased scouring and sediment input. The severe erosion and scouring suggest this site receives periodic drastic increases in flow followed by quick lower water levels which can lead to rapid inputs of accumulated nonpoint pollutants from upstream. A sewage smell was noted and conductivity was high at 425 µmhos/cm (Table 6). High amounts of upstream urban land use activities in addition to point source dischargers are likely contributing to the degraded macroinvertebrate community here. This site could be good candidate for implementation of future upstream stormwater BMPs and/or stream restoration activities. However, any issues with upstream dischargers such as Hemby Acres WWTP would need to be resolved.

Crooked Creek at SR 1547, Union County



Figure 3. Downstream view of Crooked Creek at SR 1547, Union County, NC, sampled on July 14, 2009.

Date: July 14, 2009
Drainage area: 47.3 square miles
Qualitative Visible land use (%): 80 forest, 10 residential, 10 fallow fields
Width (m): 10
Depth (m): Avg: 0.1 Max: 0.25
Canopy (% cover): 60, hardwood
Substrate (%): boulder (10), cobble (40), gravel (30), sand (10), silt/fine particulate (10)
Riparian quality: Intact wide riparian zone (>18m). Erosion moderate.
Instream habitat: Rocks abundant. Macrophytes common, sticks/leafpacks common, snags/logs rare, and undercut banks and root mats rare.
Dissolved Oxygen (mg/L): 6.5
Specific conductance (µmhos/cm): 471,**Temperature (°C):** 26.1, **pH:** 7.8, **Habitat Score:** 88

Results and Discussion

Ten EPT taxa were present at the downstream Crooked Creek site. This site received a Fair (NCBI = 6.65, EPTBI = 5.67) rating suggesting slight decline in water quality compared to the 2006 sample. EPT taxa richness and EPTBI remained similar from 2006 to 2009 (Table 5) however the NCBI value was elevated from 6.27 to 6.65. This is potentially due to the higher abundance of tolerant taxa in 2009 such as the chironomids *Cricotopus bicinctus* and *Dicrotendipes neomodestus* (Appendix 1). Both taxa are tolerant of high nutrients/organic wastes. The presence of so many low dissolved oxygen tolerant taxa such as the midges *Polypedilum illinoense*, *Phaenopsectra obediens*, and *Dicrotendipes neomodestus*; the odonates *Argia spp.* and *Ischnura spp*.; the flatworm *Dugesia tigrina*; and the slow water limpet *Laevapex fuscus* suggests the site suffers from periodic low oxygen levels compounded by the low flows common in slate belt streams. Observations at the site imply that macroinvertebrates are not limited by habitat but more likely general water quality. Conductivity was high at 471 µmhos/cm (Table 6). There are two minor dischargers and one major discharger (>1 MGD) located upstream from this sample site (Table 2) likely contributing to degraded water quality. Any upstream WWTP discharge issues would need to be resolved before additions of stormwater BMPs in order to detect positive effects on stream water quality.

Goose Creek at SR 1524, Union County



Figure 4. Upstream view of Goose Creek at SR 1524, Union County, NC, sampled on July 13, 2009.

Date: July 13, 2009
Drainage area: 8.4 square miles
Qualitative Visible land use (%): 50 forest, 30 residential, 20 golf course
Width (m): 8
Depth (m): Avg: 0.2 Max: 0.5
Canopy (% cover): 85, mixed hardwood
Substrate (%): boulder (20), cobble (20), gravel (20), sand (20), silt/fine particulate (20)
Riparian quality: Intact riparian zone. Narrow on the right bank (< 6m). Erosion severe.
Instream habitat: Rocks common. Macrophytes rare, sticks/leafpacks common, snags/logs and undercut banks/root mats common.
Dissolved Oxygen (mg/L): 6.7
Specific conductance (µmhos/cm): 121
Temperature (°C): 23.7
pH: 7.0
Habitat Score: 77

Goose Creek at SR 1524 also received a Fair bioclassification in 2009 compared to Good-Fair in 1998. Despite this rating, water quality in this reach seems the best compared to all other sample sites within the Goose Creek catchment (EPTBI = 6.11, NCBI = 6.40) (Table 5). Thirteen EPT taxa were collected at the site. Most are fairly tolerant taxa with the exception of *Chimarra spp.* and *Mystacides sepulchralus* (both rare at the site). Intolerant taxa abundant in 1998, such as *Serratella deficiens*, were absent in 2009. The intolerant beetle *Psephenus herricki* was common at the site (Appendix 1). This site is located ~100 meters downstream from the Hunley Creek WWTP (Table 2), which is a minor discharger that has had occasional violations of ammonia and chlorine. The absence of long-lived stoneflies and other common intolerant taxa could be due to multiple variables. These could include drought, periodic toxicity, lack of upstream riparian buffers, and/or runoff from the upstream golf course and residential areas leading to the increased erosion and sediment accumulation observed. This site may be a good candidate for future stormwater BMP implementation, stream bank stability, riparian buffer enhancements, and/or other restoration activities.

Goose Creek at SR 1525, Union County



Figure 5. Downstream view of Goose Creek at SR 1525, Union County, NC, sampled on July 14, 2009.

Date: July 14, 2009
Drainage area: 11.0 square miles
Qualitative Visible land use (%): 50 forest, 20 residential, 20 goat pasture, 10 fallow fields
Width (m): 10
Depth (m): Avg: 0.1 Max: 0.5
Canopy (% cover): 80, mixed hardwood
Substrate (%): bedrock (10), boulder (30), cobble (20), gravel (20), sand (10), silt/fine particulate (10)
Riparian quality: Intact riparian zone. Width 12-18m on left bank. Moderate Erosion.
Instream habitat: Rocks abundant. Macrophytes absent, sticks/leafpacks common, snags/logs and undercut banks/root mats common.
Dissolved Oxygen (mg/L): 7.1
Specific conductance (µmhos/cm): 193
Temperature (°C): 23.1
pH: 7.2
Habitat Score: 90

This Goose Creek site has improved slightly from Poor in 1998 to Fair in 2009. EPT taxa richness increased from 4 in 1998 to 6 in 2009. However, this is a 2-fold decrease in EPT taxa richness when compared to the SR 1524 site just upstream (Table 5, Figure 1). The SR 1525 site has the lowest EPTN (35) and highest NCBI (7.01) suggesting the worst water quality among all Goose Creek sites in 2009. Chironomid taxa richness doubled from 13 just upstream at the SR 1524 site to 25 at this site potentially signifying some nutrient enrichment from upstream sources. The Country Woods WWTP is the nearest of three WWTPs located within 1 mile upstream of the site (Figure 1, Table 2). A sewage smell was observed. Macroinvertebrate assemblages suggest impaired water quality despite high quality habitat suggesting either point source or nonpoint source pollution inputs at this site.

Goose Creek at U.S. 601, Union County



Figure 6. Upstream view of Goose Creek at U.S. 601, Union County, NC, sampled on July 14, 2009.

Date: July 14, 2009
Drainage area: 24.1 square miles
Qualitative Visible land use (%): 40 forest, 35 active crops, 25 fallow fields
Width (m): 10
Depth (m): Avg: 0.1 Max: 0.5
Canopy (% cover): 90, mixed hardwood
Substrate (%): boulder (25), cobble (25), gravel (10), sand (20), silt/fine particulate (20)
Riparian quality: Intact riparian zone. Width 6-12m on right bank. Moderate Erosion.
Instream habitat: Rocks abundant. Macrophytes common, sticks/leafpacks common, snags/logs and undercut banks/root mats common.
Dissolved Oxygen (mg/L): 5.8
Specific conductance (µmhos/cm): 232
Temperature (°C): 24.2
pH: 7.1
Habitat Score: 88

Goose Creek at U.S. 601 rated Fair based on benthic macroinvertebrates in 2009 for the second consecutive time since 2006 (Table 5). This site had a Poor bioclassification from 1996-2001. The Fair rating suggests a water quality improvement following the removal of discharge from the

Fairview Elementary WWTP just upstream in 2005. Despite observations of high quality habitat, a pollution tolerant benthic community assemblage continues to reside here suggesting point source dischargers and/or nonpoint source runoff limiting water quality. Four total point source dischargers are located upstream from this site (Figure 1). Conductivity was elevated (232 µmhos/cm), however, water quality improved slightly from the SR 1525 site when comparing benthic metrics (Table 5).

Goose Creek at SR 1547, Union County



Figure 7. Upstream view of Goose Creek at SR 1547, Union County, NC, sampled on July 15, 2009.

Date: July 15, 2009
Drainage area: 77.0 square miles
Qualitative Visible land use (%): 100 forests
Width (m): 11
Depth (m): Avg: 0.1 Max: 0.25
Canopy (% cover): 90, mixed hardwood
Substrate (%): boulder (20), cobble (20), gravel (20), sand (20), silt/fine particulate (20), trace of bedrock
Riparian quality: Intact wide (>18m) riparian zone. Moderate to severe erosion.
Instream habitat: Rocks abundant. Macrophytes absent, sticks/leafpacks common, snags/logs common and undercut banks/root mats rare.
Dissolved Oxygen (mg/L): 6.8
Specific conductance (µmhos/cm): 229
Temperature (°C): 21.2
pH: 7.3
Habitat Score: 86

This Goose Creek site is just upstream from its confluence with Rocky River. The benthic community assemblage at this site remained similar to that found during sampling in 1998 (Table 5). EPT abundance (69) in 2009 was much higher than in 1998 (35), however, slightly more pollution tolerant EPT taxa were present in 2009 (EPTBI = 6.47) compared to 1998 (EPTBI = 6.0). Conductivity was elevated (229 µmhos/cm). This site is downstream from Ashe Plantation WWTP, a minor permitted discharger to Duck Creek, a tributary of Goose Creek (Figure 1). Five total permitted dischargers are located upstream from this sampling station. Most of these downstream Goose Creek sites have exceptional habitat available for macroinvertrate colonization suggesting impaired water quality from upstream point source or nonpoint source pollution inputs.

Barnes Creek at SR 1303, Montgomery County



Date: July 15, 2009
Drainage area: 23.1 square miles
Qualitative Visible land use (%): 100 forest
Width (m): 11
Depth (m): Avg: 0.2 Max: 1.0
Canopy (% cover): 75, hardwood
Substrate (%): bedrock (10), boulder (30), cobble (30), gravel (15), sand (10), silt/fine particulate (5)
Riparian quality: Breaks rare. Wide (>18m) riparian zone. Minimal erosion.
Instream habitat: Rocks abundant. Macrophytes absent, sticks/leafpacks common, snags/logs rare and undercut banks/root mats common.
Dissolved Oxygen (mg/L): 7.7, **Specific conductance (µmhos/cm):** 51, **Temperature (°C):** 23.8, **pH:** 7.1, **Habitat Score:** 92

Figure 8. Downstream view of Barnes Creek at SR 1303, Union County, NC, sampled on July 15, 2009.

Barnes Creek at SR 1303 was selected for benthic sampling as a Slate Belt reference site for comparison to that of the Goose and Crooked Creek catchments. This stream is a tributary to the Uwharrie River in rural Montgomery County. The reach of stream sampled is almost completely surrounded by forest with little to no anthropogenic activity upstream. The site obtained a benthic bioclassification of either Good or Excellent every time it has been sampled since 1985. It has been rated Good on three occasions out of nine including this year. Intolerant taxa were common at this site including several fairly rare taxa for the Piedmont such as *Maccaffertium vicarium* (abundant), *Epeorus vitreus* (common), *Acroneuria abnormis* (abundant) and *Neoperla spp.* (common). Stoneflies such as *Acroneuria abnormis* are commonly found in fairly clean North Carolina Piedmont streams. No stoneflies were collected in Goose or Crooked Creeks further suggesting impaired water quality at those sites. Based on DWQ habitat forms Barnes Creek received a high habitat score (92), somewhat comparable to that of downstream reaches of Goose and Crooked Creeks (Table 6). Total EPT taxa (27) and EPT abundance (125) was at least double that of all Goose and Crooked Creek samples (Table 5). The EPTBI (4.17) and NCBI (4.97) are low suggesting good water quality within the reach. Specific conductance (51 µmhos/cm) was less than half that of any sites sampled in Goose or Crooked Creeks. Chironomid richness was moderate (18) but biomass was low (Appendix 1). Only one chironomid taxa *Cladotanytarsus sp. E* was abundant at the site and the majority of other chironomid taxa were rare. The intolerant beetles *Psephenus herricki* and *Optioservus ovalis* were also abundant in Barnes Creek.

CONCLUSIONS

Of the six Goose and Crooked Creek samples collected in July, 2009, none of them obtained a bioclassification above Fair based on macroinvertebrate assemblages. Trends suggest further impaired water quality in Goose and Crooked Creek headwaters. This is likely due to a combination of point and/or nonpoint sources in addition to low base flows notorious in the Slate Belt Ecoregion. Potentially the most important factor continuing to affect these streams is rapid expansive urbanization of the Goose and Crooked Creek headwaters. Goose Creek at SR 1524 went from a bioclassification of Good-Fair in 1998 to Fair in 2009. The mid-stream site Goose Creek at SR 1524 and U.S. 601 showed slight improvements in water quality since 1998 and 2001. The downstream Goose Creek site at SR 1547 remained at Fair consistent with historic samples. North Fork Crooked Creek at SR 1514 was rated Good-Fair in 1995. Since 1995, water quality in this reach has been on the decline to Fair in 2000 and Poor in 2009 based on benthic macroinvertebrates (Tables 4 and 5). Water quality in downstream Crooked Creek declined to Fair since 2001 when it was rated Good-Fair. A high abundance of chironomid taxa such as

Cricotopus bicinctus and *Dicrotendipes neomodestus* also suggest some nutrient/organic wastes enrichment at the SR 1547 site. Elevated conductivity, especially in the Crooked Creek catchment suggests point source discharge problems. Implementation of stormwater BMPs and stream restoration activities could benefit the Goose and Crooked Creek catchment. However, any point source discharge issues would need to be resolved before stream restoration activities are implemented.

Land Use

Agricultural and urban land use activities and associated increased impervious surface in smaller headwater streams is known to negatively affect water quality downstream (Alexander et al. 2007, Meyer et al. 2007). Commercial/Industrial and residential land use has significantly increased in the Goose and Crooked Creek watersheds since 1992 (Tetra Tech 2008). Both catchments have similar percentages of developed land. The Crooked Creek catchment has a slightly higher percentage of high density impervious surfaces; particularly commercial land use (7.4%) compared to that of the Goose Creek drainage at 4.1%.

Rapid continued urbanization in the headwaters of Goose and Crooked Creek could lead to the impaired water quality found in both upstream and downstream sample locations. Urban land use percentages are highest in the headwaters of both the Crooked and Goose Creek catchments (Figure 9). Percentage of forests continues to decrease from 2001 to 2007 throughout both catchments. Trends suggest urban areas decrease spatially as you move downstream in both drainages. These observations imply stream and/or wetland restoration efforts focused in the headwaters may benefit downstream water quality. Commercial/Industrial and residential land use in headwaters leads to more impervious surface and ultimately, to a modified hydrologic regime. Stormwater runoff over impervious surfaces with reduced riparian buffers may lead to the rapid movement of water downstream increasing scour, erosion, and sediment input. North Fork Crooked Creek at SR 1514 may be an example of this altered hydrologic flow. Virtually no course substrate was observed at this site potentially due to high flows through the channel during stormwater events. Altered hydrology in addition to fluctuated drought conditions known to occur in the Slate Belt can escalate the effects of nonpoint sources via buildup of pollutants and quick runoff of these sources into the catchment.

Future Activities

Multiple sources could be contributing to degraded water quality in Goose and Crooked Creek. Habitat quality increases and impervious surfaces decrease as you move downstream. Enhancing buffers/stormwater BMPs in the headwaters may help to filter excess stormwater pollutants before entering Goose and Crooked Creek. North Fork Crooked Creek at SR 1514 is a recommended candidate for future stormwater BMP implementation and/or stream restoration activities. This stream reach suffers from severe erosion, lack of course substrate, and narrow/patchy riparian zones. Restoration activities such as riparian buffer enhancement, stream bank stabilization, and additions of course substrate for water velocity control during storm events may benefit downstream water quality. Additions of course substrate and riparian buffer enhancements may also provide enhanced habitat favorable for macroinvertebrate colonization. Any upstream noncompliance issues with point source dischargers would need to be resolved prior to these enhancement activities.

Goose Creek at SR 1524 may also be a good candidate for future stormwater BMP implementation and/or riparian buffer widening/stream bank stabilization. Despite the Fair bioclassification, benthic metrics suggests this site has the best water quality compared to all sites in the catchment. This may be due a combination of better habitat and only one nearby upstream discharger.

Multiple point source dischargers are located upstream from Goose Creek sample sites (Figure 1, Table 2). Limiting concentrations of point source discharge downstream may also benefit aquatic life and water quality.

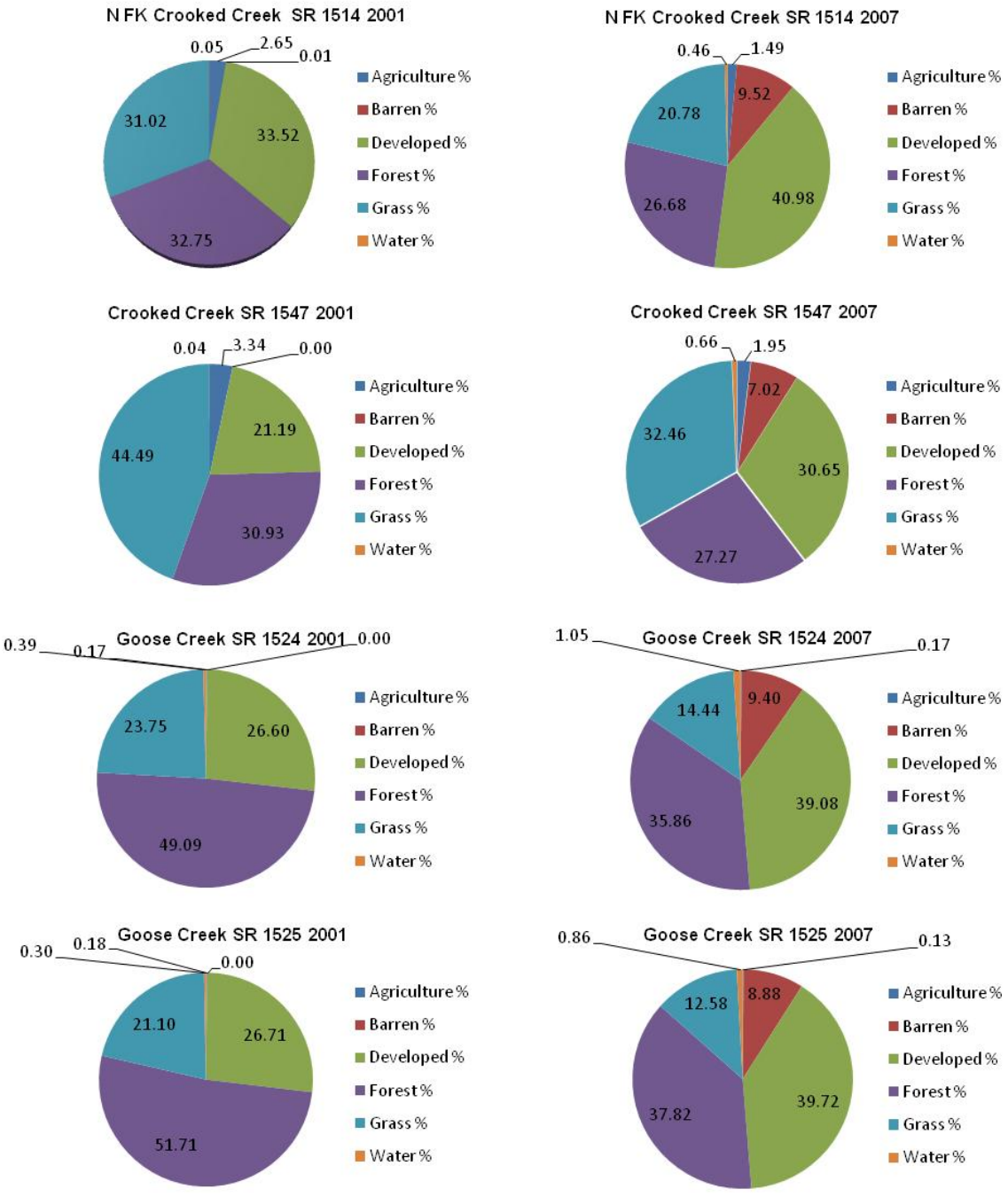
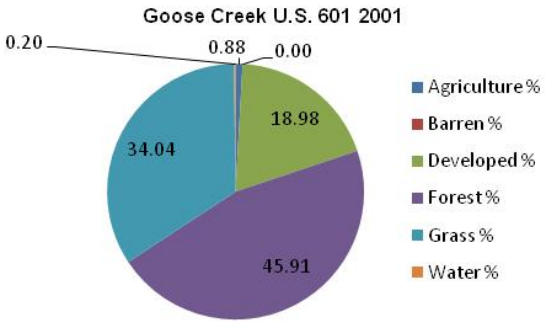
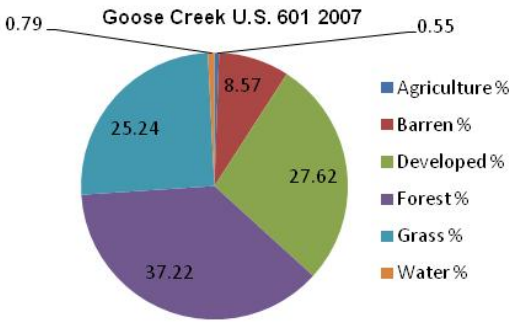
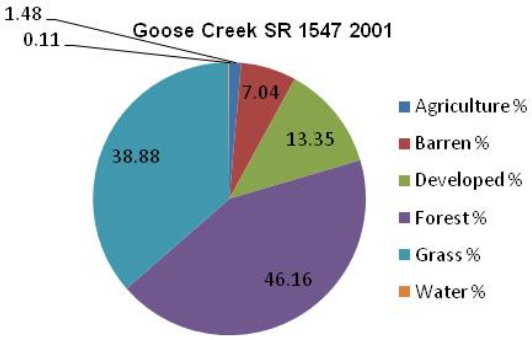


Figure 9. Land use comparisons among Goose Creek and Crooked Creek benthic sites in 2001 and 2007.







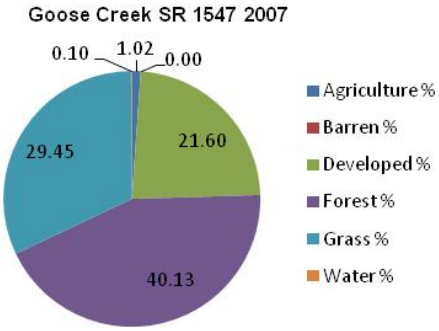


Figure 9 cont.

CC via email: Nancy Daly, Steve Kroeger, Larry Eaton, Dianne Reid, Dave Wanucha, and Tom Yokum

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Table 5. Summary benthic data for Goose Creek, Crooked Creek, and Barnes Creek study sites sampled from 1998 to 2009, Yadkin River Basin, Union and Montgomery Counties.

Stream	N FK CROOKED CR	N FK CROOKED CR	CROOKED CR	CROOKED CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	BARNES CR	BARNES CR
Site Location	SR 1514	SR 1514	SR 1547	SR 1547	SR 1524	SR 1524	SR 1525	SR 1525	US 601	US 601	SR 1547	SR 1547	SR 1303	SR 1303
County	Union	Union	Union	Union	Union	Union	Union	Union	Union	Union	Union	Union	Montgomery	Montgomery
Collection date	27-Jun-00	14-Jul-09	23-Aug-06	14-Jul-09	22-Apr-98	13-Jul-09	21-Apr-98	14-Jul-09	22-Aug-06	14-Jul-09	1-May-98	15-Jul-09	15-May-06	15-Jul-09
BAU sample number	8133	10670	10061	10743	7554	10669	7553	10671	10060	10672	7558	10744	9908	10745
Sample method	Full Scale	Full Scale	Full Scale	Full Scale	EPT	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	EPT	Full Scale	Full Scale	Full Scale
Criteria	Summer/ Piedmont	Summer/ Piedmont	Summer/ Piedmont	Summer/ Piedmont	Spring/ Piedmont	Summer/ Piedmont	Spring/ Piedmont	Summer/ Piedmont	Summer/ Piedmont	Summer/ Piedmont	Spring/ Piedmont	Summer/ Piedmont	Spring/ Piedmont	Summer/ Piedmont
Richness														
Ephemeroptera	5	2	6	5	9	6	2	3	6	5	7	7	21	19
Plecoptera	0	0	0	0	1	0	0	0	0	0	2	0	6	2
Trichoptera	2	2	5	5	6	7	2	3	5	7	2	6	10	6
Total EPT	7	4	11	10	16	13	4	6	11	12	11	13	37	27
Odonata	9	2	5	7		7	3	4	9	6		6	5	9
Megaloptera	0	0	0	0		0	0	0	0	0		0	2	3
Coleoptera	6	4	9	5		7	2	6	7	6		9	7	11
Chironomidae	16	12	24	18		13	16	25	24	24		24	31	18
non-Chironomidae Diptera	3	2	1	5		4	3	5	3	4		4	4	2
Oligochaeta	2	2	3	2		2	4	5	3	1		2	2	3
Mollusca	4	3	6	7		5	2	6	4	6		7	4	6
Other taxa	6	4	4	4		2	1	2	6	2		6	2	4
Total taxa richness	53	33	63	58		53	35	59	67	61		71	94	83
Other biological metrics														
EPT abundance	54	31	85	77	51	55	8	35	58	54	35	69	149	125
EPT Biotic Index	6.79	7.00	5.79	5.67	4.66	6.11	6.95	6.58	6.65	6.38	6.00	6.47	4.24	4.17
NCBI	6.98	7.09	6.27	6.65		6.40	6.95	7.01	6.87	6.80		6.82	5.01	4.97
Seasonal Correction							*0.20*						*0.20*	
Corrected NCBI							*7.15*						*5.21*	
Bioclassification	Fair	Poor	Good-Fair	Fair	Good-Fair	Fair	Poor	Fair	Fair	Fair	Fair	Fair	Excellent	Good

Table 6. Summary of habitat and physicochemical data for benthic sample sites within the Goose Creek, Crooked Creek, and Barnes Creek catchments, Union and Montgomery Counties, July 2009

Stream	N FK CROOKED CR	CROOKED CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	BARNES CR
Site Location	SR 1514	SR 1547	SR 1524	SR 1525	US 601	SR 1547	SR 1303
County	UNION	Union	Union	UNION	Union	UNION	UNION
Collection date	14-Jul-09	14-Jul-09	13-Jul-09	14-Jul-09	14-Jul-09	15-Jul-09	15-Jul-09
BAU sample number	10670	10743	10669	10671	10672	10744	10745
Habitat Scores							
Channel modification (5)	5	5	5	5	5	5	5
In-stream habitat (20)	11	18	18	19	19	16	20
Bottom substrate (15)	6	11	12	12	13	12	15
Pool variety (10)	8	10	8	10	8	10	10
Riffle habitats (16)	5	15	12	15	15	14	15
Bank stability/vegetation (14)	6	12	5	10	10	9	12
Light penetration (10)	10	7	10	10	10	10	7
Riparian zone width (10)	10	10	7	9	8	10	8
Total Habitat (100)	61	88	77	90	88	86	92
Other Habitat							
Average stream width (m)	5	10	8	10	10	11	11
Average stream depth (m)	0.25	0.1	0.2	0.1	0.1	0.1	0.2
Canopy (%)	90	60	85	80	90	90	75
Substrate (%)							
Bedrock	0	0	0	10	0	0	10
Boulder	0	10	20	30	25	20	30
Cobble	0	40	20	20	25	20	30
Gravel	50	30	20	20	10	20	15
Sand	25	10	20	10	20	20	10
Silt	25	10	20	10	20	20	5
Physicochemical							
Temperature (ºC)	22.5	26.1	23.7	23.1	24.2	21.0	23.8
Dissolved oxygen (mg/L)	5.2	6.5	6.7	7.1	5.8	6.8	7.7
Specific conductance (µmhos/cm)	425	471	121	193	232	229	51
pH	7.0	7.8	7.0	7.2	7.1	7.3	7.1

Appendix 1.

			CROOKED CR SR 1514 Union County	CROOKED CR SR 1547 Union County 14 Jul 2009	GOOSE CR SR 1524 Union County 13 Jul 2009	GOOSE CR SR 1525 Union County 14 Jul 2009	GOOSE CR US 601 Union County 14 Jul 2009	GOOSE CR SR 1547 Union County 15 Jul 2009	BARNES CR SR 1303 Montgomery County 15 Jul 2009
Ephemeroptera	Baetidae	ACENTRELLA FEMORELLA (WALTZ)							C
		ACENTRELLA TURBIDA							C
		BAETIS FLAVISTRIGA	R	C	A		C	A	C
		BAETIS INTERCALARIS	A	A	C	R		A	C
		BAETIS PLUTO			R				C
		CENTROPTILUM SPP							R
		HETEROCLOEON CURIOSUM							R
		PROCLOEON SPP					R	R	R
		PSEUDOCLOEON PROPINQUUM						R	
	Caenidae	CAENIS SPP		A	R	C	A	A	A
	Ephemeridae	EPHEMERA SPP							R
	Heptageniidae	EPEORUS VITREUS							C
		HEPTAGENIA MARGINALIS							C
		LEUCROCUTA SPP							A
		MACCAFFERTIUM MODESTUM		A	A	A	A	A	A
		MACCAFFERTIUM VICARIUM							A
		STENACRON INTERPUNCTATUM							C
		STENACRON PALLIDUM							C
		STENONEMA FEMORATUM							C
	Isonychiidae	ISONYCHIA SPP		C	C		C	R	A
Plecoptera	Perlidae	ACRONEURIA ABNORMIS							A
		NEOPERLA SPP							C
Trichoptera	Dipseudopsidae	PHYLOCENTROPUS SPP					R		
	Helicopsychidae	HELICOPSYCHE BOREALIS		A				R	
	Hydropsychidae	CERATOPSYCHE SPARNA							R
		CHEUMATOPSYCHE SPP	A	A	A	A	A	A	A
		HYDROPSYCHE BETTENI	A	A	A	A	A	A	C
		HYDROPSYCHE ROSSI					R		
		HYDROPSYCHE VENULARIS							R
	Hydroptilidae	HYDROPTILA SPP		A		R	C	R	
	Leptoceridae	MYSTACIDES SEPULCHRALIS			R				
		NECTOPSYCHE EXQUISITA		R	R				
		OECETIS PERSIMILIS			R		R	C	
		TRIAENODES IGNITUS			C		R		
		TRIAENODES PERNA/HELO							C
	Philopotamidae	CHIMARRA SPP			R			R	A
Odonata	Aeshnidae	BASIAESCHNA JANATA		C			C	C	C
		BOYERIA VINOSA		R	R			R	A
	Calopterygidae	CALOPTERYX SPP	C		C	A	C	R	
	Coenagrionidae	ARGIA SPP		R	C	C			R
		ENALLAGMA SPP	R		R				
		ISCHNURA SPP		R					
		NEHALENNIA SPP			R				
	Corduliidae	CORDULIIDAE						R	
		EPITHECA CYNOSURA							R
		HELOCORDULIA SPP							C
		NEUROCORDULIA SPP		R					
		SOMATOCHLORA SPP		A		R	C	R	R
	Gomphidae	GOMPHUS SPP					R		R
		HAGENIUS BREVISTYLUS				R			
		OPHIOGOMPHUS SPP					R		
		PROGOMPHUS OBSCURUS			R		R		
		STYLOGOMPHUS ALBISTYLUS			R				R
	Macromiidae	MACROMIA SPP		R				R	C
Hemiptera	Gerridae	GERRIDAE						R	
	Nepidae	RANATRA SPP							R

Appendix 1 cont.

			N FK CROOKED CR SR 1514 Union County 14 Jul 2009	CROOKED CR SR 1547 Union County 14 Jul 2009	GOOSE CR SR 1524 Union County 13 Jul 2009	GOOSE CR SR 1525 Union County 14 Jul 2009	GOOSE CR US 601 Union County 14 Jul 2009	GOOSE CR SR 1547 Union County 15 Jul 2009	BARNES CR SR 1303 Montgomery County 15 Jul 2009
Megaloptera	Corydalidae	CORYDALUS CORNUTUS							A
		NIGRONIA SERRICORNIS							A
	Sialidae	SIALIS SPP							C
Coleoptera	Dryopidae	HELICHUS SPP			R	R		R	C
	Dytiscidae	COPELATUS SPP		R					
		NEOPORUS SPP				R			C
	Elmidae	ANCYRONYX VARIEGATUS	A	A	C	C	C	C	R
		DUBIRAPHIA SPP		C	C	C		C	A
		MACRONYCHUS GLABRATUS	R	C	C	C	A	C	
		MICROCYLLOEPUS PUSILLUS			R		R	R	R
		OPTIOSERVUS OVALIS							A
		STENELMIS SPP	R	A	A	C	A	A	A
	Haliplidae	HALIPLUS SPP	R						
		PELTODYTES SPP						R	
	Hydrophilidae	BEROSUS SPP					C	C	R
		CYMBIODYTA SPP							R
		DERALLUS ALTUS							R
		ENOCHRUS SPP					R		
	Psephenidae	PSEPHENUS HERRICKI			C			R	A
Chironomidae	Chironomidae	ABLABESMYIA MALLOCHI	R	C		C	C	C	C
		ABLABESMYIA RHAMPHE GR			R	R	R		R
		CHIRONOMUS SPP			R			C	
		CLADOTANYTARSUS SP B				R	R		
		CLADOTANYTARSUS SP E				R			A
		CLADOTANYTARSUS SP F					C	R	
		CORYNONEURA SPP	R			R			
		CRICOTOPUS BICINCTUS	R	A		R		C	
		CRICOTOPUS INFUSCATUS GR						R	
		CRYPTOCHIRONOMUS SPP		A	R	R		C	
		CRYPTOTENDIPES SPP					R		
		DICROTENDIPES NEOMODESTUS		A		R		C	
		DICROTENDIPES SIMPSONI					R		
		LABRUNDINIA PILOSELLA				R			
		MICROTENDIPES PEDELLUS GR			C	A	C	R	R
		NANOCLADIUS ALTERNANTHERAE					R		
		NANOCLADIUS BRANCHICOLUS							R
		NANOCLADIUS DOWNESI							R
		NATARSIA SP A			R	R	R	C	
		ORTHOCLADIINAE		R					
		ORTHOCLADIUS CARLATUS							R
		ORTHOCLADIUS RUBICUNDUS				R			
		PARATANYTARSUS DISSIMILIS				C			
		PARATANYTARSUS QUADRATUS GR			R			R	
		PARATENDIPES SPP		R				C	R
		PHAENOPSECTRA OBEDIENS GR		C			C		
		PHAENOPSECTRA PUNCTIPES GR						R	R
		POLYPEDILUM AVICEPS							R
		POLYPEDILUM FLAVUM	C	A	R	R	R	C	R
		POLYPEDILUM ILLINOENSE GR	C	C	C	A	A	R	
		POLYPEDILUM SCALAENUM GR	R	A		R	A	C	
		PROCLADIUS SPP		C		R	R	A	
		PSEUDOCHIRONOMUS SPP					R		R
		RHEOTANYTARSUS SPP	C	C		R	R	R	R
		STENOCHIRONOMUS SPP	C		R	R	C	R	R
		STICTOCHIRONOMUS SPP					R		

Appendix 1 cont.

			N FK CROOKED CR SR 1514 Union County 14 Jul 2009	CROOKED CR SR 1547 Union County 14 Jul 2009	GOOSE CR SR 1524 Union County 13 Jul 2009	GOOSE CR SR 1525 Union County 14 Jul 2009	GOOSE CR US 601 Union County 14 Jul 2009	GOOSE CR SR 1547 Union County 15 Jul 2009	BARNES CR SR 1303 Montgomery County 15 Jul 2009
		TANYTARSUS SP A	C	A	R	R	C	C	
		TANYTARSUS SP C						C	
		TANYTARSUS SP G		A					
		TANYTARSUS SP L				C	R	R	
		TANYTARSUS SP P		C					
		TANYTARSUS SP S				R			
		TANYTARSUS SP U			R				
		TANYTARSUS SPP		R				R	
		THIENEMANIELLA SPP	A	C	C	C	R		R
		THIENEMANNIMYIA GR	A			C	C	A	R
		TRIBELOS FUSCICORNE					R		
		TRIBELOS JUCUNDUM	C	R	C	C		A	C
		XYLOTOPUS PAR					R		R
non-Chironomidae Diptera	Ceratopogonidae	CULICOIDES SPP					R		
		PALPOMYIA COMPLEX			R	R			
	Culicidae	ANOPHELES SPP		R		R		R	
	Empididae	EMPIDIDAE		C		R			
	Rhagionidae	ATHERIX SPP							R
	Simuliidae	SIMULIUM SPP	C	A	A	C	C	R	A
	Tipulidae	ANTOCHA SPP						C	
		MOLOPHILUS SPP			R				
		TIPULA SPP	R	A	C	C	A	C	
		TIPULIDAE		C			R		
Oligochaeta	Lumbriculidae	LUMBRICULIDAE	R	C	A	C		C	R
	Megadrile	MEGADRILE OLIGOCHAETE	C		R			R	C
	Tubificidae	AULODRILUS PLURISETA				R			
		BRANCHIURA SOWERBYI		R					
		LIMNODRILUS HOFFMEISTERI				R			
		SPIROSPERMA NIKOLSKYI				R			
		TUBIFICIDAE				R	R		R
Crustacea	Cambaridae	CAMBARIDAE		R	C	R	R	R	R
	Palaemonidae	PALAEMONETES SPP	R						
	Talitridae	HYALELLA SPP	C						A
Gastropoda	Ancylidae	LAEVAPEX FUSCUS		C	R		R		R
	Hydrobiidae	HYDROBIIDAE							R
	Lymnaeidae	PSEUDOSUCCINEA COLUMELLA			R	C	R		
	Physidae	PHYSA SPP	A	A	A	A	A	A	R
	Planorbidae	HELISOMA ANCEPS			R	C	C	C	
		HELISOMA TRIVOLVIS		A					
		MICROMENETUS DILATATUS		C		R		R	
	Pleuroceridae	ELIMIA SPP							C
	Viviparidae	CAMPELOMA DECISUM		A					
Bivalvia	Corbiculidae	CORBICULA FLUMINEA	A	C		R	R	R	R
	Sphaeriidae	MUSCULIUM SPP						R	
		PISIDIUM SPP			C	R		A	C
		SPHAERIUM SPP	C	A			R	R	
Other	Erpobdellidae	ERPOBDELLA/MOOREOBDELLA	R						
	Hydracarina	HYDRACARINA	R	C	R		R	R	C
	Planariidae	CURA FOREMANII		R				C	
		DUGESIA TIGRINA		C		R		C	
	Sisyridae	SISYRA SPP						R	

Appendix D:

Summary of May 2010 Fish Collections in the Goose and Crooked Creek Watersheds

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

BEVERLY EAVES PERDUE
GOVERNOR

EUGENE A. CONTI, JR.
SECRETARY

September 23, 2011

Memorandum to: Anjie Ackerman, Ecosystem Enhancement Program

From: Neil Medlin, Biological Surveys Group
Natural Environment Unit/PDEA

Subject: Summary of May 2010 Fish Collections in the Goose and Crooked Creek Watersheds, Union County

As part of the watershed assessment for the Goose and Crooked Creek watersheds, the NC Ecosystem Enhancement Program (EEP) requested the assistance of Biological Surveys Group (BSG) of North Carolina Department of Transportation (NCDOT) in the collection of fish community data within these two watersheds. The collaboration resulted in fish populations being sampled at eight (8) locations throughout the two watersheds. The description of these locations along with the EEP site numbers are outlined in Table 1 below and shown on Figure 1. All site numbers referenced throughout this report are those utilized by EEP for their assessment of the Goose and Crooked Creek watersheds.

Table 1. Fish Community Sampling Locations in the Goose and Crooked Creek Watersheds, Union County, May 2010.

EEP Site #	Stream	Location	Drainage Area (mi^2)
33	Goose Creek	SR 1524	8.4
28	Goose Creek	SR 1525	11.0
23	Goose Creek	US 601	24.1
21	Duck Creek	US 601	11.9
4	South Fork Crooked Creek	SR 1515	6.1
8	North Fork Crooked Creek	SR 1520	10.0
9	North Fork Crooked Creek	SR 1514	14.8
13	Crooked Creek	SR 1547	47.3

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1000 BIRCH RIDGE DRIVE
RALEIGH NC 27610

Methods

The fish communities were surveyed using BSG's typical fish collection protocols as described below. The primary deviation from the protocols was the lack of active and passive seining due to the shallow water and low flow conditions found throughout both watersheds during the survey month.

Typical fish surveys employ a variety of collection techniques.

Seining: This is generally defined as actively pulling a seine through the water. The technique is most often used in pool or deeper run areas.

Passive Seining: The seine is stationary, held in place by two (2) biologists. Fish can be driven into the seine by kicking/disturbing the substrate and water column from upstream to downstream to the seine, or using the backpack electrofishing unit(s) to shock from upstream to downstream to the seine. When the electrofishing unit(s) is (are) used, at least one biologist with a dip net should accompany the biologist(s) with the electrofishing unit(s) to collect any fish that do not drift into the seine. Passive seining is typically used in areas of high water velocity such as riffles or fast runs.

Backpack Electrofishing: Traditional backpack electrofishing consists of a biologist operating the electrofishing unit to stun the fish accompanied by another biologist using a dip net to collect the stunned fish. Multiple electrofisher/dip net teams may be used on larger streams to maximize sampling efficiency. This collection technique is employed in areas of slow to moderate stream flow. Habitat such as woody debris (snags and logs), rocks, and root mats and undercut banks along stream edges are generally sampled using backpack electrofishing units.

Fish collected from all techniques are temporarily held in five (5) gallon buckets until they can be identified and recorded. Voucher specimens for any questionable identifications should be preserved in 10 % formalin solution and returned to the lab for positive identification. All field data and species present are recorded on data sheets developed by the North Carolina Wildlife Resources Commission (NCWRC). The final product of the survey is a list of fish species collected at a site and the total number of individuals of each species.

The area covered during surveys may vary depending upon the purpose of the survey and the size of the stream. All habitat types (root mats and undercut banks, woody debris, and rocks) and flow regimes (fast-riffles, moderate-runs, and slow-pools) found in a stream are sampled. A minimum of five (5) sampling passes are made for each of the habitat types and flow regimes. If any new fish species are collected during the last pass, two (2) additional passes are made for that habitat type or flow regime.

In addition to the fish community data, habitat evaluations were conducted at each of the eight (8) collection sites using the NC Division of Water Quality (NCDWQ) habitat evaluation forms. Physical water quality measurements were also taken in the field using YSI hand held meters. Habitat evaluation forms and physical water quality measurements were both completed by EEP/NCDWQ personnel and are presented in Table 3.

The fish data collected during this study was generally evaluated using the criteria outlined in the NCDWQ Standard Operating Procedures Manual for their fish community data (http://portal.ncdenr.org/web/wq/ess/bau). While all 12 of the NCDWQ metrics were considered during the evaluation of the data, only those metrics that appeared to have a discernable correlation to habitat or water quality parameters are discussed.

Results

A total of 31 species of fish (Table 2) were collected from the eight (8) locations sampled in the Goose and Crooked Creek watersheds. The number of individual fish collected at the various sites ranged from a low of 186 at South Fork Crooked Creek (Site 4) to 762 at the most downstream site on Crooked Creek (Site 13). This location on Crooked Creek also had the largest watershed of the study at 47.3 mi^2. Site 13 also had the lowest percentage (17%) of tolerant individual fish, with the highest percentage of tolerant individuals (62%) being documented at Site 9 on North Fork Crooked Creek. For the eight (8) sites sampled, only one (1) of the species (highback chub, *Hybopsis hysinotus*) collected is considered to be intolerant while eight (8) species are regarded as tolerant. Tolerance values were assigned according NCDWQ criteria.

Both watersheds have dischargers and nonpoint source runoff as potential stressors. Site 8 on North Fork Crooked Creek was above a wastewater treatment plant (WWTP) effluent discharge and Site 9 was located below the discharge. The effects of the discharge were clearly evident by the increase in specific conductance from 220 µS/cm at Site 8 above the discharge to 508 µS/cm at Site 9 below the discharge. The differences in the fish community were less dramatic with the number of species decreasing from 18 at Site 8 above the discharge to 16 species at Site 9 below the discharge. The number of individuals collected decreased from 309 above the discharge to 265 below it. The largest difference in the fish community at the two sites was observed in the change in percentage of tolerant fish individuals at the two sites. The percent of tolerant individuals collected at Site 8 was 39% and increased to 62% below the discharge at Site 9. Habitat scores (Table 3) at Sites 8 and 9 were similar, suggesting that the differences in the fish community were due to water quality differences.

Two of the trophic metrics used by NCDWQ to rate fish community sites are the percentage of omnivorous + herbivorous individuals and the percentage of insectivorous individuals. These two metrics are typically inversely related to one another so only the omnivorous + herbivorous metric will be discussed here due to its close association with instream nutrient enrichment. Although both watersheds have nutrient inputs from point and nonpoint sources, four (4) of the sites sampled had percentages of omnivorous + herbivorous individuals (Table 2) that would have been in the highest scoring range of the NCDWQ criteria.

In the Goose Creek watershed, only the middle location, Site 28 on Goose Creek, had a percentage (39%) of omnivorous + herbivorous individuals high enough to drop into the middle scoring range. However, three (3) of the sites in the Crooked Creek watershed, Site 4 on South Fork Crooked Creek and Site 8 and Site 9 on North Fork Crooked Creek had percentages that would have scored in the lowest range of the NCDWQ criteria. These three (3) sites all had less than 10% omnivorous + herbivorous individuals. This was primarily due to the absence or very low abundance of omnivorous bluehead chubs,

(*Nocomis leptocephalus*). The low abundance of bluehead chubs may be due to the lack of rocky substrate (Table 3) typically preferred by this species and the prolonged periods of low/no stream flow commonly observed at these sites.

Also adversely affecting the fish fauna in the two watersheds are frequent low flow conditions experienced at least to some extent in all of the streams. Multiple locations throughout the two watersheds are at times reduced to isolated pools separated by completely dry streambeds. Fish populations are limited to only the few most tolerant species and individuals that can survive in the low dissolved oxygen (DO), high stress conditions that develop in the isolated pools. Fish are mobile and therefore able to re-inhabit areas that were dry, but the frequency of the stresses caused by low flow conditions may inhibit reestablishment of some species.

The quality of stream habitat available at the sampling locations varied throughout the two watersheds (Table 3). The NCDWQ habitat scores ranged from a high of 72 at Goose Creek at US 601 (Site 23) to a low of 35 at North Fork Crooked Creek (Site 4). In addition to having the highest habitat score, the Goose Creek at US 601 location also had the highest number of fish species found during the study (23) and was the only site at which four species of suckers were collected. The number of sucker species and may be a reflection of the parameter for pool variety score of (8/10). This was the second highest score for this parameter recorded during this study. Along with Crooked Creek at SR 1547 (Site 13), Goose Creek at US 601 (Site 23) was one of two locations where all three of the darter species found during the study were collected. However, the habitat parameter for riffle quality/quantity that may be associated with the number of darter species was low (3/16) at both sites. The low riffle parameter scores appear to be somewhat offset by the fact that Goose Creek at US 601 and Crooked Creek at SR 1547 have the largest drainage areas in their respective watersheds and therefore could be expected to have the most water flow. This hypothesis is supported by these two sites having the highest abundances of the fantail darter (*Etheostoma flabellare*); a species typically associated with moderate to higher flow conditions.

Comparison to Existing Fish Community Data

In addition to the 2010 NCDOT fish community data, prior NCDWQ data exists for four of the locations surveyed. NCDWQ fish community collection protocols (http://portal/ncdenr.org/web/wq/ess/bau) differ from those employed in this study primarily in that the NCDWQ protocol is based on collection of fish continuously from all 600 linear feet of a designated stream reach, whereas the NCDOT protocol is based on areas of potentially productive habitat. In addition, the NCDWQ protocol tends to be somewhat more intensive as is evidenced by the more than two (2) to one (1) difference in electrofisher shocking seconds for the same survey locations. A comparison of the data shows mostly similar fish communities between the two data sets and the years the data was collected (Tables 4 and 5).

Summary

There are a variety of potential impacts to the aquatic communities of the Goose and Crooked Creek watersheds including point and nonpoint sources and frequent low/no-flow conditions during periods of low rainfall. As was the case with the benthic macroinvertebrate study conducted by NCDWQ in 2009, the results of the fish community study conducted by NCDOT/EEP/NCDWQ staff in 2010 suggest the fish community is, to some degree, affected by the combination of these stressors. Reduced instream habitat variety may have also combined with these stressors to influence the fish community composition at the two sampling locations on the North Fork Crooked Creek (Sites 8 and 9) and the location on South Fork Crooked Creek (Site 4). A comparison with prior NCDWQ fish community data from four (4) sampling locations, indicated the fish communities in 2010 were overall similar to those documented in 1995 and 2006.

Appendix E:

Water Quality Integrated Analysis Report for the Goose and Crooked Creek Local Watershed Plan

Water Quality Integrated Analysis Report for the Goose and Crooked Creek Local Watershed Plan



North Carolina

Division of Water Quality

Watershed Assessment Team

August 2011

Suggested Citation:

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Cover Photo: Crooked Creek at Brief Rd.

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I. Executive summary

The North Carolina Division of Water Quality-Watershed Assessment Team (NCDWQ-WAT) initiated a short-term (August 2009-June 2010) water quality monitoring project within the Goose and Crooked Creek watersheds. The primary purposes of the monitoring were: 1) to provide water quality data to Centralina (the regional Council of Governments) and Tetra Tech, a consultant, for the development of a water quality model, and 2) to characterize water quality conditions in these watersheds. The water quality model will be completed by the end of 2011. This *Integrated Analysis Report* summarizes water quality conditions based primarily on the results of the NCDWQ-WAT sampling; however, information on a benthic macroinvertebrate assessment conducted by the NCDWQ-Biological Assessment Unit in 2009 is also presented.

Sampling was conducted from ten monitoring sites within the Goose and Crooked Creek watershed, and one reference site (Barnes Cr., Montgomery Co.). Data represent field measurements (water temperature, dissolved oxygen, percent saturation of dissolved oxygen, specific conductance, and pH), nutrients (nitrite + nitrate nitrogen, ammonia nitrogen, total Kjeldahl nitrogen and total phosphorus), total suspended solids, turbidity, copper and fecal coliform bacteria.

Low dissolved oxygen concentrations (< 4.0 mg/L) are associated with low flows and warm water temperatures. Most observations (18 of 21) of such low concentrations occurred on the North and South Forks of Crooked Creek. The NCDWQ-WAT data for pH did not reveal any spatial patterns, however using long-term temporal data from the NC Ambient Monitoring System (NCDWQ-AMS) and the Yadkin Pee Dee River Basin Associations programs show a decreasing trend for pH with the Goose and Crooked Cr. basins that is consistent with patterns found elsewhere in NC.

The highest specific conductances, and nitrite + nitrate nitrogen and total phosphorus concentrations were found at the following four sites, including one monitoring site in Goose Cr, both monitoring sites along the North Fork of Crooked Creek, and the one monitoring site in Crooked Cr. During low stream flows at these sites, concentrations for nitrite + nitrate nitrogen exceeded 10 mg/L and concentrations for total phosphorus exceeded 1.0 mg/L. There currently are three operational wastewater treatment plants (WWTPs) within the Goose/Duck Creek watershed and three within the Crooked Creek watershed. The high conductances and nutrients were due to discharges from WWTPs; however these results are not atypical of WWTPs throughout the state. There also are two inactive WWTPs (Hunley Creek and Fairfield) in the Goose Creek watershed.

Existing data from the NCDWQ-AMS monitoring station (Q8360000) on SR 1524 near Mint Hill (just below the Hunley WWTP) showed high concentrations of ammonia-nitrogen prior to the summer of 2006. During the summer of 2006 (prior to the initiation of the LWP monitoring), the Hunley WWTP discharges were rerouted to another facility, and concentrations of ammonia-nitrogen decreased significantly.

Fecal coliform bacteria was only measured from the monitoring stations in the Crooked Creek watershed, since fecal coliform issues are well documented from other monitoring in the Goose Creek watershed. Geometric means for results ranged from 167 to 425 cfu/100ml.

Water samples for total copper were collected as part of the NCDWQ-WAT monitoring effort. One monitoring station along the North Fork of Crooked Cr. showed two results greater than the 7.0 µg/L NC action level. However a special study is currently underway to better understand the potential copper toxicity levels in Goose Creek by collecting data for the biotic ligand model for copper. The completion of this study depends on additional sampling during storm events.

Stream flow data since 2000 from the US Geological Survey were used to depict periods of drought, and the range of storm flows from which the NCDWQ-WAT data were sampled. Drought conditions were present during 2000-2002, 2007 and 2009. The NCDWQ-WAT monitoring data reflected a wide range of flow conditions.

All Crooked and Goose Creek macroinvertebrate monitoring stations received Poor or Fair bioclassifications indicating continued impaired water quality. Many factors are potentially contributing to its degraded water quality including point and nonpoint sources. Increases in urban activities near headwater reaches may be leading to increased erosion, scour, sediment load, and periodic toxicity. Additionally, several permitted Wastewater Treatment Plants (WWTPs) are located upstream from benthic sampling locations likely contributing to more tolerant macroinvertebrate assemblages. Biological monitoring of fish populations were conducted by the NC Department of Transportation (NCDOT), but the results were not available at the time of writing of the current report.

Currently there are three active minor NPDES dischargers to Goose Creek/Duck/Stevens-Creeks and two active minor dischargers within the Crooked Creek watershed. All utilize ultraviolet disinfection to alleviate chlorine toxicity concerns, and will receive ammonia limits of 0.5 mg/L consistent with the Goose Creek Rules. The only major WWTP in this study area is Union County/Crooked Creek WWTP, which discharges to North Fork Crooked

Creek. This facility also uses UV disinfection (but has the option to use chlorination in case of failure) and is the only one that conducts a chronic toxicity test. The quarterly toxicity test results from 2007-2010 show 20 of 23 “Pass” test results.

II. Table of Acronyms and Measurements

Acronym/ Measurement	Definition
Acronym	
AMS	Ambient Monitoring System
BMP	Best Management Practice
CC	Crooked Creek
DC	Duck Creek
EEP	Ecosystem Enhancement Program
EL	Evaluation Level
EPT	Ephemeroptera, Plecoptera, Trichoptera
GC	Goose Creek
GIS	Geographic Information System
LWP	Local Watershed Plan
MDL	Method Detection Limit
MGD	Million Gallons per Day
NC	North Carolina
NCAC	North Carolina Administrative Code
NCBI	North Carolina Biotic Index
NCDMAC	Drought Management Advisory Council
NCDOT	North Carolina Department of Transportation
NCDWQ	North Carolina Division of Water Quality
NCDWQ-BAU	North Carolina Division of Water Quality – Biological Assessment Unit
NCDWQ-ISU	North Carolina Division of Water Quality – Intensive Survey Unit
NCDWQ-WAT	North Carolina Division of Water Quality – Watershed Assessment Team
NCEEP	North Carolina Ecosystem Enhancement Program
NCNHP	North Carolina Natural Heritage Program
NCWRC	North Carolina Wildlife Resources Commission
NPDES	National Pollution Discharge Elimination System
PQL	Practical Quantitation Limit
SOP	Standard Operating Procedure
SR	Secondary Road
TMDL	Total Maximum Daily Load
US	United States
USFWS	United States Fish and Wildlife Service

Acronym/ Measurement	Definition
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant
YPDRBA	Yadkin Pee-Dee River Basin Association

Water Quality Measurement	
°C	degrees Celsius
cfu/100 ml	colony forming units per 100 milliliters
mg/L	milligram per liter
ml	milliliters
µg/L	microgram per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
SU	Standard unit

III. Introduction

In July 2008, the North Carolina Ecosystem Enhancement Program (NCEEP) initiated a local watershed planning effort within the Goose and Crooked Creek watersheds. The purpose of this planning effort is to help address regional compensatory mitigation needs and to develop a framework in which local stakeholders can address water quality, habitat and hydrological issues. The North Carolina Division of Water Quality (NCDWQ) supports the development of the NCEEP local watershed plans (LWPs) by conducting various types of water quality assessments. These assessments routinely include: 1) a biological assessment of water quality, and 2) the measurement of various physical and chemical substances in surface waters.

The purpose of this "*Integrated Analysis Report*" is to summarize and interpret the data collected as part of the NCDWQ water quality assessments that were conducted to support the NCEEP's development of a LWP. For the Goose and Crooked Cr. LWP the NDCWQ conducted two assessments. First was an assessment of benthic macroinvertebrates conducted by the NCDWQ Biological Assessment Unit (NCDWQ-BAU) in July 2009[1].

The second assessment was the collection of physical and chemical data for the development of a water quality model (discussed briefly below). Although the primary purpose of the physical and chemical assessments was to provide data for a water quality model, the data were used to characterize water quality at each sampling location. This *Integrated Analysis Report* primarily summarizes the results of the physical and chemical monitoring.

Among the many watersheds statewide, the Goose and Crooked Creek area is noteworthy since a lot of water quality data have been collected within these watersheds through many programs. These programs include the NCDWQ Ambient Monitoring System (AMS)[2] – a network of stations established throughout the state to provide site-specific, long-term water quality information in streams. Complementing the AMS program is the Yadkin Pee Dee River Basin Association (YPDRBA) – a monitoring coalition of National Pollutant Discharge Elimination System (NPDES)[3] dischargers that combine resources to collectively fund and perform in-stream monitoring. The United States Geological Survey (USGS) operates and maintains three gaging stations along

[1] The results of the benthic macroinvertebrate assessment have been written as a memorandum (NCDWQ-BAU 2009; see: Appendix D, page 12).
[2] http://portal.ncdenr.org/web/wq/ess/eco/ams
[3] http://cfpub.epa.gov/npdes/

Goose Creek that collect time-series data measuring stream levels, and stream flow (see the section on Flow). Additionally, Charlotte and Mecklenburg County (Stormwater Services) collects water quality data in the portions of Goose Creek that are within Mecklenburg County.

Between the two watersheds (Goose and Crooked) there is considerably more ecological and water quality information pertaining to Goose Creek than Crooked Creek. This is because the *Carolina Heelsplitter (Lasmigona decorata),* a federally listed endangered mussel, is present within the Goose and Duck Creek watersheds. In 2005 an interagency team from the US Fish and Wildlife Service, the NC Wildlife Resources Commission and the NC Natural Heritage Program authored a technical report (referred to as the "Technical Support Document") that could be used to develop management strategies to restore water quality in Goose and Duck Creek [4]. This Technical Support Document provides a good review of water quality up through 2004.

In April 2009, the NC Division of Water Quality-Watershed Assessment Team (NCDWQ-WAT) began collecting physical and chemical water quality data for a water quality model to be developed by Centralina (a regional Council of Governments) and Tetra Tech, a consultant with expertise in water quality modeling. The monitoring period ended in the summer of 2010 (see Methods for details). The purpose of the model is to predict existing and future stressor[5] levels throughout both the Goose Cr. and Crooked Cr. watersheds. The modeling will be used to support identification of priority areas for management including stream, buffer, and wetland restoration, stormwater BMP retrofits, and protection measures.

This *Integrated Analysis Report* does not provide a discussion of all the water quality data collected by all monitoring programs but focuses primarily on the physical and chemical data collected by the NCDWQ-WAT between April 2009 and the summer of 2010. The NCDWQ-WAT data and data from other water quality programs are used to update the discussions in the Technical Support Document.

[4] A summary of water quality and its potential impact on this mussel was completed by the US Fish and Wildlife Service (USFWS), North Carolina Wildlife Resources Commission (NCWRC) and the NC Natural Heritage Program (NCNHP) in 2005 (USFWS *et al*. 2005).

[5] Stressors identified include increased peak flows and surface runoff volumes, sediment loading, nutrient loading, and toxic pollutants.

A. Study objectives

1. The primary objective was to collect and provide water quality data to TetraTech and Centralina for the development of a water quality model. The model is funded through an NCDWQ 319 grant[6]. Details on this model are available through the NCDWQ Nonpoint Source Pollution program. Funds for the grant were allocated in 2009 to Centralina.

   The water quality modeling effort is to be completed by December 31, 2011.

2. The second objective was to summarize the results in order to:

   a. help characterize the condition of a stream and identify specific water quality stressors;

      This was completed by summarizing and graphing the results for each station for each parameter sampled. (See Appendix C and the Results Section beginning on page 23*)*

   b. assess compliance with water quality evaluation levels[7];

      For those parameters that have a numeric water quality evaluation level (e.g. standard or action level), the results of the sampling were compared to this level. (See Appendix C and the Results Section beginning on page 23*)*

3. The third objective was to revisit some of the water quality issues in the Technical Support Document (USFWS *et al*. 2005), which addressed water quality issues for:
   - Bank / Channel Instability
   - Sediment / Suspended Solids
   - Ammonia
   - Dissolved oxygen (seasonally)
   - Chlorine
   - Nitrate / Nitrite
   - Phosphorus

[6] 319 Project Title: "Rocky River Watershed Improvement Projects"
[7] Compliance with water quality standards is done by the NCDWQ Planning Section.

- Pes*ticid*es
- Fecal coliform bacteria
- Copper

The NCDWQ-WAT monitoring data and/or data from the NCDWQ-AMS stations were used to update information on ammonia, nitrate/nitrite, phosphorus and copper. This was done in the Results Section beginning on page 23*)*

These efforts were initiated to assist in the development of a LWP being coordinated by the NCEEP and Centralina[8]. The primary intent of these water quality investigations was to identify potential stressors contributing to the degradation of water quality, habitat and hydrological functions throughout the planning area based on the results of collected data and best professional judgment. The goals of a LWP include the development of a comprehensive watershed management and restoration strategy and a project atlas identifying specific locations and projects within the planning area that, if implemented, may help to ameliorate water quality, habitat and/or hydrology problems within the watershed.

B. Watershed Planning and Key Objectives

The Goose Creek and Crooked Creeks LWP must meet two broad objectives. First, the plan must meet the requirements in federal regulations (Compensatory Mitigation for Losses of Aquatic Resources; Final Rule[9]), promulgated by the US Department of the Army, Corps of Engineers (33 CFR Parts 325 and 332) and the US Environmental Protection Agency (40 CFR Part 230) regarding compensatory mitigation. This rule encourages a watershed approach to compensatory mitigation: "*the ultimate goal of a watershed approach is to maintain and improve the quality and quantity of aquatic resources within watersheds through strategic selection of compensatory mitigation sites*" (COE §332.3 (6)(c) and EPA §230.93 (6) (c)). The LWP must comply with the requirements in this federal rule.

Secondly, the plan must meet the goals of the watershed planning partners which include local stakeholders. The LWPs are developed through a stakeholder process and often watershed issues are identified that are not needed for compensatory mitigation.

[8]For a summary see: http://www.nceep.net/services/lwps/Goose_Crooked/Goose_Crooked_1_07.pdf

[9]http://water.epa.gov/lawsregs/guidance/wetlands/upload/2008_04_10_wetlands_wetlands_mitigation_final_rule_4_10_08.pdf

Thus, the NCEEP uses watershed planning to identify the best locations to implement stream, wetland and riparian buffer restoration, and best management practices (BMPs). The planning process considers where mitigation is needed and how mitigation efforts might contribute to the improvement of water and habitat quality in the state. Watershed planning, as conducted by the NCEEP, requires Geographic Information System (GIS) data analysis, stakeholder involvement, water quality and habitat monitoring and consideration of local land uses and ordinances. It is a multidimensional process that considers science, policy and partnership.

C. Selection and Location of Monitoring Sites

1. NCDWQ-WAT Monitoring Sites

The development of the water quality model by Centralina (and Tetra Tech) was a primary factor in the selection of the NCDWQ-WAT monitoring sites. However, other water quality factors influenced the selection of monitoring sites. Table 1 summarizes the water quality concerns at each sample location. Figure 1. Locations of NCDWQ-WAT, AMS, and Coalition water quality monitoring stations and NCDWQ-BAU benthic macro-invertebrate monitoring presents a map of the NCDWQ-WAT sample locations and shows the spatial relationships between the locations of the NCDWQ-WAT sample locations and the locations of the discharge points from wastewater treatment plants (WWTPs). The relationship between the locations of the sample sites and locations of the discharges from WWTPs is discussed later in this report[10].

2. Other Monitoring Sites

Within the LWP area, there are four other programs that collect water quality data. These include the NCDWQ-AMS, the YPDRBA, Charlotte-Mecklenburg Co., and the USGS. Data from the NCDWQ-AMS and the YPDRBA were used to show the changes over time of some of the parameters, or to refine the water quality discussions expressed within the Technical Support Document (USFWS, NCWRC and NCNHP 2005).

[10] Briefly this relationship shows high specific conductance, high nitrite + nitrate nitrogen and high total phosphorus concentrations at some of the NCDWQ-WAT monitoring stations downstream of some WWTPs.

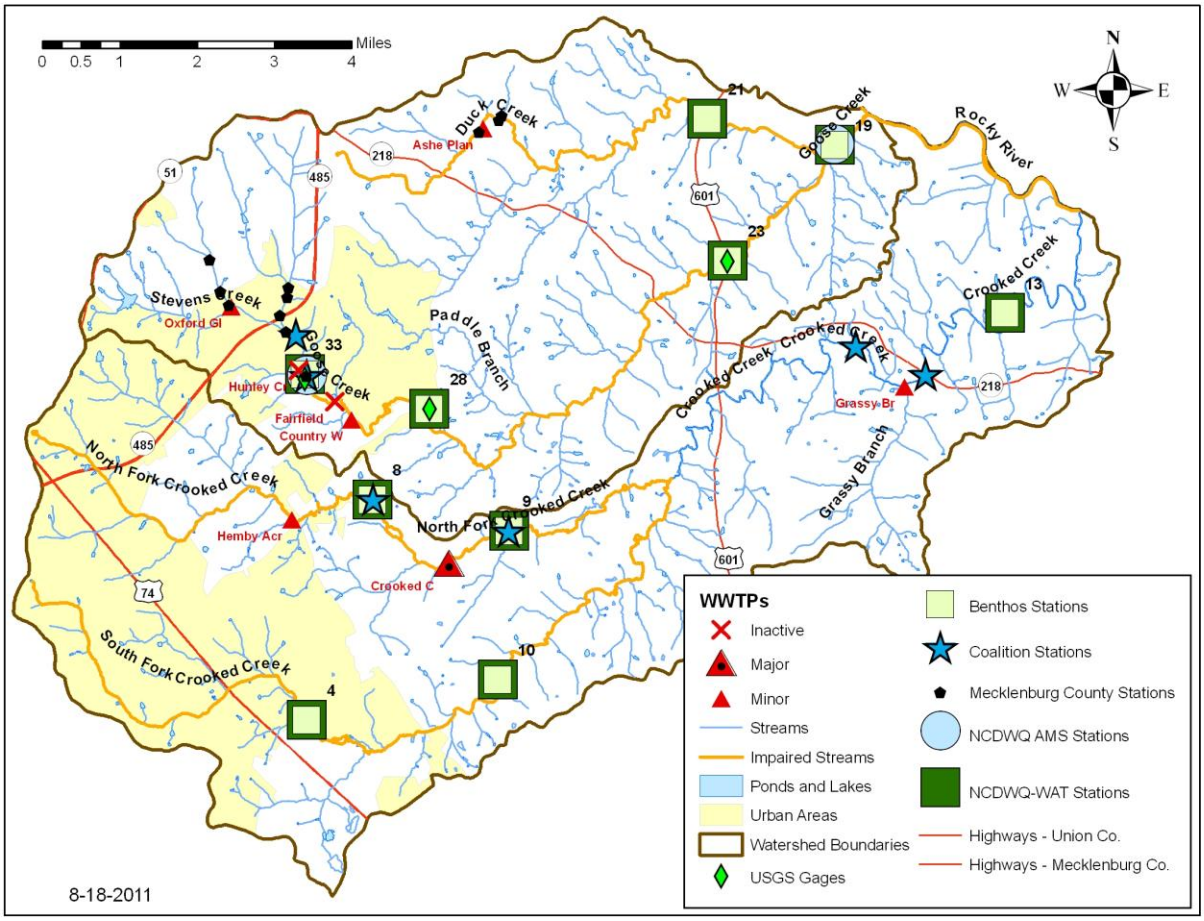


Figure 1. Locations of NCDWQ-WAT, AMS, and Coalition water quality monitoring stations and NCDWQ-BAU benthic macro-invertebrate monitoring stations[11].

[11] See Table 1 (page 11) for a description of the location of the monitoring sites.

Table 1. NCDWQ-WAT sampling locations.

Map Code	Location	Latitude	Longitude	Justification[1]
4	S Fork Crooked Cr. at Sardis Church Rd.- SR 1515	35.0663	-80.6297	Impaired stream reach; downstream from urban non-point sources; high potential for flashiness o flow and scour impacts from urban runoff; Benthos and fish data are existing. Benthic data are very old (1995).
8	N Fork Crooked Cr. at Indian Trail Fairview Rd.- SR 1520	35.1078	-80.6155	Impaired stream reach; point source and non-point source impacts; high potential for flashines of flow from urban runoff and scour impacts; Benthos and fish data exist, however benthos data are old (2000); Area is urbanizing; YPDRBA monitoring point.
9	N Fork Crooked Cr. at Rocky River Rd.- SR 1514	35.1024	-80.5842	Impaired stream reach; point source and non-point source impacts. YPDRBA monitoring point. Benthos and fish data exist, however benthos data are old (2000); area is urbanizing; need up-to-date data for lower North Fork CC; need to determine if flashiness of flow and scour impacts still are impacting benthos further downstream.
10	S Fork Crooked Cr. at Unionville Indian Trail Rd.- SR 1367	35.0744	-80.5863	Impaired stream reach; non-point source impacts. Benthos data exist however benthic data are very old (1995); need up-to-date data fo lower South Fork CC; need to determine if flashiness of flow and scour impacts still are impacting benthos further downstream.
13	Crooked Cr. at Brief Rd.- SR 1547	35.1447	-80.4717	Stream reach not impaired, but is most downstream location on CC and integrates water quality across the entire CC watershed; point source and non-point source impacts. Benthos and fish data exist, although benthos data are recent (2006), we need current data for comparison to evaluate results from the upstream sites.
19	Goose Cr. at Brief Rd.- SR 1547	35.1757	-80.5112	Impaired stream reach; most downstream location on GC; AMS site; point source and non-point source impacts. Benthos data are old (1998); this site integrates water quality across the entire GC and DC watersheds and is needed for comparison and evaluation of upstream sites.

Table 1. NCDWQ-WAT sampling locations.

Map Code	Location	Latitude	Longitude	Justification[1]
21	Duck Cr. at US 601	35.1803	-80.5404	Impaired stream reach; most downstream location on DC; point source and non-point source impacts. Benthos data exist but are old (1998); only benthos site on DC; no downstream point on DC; needed to evaluate downstream impacts of a WWTP, including flashiness of flow from upstream urbanizing areas.
23	Goose Cr. at US 601	35.1537	-80.5353	Impaired stream reach; point source and non-point source impacts. Recent (2006) benthos data exist; site needed to integrate benthic impacts of entire Goose Creek watershed above confluence with Duck Creek. USGS gage with flow plus other parameters.
28	Goose Cr. at Mill Grove Rd. - SR 1525	35.1250	-80.6029	Impaired stream reach; point source and non-point source impacts; moderately high specific conductance; USGS gage site. High potential for flashiness of flow from urban runoff and scour impacts; Benthos data exist, but are old (2000); need data to evaluate impacts of nearby WWTPs and recovery of benthos.
33	Goose Cr. at Stevens Mill Rd.- SR 1524	35.1312	-80.6315	Upstream end of impaired stream reach; point source and non-point source impacts. USGS gage site and AMS site. High potential for flashiness of flow from urban runoff and scour impacts; Benthos data exist, but are old; concerned about impacts of WWTPs.
	Barnes Cr. At SR 1303 (Montgomery Co.)	35. 4386	-80.0006	Only slate belt benthos reference stream of comparable size. No water chemistry/fecal data. Needed for overall comparisons with data from GC and CC watersheds to evaluate current and future impacts of development.

[1] Primary reason was for the data to be provided for the development of a water quality model.

Abbreviations: AMS = Ambient Monitoring System, GC = Goose Creek, CC = Crooked Creek, DC = Duck Creek, USGS = US Geological Survey, WWTP = Wastewater Treatment Plant YPDRBA = Yadkin Pee-Dee River Basin Association

D. Other NCDWQ-WAT Studies with the LWP area

In addition to the monitoring effort described above, the NCDWQ-WAT initiated two additional studies within the LWP area. Since some of the sampling locations for these two studies were also the same as those in the monitoring effort, the results in this report include the results from the two additional studies. The two studies are described briefly below.

3. Stormflow Study

There is a common misunderstanding among users of water quality data that high concentrations of pollutants measured during storm events are solely the immediate result of stormwater discharges and overland flow. A brief examination of the literature, however, suggested that, as the velocity of streams during storm events increases, pollutants associated with sediments are re-suspended and contribute a large proportion of the concentrations of pollutants observed during storm events. The stormflow study was initiated to confirm this information and to understand better how sediment resuspension affects the concentrations of pollutants observed during storm events. This study had two components to it: 1) a literature review, and 2) a field study.

The field component of the stormflow began in August 2009 and ended in June 2010. Water quality samples were taken for total phosphorus, fecal coliform bacteria, total copper, turbidity and total suspended solids at three sites:

1. Crooked Cr. at Brief Road (SR, 1547, Map Cope 13) [12])
2. Goose Cr. at US 601 (Map Code 23)
3. Goose Cr. at Mill Grove Rd. (SR 1525; Map Code 28)

The sample results from these three sites were also included as results of the monitoring study, since these three sites were also sampled as part of the LWP monitoring effort.

Projects resulting from this stormflow study include: 1) a report summarizing the literature review, and 2) a report summarizing the field study. These reports are currently in a review process. The scheduled completion date for final reports originally was March 2011.

[12] Map Codes refer to the labeled points on Figure 1. Locations of NCDWQ-WAT, AMS, and Coalition water quality monitoring stations and NCDWQ-BAU benthic macro-invertebrate monitoring and are listed Table 1

4. Biotic Ligand Model for Copper

Copper is an essential micronutrient for life but can become toxic when in high concentrations and under certain conditions. Many water quality monitoring programs include copper as a sample parameter. It is routinely measured as 'total copper', thus no information is gathered on the concentration of the dissolved fraction, which is the portion that is bioavailable and which can be toxic to aquatic life, depending on the speciation of the copper. Other factors, such as pH, concentrations of cations such as calcium, magnesium and sodium, alkalinity and variations in the concentrations of organic matter affect the toxicity of copper. Thus, this study was initiated to gather the data necessary to run the biotic ligand model developed by HydroQual[13] to assess the toxicity of copper. This model requires the sampling of a variety of parameters to calculate copper speciation and predict copper toxicity.

Five sites within the Goose Creek watershed are currently being sampled for the parameters necessary to run the biotic ligand model. These monitoring sites are:

1. Goose Cr. at Brief Rd.(SR1547; Map Code 19)
2. Goose Cr. at US601 (Map Code 23)
3. Goose Cr. at Mill Grove (SR1525; Map Code 28)
4. Goose Cr. Stevens Mill Rd.(SR1524; Map Code 33)
5. Goose Cr. at Country Woods Dr. (not on Figure 1 or Figure 2)

The results gathered to date are presented in the Results section, page 35)

E. Overview of Watershed Conditions

A detailed summary of watershed conditions is provided in a Technical Memorandum by Tetra Tech (2008). This memorandum along with other reports that also describe watershed conditions is available here at this web site:
http://www.gooseandcrooked.org/reports.php

In addition, an overview of watershed conditions for each monitoring station is provided as part of the summary for each monitoring station in Appendix A – Description of the Monitoring Stations.

[13] http://www.hydroqual.com/wr_blm.html

F. References and Benchmarks

Assessment and monitoring results collected were compared to two "evaluation levels", that is, water quality standards and action levels. The distinction among evaluation level, water quality standard, and action level is as follows:

Evaluation Levels

Evaluation level– Refers to the applicable numeric or narrative water quality standard or action level as used in the NCDWQ-AMS Station Summaries[14]. This term does not imply whether water quality standards or action levels are being met. Additional information is provided in Section IV – Results.

Water quality standard[15] – Water quality standards are state regulations or rules that protect lakes, rivers, streams and other surface water bodies from pollution. Standard specify beneficial use designations (classifications), numeric levels and narrative statements (water quality criteria) protective of the use designations, and procedures for applying the water quality criteria to wastewater dischargers and other sources of pollution. The NCDWQ has policies in place that determine whether water quality standards are being met.

Water quality action level - The concentration of a contaminant that, if exceeded, triggers treatment or other requirements that a water system must follow.

The NCDWQ-WAT may report that data have exceeded a numeric standard or action level but does not make the determination whether or not water quality action levels or standards have been violated. Determination of violations are done through the NCDWQ Planning Section.

[14] For example see the column designated "EL" (for Evaluation Level) here: http://www.esb.enr.state.nc.us/documents/CapeFearRiverBasinStationSummaries2004-2008.pdf
[15] For more information see: http://portal.ncdenr.org/web/wq/ps/csu/swstandards

IV. Methods

A. Chemical and Microbiological

Field measurements included water temperature, dissolved oxygen, dissolved oxygen saturation, specific conductance, and pH. All measurements were made *in situ* with handheld meters in a representative point of the channel that was well-mixed and flowing, generally at or near the thalweg[16]. Meter calibrations and measurements were performed in accordance with the NCDWQ Standard Operating Procedures (SOP; NCDWQ-ISU, 2006b).

All chemical and microbiological samples were collected in plastic bottles specific for the type of parameter being measured. Parameters selected for sampling included:

1. Nutrients: nitrite + nitrate nitrogen, ammonia nitrogen, total Kjeldahl nitrogen and total phosphorus
2. Residues: total suspended solids
3. Turbidity
4. Metals: copper
5. Fecal coliform bacteria.

All samples were grab samples collected by filling the sample bottles by immersion. Samples were taken during base flow conditions (defined as > 48 hours since the last measurable rain event) or during storm events. A detailed list of parameters, Practical Quantitation Limits (PQL) [17], water quality standards and action levels is provided in Appendix C.

[16] The thalweg is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel. The thalweg thus marks the natural direction (the profile) of a watercourse. The thalweg is almost always the line of fastest flow in any river (see: http://en.wikipedia.org/wiki/Thalweg.)

[17] The Practical Quantitation Limit (PQL) is defined and proposed as "*the lowest level achievable among laboratories within specified limits during routine laboratory operation". The PQL is about three to five times the calculated Method Detection Limit (MDL) and represents a practical and routinely achievable detection limit with a relatively good certainty that any reported value is reliable*". For a list of laboratory PQLs go to: http://portal.ncdenr.org/web/wq/lab/staffinfo/techassist#Practical_Quantitation_Limits

Sampling Frequency

Between August 2009 and October 2009, samples for the LWP monitoring were collected once every two weeks. Between November 2009 and June 2010 samples were collected monthly.

B. Biological Assessments and Habitat

Although the results of the biological assessments and habitat evaluations are discussed in separate memoranda (NCDWQ-BAU 2009, Tetra Tech, 2009), a brief overview is presented here since the locations selected for biological assessments were collocated with the sites selected for physical and chemical sampling.

Biological Assessments

Two biological assessments were conducted to support the development of the LWP. A benthic macroinvertebrate assessment was completed in 2009 by the NCDWQ-Biological Assessment Unit (NCDWQ-BAU) and a fish assessment was completed by the NC Department of Transportation (NCDOT) - Natural Environment Biological Surveys Group in 2010.

Benthic macroinvertebrate assessments were conducted at six[18] sites during July 2009 by NCDWQ-BAU staff. Sampling, identification, and interpretation of results for benthic macroinvertebrate communities were performed in accordance with NCDWQ-BAU Standard Operating Procedures (SOP) for Benthic Macroinvertebrates (NCDWQ 2006a).

Fish Assessments

Fish assessments were conducted at eight sites during May 2010 by the NCDOT- Natural Environment Biological Surveys Group in 2010. The NCDOT had not completed their report on the findings of the fish study as of the writing of the present water quality assessment report and hence will not be included here.

[18] Ten sites were planned to be sampled, but only six could be sampled due to drought conditions.

Habitat Assessments

The NCDWQ-BAU developed habitat evaluation procedures to help in the evaluation of species data. These procedures and accompanying field assessment forms have changed slightly over the years since they were first used in the mid-1990s. As part of the LWP field studies, habitat assessments (piedmont-mountain form) were completed during: 1) the NCDWQ-BAU benthic macroinvertebrate sampling, 2) the NCDOT fish assessment, and 3) by Tetra Tech as part of their Scoping Level Assessments (Tetra Tech, 2008).

Tetra Tech used the Stream Habitat Evaluation as specified in Appendix E of the NC Department of Environment of Natural Resources - Internal Technical Guide for Steam Work in North Carolina (NCDENR 2001). This represents an earlier version of the habitat assessment method implemented by the NCDWQ-BAU during its assessments completed in 2009. The differences between the methods used by NCDWQ-BAU in 2009 and Tetra Tech in 2008 are minor and should not affect the accuracy of the results.

C. Flow

The USGS maintains three monitoring sites along Goose Creek (Table 2). There are no USGS monitoring sites along Crooked Creek. Flow data were downloaded from the USGS monitoring site at Fairview (USGS 02124692) and graphed. Only data from this one station were examined since it has the longest record. The data and graph were used to provide a visual representation of high and low flows (and drought periods) for the period January 1, 2000-December 31, 2010. Additionally, the NCDWQ-WAT sample dates were highlighted to provide an overview of the flow conditions in which the chemical and physical sampling were completed. Although data from only one USGS monitoring station were used, the flow conditions are representative for all sample sites. Therefore if drought conditions were present during a sample date at the NCDWQ-WAT sample site at Fairview, then drought conditions were present at the other NCDWQ-WAT sample sites. Data were graphed using SigmaPlot (version 11.0) scientific graphing software. The data were graphed twice, once using a $\log_{10}$ scaling so that the lower flows could be easily discerned, and once using linear scaling, so the peak flows could be easily viewed.

Table 2. USGS monitoring sites along Goose Creek.

Site and Parameters Measured	Begin Date	End Date
USGS 02124692 Goose Cr. at Fairview, NC[1]		
Temperature water	11/9/1999	10/1/2009
Discharge	11/1/1999	present
Gage height	11/9/1999	present
Specific conductance	11/9/1999	10/1/2009
Dissolved oxygen	11/9/1999	10/1/2009
Dissolved oxygen saturation	11/9/1999	10/1/2009
pH	11/9/1999	10/1/2009
Turbidity	7/9/2006	9/27/2009
USGS 0212467595 Goose Cr. at SR1525 near Indian Trail[2]		
Discharge	9/11/2002	present
Gage height	9/11/2002	present
USGS 0212467451 Goose Cr. at SR1524 near Indian Trail[3]		
Discharge	3/31/2009	present
Gage height	3/31/2009	present

[1] http://waterdata.usgs.gov/nc/nwis/uv/?site_no=02124692&PARAmeter_cd=00065,00060
[2] http://waterdata.usgs.gov/nc/nwis/uv/?site_no=0212467595&PARAmeter_cd=00065,00060
[3] http://waterdata.usgs.gov/nc/nwis/uv/?site_no=0212467451&PARAmeter_cd=00065,00060

D. Quality Assurance/Quality Control

1. Physical and Chemical Monitoring

The NCDWQ Intensive Survey Unit's standard operating procedure (SOP; NCDWQ 2006b) was followed whenever NCDWQ field meters were used for the measurement of dissolved oxygen, dissolved oxygen saturation, water temperature, specific conductance and pH. In all cases, the NCDWQ 2006 SOP in addition to the NCDWQ Laboratory Section's: 1) Sample Submission Procedures[19] and 2) Submission Guidance Document[20] were followed for all sample collections submitted to the Laboratory Section.

[19] http://portal.ncdenr.org/web/wq/lab/staffinfo/samplesubmit
[20] http://portal.ncdenr.org/c/document_library/get_file?uuid=92a278e5-f75a-4e42-9be5-282ac0216b2a&groupId=38364

2. Biological Assessments and Habitat

The NCDWQ standard operating procedure (SOP, NCDWQ 2006a) was followed for the collection of benthic macroinvertebrates and habitat data.

E. Data Analysis and Statistics

1. Physical and Chemical Monitoring

Field monitoring data collected by the NCDWQ-WAT and chemical results provided by the Laboratory Section were entered by hand into a Microsoft Excel (Microsoft Office 2007) spreadsheet. Data were checked for accuracy using a combination of manual checking and by tabulation and graphing using JMP (version 8.0.1). A copy of these data is available on the DWQ-WAT website[21].

Special symbols and colors were assigned to results on graphs to distinguish results taken during baseflow and stormflow conditions. A blue plus symbol (+) represents a result collected during baseflow conditions, whereas a red asterisk (*) represents a result collected during stormflow conditions. A black square (▪) denotes a result that was below the PQL (akin to the "detection limit") of the Laboratory Section. No special marker or color distinctions were assigned to the results of any of the regional stations, since baseflow and stormflow designations were not part of those databases. In addition, horizontal red lines on some of the graphs represent the evaluation level (water quality standard or action level) for that parameter. For example, graphs for dissolved oxygen will show a horizontal red line at 4.0 mg/L. Results below 4.0 mg/L are those possibly not in compliance with the water quality standard for dissolved oxygen. See page 75 for an example of a graph for dissolved oxygen with a horizontal red line at 4.0 mg/L

Results for fecal coliform bacteria greater than 400 cfu/100 ml should not be interpreted as violating the water quality standard. This is because the standard is only applicable to five consecutive samples, taken within a 30 day period. The chemical sampling in the LWP planning area was not completed at this frequency. Additionally, it is common practice to sample fecal coliform bacteria and not submit the samples to the Laboratory Section within 6 hours of sample collection (the required holding time). Results collected under these conditions are still useful indicators of fecal coliform pollution, however the results cannot be used to determine if the water quality standard is being met.

[21] http://portal.ncdenr.org/web/wq/swp/ws/pdu/wat/projects

The water quality standard for fecal coliform bacteria (15A NCAC 02B .0211) (3)(e) is:

> *Organisms of the coliform group: fecal coliforms shall not exceed a geometric mean of 200/100ml (MF count) based upon at least five consecutive samples examined during any 30 day period, nor exceed 400/100ml in more than 20 percent of the samples examined during such period. Violations of the fecal coliform standard are expected during rainfall events and, in some cases, this violation is expected to be caused by uncontrollable nonpoint source pollution. All coliform concentrations are to be analyzed using the membrane filter technique unless high turbidity or other adverse conditions necessitate the tube dilution method; in case of controversy over results, the MPN 5-tube dilution technique shall be used as the reference method;*

2. Biological Assessments

Benthic macroinvertebrate taxa are identified to the lowest taxonomic level possible and are enumerated on a scale of 1 (rare) to 10 (abundant), which provides an indication of abundance. Additionally each taxon has been assigned a tolerance value with indicates the taxon's tolerance to pollution. Based on this information an NC Biotic Index (NCBI) is calculated:

$$\frac{\sum_{i=1}^{s} TV_i \, n_i}{n_t}$$

Where TVi is the tolerance value of the i^{th} taxon, s represents the total number of taxa in the sample, Ni is the relative abundance of the i^{th} taxon and Nt is the total abundance of all taxa in the sample. Biotic indices can range from 0 to 10, with the lower scores indicating a sample with more polluting intolerant taxa and better water quality. The EPT (Ephemeroptera, Plecoptera, Trichoptera) richness, either alone or in combination with the total taxa richness was used until 1990 to assign bioclassifications. EPT richness now is a component of the calculation of the NCBI, which is used to assign bioclassifications, as the EPT group is generally less tolerant to pollution.

Various metrics are calculated from the sample data, and one of five bioclassifications may be assigned to a sample site: Poor, Fair, Good-Fair, Good, or Excellent. These bioclassifications have regulatory significance since stream segments with either a Poor or Fair bioclassification may be placed on the state's impaired streams list. At this time, only bioclassifications assigned by NCDWQ are used in use support decisions.

V. Results

This section provides a short summary of all the field and chemical parameters that were assessed during the monitoring of the eleven sites, which included the reference station at Barnes Creek. All parameters are described, and the water quality standard or action level is provided when applicable (not all parameters have standards or action levels). Results that deviate from NC water quality standards or depict spatial patterns or are otherwise prominent are noted. Graphs and summary tables of all the monitoring data are provided in Appendix C – Summary Graphs and Tables for the LWP Monitoring Results.

Numeric water quality standards and practical quantitation levels (PQLs) are provided in Appendix B – Practical Quantitation Limits (PQL) and NC Water Quality Standards and Action Levels.

A. Field Data

Field meter data (water temperature, dissolved oxygen concentration, percent oxygen saturation, pH, and specific conductance) are routinely measured whenever water samples are collected. These parameters are easily and cost-effectively measured using multi-probe field meters. Field data were available for all water quality sampling dates except in a few cases in which equipment malfunction occurred.

1. Water Temperature

Water temperature is always recorded but very rarely used to diagnose water quality problems. There is a water quality standard for temperature 15A NCAC 02B .0211 (3) (j):

> *Temperature: not to exceed 2.8 degrees C (5.04 degrees F) above the natural water temperature, and in no case to exceed 29 degrees C (84.2 degrees F) for mountain and upper piedmont waters and 32 degrees C (89.6 degrees F) for lower piedmont and coastal plain Waters; the temperature for trout waters shall not be increased by more than 0.5 degrees C (0.9 degrees F) due to the discharge of heated liquids, but in no case to exceed 20 degrees C (68 degrees F).*

Results ranged from 2.1 to 27.9 ^{o}C and reflected the normal seasonal differences that occur in streams.

2. Dissolved Oxygen

Dissolved oxygen is a very important parameter since oxygen is necessary to support aquatic life. There is a NC water quality standard for dissolved oxygen (15A NCAC 02B .0211 (3) (b)):

> *Dissolved oxygen: not less than 6.0 mg/l for trout waters; for non-trout waters, not less than a daily average of 5.0 mg/l with a minimum instantaneous value of not less than 4.0 mg/l; swamp waters, lake coves or backwaters, and lake bottom waters may have lower values if caused by natural conditions*;

Table 3 summarizes the results for dissolved oxygen and their relationship to the NC water quality standard of 4.0 mg/L. Overall 21 results were below 4.0 mg/L and most (N=18; Figure 2. Dates and flow conditions in which dissolved oxygen concentrations below 4.0 mg/L were observed. A blue "+" represents flow data from the USGS gage (02124692 at Fairview); a bold, red "**X**" represents those dates when very low dissolved oxygen was observed.

) of these occurred along the North Fork and South Fork of Crooked Cr.

Table 3. Summary for dissolved oxygen results[1]

Map Code	Location	N	No. < 4	%<4
4	S Fork Crooked Cr. SR1515 (Sardis Church Rd.)	12	5	41.7
8	N Fork Crooked Cr. SR1520 (Indian Trail Fairview Rd)	13	5	38.5
9	N Fork Crooked Cr. SR1514 (Rocky River Rd)	14	2	14.3
10	S Fork Crooked Cr. SR1367 (Unionville Indian Trail Rd)	10	6	60.0
13	Crooked Cr. SR1547 (Brief Rd)	18	0	.
19	Goose Cr. SR1547 (Brief Rd.)	15	0	.
21	Duck Cr. US601	9	1	11.1
23	Goose Cr. US601	23	1	4.3
28	Goose Cr. SR1525 (Mill Grove Rd)	23	0	.
31	Goose Cr. Country Woods Dr	4	0	.
33	Goose Cr. SR1524 (Stevens Mill Rd)	17	1	5.9
43	Barnes Cr. SR1303 (Ophir Rd.)	4	0	.

N= Number of samples; No. <4 is the number of samples less than 4.0 mg/L; %<4 is the proportion (%) of samples less than 4.0 mg/L

[1]Also see Appendix C

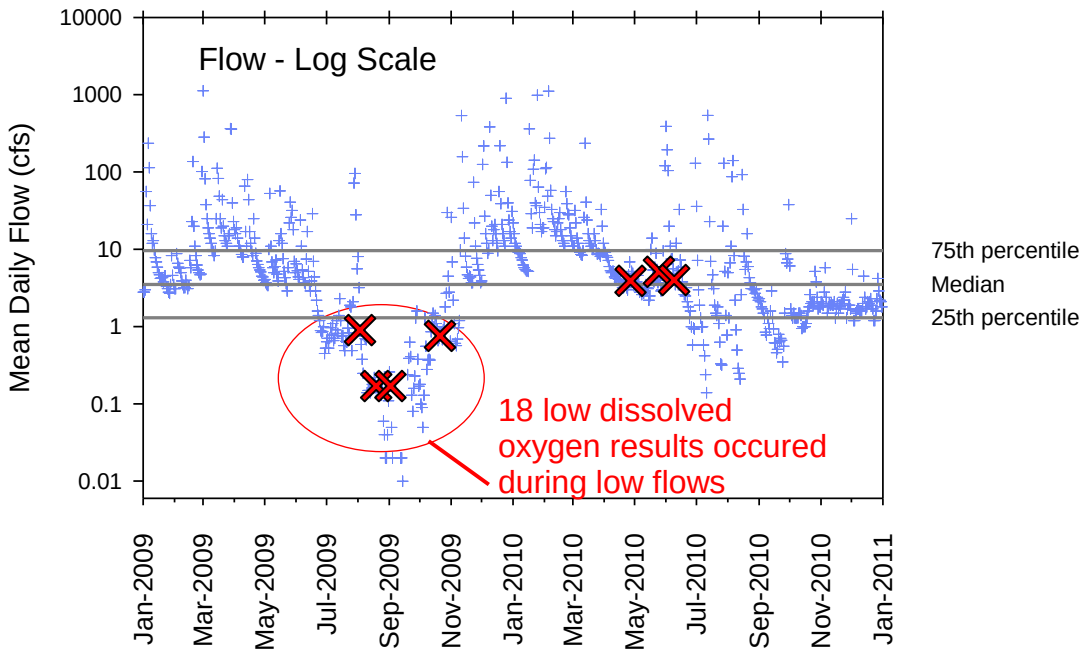


Figure 2. Dates and flow conditions in which dissolved oxygen concentrations below 4.0 mg/L were observed. A blue "+" represents flow data from the USGS gage (02124692 at Fairview); a bold, red "**X**" represents those dates when very low dissolved oxygen was observed.

3. Dissolved Oxygen Saturation

Dissolved oxygen saturation[22] is always recorded, since this parameter is routinely provided by field meters. High results (results near or exceeding 100%) may indicate photosynthetic activity by algae and aquatic plants. Although there is no water quality standard for dissolved oxygen saturation, there is a water quality standard for dissolved gases (15A NCAC 02B .0211 (3) (d): "*Gases, total dissolved: not greater than 110 percent of saturation*." Results are typically more useful when used in conjunction with dissolved oxygen and pH, since photosynthesis can result in diurnal patterns in the concentrations of these parameters. These patterns cannot be determined from monthly monitoring during daylight hours, which is similar to the frequency of monitoring conducted within the LWP area, but can be discerned using data loggers programmed to take measurements on a frequent interval (e.g. every 15 minutes).

[22] This website provides a good description of dissolved oxygen saturation: http://www.ysi.com/media/pdfs/T602-Environmental-Dissolved-Oxygen-Values-Above-100-percent-Air-Saturation.pdf

Stations with dissolved oxygen concentrations greater than 110% are summarized in Table 4. It is difficult to speculate on the reasons why three of these results occurred on March 9, 2010. Conditions in early spring with warming water temperatures and an ample light (before leaves develop on tree canopies) can promote photosynthesis resulting in high oxygen saturation or supersaturation in aquatic environments. The presence of high concentrations of nutrients also may stimulate greater photosynthetic activity.

Table 4. Stations with dissolved oxygen saturation results greater than 110%

Location	Date-Time	Result
Crooked Cr. at SR 1547 (Brief Rd.)	3/9/2010 12:30	148
Goose Cr. at US 601	3/9/2010 13:20	141
Goose Cr. at SR 1525 (Mill Grove Rd.)	3/9/2010 10:35	118
Goose Cr. at SR 1525 (Mill Grove Rd.)	4/7/2010 13:45	141

Monitoring stations with many low values (< 50% saturation) are the four stations along the north and south forks of Crooked Cr. (see Appendix C). Many of these low values corresponded with low dissolved oxygen concentration during low flow events.

4. pH

The acidity or basic nature of a solution is expressed as the pH. It is an important and useful water quality parameter, since aquatic life are adapted to certain ranges of pH. Additionally when pH decreases, many insoluble substances become more soluble and thus available for absorption. The toxicity of many compounds varies with pH. The NC water quality standard for pH is (15A NCAC 02B .0211 (3) (g)):

> *pH: shall be normal for the waters in the area, which generally shall range between 6.0 and 9.0 except that swamp waters may have a pH as low as 4.3 if it is the result of natural conditions;*

All but one of the 149 results for pH were within the range of 6 to 9 SU (SU=Standard Unit, the unit of measurement for pH.) A pH of 5.6 SU occurred at the N Fork Crooked Cr. at SR 1514 (Rocky R. Rd.) on April 27, 2010. There are no noteworthy patterns for pH among the NCDWQ-WAT monitoring stations (see Appendix C. page 77)

A temporal pattern depicting a drop in pH beginning in 2003 is evident within the Goose Cr. and Crooked Cr. LWP area using data from the NCDWQ Ambient Monitoring System,

and the Yadkin Pee Dee River Basin Association (Figure). This pattern has been noted elsewhere in the state. Reasons for this drop are not known and are being investigated.

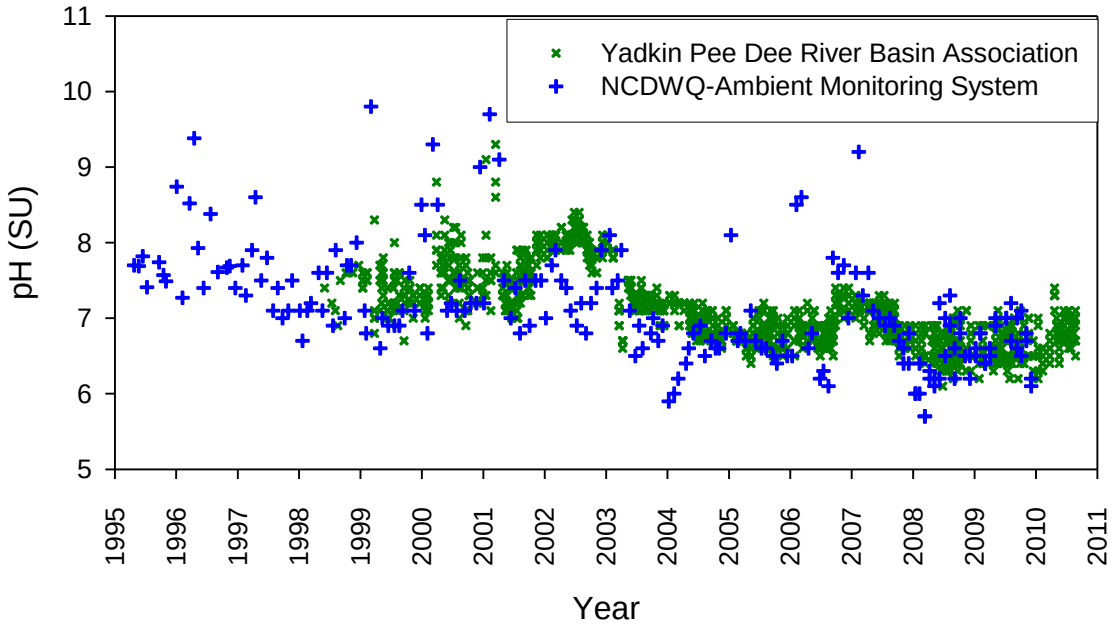


Figure 3. Results for pH collected by the NCDWQ-Ambient Monitoring System and the Yadkin Pee Dee River Basin Association) from Goose Cr. and Crooked Cr.

5. Specific Conductance

Specific conductance is a measure of the capacity of water to conduct electricity and thus is a very convenient way to estimate the total dissolved ionic species in solution. Higher values may indicate higher concentrations of pollutants. There is no water quality standard for specific conductance.

Specific conductance ranged from 43 to 664 µS/cm in the LWP area (Appendix C). This range is considerable, since specific conductance's as high as 664 µS/cm are not observed in unimpacted streams in the NC piedmont. Active waste water treatment plants (WWTPs) are located above all but two of the NCDWQ-WAT monitoring stations. Only the two monitoring sites along the South Fork of Crooked Creek do not have active waste water treatment plants upstream, although the upstream reaches of the South Fork of Crooked Creek have discharges associated with development (stormwater) and agriculture.

The monitoring sites with the highest median specific conductance are two located along the North Fork of Crooked Creek, and the one located downstream of these two stations on Crooked Cr. Figure 1 depicts the locations of the monitoring stations in

relationship to the location of WWTPs. Note the Crooked Cr. WWTP has the largest permitted capacity among all the WWTPs within the LWP area of 1.9 MGD. This WWTP is just upstream of the monitoring station at SR1514 (Rocky River Rd.) It is at this monitoring station where the highest values for specific conductance were measured.

B. Chemical and Microbiological

This section describes the results of parameters that are provided by the NCDWQ Laboratory Section through various physical and chemical analyses. These parameters are best grouped as:

1. Nutrients (ammonia nitrogen, nitrite + nitrate nitrogen, total Kjeldahl nitrogen and total phosphorus).
2. Residues (total suspended solids - TSS)
3. Turbidity
4. Metals (i.e. copper)
5. Microbiological (fecal coliform bacteria).

1. Nutrients

Nutrients represent elements essential to life and include carbon, hydrogen, nitrogen, phosphorus, potassium, magnesium, calcium and others. Plant growth can be limited if a nutrient (primarily nitrogen or phosphorus) is in a limited supply. As the supply of one of these nutrients increases, so does plant growth, which in an aquatic environment is mostly algae. High levels of nutrients can cause a number of problems, ranging from nuisance algae blooms and cloudy water to threatening drinking water and harming aquatic life.

Water quality monitoring programs often measure the concentrations of three forms of nitrogen (total Kjeldahl nitrogen, ammonia nitrogen, and nitrite + nitrate nitrogen) and phosphorus (total phosphorus). Primary sources of nutrients include wastewater discharges, and runoff from land on which nutrients are applied (e.g. urban lawns, agricultural fields).

a) Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen and ammonia nitrogen in a body of water. In addition, total nitrogen is calculated by adding the concentrations of TKN to the concentrations of nitrite + nitrate nitrogen. High measurements of TKN

typically result from sewage and manure discharges to water bodies and may reflect high concentrations of ammonia nitrogen.

Among the stations within the LWP area results (N = 143) ranged from a minimum of 0.38 mg/L at the most upstream monitoring station along Goose Cr. (SR1524-Stevens Mill Rd.) to a high of 2.20 mg/L at the furthest downstream station along Crooked Cr. (SR 1547-Brief Rd., see Total Kjeldahl Nitrogen in Appendix C). This high value occurred during a storm event. Some of the other highest results also occurred during storm events, a pattern noted in the scientific literature (Bhat et al. 2006.)

Both the monitoring station along the NF Crooked Cr. at SR1514 (Rocky R. Rd.) and the station along Crooked Cr. at SR 1547 (Brief Rd) had the highest (1.0 mg/L) median values for TKN. Both of these stations are downstream of the Crooked Cr. WWTP. Sites with the lowest median values were the Goose Cr. monitoring station at SR 1524 (the most upstream monitoring station; median = 0.30 mg/L) and the reference site at Barnes Cr. (median = 0.32 mg/L). Remaining stations had median values ranging from 0.62 to 0.70 mg/L. Although TKN is present in wastewater discharges, the two monitoring sites along the South Fork of Crooked creek with no WWTPs upstream have median TKN values not dissimilar to other monitoring sites having WWTPs upstream. Agricultural land use may also be a contributing factor, particularly in the lower portions of Duck, Goose and Crooked Creeks which have significant cropland.

b) Ammonia Nitrogen

Ammonia nitrogen, under certain conditions, can be toxic to aquatic organisms and deplete oxygen during the conversion of ammonia to nitrite and nitrate.

The discussion below is divided into two parts. The first part discusses the NCDWQ-WAT monitoring data. The second part discusses results from the NCDWQ-AMS. This second part is included since ammonia-nitrogen was identified in the Technical Support Document as a possible stressor.

NCDWQ-WAT Sample Results

Overall there are no noteworthy patterns to the concentrations for ammonia nitrogen among all the NCDWQ-WAT monitoring stations. Additionally there are no noteworthy differences between baseflow and stormflow results (Appendix C). The reference site at Barnes Creek (Montgomery Co.) did not have any results above the NCDWQ-Laboratory Section reporting limit (PQL) of 0.02 mg/L. An analysis of variance performed using the results for all monitoring stations did not result in any statistical differences among sample means (results are not shown). The highest result (0.22 mg/L) occurred at the monitoring station along Duck Creek (at US 601), however the highest median concentration (0.06 mg/L) occurred at the monitoring station along the South Fork of Crooked Creek (SR 1515-Sardis Church Rd.).

Results using NCDWQ-AMS Data

Ammonia nitrogen concentrations in Goose Cr. measured through the NCDWQ-AMS are depicted in Figure . The NCDWQ-AMS station near Mint Hill is less than one mile downstream of the Hunley WWTP. Between 1995 and 2006, this WWTP discharged high concentration of ammonia nitrogen. In 2006, wastewater from the Hunley WWTP was directed to another regional WWTP, thus removing the ammonia discharges to Goose Creek. This decrease in ammonia nitrogen is seen in Figure .

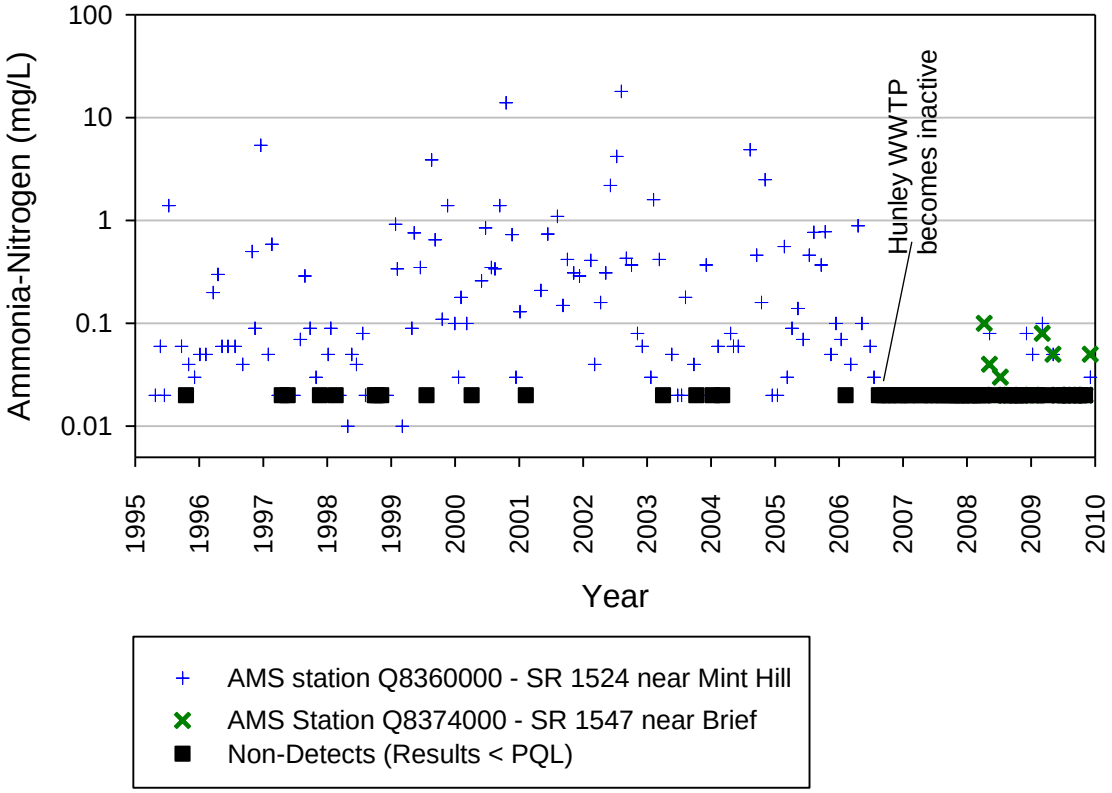


Figure 4. Ammonia nitrogen concentrations from the NCDWQ-Ambient Monitoring Stations (AMS) along Goose Creek.

c) Nitrite + nitrate Nitrogen

Nitrate nitrogen is the only nutrient for which there is a NC water quality standard (10 mg/L) for bodies of water classified as water supplies. Concentrations of nitrate exceeding 10 mg/L can cause methemoglobinemia (blue baby syndrome) in infants.

Overall the results for nitrite + nitrate nitrogen are high and reflect the influence waste water treatment plants (WWTPs) have on the concentrations for this parameter. The figure in Appendix C (page 82) depicts many results over 10.0 mg/L - the NC water quality standard for bodies of water classified as water supplies[23]. It should be noted that the analyses reported here are for nitrite + nitrate nitrogen, and the actual fraction made up of nitrate is not known. Generally, though, nitrite concentrations are very low,

[23] Although no streams within the Goose and Crooked Cr. LWP planning area have a water supply classification, the 10.0 mg/L standard for nitrate is a good beginning point for a discussion on nitrite + nitrate concentrations.

and nitrite is quickly converted to nitrate except in very cold weather. Hence, we would expect most of the nitrite + nitrate nitrogen concentrations to be in the form of nitrate. Also, none of the streams within the Goose and Crooked Cr. watershed are classified as water supplies.

The NCDWQ-WAT did not assess, during its monitoring, the effects of nutrients on water quality uses or how concentration of nutrients (e.g. nitrite + nitrate nitrogen) may be affecting water quality standards for other parameters (e.g. dissolved oxygen) that may be affected by nutrients.

NCDWQ-WAT monitoring stations in which there were no active WWTP discharges upstream did not have any results greater than 1.0 mg/L. These stations are: Goose Cr. at SR 1524 (Stevens Mill Rd.) and the two sites along the South Fork o Crooked Creek. (Additionally the reference site did not have any results exceeding 1.0 mg/L). Specific concentrations in which nitrite + nitrate nitrogen exhibit ecological effects such as algal blooms may vary geographically, however the health concerns have been established if these bodies of water were being used as drinking water.

Currently there are three on-going water quality monitoring programs within the Goose Creek and Crooked Creek LWP area. These are the NCDWQ-AMS, the YPDRBA and the Charlotte-Mecklenburg County water quality programs. Both the NCDWQ-AMS program and the Charlotte-Mecklenburg County water quality program routinely collect water quality samples within the Goose Creek watershed that include nutrients. Neither of these programs has monitoring stations within the Crooked Creek watershed. The YPDRBA program collects water quality samples within both watersheds, but only assesses nutrients within the Goose Creek watershed (not the Crooked Creek watershed[24]). Hence, there are no long-term water quality data available for the Crooked Creek watershed. Some of the highest concentrations for nitrite + nitrate nitrogen (and phosphorus – see the next section) are found at sites within the Crooked Creek watershed.

d) Phosphorus

Phosphorus is one of the necessary elements for growth of plants (algae) in freshwater ecosystems. It is often the nutrient in least supply, thus increased concentrations of phosphorus may stimulate plant growth.

[24] http://portal.ncdenr.org/c/document_library/get_file?uuid=2847305d-10dd-4b70-86ad-131e7ed17468&groupId=38364

Overall results reflect high concentrations likely due to wastewater treatment plant discharges. Among the monitoring sites with the LWP area median phosphorus concentrations ranged from 0.09 to 1.80 mg/L (see: Total Phosphorus page 82). The highest result (5.2 mg/L) occurred at monitoring site along the North Fork of Crooked Cr. at SR 1514 (Rocky River Rd.) during baseflow. This site is downstream of the Crooked Cr. WWTP.

Sites with the highest median concentrations and highest maximum values all were downstream of WWTPs (Figure). There is not a NC water quality standard for total phosphorus, nor are there any accepted thresholds as to what concentrations may have an adverse effect on freshwater streams in NC.

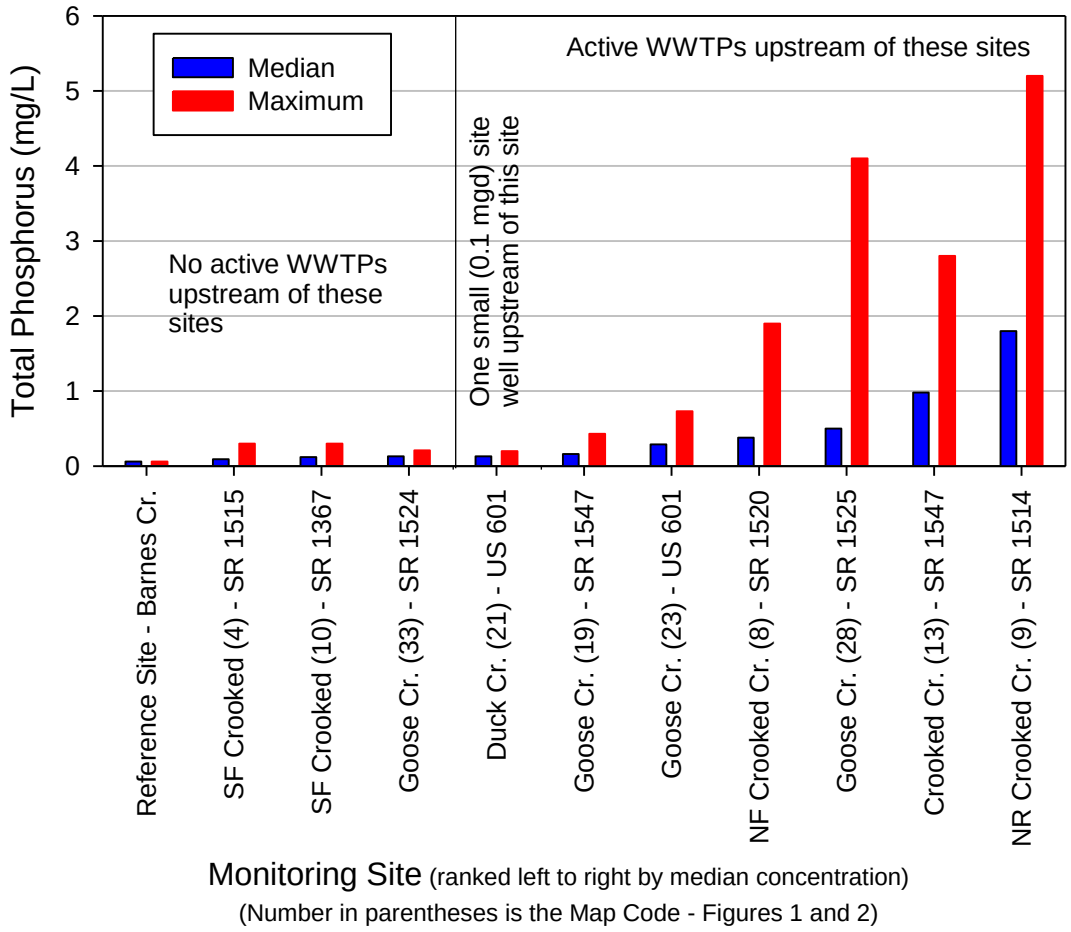


Figure 5. Relations between the median and maximum concentrations of total phosphorus and the presence of upstream wastewater treatment plants.

2. Total Suspended Solids

Total Suspended Solids (TSS) is comprised of organic and mineral particles that are transported in the water column. TSS is closely linked to land erosion and to erosion of stream banks and channels. High TSS concentrations can affect aquatic life. There is no NC water quality standard for TSS in surface waters.

Among the monitoring stations within the LWP area, results ranged from 6.2 to 162 mg/L. The highest results for TSS were measured during stormflow (Appendix C). Overall there are no notable differences in TSS results among all the sites.

3. Turbidity

Turbidity is a measure of cloudiness in water. Turbidity can be caused by soil erosion, waste discharge, urban runoff, algal growth and organisms that can stir up sediments such as fish. The NC water quality standard for turbidity varies depending on the water quality classification of a body of water. However, for all monitoring stations in the LWP area, a standard of 50 NTU applies. See Appendix C for the summary graph and table for turbidity.

Only one baseflow result from the monitoring station at SR 1524-Stevens Mill Rd. (Map Code 33) exceeded the water quality standard of 50 NTU (Appendix C). All other results for baseflow were below the standard. Most all stormflow results also exceeded the water quality standard of 50 NTU. Among the monitoring stations within the LWP area, there are no notable differences in the results for turbidity.

4. Fecal Coliform Bacteria

Historically, fecal coliform bacteria counts within Goose Creek have been high resulting in a Total Maximum Daily Load (TMDL) being developed for this watershed (see: http://portal.ncdenr.org/web/wq/ps/mtu/tmdl/tmdls#yadkin). The NCDWQ-WAT did not sample for fecal coliform bacteria within the Goose Creek watershed as part of the LWP monitoring since monitoring by other programs led to a TMDL for fecal coliform bacteria. However, the NCDWQ-WAT did sample fecal coliform bacteria as part of its Stormflow Study at two Goose Cr. sites, and those results are included in the summary graphs for Fecal Coliform Bacteria (Appendix C). Among the monitoring stations in the Crooked Cr. watershed geometric means for fecal coliform ranged from 167 to 425 cfu/100ml.

5. Copper

A good introduction to copper and water quality is found on the Environmental Protection Agency's web site[25]:

> *Copper is an abundant naturally occurring trace element found in the earth's crust that is also found in surface waters. Copper is a micronutrient at low concentrations and is essential to virtually all plants and animals. At higher concentrations copper can become toxic to aquatic life. Mining, leather and leather products, fabricated metal products, and electric equipment are a few of the industries with copper-bearing discharges that contribute to manmade discharges of copper into surface waters. Municipal effluents may also contribute additional copper loadings to surface waters."*

The NCDWQ-WAT collected water samples for copper as part of the monitoring effort to support the development of the LWP within the Goose and Crooked Cr watershed. Additionally the NCDWQ-WAT collected copper samples as part of the stormflow and biotic ligand model studies (see Section III-D, Other NCDWQ-WAT Studies within the LWP area).

Within Goose Creek, copper was one of the water quality parameters of concern listed within the Technical Support Document (USFWS *et al*. 2005; page 11):

> *Copper was listed as a parameter of concern for Goose Creek following the NCDWQ's summary of water chemistry data (NCDWQ 2002). The concern was raised because 20% of the values recorded by NCDWQ exceeded the State's 7 µg/l action level (Figure 8[26]). Many waterbodies in the Yadkin basin exceed this action level, and it is probable that a significant portion of the exceedences are associated with suspended copper (i.e., that attached to suspended sediment). No data for dissolved copper, the most toxic form to aquatic life, are available.*

Data from all three studies (Monitoring, Stormflow, and Biotic Ligand Model are presented here.

Copper Results from the LWP Monitoring

Copper results from the monitoring data are presented in Appendix C). Among all but one monitoring station there are no results above the NC action level of 7.0 µg/L. At the

[25] http://water.epa.gov/scitech/swguidance/waterquality/standards/criteria/aqlife/pollutants/copper/fs-2007.cfm

[26] "Figure 8" is in USFWS *et al*. 2005; page 12)

monitoring site along North Fork Crooked Cr (SR 1514-Rocky River Rd, Map Code 2 – see Figure 1. Locations of NCDWQ-WAT, AMS, and Coalition water quality monitoring stations and NCDWQ-BAU benthic macro-invertebrate monitoring) copper concentrations appear slightly higher than the remaining stations with two results greater than 7.0 µg/L (the NC action level).

Copper Results from the Stormflow Study

The stormflow study was initiated to better understand how sediment resuspension affects the concentrations of pollutants observed during storm events. Figure depicts the concentrations of copper from three stations associated with natural flows (NF; baseflow and storm events) and with a simulated stormflow (SS) event in which bed sediments were gently resuspended. All results from baseflow conditions were below the NC action level (7.0 µg/L). Results show higher concentrations of copper during both natural and simulated stormflow events (Figure). Thus, it probable that a significant portion of the exceedences are associated with suspended copper (i.e., that attached to suspended sediment).

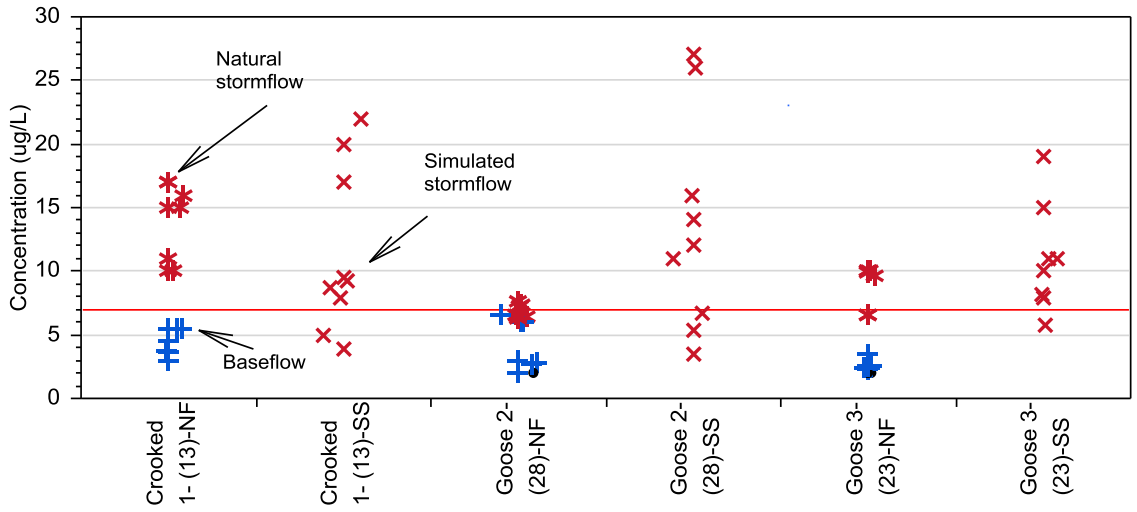


Figure 6. Copper concentrations from the Stormflow Study.

Crooked 1=Crooked Cr. at Brief Road (Map Cope 13), Goose 2=Goose Cr. at Mill Grove Rd. (Map Code 28), Goose 3=Goose Cr. at US 601 (Map Code 23). NF=Natural Flow; SS=Simulated Stormflow. The red solid line at 7.0 µg/L represents the NC action level.

Copper Results from the Biotic Ligand Model

Data collection for the Biotic Ligand Model (BLM) study for copper is continuing, however the results, to date, are presented in Figure . There are no results greater than the NC action level of 7.0 ug/L. Potential toxicity issues will be addressed once all data are collected and analyzed.

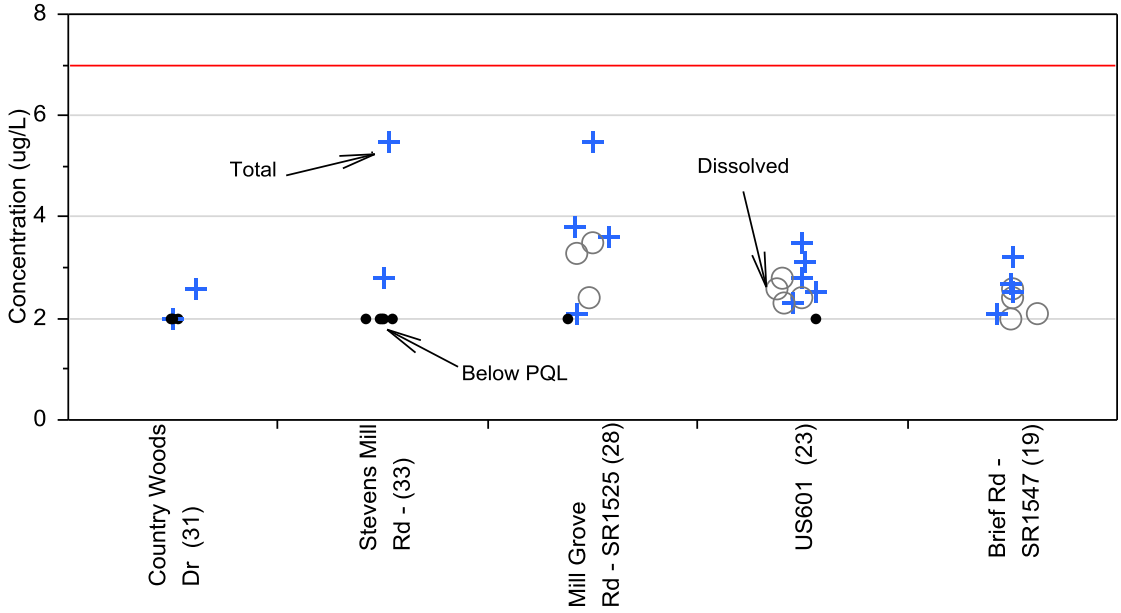


Figure 7. Copper concentrations obtained from the biotic ligand model study.

The red solid line at 7.0 µg/L represents the NC action level.

Copper Results from the NCDWQ – Ambient Monitoring Program

The Technical Support Document raised copper as a water quality concern "… *because 20% of the values recorded by NCDWQ exceeded the State's 7 µg/l action level (Figure 8")*[27]. Figure in the Technical Support Document (USFWS *et al.* 2005) depicted copper results from the NCDWQ ambient monitoring system station at Goose Cr. near Mint Hill (Station No. Q8360000) for the period 1995-2004). This figure is recreated below (Figure) using all copper results (1995-2007.), and shows that thirteen of 91 measurements (14 %) exceeded the *7* µg/l action level.

[27] "Figure 8" is in USFWS *et al.* 2005; page 12)

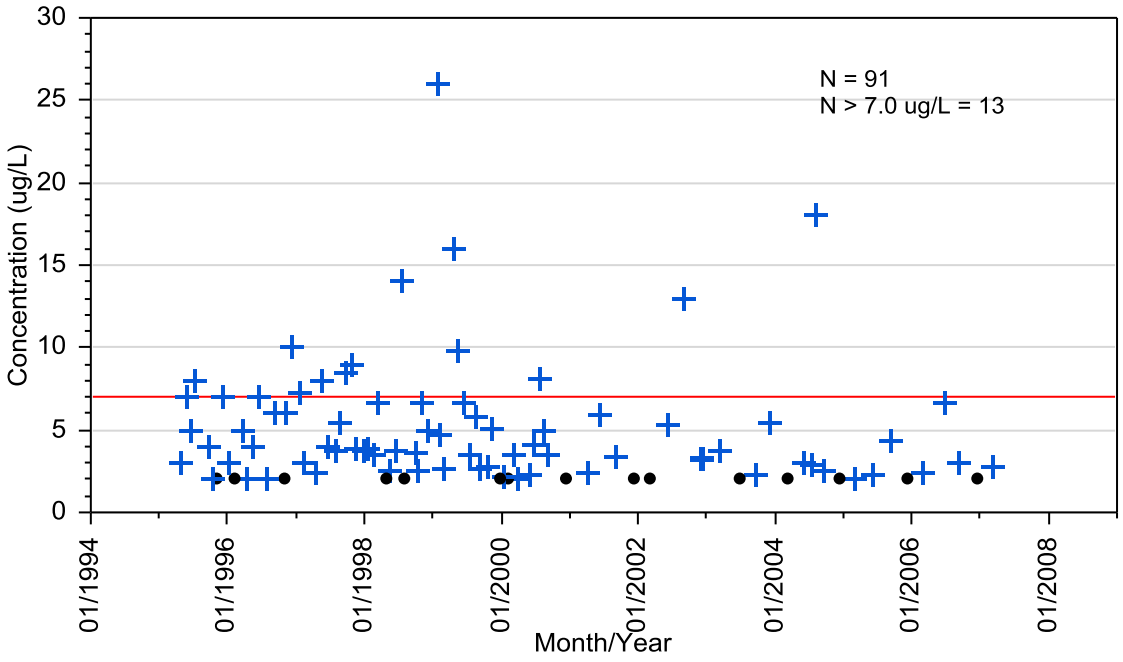


Figure 8. Copper concentrations measured from the NCDWQ ambient monitoring system station Goose Cr. at SR 1524 near Mint Hill (Q8360000).

The black dots represent results less than the laboratory's PQL. The red solid line at 7.0 µg/L represents the NC action level.

C. Biological Assessments and Habitat

Periodic monitoring of water chemistry does not give a complete picture of conditions that affect the integrity of the biological communities living in the streams. Water quality may fluctuate considerably among sampling periods, and critical events that impact aquatic life may be missed. Long-term changes in water quality also may be missed with the relatively short-term monitoring programs that occur in most watersheds. The biological community (benthic macroinvertebrates and fish) effectively integrates the impacts of all conditions within the stream over time and provides a tool to separate effects of water chemistry from habitat. More diversity and numbers of intolerant species usually indicate better water and habitat quality.

The following is a summary of the benthic macroinvertebrate results from the Executive Summary of the NCDWQ-BAU memorandum (see Appendix D, page 88):

> *In July of 2009… (EEP) requested that the BAU conduct benthic macroinvertebrate sampling at 10 sites within the Goose Creek and Crooked Creek catchments to support the development of a Local*

Watershed Plan (LWP) and for potential uses in both wetland and stream restoration projects (NCDWQ 2009). Barnes Creek, a tributary to the Uwharrie River in the Yadkin Basin was the Slate Belt Level IV Ecoregion reference stream selected for this study. Four of the 10 selected sampling locations in the Goose and Crooked Creek catchments were not sampled due to lack of sufficient stream flows. As requested, benthic macroinvertebrate sampling was conducted at seven locations during the summer of 2009.

All Crooked and Goose Creek macroinvertebrate monitoring stations within this study received Poor or Fair bioclassifications indicating continued impaired water quality in the catchment.

Many factors are potentially contributing to its degraded water quality including point and nonpoint sources. Increases in urban activities near headwater reaches may be leading to increased erosion, scour, sediment load, and periodic toxicity. Additionally, several permitted Wastewater Treatment Plants (WWTPs) are located upstream from benthic sampling locations likely contributing to more tolerant macroinvertebrate assemblages.

Studies suggest drought conditions in the Slate Belt Level IV Ecoregion continue to affect benthic communities up to one year following recovery (NCDWQ 2004). Severe drought conditions observed in 2007 and 2008 without persistent flows subsequent to the drought may contribute to lack of macroinvertebrate colonization. Fluctuating drought conditions could lead to escalated point and nonpoint source pollution via pollutants remaining in stagnant streams for longer periods and/or accumulated pollutant runoff during storm events. Either of these factors could contribute to inputs of higher pollutant concentrations and the streams ultimate degraded state, especially at headwater sampling locations in the Slate Belt Ecoregion.

Habitat

Habitat assessments also are conducted routinely in association with biological community assessments to evaluate the quality of in-stream habitat and conditions in the riparian zone that may impact aquatic life. Habitat assessments indicate if a variety of substrate types are present, the condition of stream banks and quality of riffles and pools, as well as provide a brief assessment of conditions in the riparian zone. Aquatic habitat assessments coupled with chemical and physical monitoring, can help ascertain reasons for the condition of fish and aquatic insect communities. If the habitat present is capable of supporting and maintaining a diversity of aquatic life, and the diversity of aquatic communities is depressed compared with reference conditions, then other water quality stressors may be responsible for the lack of diversity. Habitat conditions also provide evidence of altered flow regimes or hydrology due to increases in impervious surfaces in a watershed, deforestation or other perturbations such as hurricanes.

The NCDWQ-BAU memorandum (NCDWQ 2009,see Appendix D) does not provide a separate summary for habitat, since the habitat assessment is used to help interpret the benthic macroinvertebrate assessments. However, the memorandum does provide the habitat scores for each sampling location in Table 6, which is found on page 106. The habitat Total Scores reported by NCDWQ-BAU ranged from 61 to 90 within the LWP area and 92 in the benthic reference, Barnes Creek. The lowest score (61) occurred in North Fork Crooked Creek at SR1514 and was a reflection of poor scores for the submetrics In-Stream Habitat, Bottom Substrate, Riffle Habitat, and Bank Stability. The second lowest score (77) occurred in Goose Creek at SR1524 and reflected poor Bank Stability. All other scores within the LWP area were 86 or higher. Habitat scores from the NCDWQ-BAU assessment (NCDWQ 2009) and the NCDOT (memo in progress) fish assessment also are provided as part of Appendix A – Description of the Monitoring Stations.

Tetra Tech (2008) completed a watershed-wide assessment of aquatic habitat, representing 37 locations.

D. Flow

Flow can influence concentrations of pollutants in streams (e.g. see higher turbidity levels during storm flow in Appendix C) and aquatic life (e.g. Golladay *et al*. 2004). In this *Integrated Analysis Report* flow data were used for two purposes. First, North Carolina during the past decade experienced periods of drought. To illustrate this, flow

data since 2000 were graphed to provide a visual representation of stream flow, and, secondly, to show the range in flows during which the physical and chemical samples were taken.

Droughts in North Carolina since 1997 have been noted by the USGS (Weaver 2005, Bales 2008). The North Carolina Drought Management Advisory Council referred to the 2007 drought as the "*Worst Drought in North Carolina Since 1895. The drought in 2007 was the worst for North Carolina since record keeping began in North Carolina in 1895. In 2007, conditions in the state went from no drought to record drought in less than one year*" (NCDMAC 2009). Much of the stream flow within Goose Cr. was low[28] (flow less than the 25th percentile) during many years during the past decade (Figure 9, page 42). The NCDWQ-WAT monitoring activities were initiated during the 2009 drought; some monitoring stations could not be sampled due to lack of flow.

One generally accepted relationship between stream flow and pollutants is that where pollutants originate from point sources, such as WWTPs, the concentrations of pollutants will increase as stream flow decreases. This is due to less stream water to dilute the pollutants so pollutant concentrations increase. This relationship can be visualized through flow-concentration curves[29]. A flow-concentration curve for one of the NCDWQ-WAT sample sites downstream of the Crooked Cr WWTP would likely reveal this relationship between flow and pollutant concentrations. However, due to a very small sample size for pollutant concentrations and the lack of flow information, this was not done.

[28] Periods of low flow within Goose Cr., as indicated through the USGS gaging station, is indicative of low flow within the Goose and Crooked Cr. watersheds, due to periods of decreased precipitation.
[29] For example see: http://wql-data.heidelberg.edu/2.e.%20Concentration-Flow%20Relationships.pdf

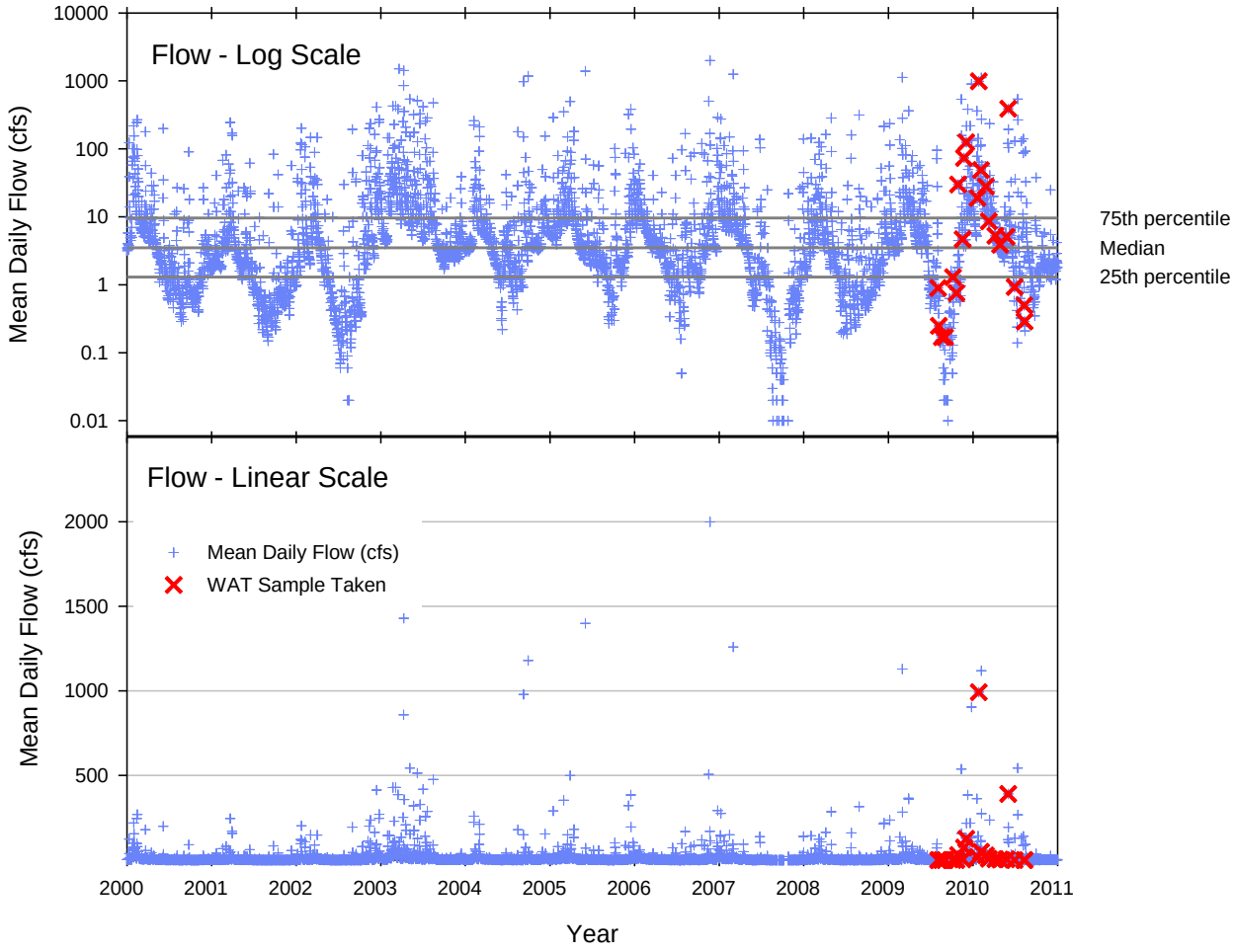


Figure 9. Flow at the USGS gaging station (02124692) along Goose Cr. at Fairview.

The red "X" represents a NCDWQ sample taken as part of: 1) the LWP monitoring effort, 2) the stormflow study, or 3) the biotic ligand model study.

VI. Discussion

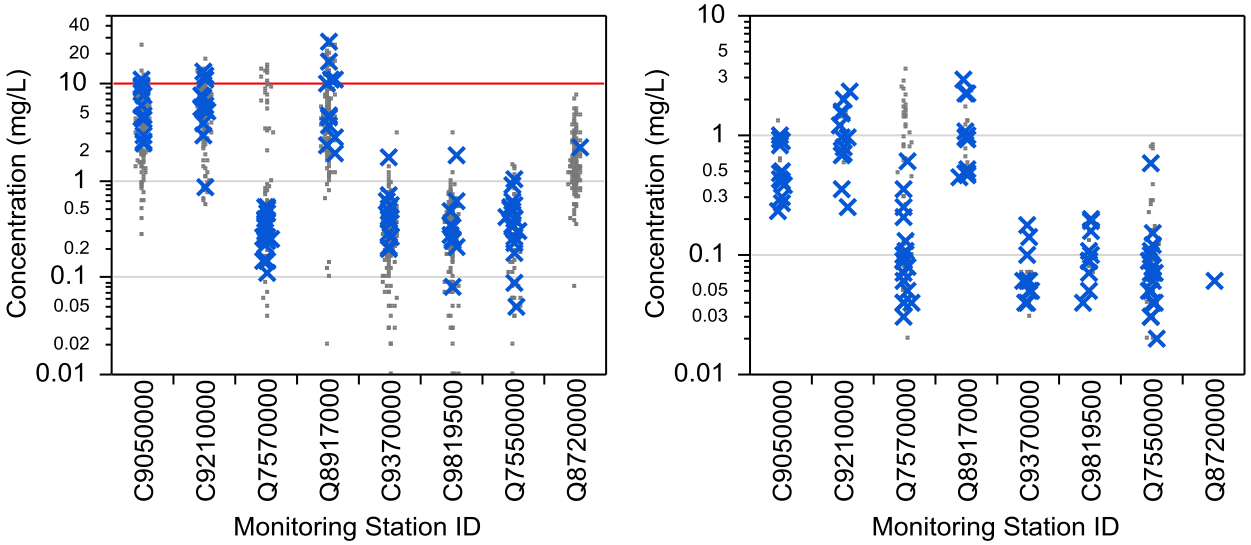
The characterization of water quality in this report was limited to a summary of physical and chemical data collected over a period of 14 months from ten sites, which were obtained primarily to support the development of a water quality model. However, the data were also useful in describing the physical and chemical conditions at the ten sites within the watershed. The Goose and Crooked Creek watershed is within close proximity to Charlotte, NC and portions of this watershed have been and are becoming developed. As a result, many factors, such as discharges from stormwater, wastewater treatment and non-point sources, contribute to water quality conditions.
In 2005, the Technical Support Document (USFWS et al. 2005) outlined a variety of water quality concerns within the Goose Creek watershed. These included:

1. Bank / Channel Instability
2. Sediment / Suspended Solids
3. Ammonia
4. Dissolved oxygen (seasonally)
5. Chlorine
6. Nitrate / Nitrite
7. Phosphorus
8. Pesticides
9. Fecal coliform bacteria
10. Copper

It is likely all of these concerns would apply to water quality in the Crooked Creek watershed, since the Goose Creek and Crooked Creek watersheds are contiguous. Although this *Integrated Analysis Report* focuses only on physical and chemical results, the reader should not ignore that other factors (e.g. bank and channel instability, suspended sediment) are important water quality considerations as well but are not addressed here.

The Results section discussed the role WWTPs have on concentrations of nutrients within the Goose Creek and Crooked Creek watersheds. Water quality monitoring sites located downstream of WWTPs are more likely to show results with higher concentrations of nutrients than monitoring sites without WWTPs upstream. This observation is not limited to the Goose and Crooked Cr. watershed, but can be found throughout the state.

Figure depicts concentrations of nitrite + nitrate nitrogen and total phosphorus from eight NCDWQ-AMS monitoring stations located within a 25-mile radius but outside of the Goose and Crooked Cr. LWP planning area (Table 5). The four stations on the left side of the figure are located downstream of major (effluent > 1 MGD) discharges, whereas the four stations on the right are either not downstream of any wastewater treatment plants or are downstream of those WWTPs classified as minor. Another way of visualizing how discharges from WWTPs can influence concentrations of nutrients is to sample upstream and downstream of a WWTP. The NCDWQ-AMS monitoring stations Q7550000 and Q7570000 are located upstream (~ 2 miles) and downstream (~3 miles) of the Mallard Creek wastewater treatment plant (NPDES permit number NC0030210) respectively. Monitoring results for these two stations are also depicted on Figure , and show higher concentrations at the monitoring site downstream of the WWTP.



A. Nitrite + Nitrate

B. Total phosphorus

Figure 10. Contribution that WWTPs may have on: A) nitrite + nitrate nitrogen, and B) total phosphorus concentrations at water quality monitoring sites

The red horizontal line at 10 mg/L on the graph for nitrite-nitrate represents the water quality standard for nitrate for bodies of water classified as water supplies. The blue X symbols represent results since January 1, 2009, a period that is similar to the one used for monitoring within the Goose and Crooked Creek watersheds. See Table 5 for a description of the locations of the monitoring sites.

Table 5. Location of the NC Division of Water Quality Ambient Monitoring Stations used in Figure .

Station ID	Location
C9050000	Sugar Crk at NC 51 at Pineville
C9210000	Little Sugar Crk at NC 51 at Pineville
Q7570000	Mallard Crk at Morehead Rd (SR 1300) near Harrisburg
Q8917000	Richardson Crk at SR 1649 near Fairfield
C9370000	McAlpine Crk at SR 3356 Sardis Rd near Charlotte
C9819500	Twelve Mile Crk at NC 16 near Waxhaw
Q7550000	Mallard Crk at Pavillion Rd. near Harrisburg
Q8720000	Long Crk at SR 1917 near Rocky River Springs

Note that the concentrations of nitrite + nitrate nitrogen and total phosphorus from the monitoring stations located outside the Goose and Crooked Creek LWP planning area and downstream of WWTPs are not dissimilar to those sites located downstream of WWTPs within the LWP planning area (see Appendix C, pages 82 and 83). Although concentrations for nutrients are likely to be greater at monitoring locations downstream of WWTPs, the impacts of nitrite + nitrate, and phosphorus on stream ecosystems are not well understood as they are in lakes and reservoirs. Additionally, WWTPs typically receive extremely high concentrations of ammonia nitrogen (>25 mg/L) – a form of nitrogen that if discharged to streams untreated would have serious impacts to stream ecosystems. One component of the wastewater treatment process that is closely controlled and regulated is the conversion of ammonia nitrogen to nitrite + nitrate nitrogen. Thus, concentrations of nitrite-nitrate are often greater downstream of WWTP discharges, especially under low streamflow conditions. For example, effluent data for the Crooked Creek WWTP for 2009 showed consistently non-detectable ammonia concentrations, while total nitrogen concentrations ranged from 20 to 39 mg/L, indicating that all ammonia had been converted to other forms of nitrogen.

With regard to current active NPDES dischargers to Goose Creek/Duck/Stevens Creeks - there were initially six active dischargers but only three were active during the LWP monitoring:

1. Aqua North Carolina/Country Wood (NPDES permit # NC0065684);
2. Aqua North Carolina/Ashe Plantation (# NC0065749);
3. Aqua North Carolina/Oxford Glenn (#NC0063584).

All three remaining Aqua North Carolina WWTPs utilize ultraviolet (UV) disinfection to alleviate chlorine toxicity concerns, and will receive ammonia limits of 0.5 mg/l NH3-N consistent with the Goose Creek Rules. Previously active dischargers that are now off-line included: Fairview Elementary (# NC0034762, not shown on map) switched to on-site septic, Union County PWD/Hunley Creek (#NC0072508) connected to Union County

system in 2006, and Goose Creek Utility/Fairfield Plantation (NC0034762) was connected to Union County in 2011. The only major WWTP in this study area is Union County/Crooked Creek WWTP (# NC0069841), which discharges to North Fork Crooked Creek. This is the only facility that conducts a chronic toxicity test. The quarterly toxicity test results from 2007-2010 show 20 of 23 "Pass" test results.

Urban runoff, agriculture and WWTP discharges all likely had an influence on the concentrations of nutrients in the greater Goose and Crooked Creek watersheds. However, the primary contributors to nutrient concentrations during low flows in the streams appear to be the WWTPs, as nutrient concentrations downstream from the plants generally were much higher than those upstream from the influence of WWTPs. Both urban runoff and agricultural activities would be more important contributors during moderate to high flow conditions.

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Appendices (see separate document for appendices)

Appendix A. Description of the Monitoring stations

Appendix B. Practical Quantitation Limits (PQL) and NC Water Quality Standards and Action Levels

Appendix C. Summary Graphs and Tables for the LWP Monitoring Results

Appendix D. Benthic Macroinvertebrate Memorandum

Appendices to the Goose-Crooked Creek Final Report

Appendix A. Description of the Monitoring stations

Appendix B. Practical Quantitation Limits (PQL) and NC Water Quality Standards and Action Levels

Appendix C. Summary Graphs ant Tables for the LWP Monitoring Results

Appendix D. Benthic Macroinvertebrate Memorandum

A. Appendix A – Description of the Monitoring Stations

Goose Creek at Stevens Mill Rd. (SR1524)

MAP CODE: 33
EEP Subwatershed ID: GC9
LATITUDE: 35.1312
LONGITUDE: -80.6315
STREAM CLASSIFICATION: C
DRAINAGE AREA: 8.5 sq. mi
NCDWQ-BAU Bioclassifications: Good-Fair (1998); Fair (2009)
NCDWQ-BAU Habitat Score: 77 (2009)
NCDWQ-WAT Habitat Score: 65 (2010)
Cumulative Imperviousness 10%

The stream at this site has high, steep banks in some places, but also has access to an extensive flood plain forest area. Channel substrate is a mix of sand, gravel, cobble, boulder and bedrock, with habitat scores in 2009 of 65 and 77 out of 100, indicating moderately good habitat for aquatic organisms.

The 8.5 square mile drainage area consists primarily of forest and developed areas, with a moderate cumulative imperviousness (10%) compared to other sampling sites in this study. One permitted point source discharge is located upstream of this site, with a permitted flow of about 0.08 MGD.
During low flow periods, flow was always present at this site.

This site was chosen to be monitored for water chemistry due to its location at the upstream end of the impaired reach of Goose Creek, and the availability of benthic data. The water chemistry results indicate a low to moderate level of impacts from point and non-point pollution: specific conductance, nutrients and copper here were among the lower values observed in Goose Creek, while turbidity, suspended solids and fecal coliform bacteria were moderate to high compared to other sites.

DRAFT



Figure A-1. Goose Creek at Stevens Mill Rd. (SR1524)
Top: upstream. Bottom: downstream.

DRAFT

Goose Creek at Mill Grove Rd. (SR1525)

MAP CODE: 28
EEP Subwatershed ID: GC8
LATITUDE: 35.1250
LONGITUDE: -80.6029
STREAM CLASSIFICATION: C
DRAINAGE AREA: 11 sq. mi.
NCDWQ-BAU Bioclassifications: Poor (1998), Fair (2009)
NCDWQ-BAU Habitat Score: 90 (2009)
NCDWQ-WAT Habitat Score: 68 (2010)
Cumulative Imperviousness 10%

The stream at this site has high, steep banks in some places, but also has access to an extensive flood plain forest area. Channel substrate is a mix of sand, gravel, cobble, boulder and bedrock, with habitat scores in 2009 of 68 and 90 out of 100, indicating either moderate or very good habitat for aquatic organisms. *[It is not clear why the two habitat scores showed such a large discrepancy.]*

The 11 square mile drainage area consists primarily of forest and developed areas, with a moderate cumulative imperviousness (10%) compared to other sampling sites in this study. A total of three permitted point source discharges are located upstream of this site, with total permitted flows of about 0.8 MGD.

During low flow periods, flow was always present at this site.

This site was chosen to be monitored for water chemistry due to its location within the impaired reach of Goose Creek and downstream of a WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a moderate to high level of impact due to both point and non-point pollution: values of most parameters were among the highest observed on Goose Creek, and distinctly higher than the site immediately upstream. This was true for both baseflow and stormflow samples taken here.

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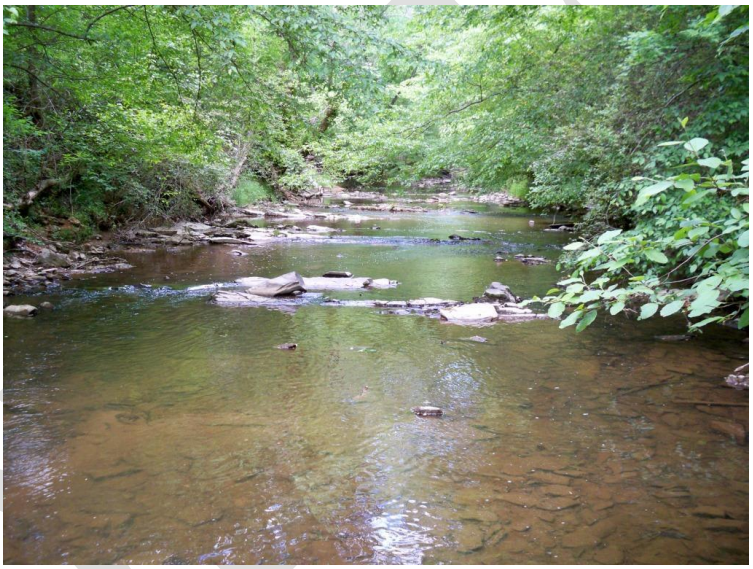


Figure A-2. Goose Creek at Mill Grove Rd. (SR1525)
Top: upstream. Bottom: further upstream.

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Goose Creek at US 601

MAP CODE: 23
EEP Subwatershed ID: GC4
LATITUDE: 35.1537
LONGITUDE: -80.5353
STREAM CLASSIFICATION: C
DRAINAGE AREA: 24 sq. mi. USGS
NCDWQ-BAU Bioclassifications: Poor (1996, 1998, 2001), Fair (2006, and 2009)
NCDWQ-BAU Habitat Score: 88 (2009)
NCDWQ-WAT Habitat Score: 72 (2010)
Cumulative Imperviousness 7%

The stream at this site has high, steep banks in some places, but also has access to an extensive flood plain forest area. Channel substrate is a mix of sand, gravel, cobble, boulder and bedrock, with a habitat score of 88 out of 100, indicating very good habitat for aquatic organisms.

The 24 square mile drainage area consists primarily of forest, agriculture and developed areas, with the third-to-lowest cumulative imperviousness (7%) of sampling sites in this study. A total of four permitted point source discharges are located upstream of this site, with total permitted flows of about 0.9 MGD.

During low flow periods, this site showed very low flows but did not reach zero flow except on the September 17, 2009 sampling date.

This site was chosen to be monitored for water chemistry due to its location within the impaired reach of Goose Creek, but not immediately downstream of a WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a moderate to high level of impact due to both point and non-point pollution: values of most parameters were among the highest observed on Goose Creek, but somewhat lower than the site immediately upstream. This was true for both baseflow and stormflow samples taken here.

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Figure A-3. Goose Creek at US 601.
Top: upstream. Bottom: downstream.

DRAFT

Duck Creek at US 601

MAP CODE: 21
Subwatershed ID: DC2
LATITUDE: 35.1803
LONGITUDE: -80.5404
STREAM CLASSIFICATION: C
DRAINAGE AREA: 9 sq. mi. approx.
NCDWQ-BAU Bioclassifications: Fair (1998), Not sampled due to low flow (2009)
NCDWQ-WAT Habitat Score: 63 (2010)
Cumulative Imperviousness 4%

The stream at this site has high, steep banks in some places, but also has access to an extensive flood plain forest area. Channel substrate is a mix of sand, gravel, cobble, boulder and bedrock, with a habitat score of 63 out of 100, indicating moderately good habitat for aquatic organisms.

The nine square mile drainage area consists primarily of forest, agriculture and residential areas, with the lowest cumulative imperviousness (4%) of all sampling sites in this study. One permitted point source discharge (Ashe Plantation, 0.1 MGD) is located upstream of this site.

During low flow periods, this site showed the lowest flows of all sampling sites. It could not be sampled on the September 2 and 17, and October 6 and 21, 2009 sampling dates. By the November 17, 2009 sampling date adequate flow had resumed.

This site was chosen to be monitored for water chemistry due to its location within the impaired reach of Duck Creek, but not immediately downstream of a WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a low to moderate level of impact due to both point and non-point pollution: values of most parameters were among the lowest observed in this study. This was true for both baseflow and stormflow samples taken here.

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Figure A-4. Duck Creek at US 601.
Top: upstream. Bottom: downstream

DRAFT

Goose Creek at Brief Rd. (SR1547)

MAP CODE: 19
EEP Subwatershed ID: GC1
LATITUDE: 35.1757
LONGITUDE: -80.5112
STREAM CLASSIFICATION: C Impaired
DRAINAGE AREA: 38 sq. mi. approx.
NCDWQ-BAU Bioclassifications: Fair (1998 and 2009)
NCDWQ-BAU Habitat Score: 86 (2009)
Cumulative Imperviousness 5%

The stream at this site has high, steep banks in some places, but also has access to an extensive flood plain forest area. Channel substrate is a mix of sand, gravel, cobble, boulder and bedrock, with a habitat score of 86 out of 100, indicating very good habitat for aquatic organisms.

The 38 square mile drainage area consists primarily of forest, agriculture and developed areas, with the second-to-lowest cumulative imperviousness (5%) of sampling sites in this study. A total of five permitted point source discharges are located upstream of this site, with total permitted flows of about one MGD.

During low flow periods, this site showed very low flows but did not reach zero flow except on the September 17, 2009 sampling date.

This site was chosen to be monitored for water chemistry due to its location within the impaired reach of Goose Creek, but not immediately downstream of a WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a moderate to high level of impact due to both point and non-point pollution: values of most parameters were among the highest observed on Goose Creek, and very similar to the site immediately upstream. This was true for both baseflow and stormflow samples taken here.

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Figure A-5. Goose Creek at Brief Rd. (SR1547).
Top: upstream. Bottom: downstream

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North Fork Crooked Creek at Indian Trail Fairview Rd. (SR1520)

MAP CODE: 8
EEP Subwatershed ID: NF4
LATITUDE: 35.1078
LONGITUDE: -80.6155
STREAM CLASSIFICATION: C Impaired
DRAINAGE AREA: 9 sq. mi. approx.
NCDWQ-BAU Bioclassifications: Fair (2000), Not sampled due to low flow (2009)
NCDWQ-WAT Habitat Score: 56 (2010)
Cumulative Imperviousness 15%

The stream is incised, with steep banks in most places. The channel substrate is mostly sand, with limited habitat for aquatic organisms (Habitat Score 56 out of 100).

The nine square mile drainage area above this site includes residential, commercial and undeveloped forest areas; drainage includes parts of the highly developed I-485 and US 74 corridors. Imperviousness is the third highest among the sampling locations in this study. One permitted point source (Hemby Acres WWTP, 0.3 MGD) discharges upstream of this site.

During low flow periods, the stream was never dry, but no visible current was noted on some occasions.

This site was chosen to be monitored for water chemistry due to its location within the impaired reach of Crooked Creek, but not immediately downstream of a large WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a moderate to high level of impact due to mostly non-point pollution: values of most parameters were among the highest observed on Crooked Creek. This was true for both baseflow and stormflow samples taken here.

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Figure A-6. N. Fork Crooked Creek at Indian Trail Fairview Rd. (SR1520).
Top: upstream. Bottom: downstream

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North Fork Crooked Creek at Rocky River Rd. (SR1514)

MAP CODE: 9
EEP Subwatershed ID: NF2
LATITUDE: 35.1024
LONGITUDE: -80.5842
STREAM CLASSIFICATION: C Impaired
DRAINAGE AREA: 15 sq. mi. approx.
NCDWQ-BAU Bioclassifications: Good-Fair (1995), Fair (2000), Poor (2009)
NCDWQ-BAU Habitat Score (2009): 61
NCDWQ-WAT Habitat Score (2010): 49
Cumulative Imperviousness 14%

The stream is incised, with steep banks in most places. The channel substrate is mostly sand.

The 15 square mile drainage area includes the nine square miles of the SR1520 site (above), which is highly developed. It also includes six square miles of mostly residential area, for a cumulative imperviousness of 14%. Two permitted point source discharge points exist upstream of this site. The first is the Hemby Acres facility noted for the SR1520 site, and the second is the discharge point for the Crooked Creek #2 WWTP, noted in the South Fork Crooked Creek at Sardis Rd. description. This latter facility is classified as a Major discharger, with a permitted discharge rate of 1.9 MGD.

During low flow periods, the stream was never dry, and current was always discernible.

This site was chosen to be monitored for water chemistry due to its location within the impaired reach of Crooked Creek, and immediately downstream of a major WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a moderate to high level of impact due to both point and non-point pollution: values of most parameters were among the highest observed in this study and higher than the site immediately upstream. This was true for both baseflow and stormflow samples taken here. Nitrate + nitrite, total phosphorus and specific conductance were very high during low flow conditions.

DRAFT



Figure A-7. N. Fork Crooked Creek at Rocky River Rd. (SR1514).
Top: upstream. Bottom: downstream

DRAFT

South Fork Crooked Creek at Sardis Church Rd. (SR1515)

MAP CODE: 4
EEP Subwatershed ID: SF5
LATITUDE: 35.0663
LONGITUDE: -80.6297
STREAM CLASSIFICATION: C Impaired
DRAINAGE AREA: 6 sq. mi. approx.
NCDWQ-BAU Bioclassifications: Fair (1995), Not sampled due to low flow (2009)
NCDWQ-WAT Habitat Score: 35 (2010)
Cumulative Imperviousness 24%

The stream is incised, with steep banks. The channel substrate is mostly sand, with limited habitat for aquatic organisms (Habitat Score 35 out of 100). No riffles are visible within the reach.

Land use upstream of this site is mostly residential and commercial, with remnants of forest. Cumulative imperviousness at this site (24%) is the highest of any of the monitoring sites in this study. The drainage area includes more than one mile of the US 74 (Independence Blvd) corridor. The Crooked Creek #2 WWTP treatment facilities are located just upstream of this site, but its discharge point is not. The treated effluent from this facility is pumped to a discharge point on the North Fork of Crooked Creek, upstream of Rocky River Road (see Description of North Fork Crooked Creek at Rocky River Rd. (SR1514). There are no permitted point source discharges upstream of this site.

During low flow periods, the stream was never dry, but no visible current was noted on some occasions.

This site was chosen to be monitored for water chemistry due to its location within the impaired reach of Crooked Creek, but not downstream of a WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a low level of impact due to mostly non-point pollution: values of most parameters were among the lowest observed on Crooked Creek. This was true for both baseflow and stormflow samples taken here.

DRAFT



Figure A-8. S. Fork Crooked Cr. at Unionville Indian Trail Rd. (SR1367).
Top: upstream. Bottom: downstream

DRAFT

South Fork Crooked Creek at Unionville Indian Trail Rd. (SR1367)

MAP CODE: 10
EEP Subwatershed ID: SF3
LATITUDE: 35.0744
LONGITUDE: -80.5863
STREAM CLASSIFICATION: C Impaired
DRAINAGE AREA: 12 sq. mi. approx.
NCDWQ-BAU Bioclassifications: Fair (1995), Not sampled due to low flow (2009)
Cumulative Imperviousness 18%

The stream channel is slightly to moderately incised. The channel substrate is a mix of gravel, cobble and boulder, with minimal sand. Habitat for aquatic organisms appears to be adequate, but a numerical Habitat Assessment was not done at this site. Riffles and pools are both present during periods of adequate flow.

The twelve square mile drainage area at this site includes the six square miles described for the site on Sardis Rd., which is highly developed, plus another six square miles of less highly developed land. The resulting cumulative imperviousness is 18%, ranking second highest among all sampling sites. There are no permitted point source discharges upstream of this site.

This site had extremely low or zero flow for the second-longest period of any of the sites sampled for this study. Flow was too low to sample on three occasions: August 19, September 2 and September 17, 2009. By October 9, flow had returned.

This site was chosen to be monitored for water chemistry due to its location within the impaired reach of Crooked Creek, but not downstream of a WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a low level of impact due to mostly non-point pollution: values of most parameters were among the lowest observed on Crooked Creek, and very similar to the site immediately upstream on the South Fork of Crooked Creek. This was true for both baseflow and stormflow samples taken here.

DRAFT



Figure A-9. S. Fork Crooked Cr. at Unionville Indian Trail Rd. (SR1367).
Top: upstream. Bottom: downstream.

DRAFT

Crooked Creek at Brief Rd. (SR1547)

MAP CODE: 13
EEP Subwatershed ID: CC2
LATITUDE: 35.1447
LONGITUDE: -80.4717
STREAM CLASSIFICATION: C Not Impaired
DRAINAGE AREA: 48 sq. mi. approx.
NCDWQ-BAU Bioclassifications: Fair (1996), Good-Fair (2001), Good-Fair (2006), Fair (2009)
NCDWQ-BAU Habitat Score (2009): 88
NCDWA-WAT Habitat Score (2010): 71
Cumulative Imperviousness 10%

The stream channel is slightly to moderately incised. The channel substrate is a mix of gravel, cobble and boulder, with minimal sand. Habitat for aquatic organisms was assessed as good, with scores of 71 and 88 out of 100.

The 48 square mile drainage area includes the highly developed areas in the headwaters of both the North and South Forks of Crooked Creek, but also includes the predominantly agricultural and forest areas of the lower Crooked Creek drainage. Cumulative imperviousness is estimated at 10%. Point source discharges upstream of this site include Hemby Acres, Crooked Creek #2, and Grassy Branch WWTP, with a total permitted flow of 2.25 MGD.

During low flow periods, flow was always present at this site. Filamentous algae growth was often present here.

This site was chosen to be monitored for water chemistry due to its location downstream of the impaired reach of Crooked Creek, and not immediately downstream of a major WWTP. Another factor was the availability of benthic data. The water chemistry results indicate a moderate to high level of impact due to both point and non-point pollution: values of most parameters were among the highest observed in this study, but lower than the sites immediately upstream on the North Fork. This was true for both baseflow and stormflow samples taken here. Nitrate + nitrite, total phosphorus and specific conductance were high during low flow conditions, while copper and total phosphorus were notably high during stormflow conditions.

DRAFT



Figure A-10. Crooked Creek at Brief Rd. (SR1547).
Top: upstream. Bottom: downstream.

Barnes Creek at Ophir Rd. (SR1303) Reference Location

MAP CODE: n/a;
EEP Subwatershed ID: n/a
LATITUDE: 35.4386
LONGITUDE: -80.0006
STREAM CLASSIFICATION: C
DRAINAGE AREA: 21 sq. mi. approx.
NCDWQ-BAU Bioclassifications: Nine times since 1985; Excellent – 6 times, Good – 3 times including 2009
NCDWQ-BAU Habitat Score: 92 (2009)
Cumulative Imperviousness: unknown

This site has served as a slate belt benthic reference location for many years. It is located in the Uwharrie National Forest. The stream at this site has access to an extensive flood plain forest area. Channel substrate is a mix of sand, gravel, cobble, boulder and bedrock, with a habitat score in 2009 of 92 out of 100, indicating very good habitat for aquatic organisms.

The 21 square mile drainage area consists almost entirely of forest. Cumulative imperviousness, while not known quantitatively, would be very low. No permitted point source discharges are located upstream of this site.

During low flow periods, flow was always present at this site.

This site was chosen for water chemistry monitoring due to its status as a benthic reference location, with Good to Excellent bioclassifications. Water chemistry results at this location during baseflow conditions indicated very low levels of impact from point or non-point sources: values for all parameters were consistently the lowest among all locations sampled. No stormflow samples were taken at this site.

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Figure A-11. Barnes Creek at Ophir Rd. (SR1303)
Top: upstream. Bottom: downstream

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B. Appendix B – Practical Quantitation Limits (PQL) and NC Water Quality Standards and Action Levels

Parameter	PQL	Standards and Action Levels	
		Class C, WS-II and WS-IV	
Field measurements			
Dissolved oxygen (mg/L)	0.1	4.0 (instantaneous) 5.0 (daily mean)	
Saturation of dissolved gases (%)	1	110%[1]	
Specific conductance (µS/cm)	1	--	
Water temperature (C)	0.1	32	
pH (SU)	0.1	6.0-9.0	
Fecal coliform bacteria (cfu/100 ml)	1	Geometric mean > 200[2] >20% samples > 400	
		Class C	Classes WS-II and WS-IV
Nutrients (mg/L)			
Ammonia as N	0.01	--	--
Nitrite+Nitrate as N	0.01	--	10.0 (NO_3^-)
Total Kjeldahl Nitrogen as N	0.20	--	--
Total phosphorus	0.02	--	--
Metals, total			
Arsenic (As; µg/L)	2	50	10
Cadmium (Cd; µg/L)	1	2.0	--
Copper (Cu; µg/L)	2	7[3]	7[3]
Iron (Fe; µg/L)	50	1000[3]	--
Nickel (N; µg/L)	10	88	25
Zinc (Zn; µg/L)	10	50[3]	50[3]
Other			
Total suspended solids (mg/L)	6.2	--	--
Turbidity (NTU)	2	50	50

[1] Standard applies to all dissolved gases combined, not just oxygen alone

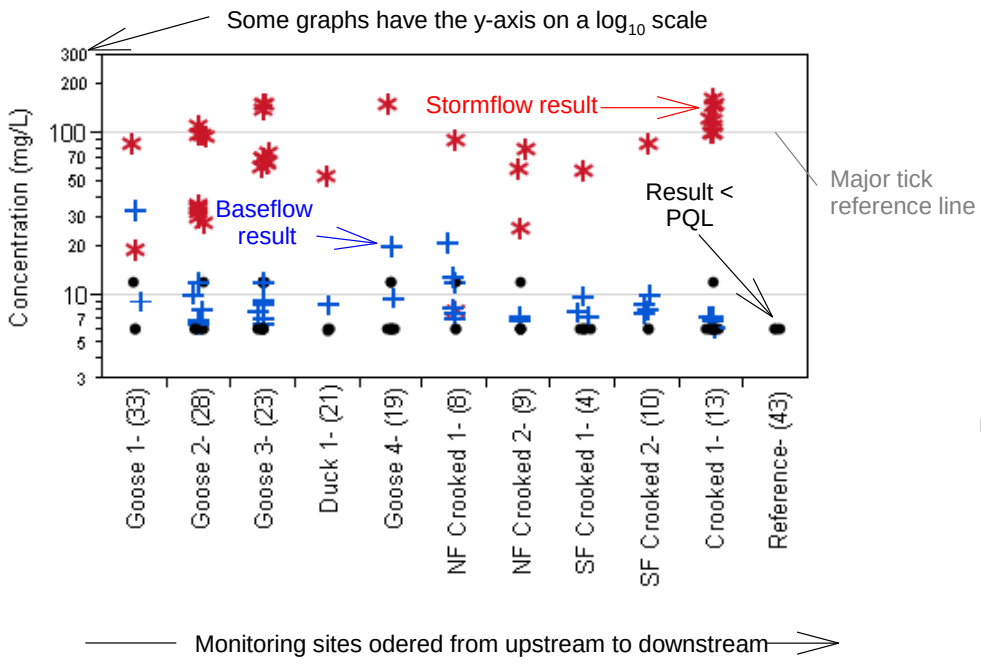
[2] Standard is based on five consecutive samples taken during a 30-day period

[3] Action level

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C. Appendix C– Summary Graphs and Tables for the LWP Monitoring Results

Understanding the summary graphs and tables



--Blue plus symbols (+) = Baseflow result

--Red asterisk symbols (*)= Stormflow result

--Black dots (•) = Result less than the NCDWQ-Laboratory Section method detection level (PQL)

-- Sites are ordered from left to right to represent upstream sites (e.g. Goose 1) to downstream sites (e.g. Goose 4)

-- Parameters with reference levels (e.g. water quality standard) will have a horizontal line depicting the reference level

Key to the graphs

Key to the Tables

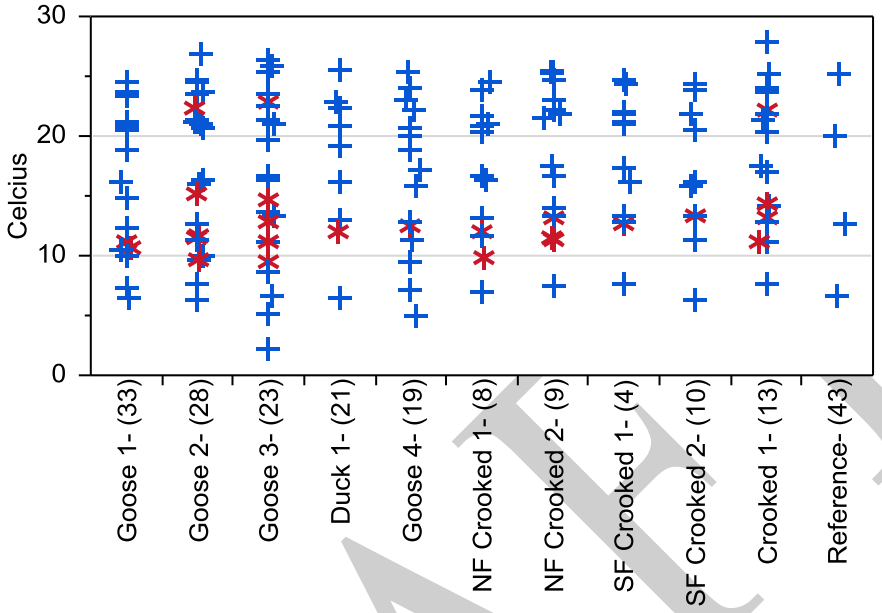
Creek (Map Code)	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	0.03	0.02	0.02	0.02	0.03	0.13
Goose 2- (28)	SR 1525- Mill Grove Rd.	18	0.05	0.02	0.02	0.05	0.08	0.12

Under the column Creek (Map Code) the map code is used on Figures 1 and 2.

N= Number of samples; x̄ = mean; Min = minimum; 25% = 25th percentile 50%=median; 75%=75th percentile; Max=maximum

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Water Temperature



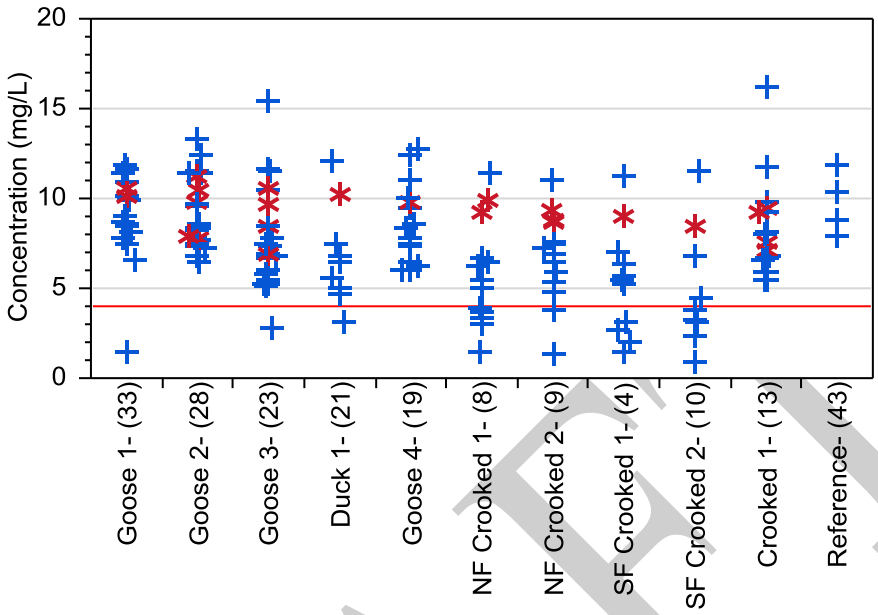
Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	16.0	6.5	10.6	16.1	21.0	24.5
Goose 2- (28)	SR 1525- Mill Grove Rd.	23	16.9	6.4	11.4	16.4	22.4	26.9
Goose 3- (23)	US 601	23	16.3	2.1	11.2	16.4	22.9	26.3
Duck 1- (21)	US 601	9	17.6	6.5	12.5	19.2	22.7	25.5
Goose 4- (19)	SR 1547-Brief Rd.	15	16.4	5.0	11.4	17.2	22.2	25.4
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	16.8	7.0	11.9	16.6	21.4	24.5
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	14	17.4	7.5	12.7	17.1	22.4	25.4
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	12	17.9	7.6	13.0	19.2	22.0	24.7
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	10	16.7	6.4	12.9	16.1	22.4	24.3
Crooked 1- (13)	SR 1547-Brief Rd.	18	18.3	7.7	13.0	19.0	23.7	27.9
Reference- (43)	SR 1303 Ophir Rd.	4	16.1	6.7	8.2	16.3	23.9	25.2

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Dissolved Oxygen



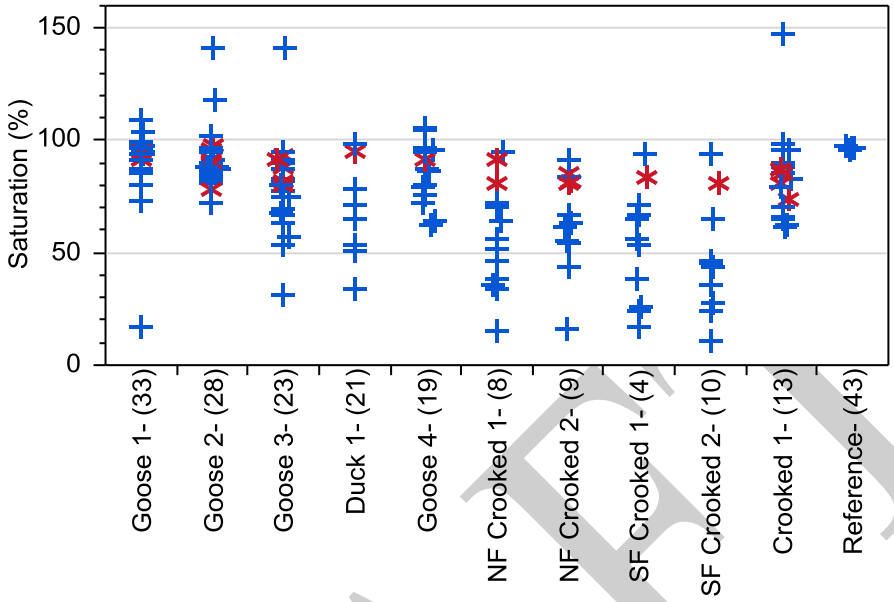
(Solid red line represents the NC water quality standard of 4.0 mg/L)

Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	9.0	1.5	8.0	9.0	10.8	11.9
Goose 2- (28)	SR 1525- Mill Grove Rd.	23	9.1	6.4	7.5	8.3	11.2	13.3
Goose 3- (23)	US 601	23	7.9	2.8	5.8	7.3	9.7	15.5
Duck 1- (21)	US 601	9	6.8	3.1	4.9	6.4	8.9	12.1
Goose 4- (19)	SR 1547-Brief Rd.	15	8.6	6.0	6.5	8.3	10.0	12.8
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	5.8	1.4	3.5	5.4	8.0	11.5
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	14	6.8	1.3	5.2	7.1	8.7	11.0
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	12	5.1	1.5	2.2	5.3	6.8	11.2
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	10	4.8	0.9	2.9	3.8	7.2	11.6
Crooked 1- (13)	SR 1547-Brief Rd.	18	8.1	5.4	6.4	7.4	9.3	16.2
Reference- (43)	SR 1303 Ophir Rd.	4	9.7	7.9	8.1	9.6	11.5	11.9

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Dissolved Oxygen Saturation

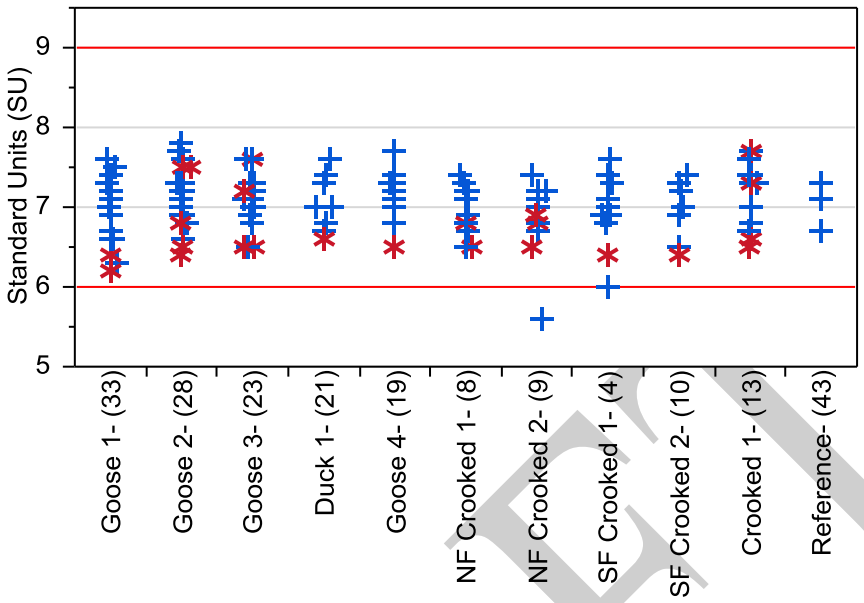


Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	89	17	86	94	99	109
Goose 2- (28)	SR 1525- Mill Grove Rd.	23	92	72	85	90	96	141
Goose 3- (23)	US 601	23	79	31	68	80	90	141
Duck 1- (21)	US 601	9	69	34	52	71	87	99
Goose 4- (19)	SR 1547-Brief Rd.	15	86	62	76	87	96	106
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	58	15	37	56	77	95
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	14	69	16	55	74	84	92
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	12	51	17	25	55	70	94
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	10	47	11	27	45	69	94
Crooked 1- (13)	SR 1547-Brief Rd.	18	84	61	69	84	92	148
Reference- (43)	SR 1303 Ophir Rd.	4	97	96	96	97	98	98

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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pH



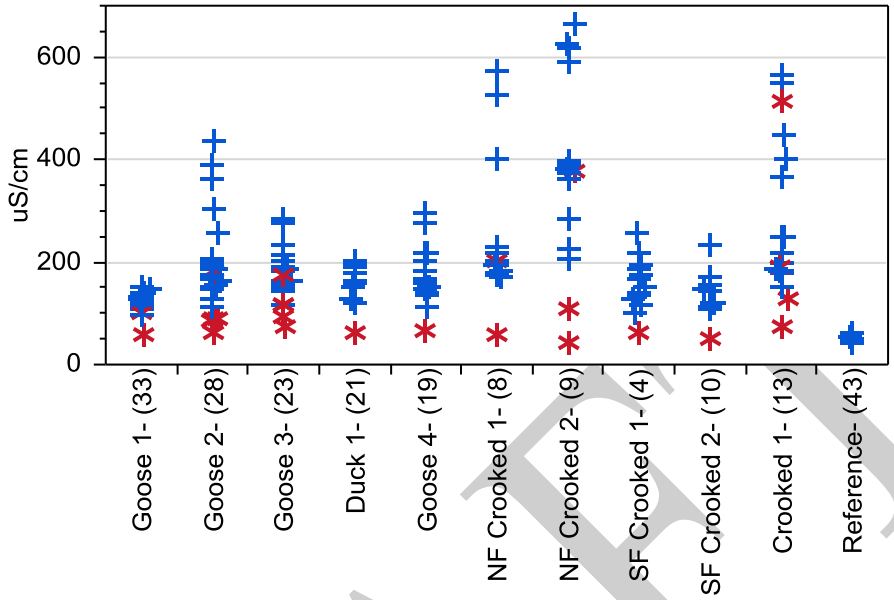
(Solid red lines represent the NC water quality standard of 6 and 9 SU; Results should be within this range)

Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	16	6.9	6.2	6.6	7.1	7.3	7.6
Goose 2- (28)	SR 1525- Mill Grove Rd.	21	7.1	6.4	6.9	7.2	7.4	7.8
Goose 3- (23)	US 601	21	7.1	6.5	6.9	7.1	7.3	7.6
Duck 1- (21)	US 601	8	7.1	6.6	6.7	7.0	7.4	7.6
Goose 4- (19)	SR 1547-Brief Rd.	14	7.1	6.5	7.0	7.2	7.3	7.7
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	12	7.0	6.5	6.7	7.0	7.2	7.4
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	12	6.9	5.6	6.7	7.0	7.2	7.4
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	11	6.9	6.0	6.8	7.0	7.3	7.6
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	8	7.0	6.4	6.6	7.1	7.3	7.4
Crooked 1- (13)	SR 1547-Brief Rd.	16	7.2	6.5	6.9	7.3	7.4	7.7
Reference- (43)	SR 1303 Ophir Rd.	3	7.0	6.7	6.7	7.1	7.3	7.3

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Specific Conductance

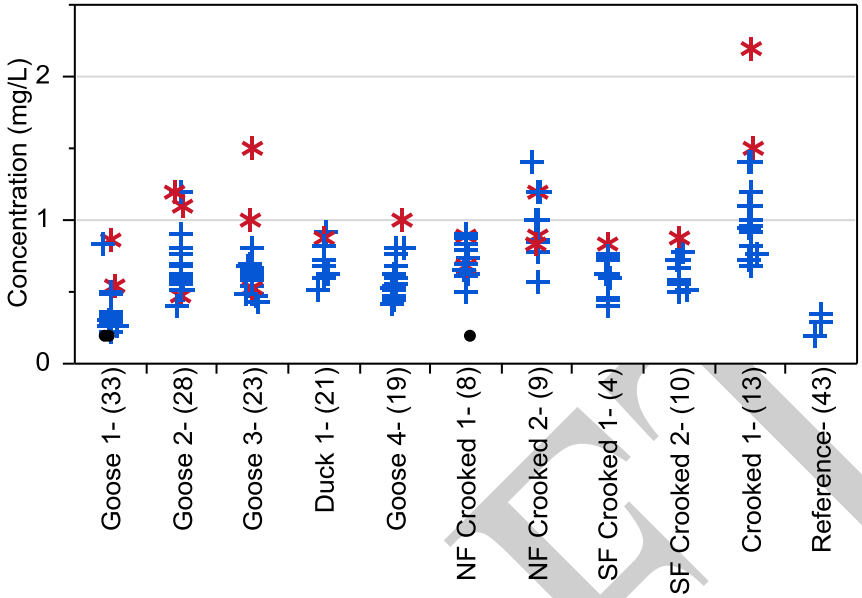


Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	18	125	58	115	132	139	150
Goose 2- (28)	SR 1525- Mill Grove Rd.	24	193	62	134	179	206	434
Goose 3- (23)	US 601	24	169	72	143	160	200	284
Duck 1- (21)	US 601	10	155	63	126	162	192	202
Goose 4- (19)	SR 1547-Brief Rd.	16	173	68	139	162	212	296
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	14	250	57	177	198	272	572
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	15	377	43	225	379	592	664
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	13	156	64	123	152	190	255
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	11	137	49	113	142	154	234
Crooked 1- (13)	SR 1547-Brief Rd.	19	294	73	183	218	446	564
Reference- (43)	SR 1303 Ophir Rd.	4	53	44	46	53	60	62

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Total Kjeldahl Nitrogen

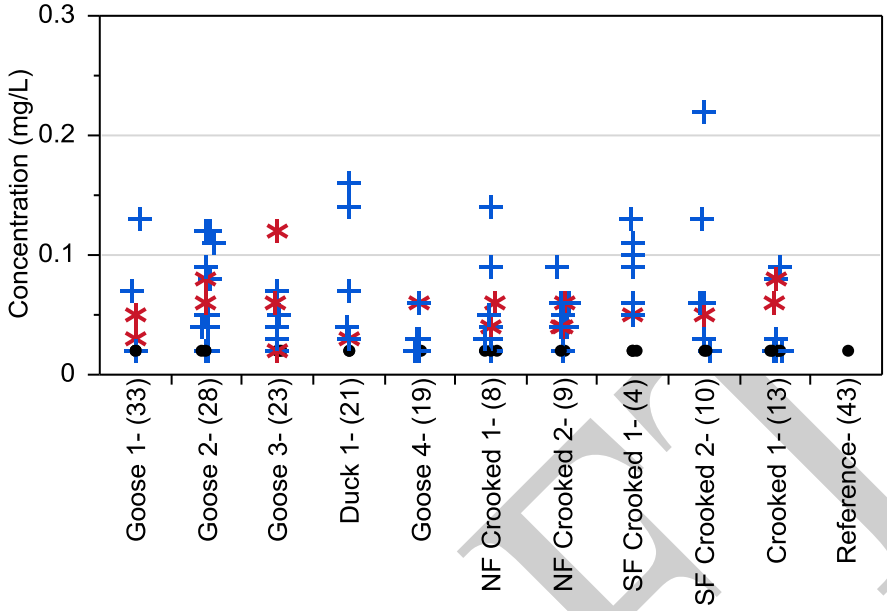


Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	0.38	0.20	0.26	0.30	0.49	0.86
Goose 2- (28)	SR 1525- Mill Grove Rd.	18	0.71	0.40	0.54	0.63	0.83	1.20
Goose 3- (23)	US 601	17	0.67	0.43	0.51	0.63	0.69	1.50
Duck 1- (21)	US 601	8	0.72	0.51	0.61	0.70	0.86	0.92
Goose 4- (19)	SR 1547-Brief Rd.	15	0.62	0.42	0.51	0.60	0.77	1.00
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	0.69	0.20	0.62	0.70	0.86	0.90
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	13	1.00	0.57	0.85	1.00	1.20	1.40
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	12	0.64	0.40	0.50	0.68	0.75	0.84
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	9	0.66	0.50	0.54	0.66	0.75	0.87
Crooked 1- (13)	SR 1547-Brief Rd.	23	1.06	0.68	0.82	1.00	1.20	2.20
Reference- (43)	SR 1303 Ophir Rd.	4	0.30	0.20	0.22	0.32	0.35	0.35

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Ammonia Nitrogen

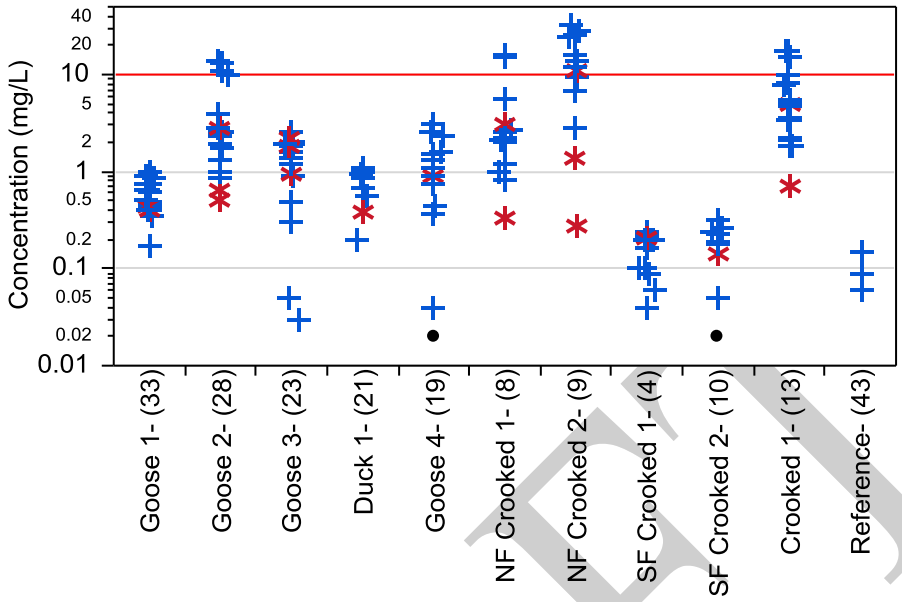


Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	0.03	0.02	0.02	0.02	0.03	0.13
Goose 2- (28)	SR 1525- Mill Grove Rd.	18	0.05	0.02	0.02	0.05	0.08	0.12
Goose 3- (23)	US 601	17	0.04	0.02	0.02	0.04	0.06	0.12
Duck 1- (21)	US 601	8	0.06	0.02	0.02	0.04	0.12	0.16
Goose 4- (19)	SR 1547-Brief Rd.	15	0.03	0.02	0.02	0.02	0.03	0.06
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	0.05	0.02	0.02	0.04	0.06	0.14
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	13	0.04	0.02	0.02	0.04	0.06	0.09
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	12	0.07	0.02	0.03	0.06	0.11	0.13
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	9	0.07	0.02	0.02	0.05	0.10	0.22
Crooked 1- (13)	SR 1547-Brief Rd.	23	0.03	0.02	0.02	0.02	0.03	0.09
Reference- (43)	SR 1303 Ophir Rd.	4	0.02	0.02	0.02	0.02	0.02	0.02

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Nitrite+Nitrate Nitrogen



(Note: Y-axis is on a $\log_{10}$ scale; Solid red line represents the NC water quality standard of 10.0 mg/L for bodies of water classified as water supplies. No monitoring sites in the Goose Cr. and Crooked Crs. LWP have a water supply classification. The standard line was added for reference purposes only.)

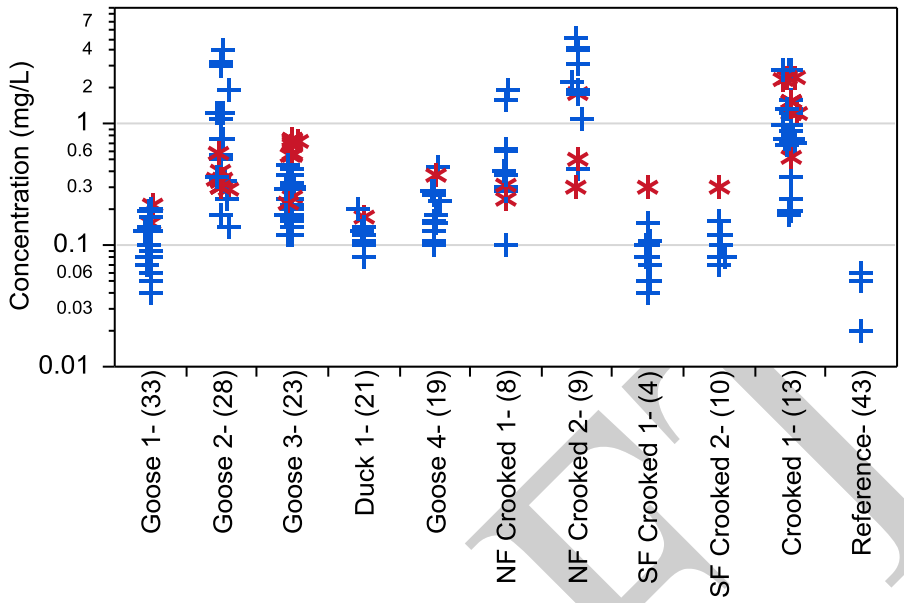
Creek (Map Code)[1]	Location	N	$\bar{x}$	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	0.57	0.17	0.41	0.50	0.75	1.00
Goose 2- (28)	SR 1525- Mill Grove Rd.	18	4.11	0.50	1.23	2.40	5.43	14.00
Goose 3- (23)	US 601	17	1.33	0.03	0.70	1.60	1.90	2.50
Duck 1- (21)	US 601	8	0.71	0.20	0.43	0.76	0.98	1.10
Goose 4- (19)	SR 1547-Brief Rd.	15	1.21	0.02	0.45	1.10	1.60	3.00
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	4.20	0.33	1.10	2.20	4.40	16.00
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	13	14.28	0.28	4.80	12.00	25.50	32.00
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	12	0.15	0.04	0.09	0.18	0.21	0.24
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	9	0.18	0.02	0.10	0.19	0.25	0.32
Crooked 1- (13)	SR 1547-Brief Rd.	23	6.80	0.72	3.40	5.20	10.00	18.00
Reference- (43)	SR 1303 Ophir Rd.	4	0.11	0.06	0.07	0.12	0.15	0.15

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Total Phosphorus



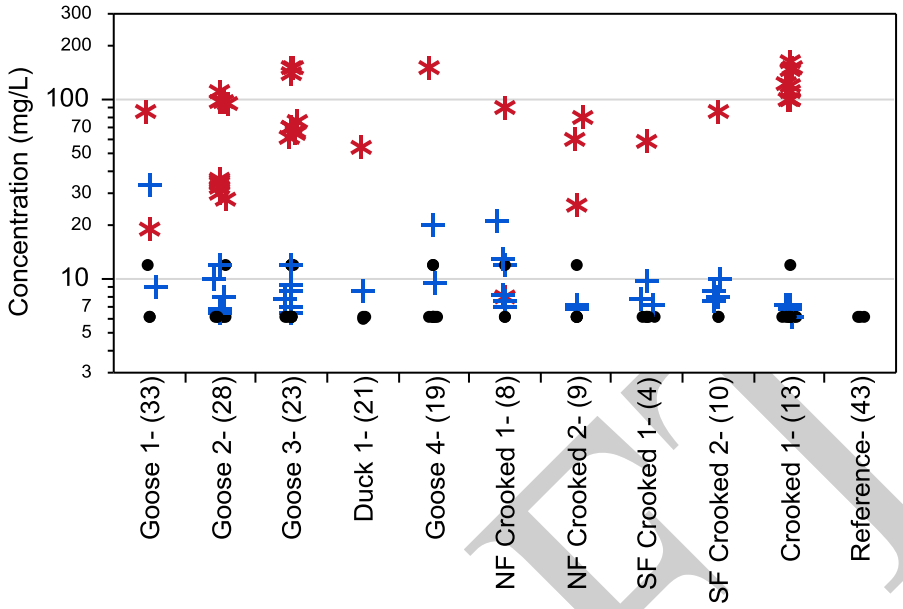
(Note: Y-axis is on a $\log_{10}$ scale)

Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	0.12	0.04	0.08	0.13	0.18	0.21
Goose 2- (28)	SR 1525- Mill Grove Rd.	35	0.82	0.14	0.33	0.50	0.74	4.10
Goose 3- (23)	US 601	34	0.36	0.12	0.20	0.29	0.54	0.73
Duck 1- (21)	US 601	8	0.13	0.08	0.10	0.13	0.16	0.20
Goose 4- (19)	SR 1547-Brief Rd.	15	0.21	0.10	0.13	0.16	0.28	0.43
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	0.57	0.10	0.29	0.38	0.61	1.90
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	13	2.19	0.30	0.80	1.80	3.60	5.20
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	12	0.10	0.04	0.06	0.09	0.11	0.30
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	9	0.13	0.07	0.08	0.12	0.14	0.30
Crooked 1- (13)	SR 1547-Brief Rd.	40	1.18	0.18	0.69	0.98	1.50	2.80
Reference- (43)	SR 1303 Ophir Rd.	4	0.05	0.02	0.03	0.06	0.06	0.06

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Total Suspended Solids



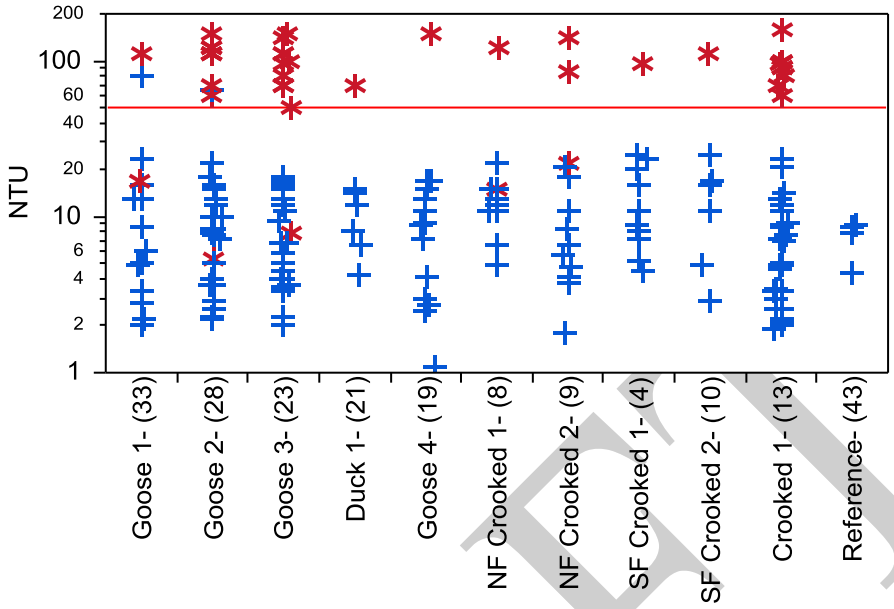
(Note: Y-axis is on a $\log_{10}$ scale)

Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	17	13.7	6.2	6.2	6.2	10.5	86.0
Goose 2- (28)	SR 1525- Mill Grove Rd.	35	22.0	6.2	6.2	6.2	30.0	110.0
Goose 3- (23)	US 601	34	32.8	6.2	6.2	10.6	65.5	150.0
Duck 1- (21)	US 601	8	12.7	6.0	6.2	6.2	8.5	54.0
Goose 4- (19)	SR 1547-Brief Rd.	15	17.7	6.2	6.2	6.2	12.0	150.0
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	15.7	6.2	6.2	8.0	12.5	91.0
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	13	18.1	6.2	6.2	6.2	19.0	80.0
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	12	11.0	6.2	6.2	6.2	7.7	58.0
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	9	16.1	6.2	6.2	7.5	9.3	86.0
Crooked 1- (13)	SR 1547-Brief Rd.	40	35.2	6.2	6.2	6.2	78.0	162.0
Reference- (43)	SR 1303 Ophir Rd.	4	6.2	6.2	6.2	6.2	6.2	6.2

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Turbidity



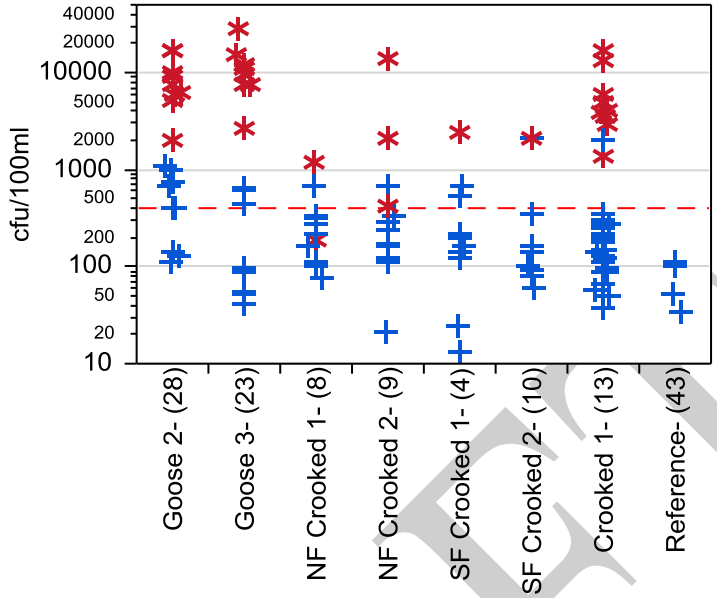
(Solid red line represents the NC water quality standard of 50 NTU)

Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	16	20	2	4	9	17	110
Goose 2- (28)	SR 1525- Mill Grove Rd.	34	38	2	5	11	66	150
Goose 3- (23)	US 601	33	35	2	4	11	70	150
Duck 1- (21)	US 601	7	19	4	7	12	15	70
Goose 4- (19)	SR 1547-Brief Rd.	14	19	1	3	9	16	150
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	12	22	5	11	14	15	120
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	13	26	2	4	8	22	140
SF Crooked 1- (4)	SR 1515- Sardis Church Rd.	11	20	5	7	11	23	95
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	8	25	3	6	16	23	110
Crooked 1- (13)	SR 1547-Brief Rd.	38	30	2	3	9	63	160
Reference- (43)	SR 1303 Ophir Rd.	4	7	4	5	8	9	9

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

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Fecal Coliform Bacteria



(Note: Y-axis is on a $\log_{10}$ scale; The dashed red line is the evaluation level of 400 cfu/100 ml)

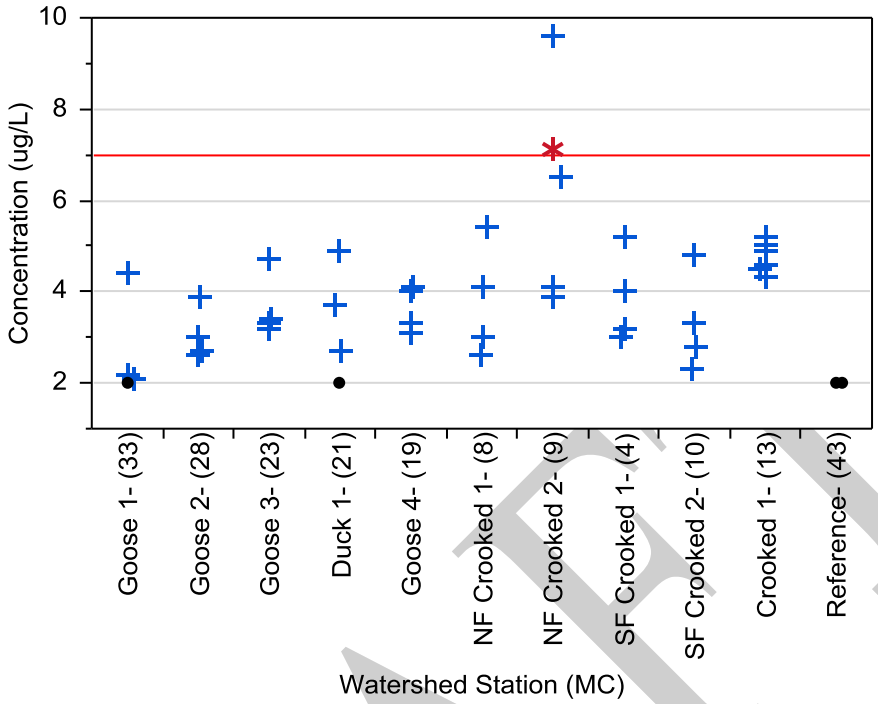
Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 2- (28)	SR 1525- Mill Grove Rd.	18	1691	110	410	1550	7925	17000
Goose 3- (23)	US 601	18	1168	41	92	1615	11250	28000
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	13	224	77	105	220	320	1200
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	13	300	21	115	240	550	14000
SF Crooked 1- (4)	SR 1515- Sardis Church Rd	12	167	13	120	150	453	2400
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	9	227	61	87	140	1225	2100
Crooked 1- (13)	SR 1547-Brief Rd.	40	425	37	123	235	2000	17000
Reference- (43)	SR 1303 Ophir Rd.	4	67	35	39	76	108	110

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

GM=Geometric Mean

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Copper



(Solid red line represents the NC action level of 7 µg/L)

Creek (Map Code)[1]	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	4	2.7	2.0	2.0	2.2	3.9	4.4
Goose 2- (28)	SR 1525- Mill Grove Rd.	4	3.1	2.6	2.6	2.9	3.7	3.9
Goose 3- (23)	US 601	4	3.7	3.2	3.2	3.4	4.4	4.7
Duck 1- (21)	US 601	4	3.3	2.0	2.2	3.2	4.6	4.9
Goose 4- (19)	SR 1547-Brief Rd.	4	3.6	3.1	3.2	3.7	4.1	4.1
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	4	3.8	2.6	2.7	3.6	5.1	5.4
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	5	6.2	3.9	4.0	6.5	8.4	9.6
SF Crooked 1- (4)	SR 1515- Sardis Church Rd	4	3.9	3.0	3.1	3.6	4.9	5.2
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	4	3.3	2.3	2.4	3.1	4.4	4.8
Crooked 1- (13)	SR 1547-Brief Rd.	7	4.7	4.3	4.3	4.6	5.0	5.2
Reference- (43)	SR 1303 Ophir Rd.	4	2.0	2.0	2.0	2.0	2.0	2.0

[1] Map Codes refer to the labeled points on **Error! Reference source not found.** (page **Error! Bookmark not defined.**) and **Error! Reference source not found.** (page **Error! Bookmark not defined.**)

Summary is based only on the data obtained for monitoring. Copper results from the stormflow study and the biotic ligand model study are discussed in the Results section.

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Appendix D. -- Baseline Macroinvertebrate Monitoring in the Goose and Crooked Creek Drainages

Division of Water Quality
Biological Assessment Unit, November 16, 2009

To: Anjie Ackerman (Environmental Planner, Ecosystem Enhancement Program)

Through: Eric Fleek (Acting Biological Assessment Unit Supervisor) EF
and Jay Sauber (Acting Environmental Sciences Section Chief)

From: Victor Holland (Environmental Specialist) VH

Subject: Ecosystem Enhancement Program (EEP) Baseline Macroinvertebrate Monitoring in the Goose and Crooked Creek Drainages (Yadkin Subbasin 12), Union County, July 2009.

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EXECUTIVE SUMMARY

In July of 2009, Anjie Ackerman (EEP) requested that the BAU conduct benthic macroinvertebrate sampling at 10 sites within the Goose Creek and Crooked Creek catchments to support the development of a Local Watershed Plan (LWP) and for potential uses in both wetland and stream restoration projects (NCDWQ 2009). Barnes Creek, a tributary to the Uwharrie River in the Yadkin Basin was the Slate Belt Level IV Ecoregion reference stream selected for this study. Four of the 10 selected sampling locations in the Goose and Crooked Creek catchments were not sampled due to lack of sufficient stream flows. As requested, benthic macroinvertebrate sampling was conducted at seven locations during the summer of 2009.

All Crooked and Goose Creek macroinvertebrate monitoring stations within this study received Poor or Fair bioclassifications indicating continued impaired water quality in the catchment.
Many factors are potentially contributing to its degraded water quality including point and nonpoint sources. Increases in urban activities near headwater reaches may be leading to increased erosion, scour, sediment load, and periodic toxicity. Additionally, several permitted Wastewater Treatment Plants (WWTPs) are located upstream from benthic sampling locations likely contributing to more tolerant macroinvertebrate assemblages.

Studies suggest drought conditions in the Slate Belt Level IV Ecoregion continue to affect benthic communities up to one year following recovery (NCDWQ 2004). Severe drought conditions observed in 2007 and 2008 without persistent flows subsequent to the drought may contribute to lack of macroinvertebrate colonization. Fluctuating drought conditions could lead to escalated point and nonpoint source pollution via pollutants remaining in stagnant streams for longer periods and/or accumulated pollutant runoff during storm events. Either of these factors could contribute to inputs of higher pollutant concentrations and the streams ultimate degraded state, especially at headwater sampling locations in the Slate Belt Ecoregion. The attached report details the data collection, analysis, and conclusions.

Division of Water Quality
Biological Assessment Unit
November 16, 2009

Macroinvertebrate Monitoring in Goose and Crooked Creek (Yadkin HUC 03040105), July 2009

INTRODUCTION

Goose Creek and Crooked Creek flow northeasterly into Rocky River. North and South Fork Crooked Creek are tributaries to Crooked Creek and Duck Creek is a tributary to Goose Creek (Figure 1). The Goose Creek catchment has been more comprehensively studied than the Crooked Creek drainage in the last decade due to the presence of the Federally Endangered Carolina heelsplitter (*Lasmigona decorata*). Increased urbanization in the headwaters of Goose and Crooked Creeks is a continuing concern regarding this endangered mussel species and water quality in general. The goal of this study is to determine current water quality status of both the headwaters and downstream segments of Goose and Crooked Creeks. Water chemistry and fecal coliform counts will occur in conjunction with benthic samples (NCDWQ 2009). An additional goal is to identify segments of the streams with potential for further stormwater Best Management Practices (BMPs) and/or stream/wetland restoration efforts.

WATERSHED DESCRIPTION

The Goose and Crooked Creek drainages are located in rapidly developing areas within Mecklenburg and Union counties, NC in the Yadkin River Basin (HUC 03040105). Barnes Creek (HUC 03040103), a tributary to the Uwharrie River, is the reference site sampled in the Yadkin-Pee Dee River Basin. This reference site is located approximately 80 miles southeast of the Goose and Crooked Creek catchments. All macroinvertebrate monitoring stations (Table 3 and Figure 1) are located in the Carolina Slate Belt Level IV Ecoregion (Griffith et al. 2002). This ecoregion extends from southern Virginia to eastern Georgia. It is known to exhibit poorly sustained base flows due to thin soils with low water storage capacities during base-flow periods (Weaver et al. 1998).

Upstream reaches are experiencing rapid urbanization while downstream locations are dominated by rural areas with the presence of some active agriculture. Potential point source stressors include current active NPDES dischargers within these catchments. All active permitted NPDES dischargers upstream from proposed benthic sampling locations (Figure 1) are listed in Table 2. There is only one active major NPDES permitted discharger (discharge > 1 MGD) located within the sampling area. Two active Ambient Monitoring System (AMS) stations are located within the Goose Creek catchment (Table 1 and Figure 1). There are no AMS stations within the Crooked Creek drainage.

Duck Creek, North and South Fork Crooked Creek, Crooked Creek and Goose Creek are all Class C waters from their source to eventual confluence with Rocky River. Duck Creek, North and South Fork Crooked Creek, and Goose Creek are currently listed as impaired on the 303d list for fecal coliform bacteria and biological integrity (benthos). Main-stem Crooked Creek downstream from North and South Fork Crooked Creek is not currently listed as impaired. Causes of impairment are likely due to both nonpoint and point source stressors, including increased urban runoff leading to flow flashiness and scour impacts.

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PREVIOUS MONITORING WITHIN THE STUDY AREA

Table 4 shows results of all historic macroinvertebrate sampling locations within the study area. North Fork Crooked Creek has rated Good-Fair or Fair since 1995. South Fork Crooked Creek was only sampled in 1995 when it rated Fair. In 2009 this location was not sampled due to low flow and water levels. Crooked Creek at SR 1547 increased from a Fair to Good-Fair rating between 1996 and 2001. Duck Creek rated Fair in 1998 and could not be sampled in 2009 due to low flow conditions. Goose Creek at SR 1524 and SR 1525 received Good-Fair and Poor ratings respectively in 1998. From 1996 to 2001 Goose Creek at U.S. 601 was rated Poor based on benthic samples but in 2006 was rated Fair suggesting slightly better water quality. Goose Creek at SR 1547 was rated Fair in 1998 and was not sampled again until 2009. Barnes Creek at SR 1303 is the Slate Belt Ecoregion reference stream selected for this study and has rated either Good or Excellent since 1985.

In 2009, four out of the 10 macroinvertebrate monitoring locations in the Goose and Crooked Creek catchments were not sampled due to lack of sufficient flows including: Duck Creek at U.S. 601, South Fork Crooked Creek at SR 1515 and SR 1367, and North Fork Crooked Creek at SR 1520.

METHODS

Habitat Evaluation

Qualitative habitat and land use data collections were conducted at all sampling locations to assess the presence/absence of in-stream habitat and potential sources of stressors within the catchment. Habitat parameters assessed included: channel modification; relative abundance of in-stream structure; substrate type; presence of riffles/pools; riparian zone width and function, and stability as it relates to erosion and surrounding land use. This evaluation results in a score from 1 to 100. Higher numbers typically reflect increased habitat quality with reduced anthropogenic influence.

Physical-Chemical

Several physicochemical properties are collected at each sampling site. Field measurements include specific conductance, water temperature, pH, and dissolved oxygen using both YSI 85 and Accumet AP 61 meter. Pre and post-meter calibrations were completed daily.

Benthos

In July, 2009 macroinvertebrates were collected from Goose, Crooked, and Barnes Creek (reference) sampling locations (Table 3). The Division of Water Quality's Standard Qualitative (Full Scale) sampling methods were used. Full scale samples are conducted in wadeable streams with drainage areas > 3 mi^2 (NCDWQ 2005). This sampling method consists of 10 separate samples including three sweep-net samples; two kick net samples, one leaf pack, two fine-mesh log and/or rock wash, one sand sample, and visuals of substrates not otherwise easily sampled by previous techniques. Habitats such as riffles, macrophytes, root mats/undercut banks, and detritus deposits are sampled using these techniques. Samples are picked at the site and preserved in ethanol for laboratory analysis. Benthic sampling is performed to obtain an inventory of aquatic fauna at the specific sampling location. Each taxon is classified as Rare (1-2 specimens, denoted by "R" on taxa tables), Common (3-9 specimens, "C"), Abundant (≥ 10 specimens, "A"). Data from each site is entered into a database.

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Data Analyses

Several data-analysis summaries (metrics) are used to detect water quality issues. These metrics are based on long-term intensive studies showing that unstressed stream/river systems generally exhibit higher macroinvertebrate diversity and higher proportions of pollution intolerant taxa. On the contrary, relatively higher proportions of pollution tolerant taxa are found in polluted streams and rivers. Diversity of benthic fauna is evaluated using taxa richness defined as the total number of different taxa present (S). Stream communities are evaluated using a biotic index that is generated from the reaction of various taxa to different stressors. This is known as the North Carolina Biotic Index (NCBI or BI) (NCDWQ 2005). These values allow comparisons among sample sites and reference sites. Individual species and associated community biotic index values are rated on a 0-10 scale. Higher values represent more tolerant taxa and potential stream pollution. Indicator taxa, EPT abundance (EPT N), EPTBI, and S are used to further elucidate between-site differences. All stream stations received bioclassifications based on biocriteria for wadeable streams with drainage areas > 3 mi^2 (Full Scale). There are five possible classifications including: Excellent, Good, Good-Fair, Fair, and Poor. Bioclassifications were generated based on the NCBI, EPTBI, and EPTS thresholds for the Piedmont Ecoregion and Full-Scale macroinvertebrate collection method.

Land Use Analysis

A land use analysis was conducted using Geographic Information Systems (GIS) for the Goose Creek and Crooked Creek catchments. Percentages were calculated from both 2001 and 2007 GIS rasters for Union County, NC to observe spatial and temporal trends among sample sites. The proportions represent land use parameters upstream from each sample site. Land use parameters include: agricultural, barren land, developed (urban), forest, grass, and water bodies. Data from 2007 was obtained from Tetra Tech, Inc.

MONITORING SITES

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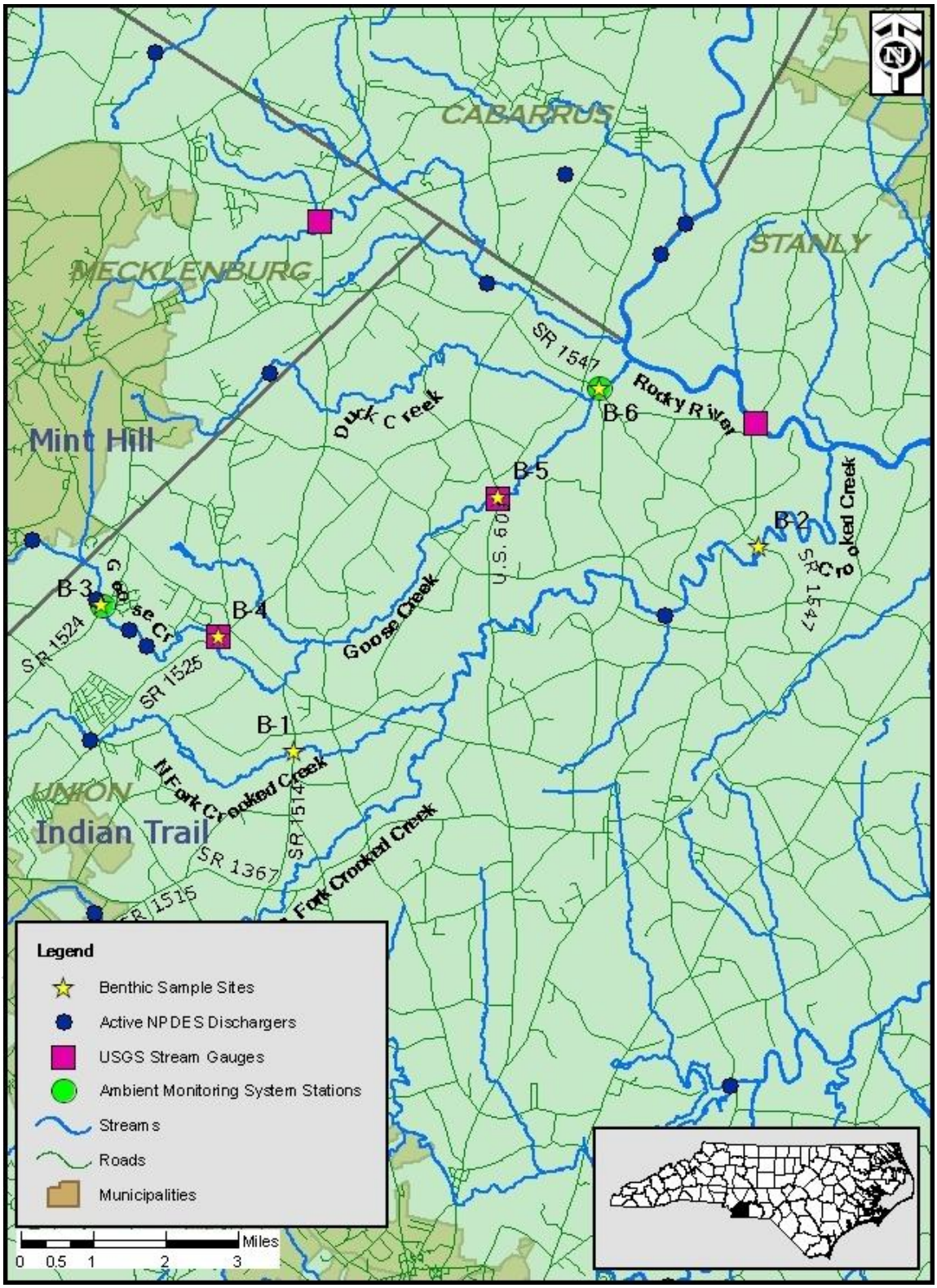


Figure 1. Location of macroinvertebrate monitoring stations (yellow stars) sampled in July, 2009.

Table 1. Active Ambient Monitoring System Stations within the Goose Creek catchment.

Station	Location	Class
Q8360000	Goose Creek at SR 1524	C
Q8374000	Goose Creek at SR 1547	C

Table 2. Permitted active NPDES dischargers located upstream from proposed sampling locations.

Permit	Facility	County	Receiving Water Body	Permitted Flow (MGD)
NC0069841	Crooked Creek WWTP #2	Union	S. Fork Crooked Creek	1.9
NC0035041	Hemby Acres WWTP	Union	N. Fork Crooked Creek	0.3
NC0063584	Oxford Glen WWTP	Mecklenburg	Stevens Creek	0.075
NC0072508	Hunly Creek WWTP	Union	Goose Creek	0.02
NC0034762	Fairfield Plantation WWTP	Union	Goose Creek	0.07
NC0065684	Country Wood WWTP	Union	Goose Creek	0.67
NC0065749	Ashe Plantation WWTP	Mecklenburg	Duck Creek	0.1
NC00685812	Grassy Branch WWTP	Union	Grassy Branch	0.05

Table 3. Macroinvertebrate monitoring stations in the Goose Creek, Crooked Creek, and Barnes Creek catchments, July, 2009.

Stream	N FK CROOKED CR	CROOKED CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	BARNES CR
Site Location	SR 1514	SR 1547	SR 1524	SR 1525	US 601	SR 1547	SR 1303
County	Union	Union	Union	Union	Union	Union	Montgomery
Site ID	QB358	QB344	QB351	QB352	QB355	QB354	QB276
Basin	Yadkin	Yadkin	Yadkin	Yadkin	Yadkin	Yadkin	Yadkin
Subbasin	12	12	12	12	12	12	9
Latitude (º)	35.1024	35.1450	35.1301	35.1250	35.1539	35.1759	35.4396
Longitude (º)	-80.5854	-80.4717	-80.6310	-80.6028	-80.5350	-80.5116	-79.9979
Drainage area (mi²)	15.1	47.3	8.4	11.0	24.1	44.0	23.1
Stream Segment AU	13-17-20-1	13-17-20	13-17-18b	13-17-18b	13-17-18b	13-17-18b	13-2-18-(2.5)
Stream Classification	C	C	C	C	C	C	C
Level 4 Ecoregion	45c	45c	45c	45c	45c	45c	45c
Type of Sample	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale
Map #	B-1	B-2	B-3	B-4	B-5	B-6	B-7

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Table 4. Sites previously sampled in the Goose Creek, Crooked Creek, and Barnes Creek catchments.

Waterbody	Location	County	Date	Sample Type	Total EPT Taxa	EPT BI	Total Taxa	BI	Bioclass
N FK CROOKED CR	SR 1514	UNION	9/12/1995	Full Scale	12	5.79	59	6.46	Good-Fair
	SR 1514	UNION	6/27/2000	Full Scale	7	6.79	53	6.98	Fair
N FK CROOKED CR	SR 1520	UNION	6/27/2000	Full Scale	6	6.50	57	7.23	Fair
S FK CROOKED CR	SR 1367	UNION	9/12/1995	Full Scale	8	6.22	42	6.71	Fair
S FK CROOKED CR	SR 1515	UNION	9/13/1995	Full Scale	5	6.83	54	6.89	Fair
CROOKED CR	SR 1547	UNION	8/20/1996	EPT	12	4.93			Fair
	SR 1547	UNION	8/22/2001	Full Scale	18	5.16	68	5.93	Good-Fair
	SR 1547	UNION	8/23/2006	Full Scale	11	5.79	63	6.27	Good-Fair
DUCK CR	US 601	UNION	4/21/1998	Full Scale	14	5.52	64	6.42	Fair
GOOSE CR	SR 1524	UNION	4/22/1998	EPT	16	4.66			Good-Fair
GOOSE CR	SR 1525	UNION	4/21/1998	Full Scale	4	6.95	35	6.95	Poor
GOOSE CR	US 601	UNION	8/20/1996	EPT	2	6.07			Poor
	US 601	UNION	4/21/1998	Full Scale	10	5.88	47	7.37	Poor
	US 601	UNION	8/22/2001	Full Scale	5	5.98	48	7.16	Poor
	US 601	UNION	8/22/2006	Full Scale	11	6.65	67	6.87	Fair
GOOSE CR	SR 1547	UNION	5/1/1998	EPT	11	6.00			Fair
BARNES CR	SR 1303	MONTGOMERY	5/20/1985	Full Scale	36	3.88	100	4.83	Excellent
	SR 1303	MONTGOMERY	8/1/1985	Full Scale	29	3.89	87	4.81	Excellent
	SR 1303	MONTGOMERY	7/8/1987	Full Scale	27	3.79	90	4.93	Good
	SR 1303	MONTGOMERY	7/20/1987	EPT	28	4.05			Excellent
	SR 1303	MONTGOMERY	7/11/1989	Full Scale	24	3.80	83	4.89	Good
	SR 1303	MONTGOMERY	8/7/1996	Full Scale	36	3.41	99	4.46	Excellent
	SR 1303	MONTGOMERY	8/9/2001	Full Scale	40	3.55	108	4.22	Excellent
	SR 1303	MONTGOMERY	9/28/2001	Full Scale	38	3.03	79	4.16	Excellent

RESULTS AND DISCUSSION

North Fork Crooked Creek, SR 1514, Union County



Figure 2. Upstream view of North Fork Crooked Creek at SR 1514, Union County, NC, sampled on July 14, 2009.

Date: July 14, 2009
Drainage area: 15.1 square miles
Qualitative Visible land use (%): 30 forest, 30 residential, 40 fallow fields
Width (m): 5
Depth (m): Avg: 0.2 Max: 0.5
Canopy (% cover): 90, mixed hardwood
Substrate (%): boulder (0), cobble (0), gravel (50), sand (25), silt/fine particulate (25)
Riparian quality: riparian zone intact (>18m)
Instream habitat: Rocks and macrophytes absent. Sticks/leafpacks and snags/logs are common. Undercut banks abundant.
Dissolved Oxygen (mg/L): 5.2
Specific conductance (µmhos/cm): 425
Temperature (°C): 22.5
pH: 7
Habitat Score: 61

North Fork Crooked Creek at SR 1514 had the lowest EPT taxa richness (4) and abundance (EPTN = 31) and highest NCBI (7.09) (Table 5, Appendix 1) compared to all other sampling locations. Tolerant taxa were dominant at this site including: *Hydropsyche betteni* (abundant) and *Cheumatopsyche spp.* (abundant). *Maccaffertium modestum* was absent from this site and abundant at all other sampling sites within this study suggesting a lack of riffle habitat. Low flows were noted at the site in addition to lack of habitat favorable for macroinvertebrate colonization including the absence of cobble riffle substrates and submerged root mats. Additionally, this stream segment is suffering from severe bank erosion leading to increased scouring and sediment input. The severe erosion and scouring suggest this site receives periodic drastic increases in flow followed by quick lower water levels which can lead to rapid inputs of accumulated nonpoint pollutants from upstream. A sewage smell was noted and conductivity was high at 425 µmhos/cm (Table 6). High amounts of upstream urban land use activities in addition to point source dischargers are likely contributing to the degraded macroinvertebrate community here. This site could be good candidate for implementation of future upstream stormwater BMPs and/or stream restoration activities. However, any compliance issues with upstream dischargers such as Hemby Acres WWTP would need to be resolved.

Crooked Creek at SR 1547, Union County



Figure 3. Downstream view of Crooked Creek at SR 1547, Union County, NC, sampled on July 14, 2009.

Date: July 14, 2009
Drainage area: 47.3 square miles
Qualitative Visible land use (%): 80 forest, 10 residential, 10 fallow fields
Width (m): 10
Depth (m): Avg: 0.1 Max: 0.25
Canopy (% cover): 60, hardwood
Substrate (%): boulder (10), cobble (40), gravel (30), sand (10), silt/fine particulate (10)
Riparian quality: Intact wide riparian zone (>18m). Erosion moderate.
Instream habitat: Rocks abundant. Macrophytes common, sticks/leafpacks common, snags/logs rare, and undercut banks and root mats rare.
Dissolved Oxygen (mg/L): 6.5
Specific conductance (µmhos/cm): 471,**Temperature (°C):** 26.1, **pH:** 7.8, **Habitat Score:** 88

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Results and Discussion

Ten EPT taxa were present at the downstream Crooked Creek site. This site received a Fair (NCBI = 6.65, EPTBI = 5.67) rating suggesting slight decline in water quality compared to the 2006 sample. EPT taxa richness and EPTBI remained similar from 2006 to 2009 (Table 5) however the NCBI value was elevated from 6.27 to 6.65. This is potentially due to the higher abundance of tolerant taxa in 2009 such as the chironomids *Cricotopus bicinctus* and *Dicrotendipes neomodestus* (Appendix 1). Both taxa are tolerant of high nutrients/organic wastes. The presence of so many low dissolved oxygen tolerant taxa such as the midges: *Polypedilum illinoense*, *Phaenopsectra obediens*, and *Dicrotendipes neomodestus*, Odonates: *Argia spp.* and *Ischnura spp*., flatworm *Dugesia tigrina*, and slow water limpet *Laevapex fuscus* suggest the site could suffer from periodic low oxygen levels compounded by low flows common in slate belt streams. Observations at the site imply that macroinvertebrates are not limited by habitat but more likely general water quality. Conductivity was high at 471 µmhos/cm (Table 6). There are two minor dischargers and one major discharger (>1 MGD) located upstream from this sample site (Table 2) likely contributing to degraded water quality. Any upstream WWTP discharge issues would need to be resolved before additions of future stormwater BMPs in order to detect a positive effect on stream water quality.

Goose Creek at SR 1524, Union County



Figure 4. Upstream view of Goose Creek at SR 1524, Union County, NC, sampled on July 13, 2009.

Date: July 13, 2009
Drainage area: 8.4 square miles
Qualitative Visible land use (%): 50 forest, 30 residential, 20 golf course
Width (m): 8
Depth (m): Avg: 0.2 Max: 0.5
Canopy (% cover): 85, mixed hardwood
Substrate (%): boulder (20), cobble (20), gravel (20), sand (20), silt/fine particulate (20)
Riparian quality: Intact riparian zone. Narrow on the right bank (< 6m). Erosion severe.
Instream habitat: Rocks common. Macrophytes rare, sticks/leafpacks common, snags/logs and undercut banks/root mats common.
Dissolved Oxygen (mg/L): 6.7
Specific conductance (µmhos/cm): 121
Temperature (°C): 23.7
pH: 7.0
Habitat Score: 77

Goose Creek at SR 1524 also received a Fair bioclassification in 2009 compared to Good-Fair in 1998. Despite this rating, water quality in this reach seems the best compared to all other sample sites within the Goose Creek catchment (EPTBI = 6.11, NCBI = 6.40) (Table 5). Thirteen EPT taxa were collected at the site. Most are fairly tolerant taxa with the exception of *Chimarra spp.* and *Mystacides sepulchralus* (both rare at the site). Intolerant taxa abundant in 1998, such as *Serratella deficiens*, were absent in 2009. The intolerant beetle *Psephenus herricki* was common at the site (Appendix 1). This site is located ~100 meters downstream from the Hunley Creek WWTP (Table 2), which is a minor discharger that has had occasional violations of ammonia and chlorine. The absence of long-lived stoneflies and other common intolerant taxa could be due to multiple variables. These could include drought, periodic toxicity, lack of upstream riparian buffers, and/or runoff from the upstream golf course and residential areas leading to the increased erosion and sediment accumulation observed. This site may be a good candidate for future stormwater BMP implementation, stream bank stability, riparian buffer enhancements, and/or other restoration activities.

Goose Creek at SR 1525, Union County



Figure 5. Downstream view of Goose Creek at SR 1525, Union County, NC, sampled on July 14, 2009.

Date: July 14, 2009
Drainage area: 11.0 square miles
Qualitative Visible land use (%): 50 forest, 20 residential, 20 goat pasture, 10 fallow fields
Width (m): 10
Depth (m): Avg: 0.1 Max: 0.5
Canopy (% cover): 80, mixed hardwood
Substrate (%): bedrock (10), boulder (30), cobble (20), gravel (20), sand (10), silt/fine particulate (10)
Riparian quality: Intact riparian zone. Width 12-18m on left bank. Moderate Erosion.
Instream habitat: Rocks abundant. Macrophytes absent, sticks/leafpacks common, snags/logs and undercut banks/root mats common.
Dissolved Oxygen (mg/L): 7.1
Specific conductance (µmhos/cm): 193
Temperature (°C): 23.1
pH: 7.2
Habitat Score: 90

This Goose Creek site has improved slightly from Poor in 1998 to Fair in 2009. EPT taxa richness increased from 4 in 1998 to 6 in 2009. However, this is a 2-fold decrease in EPT taxa richness when compared to the SR 1524 site just upstream (Table 5, Figure 1). The SR 1525 site has the lowest EPTN (35) and highest NCBI (7.01) suggesting the worst water quality among all Goose Creek sites in 2009. Chironomid taxa richness doubled from 13 just upstream at the SR 1524 site to 25 at this site potentially signifying some nutrient enrichment from upstream sources. The Country Woods WWTP is the nearest of three WWTPs located within 1 mile upstream of the site (Figure 1, Table 2). A sewage smell was observed. Macroinvertebrate assemblages suggest impaired water quality despite high quality habitat suggesting either point source or nonpoint source pollution inputs at this site.

Goose Creek at U.S. 601, Union County



Figure 6. Upstream view of Goose Creek at U.S. 601, Union County, NC, sampled on July 14, 2009.

Date: July 14, 2009
Drainage area: 24.1 square miles
Qualitative Visible land use (%): 40 forest, 35 active crops, 25 fallow fields
Width (m): 10
Depth (m): Avg: 0.1 Max: 0.5
Canopy (% cover): 90, mixed hardwood
Substrate (%): boulder (25), cobble (25), gravel (10), sand (20), silt/fine particulate (20)
Riparian quality: Intact riparian zone. Width 6-12m on right bank. Moderate Erosion.
Instream habitat: Rocks abundant. Macrophytes common, sticks/leafpacks common, snags/logs and undercut banks/root mats common.
Dissolved Oxygen (mg/L): 5.8
Specific conductance (µmhos/cm): 232
Temperature (°C): 24.2
pH: 7.1
Habitat Score: 88

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Goose Creek at U.S. 601 rated Fair based on benthic macroinvertebrates in 2009 for the second consecutive time since 2006 (Table 5). This site had a Poor bioclassification from 1996-2001. The Fair rating suggests a water quality improvement following the removal of discharge from the Fairview Elementary WWTP just upstream in 2005. Despite observations of high quality habitat, a pollution tolerant benthic community assemblage continues to reside here suggesting point source dischargers and/or nonpoint source runoff limiting water quality. Four total point source dischargers are located upstream from this site (Figure 1). Conductivity was elevated (232 µmhos/cm), however, water quality improved slightly from the SR 1525 site when comparing benthic metrics (Table 5).

Goose Creek at SR 1547, Union County



Figure 7. Upstream view of Goose Creek at SR 1547, Union County, NC, sampled on July 15, 2009.

Date: July 15, 2009
Drainage area: 77.0 square miles
Qualitative Visible land use (%): 100 forests
Width (m): 11
Depth (m): Avg: 0.1 Max: 0.25
Canopy (% cover): 90, mixed hardwood
Substrate (%): boulder (20), cobble (20), gravel (20), sand (20), silt/fine particulate (20), trace of bedrock
Riparian quality: Intact wide (>18m) riparian zone. Moderate to severe erosion.
Instream habitat: Rocks abundant. Macrophytes absent, sticks/leafpacks common, snags/logs common and undercut banks/root mats rare.
Dissolved Oxygen (mg/L): 6.8
Specific conductance (µmhos/cm): 229
Temperature (°C): 21.2
pH: 7.3
Habitat Score: 86

This Goose Creek site is just upstream from its confluence with Rocky River. The benthic community assemblage at this site remained similar to that found during sampling in 1998 (Table 5). EPT abundance (69) in 2009 was much higher than in 1998 (35), however, slightly more pollution tolerant EPT taxa were present in 2009 (EPTBI = 6.47) compared to 1998 (EPTBI = 6.0). Conductivity was elevated (229 µmhos/cm). This site is downstream from Ashe Plantation WWTP, a minor permitted discharger to Duck Creek, a tributary of Goose Creek (Figure 1). Five total permitted dischargers are located upstream from this sampling station. Most of these downstream Goose Creek sites have exceptional habitat available for macroinvertrate colonization suggesting impaired water quality from upstream point source or nonpoint source pollution inputs.

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Barnes Creek at SR 1303, Montgomery County



Date: July 15, 2009
Drainage area: 23.1 square miles
Qualitative Visible land use (%): 100 forest
Width (m): 11
Depth (m): Avg: 0.2 Max: 1.0
Canopy (% cover): 75, hardwood
Substrate (%): bedrock (10), boulder (30), cobble (30), gravel (15), sand (10), silt/fine particulate (5)
Riparian quality: Breaks rare. Wide (>18m) riparian zone. Minimal erosion.
Instream habitat: Rocks abundant. Macrophytes absent, sticks/leafpacks common, snags/logs rare and undercut banks/root mats common.
Dissolved Oxygen (mg/L): 7.7, **Specific conductance (µmhos/cm):** 51, **Temperature (°C):** 23.8, **pH:** 7.1, **Habitat Score:** 92

Figure 8. Downstream view of Barnes Creek at SR 1303, Union County, NC, sampled on July 15, 2009.

Barnes Creek at SR 1303 was selected for benthic sampling as a Slate Belt reference site for comparison to that of the Goose and Crooked Creek catchments. This stream is a tributary to the Uwharrie River in rural Montgomery County. The reach of stream sampled is almost completely surrounded by forest with little to no anthropogenic activity upstream. The site obtained a benthic bioclassification of either Good or Excellent every time it has been sampled since 1985. It has been rated Good on three occasions out of nine including this year. Intolerant taxa were common at this site including several fairly rare taxa for the Piedmont such as *Maccaffertium vicarium* (abundant), *Epeorus vitreus* (common), *Acroneuria abnormis* (abundant) and *Neoperla spp.* (common). Stoneflies such as *Acroneuria abnormis* are commonly found in fairly clean North Carolina Piedmont streams. No stoneflies were collected in Goose or Crooked Creeks further suggesting impaired water quality at those sites. Based on DWQ habitat forms Barnes Creek received a high habitat score (92), somewhat comparable to that of downstream reaches of Goose and Crooked Creeks (Table 6). Total EPT taxa (27) and EPT abundance (125) was at least double that of all Goose and Crooked Creek samples (Table 5). The EPTBI (4.17) and NCBI (4.97) are low suggesting good water quality within the reach. Specific conductance (51 µmhos/cm) was less than half that of any sites sampled in Goose or Crooked Creeks. Chironomid richness was moderate (18) but biomass was low (Appendix 1). Only one chironomid taxa *Cladotanytarsus sp. E* was abundant at the site and the majority of other chironomid taxa were rare. The intolerant beetles *Psephenus herricki* and *Optioservus ovalis* were also abundant in Barnes Creek.

SUMMARY

Of the six Goose and Crooked Creek samples collected in July, 2009, none of them obtained a bioclassification above Fair based on macroinvertebrate assemblages. Trends suggest further impaired water quality in Goose and Crooked Creek headwaters. This is likely due to a combination of point and/or nonpoint sources in addition to low base flows notorious in the Slate Belt Ecoregion. Potentially the most important factor continuing to affect these streams is rapid expansive urbanization of the Goose and Crooked Creek headwaters. Goose Creek at SR 1524 went from a bioclassification of Good-Fair in 1998 to Fair in 2009. The mid-stream site Goose Creek at SR 1524 and U.S. 601 showed slight improvements in water quality since 1998 and 2001. The downstream Goose Creek site at SR 1547 remained at Fair consistent with historic

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samples. North Fork Crooked Creek at SR 1514 was rated Good-Fair in 1995. Since 1995, water quality in this reach has been on the decline to Fair in 2000 and Poor in 2009 based on benthic macroinvertebrates (Tables 4 and 5). Water quality in downstream Crooked Creek declined to Fair since 2001 when it was rated Good-Fair. A high abundance of chironomid taxa such as *Cricotopus bicinctus* and *Dicrotendipes neomodestus* also suggest some nutrient/organic wastes enrichment at the SR 1547 site. Elevated conductivity, especially in the Crooked Creek catchment suggests point source discharge problems. Implementation of stormwater BMPs and stream restoration activities could benefit the Goose and Crooked Creek catchment. However, any point source discharge issues would need to be resolved before stream restoration activities are implemented.

Land Use

Agricultural and urban land use activities and associated increased impervious surface in smaller headwater streams is known to negatively affect water quality downstream (Alexander et al. 2007, Meyer et al. 2007). Commercial/Industrial and residential land use has significantly increased in the Goose and Crooked Creek watersheds since 1992 (Tetra Tech 2008). Both catchments have similar percentages of developed land. The Crooked Creek catchment has a slightly higher percentage of high density impervious surfaces; particularly commercial land use (7.4%) compared to that of the Goose Creek drainage at 4.1%.

Rapid continued urbanization in the headwaters of Goose and Crooked Creek could lead to the impaired water quality found in both upstream and downstream sample locations. Urban land use percentages are highest in the headwaters of both the Crooked and Goose Creek catchments (Figure 9). Percentage of forests continues to decrease from 2001 to 2007 throughout both catchments. Trends suggest urban areas decrease spatially as you move downstream in both drainages. These observations imply stream and/or wetland restoration efforts focused in the headwaters may benefit downstream water quality. Commercial/Industrial and residential land use in headwaters leads to more impervious surface and ultimately, to a modified hydrologic regime. Stormwater runoff over impervious surfaces with reduced riparian buffers may lead to the rapid movement of water downstream increasing scour, erosion, and sediment input. North Fork Crooked Creek at SR 1514 may be an example of this altered hydrologic flow. Virtually no course substrate was observed at this site potentially due to high flows through the channel during stormwater events. Altered hydrology in addition to fluctuated drought conditions known to occur in the Slate Belt can escalate the effects of nonpoint sources via buildup of pollutants and quick runoff of these sources into the catchment.

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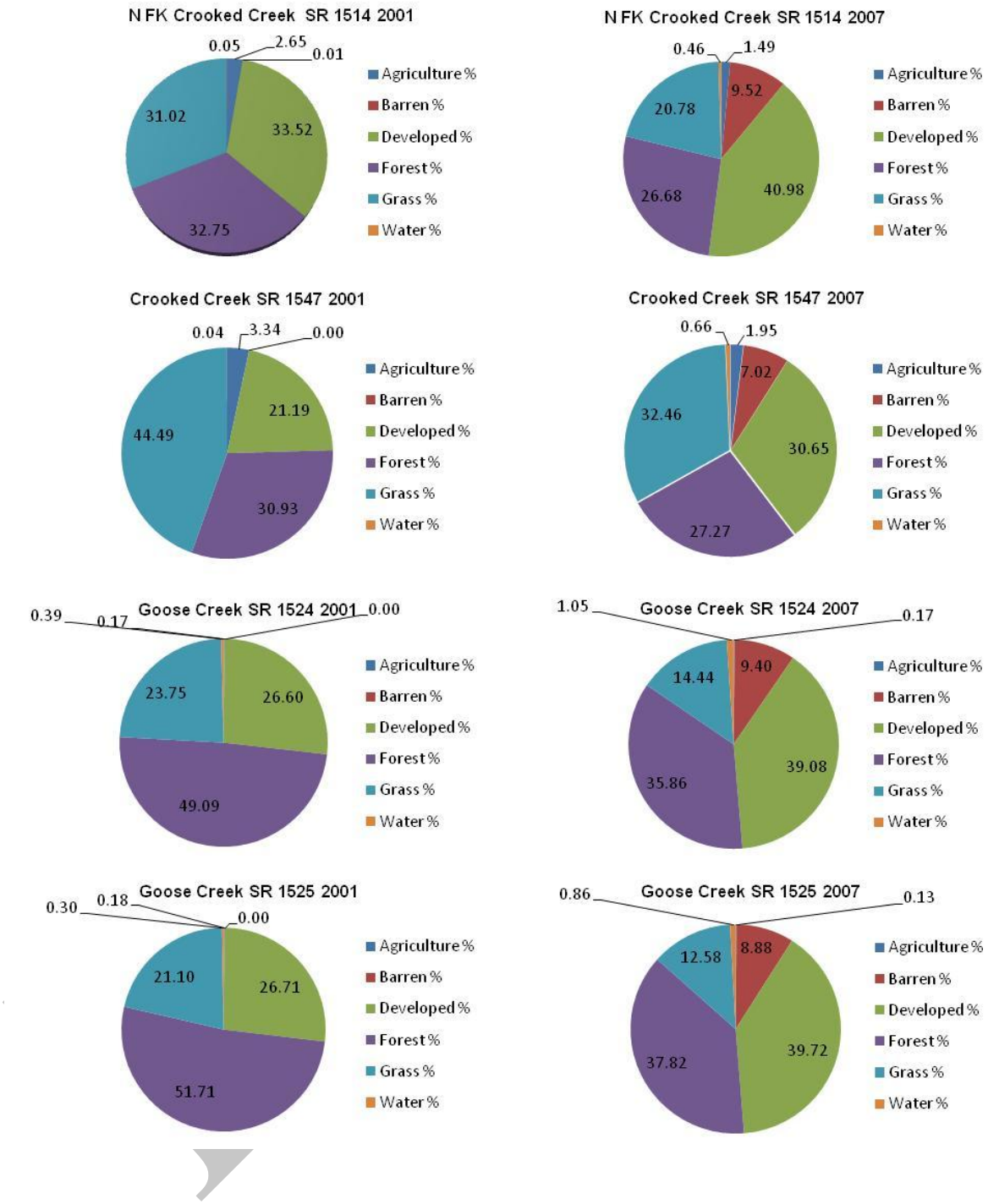


Figure 9. Land use comparisons among Goose Creek and Crooked Creek benthic sites in 2001 and 2007.

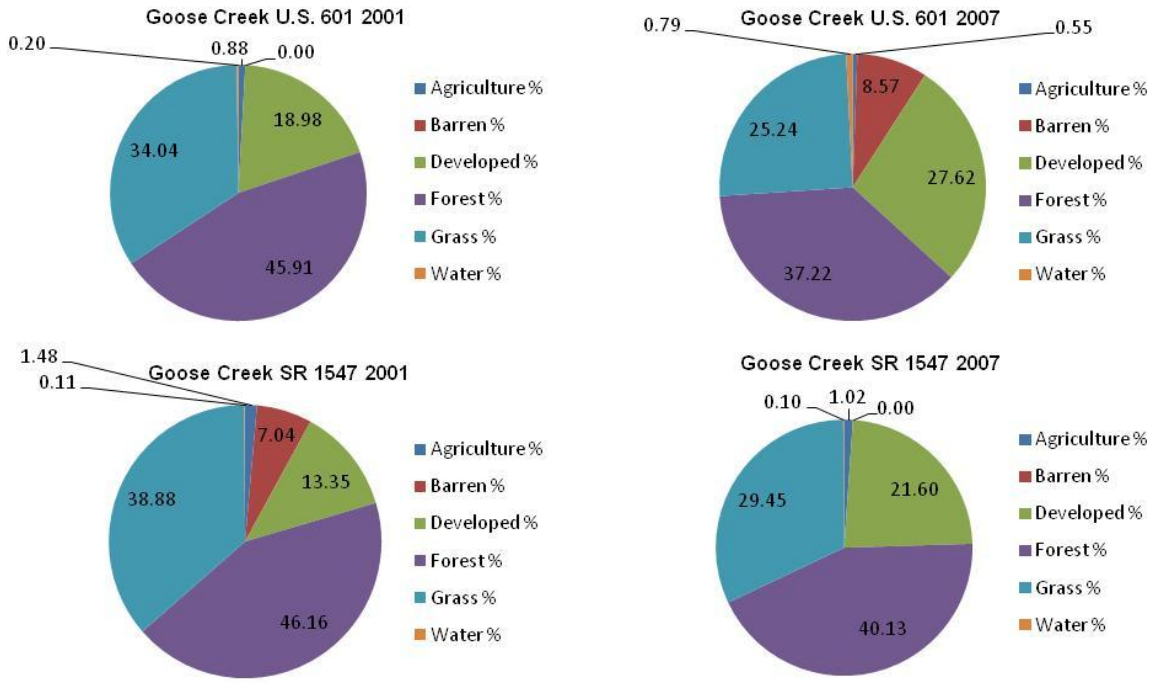


Figure 9 cont.

CONCLUSIONS

- Benthic macroinvertebrate data suggests water quality degradation in the North Fork Crooked Creek at SR 1514 and Goose Creek at SR 1524. This impaired water quality in the headwaters may be due to increased stormwater runoff from rapidly expanding commercial/industrial and residential land use and/or point source dischargers located upstream from the sites.
- Benthic samples suggest impaired waters in Crooked Creek at SR 1547 for the first time since 1996. The exact source of this impairment is not known. Possibilities include the presence of upstream dischargers in combination with increased impervious surface in the headwaters leading to stormwater runoff events. Pollutants entering Crooked Creek could be escalated during fluctuating drought conditions common in the Slate Belt.
- North Fork Crooked Creek at SR 1514 is a recommended candidate for future stormwater BMP implementation and/or stream restoration activities. This stream reach suffers from severe erosion, lack of course substrate, and narrow/patchy riparian zones. restoration activities such as riparian buffer enhancement, stream bank stabilization, and additions of course substrate for water velocity control during storm events may benefit downstream water quality. Additions of course substrate and riparian buffer enhancements may also provide enhanced habitat favorable for macroinvertebrate colonization. Any upstream noncompliance issues with point source dischargers would need to be resolved prior to these enhancement activities.
- Goose Creek at SR 1524 may also be a good candidate for future stormwater BMP implementation and/or riparian buffer widening/stream bank stabilization. Despite the Fair bioclassification, benthic metrics suggests this site has the best water quality compared to all sites in the catchment. This may be due a combination of better habitat and only one nearby upstream discharger.

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- Multiple sources could be contributing to degraded water quality in Goose and Crooked Creek. Habitat quality increases and impervious surfaces decrease as you move downstream. Enhancing buffers/stormwater BMPs in the headwaters may help to filter excess stormwater pollutants before entering Goose and Crooked Creek. Multiple point source dischargers are located upstream from Goose Creek sample sites (Figure 1, Table 2). Limiting concentrations of point source discharge downstream may also benefit aquatic life and water quality.

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Table 5. Summary benthic data for Goose Creek, Crooked Creek, and Barnes Creek study sites sampled from 1998 to 2009, Yadkin River Basin, Union and Montgomery Counties.

Stream	N FK CROOKED CR	N FK CROOKED CR	CROOKED CR	CROOKED CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	BARNES CR	BARNES CR
Site Location	SR 1514	SR 1514	SR 1547	SR 1547	SR 1524	SR 1524	SR 1525	SR 1525	US 601	US 601	SR 1547	SR 1547	SR 1303	SR 1303
County	Union	Union	Union	Union	Union	Union	Union	Union	Union	Union	Union	Union	Montgomery	Montgomery
Collection date	27-Jun-00	14-Jul-09	23-Aug-06	14-Jul-09	22-Apr-98	13-Jul-09	21-Apr-98	14-Jul-09	22-Aug-06	14-Jul-09	1-May-98	15-Jul-09	15-May-06	15-Jul-09
BAU sample number	8133	10670	10061	10743	7554	10669	7553	10671	10060	10672	7558	10744	9908	10745
Sample method	Full Scale	Full Scale	Full Scale	Full Scale	EPT	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	EPT	Full Scale	Full Scale	Full Scale
Criteria	Summer/ Piedmont	Summer/ Piedmont	Summer/ Piedmont	Summer/ Piedmont	Spring/ Piedmont	Summer/ Piedmont	Spring/ Piedmont	Summer/ Piedmont	Summer/ Piedmont	Summer/ Piedmont	Spring/ Piedmont	Summer/ Piedmont	Spring/ Piedmont	Summer/ Piedmont
Richness														
Ephemeroptera	5	2	6	5	9	6	2	3	6	5	7	7	21	19
Plecoptera	0	0	0	0	1	0	0	0	0	0	2	0	6	2
Trichoptera	2	2	5	5	6	7	2	3	5	7	2	6	10	6
Total EPT	7	4	11	10	16	13	4	6	11	12	11	13	37	27
Odonata	9	2	5	7		7	3	4	9	6		6	5	9
Megaloptera	0	0	0	0		0	0	0	0	0		0	2	3
Coleoptera	6	4	9	5		7	2	6	7	6		9	7	11
Chironomidae	16	12	24	18		13	16	25	24	24		24	31	18
non-Chironomidae Diptera	3	2	1	5		4	3	5	3	4		4	4	2
Oligochaeta	2	2	3	2		2	4	5	3	1		2	2	3
Mollusca	4	3	6	7		5	2	6	4	6		7	4	6
Other taxa	6	4	4	4		2	1	2	6	2		6	2	4
Total taxa richness	53	33	63	58		53	35	59	67	61		71	94	83
Other biological metrics														
EPT abundance	54	31	85	77	51	55	8	35	58	54	35	69	149	125
EPT Biotic Index	6.79	7.00	5.79	5.67	4.66	6.11	6.95	6.58	6.65	6.38	6.00	6.47	4.24	4.17
NCBI	6.98	7.09	6.27	6.65		6.40	6.95	7.01	6.87	6.80		6.82	5.01	4.97
Seasonal Correction							*0.20*						*0.20*	
Corrected NCBI							*7.15*						*5.21*	
Bioclassification	Fair	Poor	Good-Fair	Fair	Good-Fair	Fair	Poor	Fair	Fair	Fair	Fair	Fair	Excellent	Good

Table 6. Summary of habitat and physicochemical data for benthic sample sites within the Goose Creek, Crooked Creek, and Barnes Creek catchments, Union and Montgomery Counties, July 2009

Stream	N FK CROOKED CR	CROOKED CR	GOOSE CR	GOOSE CR	GOOSE CR	GOOSE CR	BARNES CR
Site Location	SR 1514	SR 1547	SR 1524	SR 1525	US 601	SR 1547	SR 1303
County	UNION	Union	Union	UNION	Union	UNION	UNION
Collection date	14-Jul-09	14-Jul-09	13-Jul-09	14-Jul-09	14-Jul-09	15-Jul-09	15-Jul-09
BAU sample number	10670	10743	10669	10671	10672	10744	10745
Habitat Scores							
Channel modification (5)	5	5	5	5	5	5	5
In-stream habitat (20)	11	18	18	19	19	16	20
Bottom substrate (15)	6	11	12	12	13	12	15
Pool variety (10)	8	10	8	10	8	10	10
Riffle habitats (16)	5	15	12	15	15	14	15
Bank stability/vegetation (14)	6	12	5	10	10	9	12
Light penetration (10)	10	7	10	10	10	10	7
Riparian zone width (10)	10	10	7	9	8	10	8
Total Habitat (100)	61	88	77	90	88	86	92
Other Habitat							
Average stream width (m)	5	10	8	10	10	11	11
Average stream depth (m)	0.25	0.1	0.2	0.1	0.1	0.1	0.2
Canopy (%)	90	60	85	80	90	90	75
Substrate (%)							
Bedrock	0	0	0	10	0	0	10
Boulder	0	10	20	30	25	20	30
Cobble	0	40	20	20	25	20	30
Gravel	50	30	20	20	10	20	15
Sand	25	10	20	10	20	20	10
Silt	25	10	20	10	20	20	5
Physicochemical							
Temperature (ºC)	22.5	26.1	23.7	23.1	24.2	21.0	23.8
Dissolved oxygen (mg/L)	5.2	6.5	6.7	7.1	5.8	6.8	7.7
Specific conductance (µmhos/cm)	425	471	121	193	232	229	51
pH	7.0	7.8	7.0	7.2	7.1	7.3	7.1

Appendix 1.

			CROOKED CR SR 1514 Union County	CROOKED CR SR 1547 Union County 14 Jul 2009	GOOSE CR SR 1524 Union County 13 Jul 2009	GOOSE CR SR 1525 Union County 14 Jul 2009	GOOSE CR US 601 Union County 14 Jul 2009	GOOSE CR SR 1547 Union County 15 Jul 2009	BARNES CR SR 1303 Montgomery County 15 Jul 2009
Ephemeroptera	Baetidae	ACENTRELLA FEMORELLA (WALTZ)							C
		ACENTRELLA TURBIDA							C
		BAETIS FLAVISTRIGA	R	C	A		C	A	C
		BAETIS INTERCALARIS	A	A	C	R		A	C
		BAETIS PLUTO			R				C
		CENTROPTILUM SPP							R
		HETEROCLOEON CURIOSUM							R
		PROCLOEON SPP					R	R	R
		PSEUDOCLOEON PROPINQUUM						R	
	Caenidae	CAENIS SPP		A	R	C	A	A	A
	Ephemeridae	EPHEMERA SPP							R
	Heptageniidae	EPEORUS VITREUS							C
		HEPTAGENIA MARGINALIS							C
		LEUCROCUTA SPP							A
		MACCAFFERTIUM MODESTUM		A	A	A	A	A	A
		MACCAFFERTIUM VICARIUM							A
		STENACRON INTERPUNCTATUM							C
		STENACRON PALLIDUM							C
		STENONEMA FEMORATUM							C
	Isonychiidae	ISONYCHIA SPP		C	C		C	R	A
Plecoptera	Perlidae	ACRONEURIA ABNORMIS							A
		NEOPERLA SPP							C
Trichoptera	Dipseudopsidae	PHYLOCENTROPUS SPP					R		
	Helicopsychidae	HELICOPSYCHE BOREALIS		A				R	
	Hydropsychidae	CERATOPSYCHE SPARNA							R
		CHEUMATOPSYCHE SPP	A	A	A	A	A	A	A
		HYDROPSYCHE BETTENI	A	A	A	A	A	A	C
		HYDROPSYCHE ROSSI					R		
		HYDROPSYCHE VENULARIS							R
	Hydroptilidae	HYDROPTILA SPP		A		R	C	R	
	Leptoceridae	MYSTACIDES SEPULCHRALIS			R				
		NECTOPSYCHE EXQUISITA		R	R				
		OECETIS PERSIMILIS			R		R	C	
		TRIAENODES IGNITUS			C		R		
		TRIAENODES PERNA/HELO							C
	Philopotamidae	CHIMARRA SPP			R			R	A
Odonata	Aeshnidae	BASIAESCHNA JANATA		C			C	C	C
		BOYERIA VINOSA		R	R			R	A
	Calopterygidae	CALOPTERYX SPP	C		C	A	C	R	
	Coenagrionidae	ARGIA SPP		R	C	C			R
		ENALLAGMA SPP	R		R				
		ISCHNURA SPP		R					
		NEHALENNIA SPP			R				
	Corduliidae	CORDULIIDAE						R	
		EPITHECA CYNOSURA							R
		HELOCORDULIA SPP							C
		NEUROCORDULIA SPP		R					
		SOMATOCHLORA SPP		A		R	C	R	R
	Gomphidae	GOMPHUS SPP					R		R
		HAGENIUS BREVISTYLUS				R			
		OPHIOGOMPHUS SPP					R		
		PROGOMPHUS OBSCURUS			R		R		
		STYLOGOMPHUS ALBISTYLUS			R				R
	Macromiidae	MACROMIA SPP		R				R	C
Hemiptera	Gerridae	GERRIDAE						R	
	Nepidae	RANATRA SPP							R

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Appendix 1 cont.

			N FK CROOKED CR SR 1514 Union County 14 Jul 2009	CROOKED CR SR 1547 Union County 14 Jul 2009	GOOSE CR SR 1524 Union County 13 Jul 2009	GOOSE CR SR 1525 Union County 14 Jul 2009	GOOSE CR US 601 Union County 14 Jul 2009	GOOSE CR SR 1547 Union County 15 Jul 2009	BARNES CR SR 1303 Montgomery County 15 Jul 2009
Megaloptera	Corydalidae	CORYDALUS CORNUTUS							A
		NIGRONIA SERRICORNIS							A
	Sialidae	SIALIS SPP							C
Coleoptera	Dryopidae	HELICHUS SPP			R	R		R	C
	Dytiscidae	COPELATUS SPP		R					
		NEOPORUS SPP				R			C
	Elmidae	ANCYRONYX VARIEGATUS	A	A	C	C	C	C	R
		DUBIRAPHIA SPP		C	C	C		C	A
		MACRONYCHUS GLABRATUS	R	C	C	C	A	C	
		MICROCYLLOEPUS PUSILLUS			R		R	R	R
		OPTIOSERVUS OVALIS							A
		STENELMIS SPP	R	A	A	C	A	A	A
	Haliplidae	HALIPLUS SPP	R						
		PELTODYTES SPP						R	
	Hydrophilidae	BEROSUS SPP					C	C	R
		CYMBIODYTA SPP							R
		DERALLUS ALTUS							R
		ENOCHRUS SPP					R		
	Psephenidae	PSEPHENUS HERRICKI			C			R	A
Chironomidae	Chironomidae	ABLABESMYIA MALLOCHI	R	C		C	C	C	C
		ABLABESMYIA RHAMPHE GR			R	R	R		R
		CHIRONOMUS SPP			R			C	
		CLADOTANYTARSUS SP B				R	R		
		CLADOTANYTARSUS SP E				R			A
		CLADOTANYTARSUS SP F					C	R	
		CORYNONEURA SPP	R			R			
		CRICOTOPUS BICINCTUS	R	A		R		C	
		CRICOTOPUS INFUSCATUS GR						R	
		CRYPTOCHIRONOMUS SPP		A	R	R		C	
		CRYPTOTENDIPES SPP					R		
		DICROTENDIPES NEOMODESTUS		A		R		C	
		DICROTENDIPES SIMPSONI					R		
		LABRUNDINIA PILOSELLA				R			
		MICROTENDIPES PEDELLUS GR			C	A	C	R	R
		NANOCLADIUS ALTERNANTHERAE					R		
		NANOCLADIUS BRANCHICOLUS							R
		NANOCLADIUS DOWNESI							R
		NATARSIA SP A			R	R	R	C	
		ORTHOCLADIINAE		R					
		ORTHOCLADIUS CARLATUS							R
		ORTHOCLADIUS RUBICUNDUS				R			
		PARATANYTARSUS DISSIMILIS				C			
		PARATANYTARSUS QUADRATUS GR			R			R	
		PARATENDIPES SPP		R				C	R
		PHAENOPSECTRA OBEDIENS GR		C			C		
		PHAENOPSECTRA PUNCTIPES GR						R	R
		POLYPEDILUM AVICEPS							R
		POLYPEDILUM FLAVUM	C	A	R	R	R	C	R
		POLYPEDILUM ILLINOENSE GR	C	C	C	A	A	R	
		POLYPEDILUM SCALAENUM GR	R	A		R	A	C	
		PROCLADIUS SPP		C		R	R	A	
		PSEUDOCHIRONOMUS SPP					R		R
		RHEOTANYTARSUS SPP	C	C		R	R	R	R
		STENOCHIRONOMUS SPP	C		R	R	C	R	R
		STICTOCHIRONOMUS SPP					R		

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Appendix 1 cont.

			N FK CROOKED CR SR 1514 Union County 14 Jul 2009	CROOKED CR SR 1547 Union County 14 Jul 2009	GOOSE CR SR 1524 Union County 13 Jul 2009	GOOSE CR SR 1525 Union County 14 Jul 2009	GOOSE CR US 601 Union County 14 Jul 2009	GOOSE CR SR 1547 Union County 15 Jul 2009	BARNES CR SR 1303 Montgomery County 15 Jul 2009
		TANYTARSUS SP A	C	A	R	R	C	C	
		TANYTARSUS SP C						C	
		TANYTARSUS SP G		A					
		TANYTARSUS SP L				C	R	R	
		TANYTARSUS SP P		C					
		TANYTARSUS SP S				R			
		TANYTARSUS SP U			R				
		TANYTARSUS SPP		R				R	
		THIENEMANIELLA SPP	A	C	C	C	R		R
		THIENEMANNIMYIA GR	A			C	C	A	R
		TRIBELOS FUSCICORNE					R		
		TRIBELOS JUCUNDUM	C	R	C	C		A	C
		XYLOTOPUS PAR					R		R
non-Chironomidae Diptera	Ceratopogonidae	CULICOIDES SPP					R		
		PALPOMYIA COMPLEX			R	R			
	Culicidae	ANOPHELES SPP		R		R		R	
	Empididae	EMPIDIDAE		C		R			
	Rhagionidae	ATHERIX SPP							R
	Simuliidae	SIMULIUM SPP	C	A	A	C	C	R	A
	Tipulidae	ANTOCHA SPP						C	
		MOLOPHILUS SPP			R				
		TIPULA SPP	R	A	C	C	A	C	
		TIPULIDAE		C			R		
Oligochaeta	Lumbriculidae	LUMBRICULIDAE	R	C	A	C		C	R
	Megadrile	MEGADRILE OLIGOCHAETE	C		R			R	C
	Tubificidae	AULODRILUS PLURISETA				R			
		BRANCHIURA SOWERBYI		R					
		LIMNODRILUS HOFFMEISTERI				R			
		SPIROSPERMA NIKOLSKYI				R			
		TUBIFICIDAE				R	R		R
Crustacea	Cambaridae	CAMBARIDAE		R	C	R	R	R	R
	Palaemonidae	PALAEMONETES SPP	R						
	Talitridae	HYALELLA SPP	C						A
Gastropoda	Ancylidae	LAEVAPEX FUSCUS		C	R		R		R
	Hydrobiidae	HYDROBIIDAE							R
	Lymnaeidae	PSEUDOSUCCINEA COLUMELLA			R	C	R		
	Physidae	PHYSA SPP	A	A	A	A	A	A	R
	Planorbidae	HELISOMA ANCEPS			R	C	C	C	
		HELISOMA TRIVOLVIS		A					
		MICROMENETUS DILATATUS		C		R		R	
	Pleuroceridae	ELIMIA SPP							C
	Viviparidae	CAMPELOMA DECISUM		A					
Bivalvia	Corbiculidae	CORBICULA FLUMINEA	A	C		R	R	R	R
	Sphaeriidae	MUSCULIUM SPP						R	
		PISIDIUM SPP			C	R		A	C
		SPHAERIUM SPP	C	A			R	R	
Other	Erpobdellidae	ERPOBDELLA/MOOREOBDELLA	R						
	Hydracarina	HYDRACARINA	R	C	R		R	R	C
	Planariidae	CURA FOREMANII		R				C	
		DUGESIA TIGRINA		C		R		C	
	Sisyridae	SISYRA SPP						R	

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Appendix F:

Copper Concentrations in Goose Creek, Union County, NC:

Data Collection for Use with the Biotic Ligand Model for Copper Toxicity

COPPER CONCENTRATIONS IN GOOSE CREEK, UNION COUNTY, NORTH CAROLINA: DATA COLLECTION FOR USE WITH THE BIOTIC LIGAND MODEL FOR COPPER TOXICITY

A Report to the North Carolina Ecosystem Enhancement Program

Watershed Assessment Team

June 8, 2011

ABSTRACT

Goose Creek and its associated watershed, Duck Creek, are home to populations of the federally-listed, and North Carolina and South Carolina listed endangered mussel, the Carolina Heelsplitter (*Lasmigona decorata*). The NC Division of Water Quality (NCDWQ) Watershed Assessment Team (WAT) collected ambient data which could be used in the Biotic Ligand Model (BLM) by the U.S. Fish and Wildlife Service (USFWS) to evaluate potential copper toxicity in the Goose Creek watershed (Union Co., NC). Data collection began with a preliminary sampling in December 2009 and was followed by four full-scale samplings at five locations on Goose Creek in January, February, April and August 2010. Water quality variables measured specifically for the BLM included dissolved copper, water temperature, pH, dissolved organic carbon (DOC), calcium, magnesium, sodium, potassium, sulfate (SO_4), chloride, alkalinity, and hardness. Additional data on total copper concentrations were obtained from two related WAT water quality projects (LWP monitoring and a Stormflow Interpretation special study) in the Goose Creek watershed and from an Ambient Monitoring System station on Goose Creek at SR 1524 near Mint Hill to provide a broader range of data for comparative and interpretive purposes. Flow records were downloaded from the USGS gage 02124692 on Goose Creek at Fairview, NC.

Copper concentrations measured for the BLM study were consistently below the 7.0 µg/L NC Action Level (AL). Total copper ranged between < 2 and 5 µg/L, and dissolved copper concentrations fell between < 2 and 4 µg/L. Total copper concentrations at sites in the Goose Creek watershed fell consistently between < 2 and 5 µg/L during LWP monitoring. In the stormflow special study, total copper concentrations during baseflow fell consistently below the 7.0 µg/L AL, whereas concentrations measured during natural stormflow ranged from slightly below the AL to as high as 17 µg/L. Dissolved copper was not measured for either of these studies. Copper concentrations from the AMS station on Goose Creek between 1995 and 2008 ranged from < 2 µg/L to over 25 µg/L. Thirteen of 91 measurements (14%) during this time frame exceeded exceeding the 7.0 µg/L, and 15 were below the Practical Quantitation Limit (PQL) of 2 µg/L. Only two of the 13 exceedences of the AL have occurred since 2001.

There was no distinction as to which of the AMS samples were collected during baseflow and which were collected during higher flows.

At the time of writing of this report, we are not certain how to interpret the potential for copper toxicity, due to complications with the data collected during the three minor storm events occurring in December 2009 and January and February 2010. Successful completion of this study was contingent upon being able to sample under multiple flow regimes, which was accomplished with the possible exception of substantial stormflows. Water temperatures during the three December, January, and February sampling dates also were lower than a 10^{o} C criterion for calculation of copper toxicity using the BLM. WAT personnel were unaware of this criterion until after sampling these events. Additional sampling under stormflow conditions may be necessary to complete the dataset needed to use the BLM. However, the USFWS staff who are more familiar with the model will need to make that decision. Any further sampling on this project probably will have to be approved by agreement between the NC Department of Transportation (NCDOT) and the NC Ecosystem Enhancement Program (NCEEP).

INTRODUCTION

Copper is an abundant trace element found in the earth's crust and is a naturally occurring element that is generally present in surface waters. Copper is a micronutrient at low concentrations and is recognized as essential to virtually all plants and animals. However, elevated levels of copper have been linked to adverse effects on aquatic organisms including freshwater mussels (March et. al. 2007, Wang, et al. 2009).

Copper was listed as concern for Goose Creek following the NCDWQ's summary of water chemistry data (NCDWQ 2002). Data were collected by the NCDWQ ambient monitoring system (AMS) station at Goose Creek near Mint Hill (Station No. Q8360000) for the period 1995-2004).

The concern was raised because 20% of the values recorded by NCDWQ exceeded the State's 7 µg/l action level. The Goose and Duck Creek watersheds contain populations of the federally-listed, and North Carolina and South Carolina listed endangered mussel – the Carolina Heelsplitter (Lasmigona *decorata*). This species is only found within North and South Carolina (Figure 1). The Carolina heelsplitter has been reduced to only eight surviving populations, six in South Carolina, and two in North Carolina. The North Carolina populations are in Goose, Duck and Waxhaw Creeks (Mecklenburg and Union Counties).

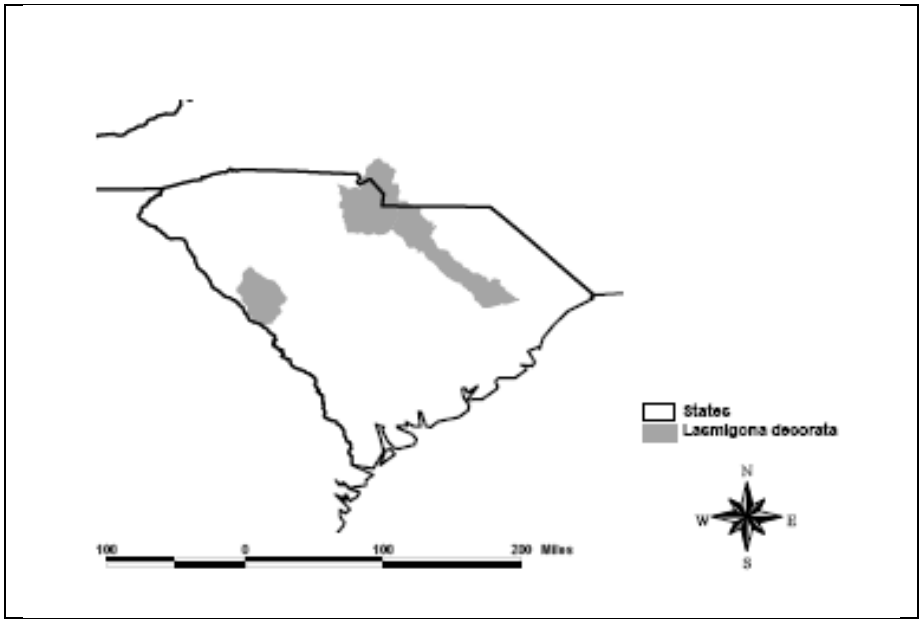


Figure 1. Distribution of the Carolina Heelsplitter (*Lasmigona decorata*) in North Carolina and South Carolina (http://www.dnr.sc.gov/cwcs/pdf/CarolinaHeelsplitter.pdf)

A review of water quality factors that could affect populations of the Carolina Heelsplitter (USFWS, NCWRC and NCNHP 2005) was completed by an interagency team from the US Fish and Wildlife Service (USFWS), the NC Wildlife Resources Commission (NCWRC) and the NC Natural Heritage Program (NCNHP). This report indicated several factors that potentially could affect populations of the Carolina Heelsplitter in Goose Creek, including:

1. Bank / Channel Instability
2. Sediment / Suspended Solids
3. Ammonia
4. Dissolved oxygen
5. Chlorine
6. Nitrate / Nitrite
7. Phosphorus
8. Pesticides
9. Fecal coliform bacteria
10. Copper

Currently, a local watershed plan (LWP) is under development by the NCEEP for the Goose and Crooked Creek watersheds in North Carolina. (Crooked Creek is a watershed contiguous to the Goose Creek watershed.) The LWP is being developed to support compensatory mitigation needs in compliance with federal regulations. To support the development of the LWP, the NCDWQ-WAT initiated water quality monitoring and assessments within the Goose and Crooked Creek watersheds. One part of the water quality assessment effort was the collection of water samples for copper.

Historically, the NCDWQ has analyzed water quality samples for metals, including copper, as total concentrations. In this case, results reflected both dissolved metals and metals associated with particulate matter. However, the dissolved forms of metals most often affect aquatic life. Therefore, the measurement of total copper concentrations may not adequately address the issue of potential copper toxicity to aquatic organisms.

The Biotic Ligand Model (BLM) is a bioavailability model that uses receiving water body characteristics and monitoring data to describe possible toxicological effects of copper to aquatic organisms. The model is referred to as the biotic ligand model -- the term “biotic” refers to living organism; the term “ligand” refers to any molecule that binds to another. The BLM requires results for dissolved copper, water temperature, pH, dissolved organic carbon (DOC), calcium, magnesium, sodium, potassium, sulfate (SO_4), chloride, alkalinity, and hardness.

OBJECTIVES

The objectives of this project were to collect water quality data for use in the BLM to evaluate potential copper toxicity to aquatic organisms, specifically to determine if copper toxicity is a factor impacting populations of Carolina Heelsplitter in the Goose Creek watershed.

APPROACH

The NCDWQ-WAT initiated water quality monitoring activities in 2009 that could provide insight into the potential copper toxicity issue that was identified by the USFWS, NCWRC and NCNHP (2005). Specifically, the NCDWQ-WAT would collect water samples for the analytes necessary to run the BLM, a toxicity model for copper developed by Hydro Qual[1]. The Goose Creek watershed in Union County, NC, was selected because of concern about copper toxicity as a factor impacting the Carolina Heelsplitter. This special project is a component of ongoing monitoring activities being conducted in support of the LWP for Goose and Crooked Creeks.

A total of five sampling locations were selected in the Goose Creek watershed (Table 1 and Figure 2). These watersheds have drainage areas that range from less than five to more than 40 square miles. The intent of the project was to collect samples under a range of flow conditions. One station (station 4, Goose Creek at US 601) was sampled in December 2009, and all five were sampled during January, February, April and August of 2010 (Table 2). The three winter samples were collected under moderately high flow conditions of a minor storm event. The April and August samples were collected under baseflow conditions.

Table 1. Water sample collection sites for the biotic ligand model for copper.

Map Code	Location	Latitude	Longitude
1	Goose Cr. at Country Woods Dr.	35.1455	-80.6357
2	Goose Cr. at Stevens Mill Rd (SR 1524)	35.1312	-80.6315
3	Goose Cr. at Mill Grove Rd. (SR 1525)	35.1250	-80.6029
4	Goose Cr. at US 601	35.1537	-80.5353
5	Goose Cr. at Brief Rd (SR 1547)	35.1757	-80.5112

Sampling included field measurements (water temperature, dissolved oxygen concentration and percent saturation, pH, and specific conductance) and water samples for analysis by the NCDWQ analytical laboratory. Laboratory analyses were conducted on unfiltered samples for turbidity, total suspended residues, total alkalinity, chloride, sulfate, sulfide, copper, calcium, magnesium, sodium and potassium. Field-filtered samples were analyzed for dissolved organic

[1] http://www.hydroqual.com/wr_blm.html

carbon, copper, calcium, magnesium, sodium and potassium. Field blanks (QA) samples of purified water, both unfiltered and filtered in the field, were sent to the lab for analysis of turbidity, suspended residue, dissolved organic carbon and the metals listed above. One blank sampling) will be analyzed. Flow conditions at the time of sampling were recorded by reading USGS staff gages at Locations 3 and 4 (Figure 2), and estimated by reference stage measurements[2] at the other three locations.

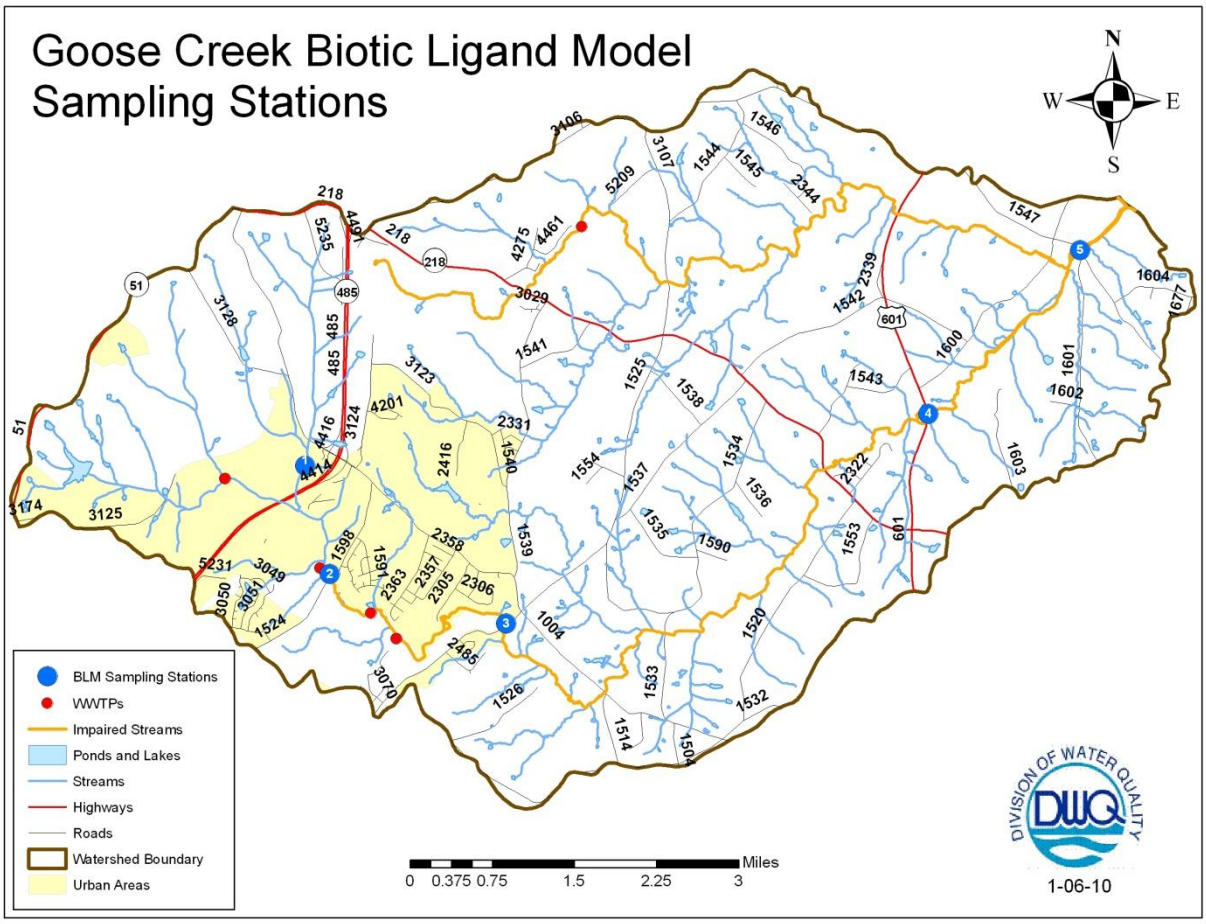


Figure 2. Location of sampling sites in the Goose Creek watershed for use in the BLM.

RESULTS AND DISCUSSION

This report summarizes data collected by NCDW-WAT for the BLM and two other ongoing studies in the Goose Creek watershed and also data collected as part of the AMS in Goose Creek. These supplementary data also are summarized here to provide a broader range of data

[2] Reference stage data is obtained by measuring the distance to the surface of the stream from a known (i.e. "reference") point on a bridge.

for comparative and interpretive purposes. Data collected for the BLM include both total copper and dissolved copper, whereas the data collected by WAT in the two associated studies at Goose Creek and the AMS data all report only total copper concentrations. All raw data collected for the BLM are shown in the Appendix at the end of this report.

Table 2. Biotic ligand model sample dates.

		Sample Date					
Map Code	Location	12/2/2009	1/20/2010	2/4/2010	4/7/2010	8/10-2010	8/11/2010
1	Goose Cr. at Country Woods Dr.		X	X	X	X	
2	Goose Cr. at Stevens Mill Rd (SR 1524)		X	X	X	X	
3	Goose Cr. at Mill Grove Rd. (SR 1525)		X	X	X	X	
4	Goose Cr. at US 601	X	X	X	X		X
5	Goose Cr. at Brief Rd (SR 1547)		X	X	X		X

Biotic Ligand Model Study

Concentrations of copper (both dissolved and total) measured as part of the data collection for the BLM study during the flow conditions occurring between December 2009 and August 2010 ranged from below the PQL (2 µg/L) to slightly higher than 5 µg/L (Figure 3). These all were below the NC action level (7.0. µg/L), the level above which NC generally considers copper to be a potential hazard for chronic toxicity to aquatic organisms. These data suggest that copper toxicity may be of less concern in Goose Creek than previously thought. However, the NC action level (AL) is based on total copper, whereas soluble copper is the actively toxic component. Also, copper toxicity is highly dependent on other water quality factors. A more accurate evaluation of copper toxicity cannot be provided until the data can be analyzed in the BLM by the USFWS.

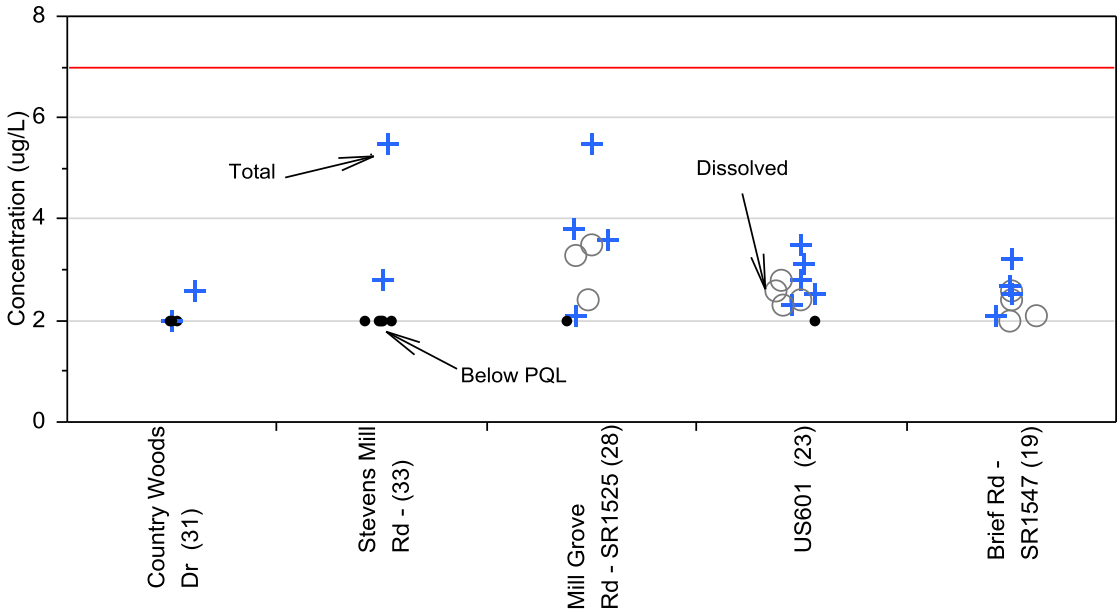


Figure 3. Copper concentrations (both filtered and Total [unfiltered]) obtained from the biotic ligand model study. The red solid line at 7.0 µg/L represents the NC action level.

The NCDWQ-WAT has two primary concerns with the dataset collected during this study. First, the water temperatures during the December, January and February samplings were lower than the 10^{o} C criterion for calculations of copper toxicity using the Biotic Ligand Model (Figure 4). WAT personnel were unaware of this criterion until after conducting these sampling events. Also, the range of flow conditions may have been inadequate for good model development. Stream flows in Goose Creek that have been sampled thus far for the BLM study do not include any substantial stormflows (Figure 4). The three "stormflow" events that occurred during December through February fell between 10 and slightly over 100 cfs discharge. Significantly higher flows occur during significant storm events and potentially would have resulted in substantially higher copper concentrations in the water column. Further sampling over a wider range of stream flows, particularly substantially higher stormflow events occurring during warmer weather, may be necessary to provide sufficient data to use the BLM to evaluate copper toxicity in Goose Creek.

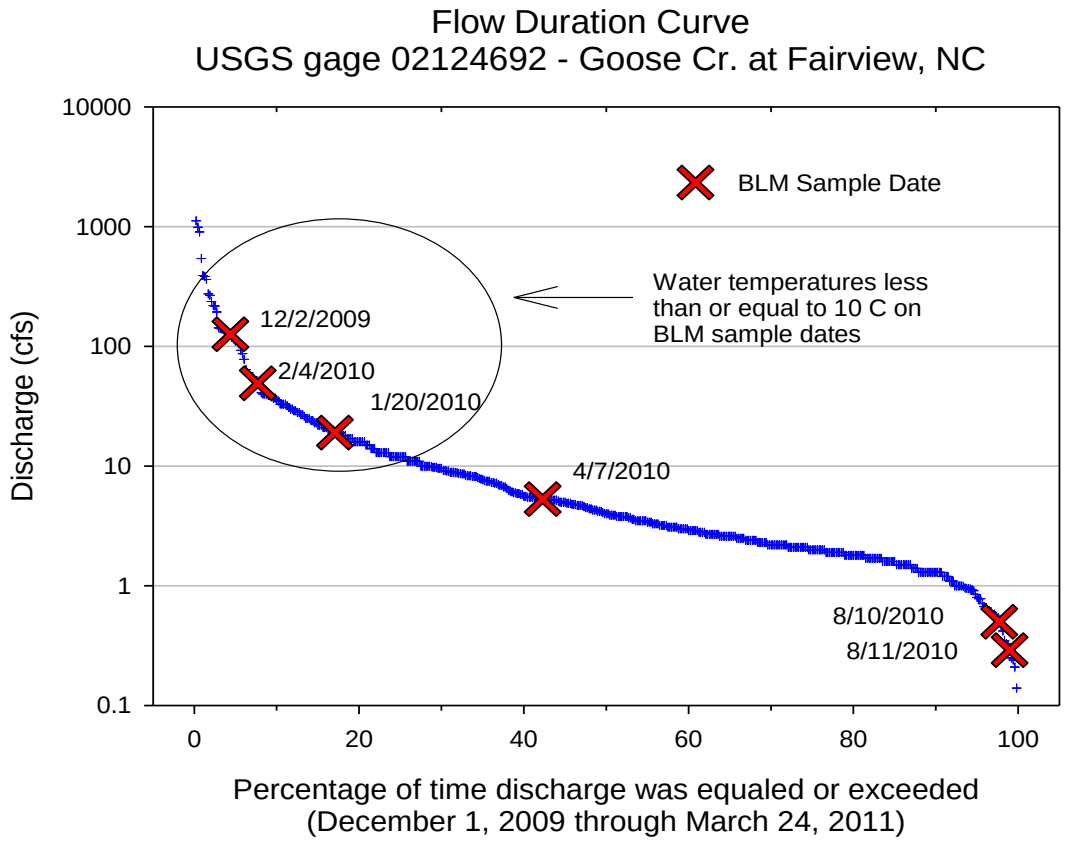


Figure 4. Flow (discharge) at the downstream gage on Goose Creek.

Goose-Crooked Creek LWP Monitoring

Monitoring for the Goose-Crooked Creek Local Watershed Plan (LWP) occurred during April 2009 through August 2010. Total (unfiltered) copper concentrations were monitored as part of the assessments of water quality conditions within the LWP area and have been reported previously (NCDWQ 2011a). Copper concentrations measured at four stations on Goose Creek and one on its tributary, Duck Creek (Table 4 and Figure 5) ranged from below the PQL to about 6.5 µg/L. The data for Goose Creek sites and most Crooked Creek sites were within the same range as the unfiltered (total) copper data in the BLM study. The two instances shown where copper concentrations exceeded the 7.0 µg/L AL occurred at a station on North Fork Crooked Creek (SR 1514, Rocky River Rd.), which was not directly within the Goose Creek watershed and not within the presently known habitat of the Carolina Heelsplitter. Dissolved copper and other variables associated with copper toxicity (for the BLM) were not sampled during the LWP monitoring.

Table 4. Ranges and median total copper concentrations in the Goose-Crooked Creek LWP area, April 2009 - August 2010.

Map Code	Location	N	x̄	Min	25%	50%	75%	Max
Goose 1- (33)	SR 1524-Stevens Mill Rd.	4	2.7	2.0	2.0	2.2	3.9	4.4
Goose 2- (28)	SR 1525- Mill Grove Rd.	4	3.1	2.6	2.6	2.9	3.7	3.9
Goose 3- (23)	US 601	4	3.7	3.2	3.2	3.4	4.4	4.7
Duck 1- (21)	US 601	4	3.3	2.0	2.2	3.2	4.6	4.9
Goose 4- (19)	SR 1547-Brief Rd.	4	3.6	3.1	3.2	3.7	4.1	4.1
NF Crooked 1- (8)	SR 1520-Indian Trail Fairview Rd.	4	3.8	2.6	2.7	3.6	5.1	5.4
NF Crooked 2- (9)	SR 1514- Rocky River Rd.	5	6.2	3.9	4.0	6.5	8.4	9.6
SF Crooked 1- (4)	SR 1515- Sardis Church Rd	4	3.9	3.0	3.1	3.6	4.9	5.2
SF Crooked 2- (10)	SR 1367-Unionville Indian Trail Rd.	4	3.3	2.3	2.4	3.1	4.4	4.8
Crooked 1- (13)	SR 1547-Brief Rd.	7	4.7	4.3	4.3	4.6	5.0	5.2
Reference- (43)	SR 1303 Ophir Rd.	4	2.0	2.0	2.0	2.0	2.0	2.0

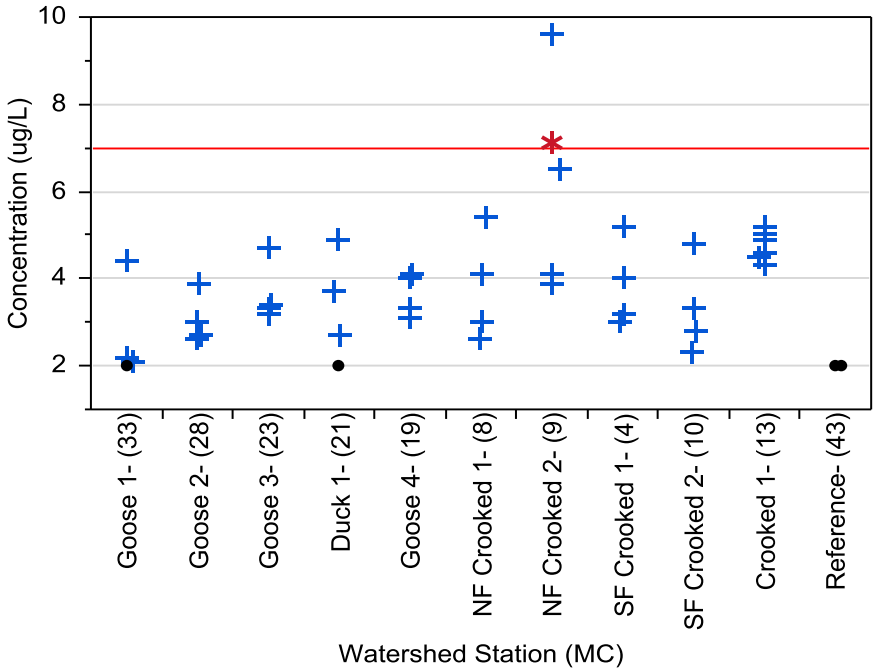


Figure 5. Concentrations of total copper during Goose-Crooked Creek LWP monitoring between April 2009 and June 2010. The solid red line represents the NC action level of 7 µg/L. Black dots (.) are values below the PQL of 2 µg/L; blue + signs represent baseflow; red asterisks (*) are stormflow samples.

Stormflow Interpretation Special Study

The stormflow study (NCDWQ 2011b) was initiated to improve our understanding of how sediment resuspension affects the concentrations of pollutants measured in the water column during storm events. In this study, three stations were sampled during baseflow and stormflow, and the turbulence occurring during stormflow was simulated by wading back and forth across the stream above each baseflow sampling location to re-suspend bottom sediments. Results from this project show higher total copper concentrations during both natural and simulated stormflow events compared with baseflow (Figure 6). All results from baseflow conditions were below the NC action level (7.0 µg/L) and many were near or below the PQL of 2.0 µg/L. These data were within the same range as the unfiltered (total) copper data in the BLM study. Most of the total copper concentrations measured during natural stormflow and simulated stormflow exceeded the action level. It also should be noted that none of the three natural stormflow events were of large magnitude, and two of the three events were sampled on the descending limb of the hydrograph. Most likely, copper concentrations would have been substantially greater had they been sampled on the rising limb. It is probable that a significant portion of the exceedences are associated with suspended copper (i.e., that attached to suspended sediment). Dissolved copper and other variables associated with copper toxicity (for the BLM) were not sampled in this study.

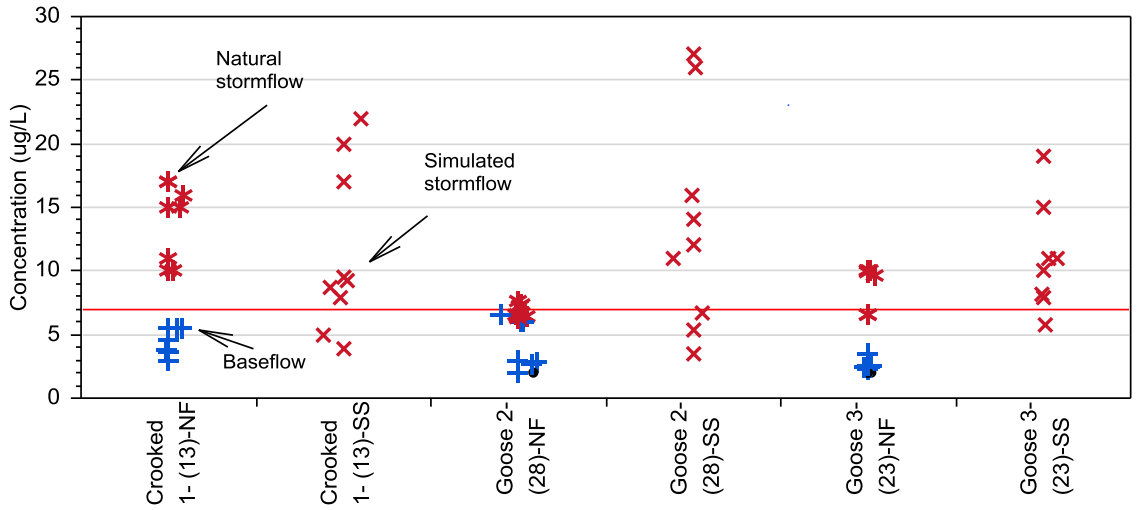


Figure 6. Copper concentrations from the Stormflow Interpretation Special Study. Crooked 1=Crooked Creek at Brief Road (Map Cope 13), Goose 2=Goose Creek at Mill Grove Rd. (Map Code 28), Goose 3=Goose Creek at US 601 (Map Code 23). NF=Natural Flow; SS=Simulated Stormflow. The red solid line at 7.0 µg/L represents the NC action level. Black dots (.) are values below the PQL of 2 µg/L; blue + signs represent baseflow; red asterisks (*) are stormflow samples; red X are simulated stormflow.

Ambient Monitoring System (AMS) Data

The ambient monitoring system maintains a monitoring station on Goose Creek near Mint Hill NC (Station No. Q8360000). All copper data were downloaded from the EPA STORET database for the period 1995 to 2007. A total of 91 measurements of total copper were made, and 13 (14%) of these exceeded the 7 µg/l action level (Figure 7). Fifteen of the measurements (16%) were below the 2 µg/l PQL. There also have been no exceedences since 2004.

In the AMS data, there is no distinction among samples collected at high flow rates vs. those collected at low flow rates. The summary of water chemistry data in the NCDWQ (2002) report indicated that many other water bodies in the Yadkin basin also exceeded the action level. No data for are available in the AMS datasets for dissolved copper, the most toxic form to aquatic life. It is probable that a significant portion of the exceedences observed for Goose Creek as well as other locations in the Yadkin basin are associated with suspended copper (i.e., that attached to suspended sediments).

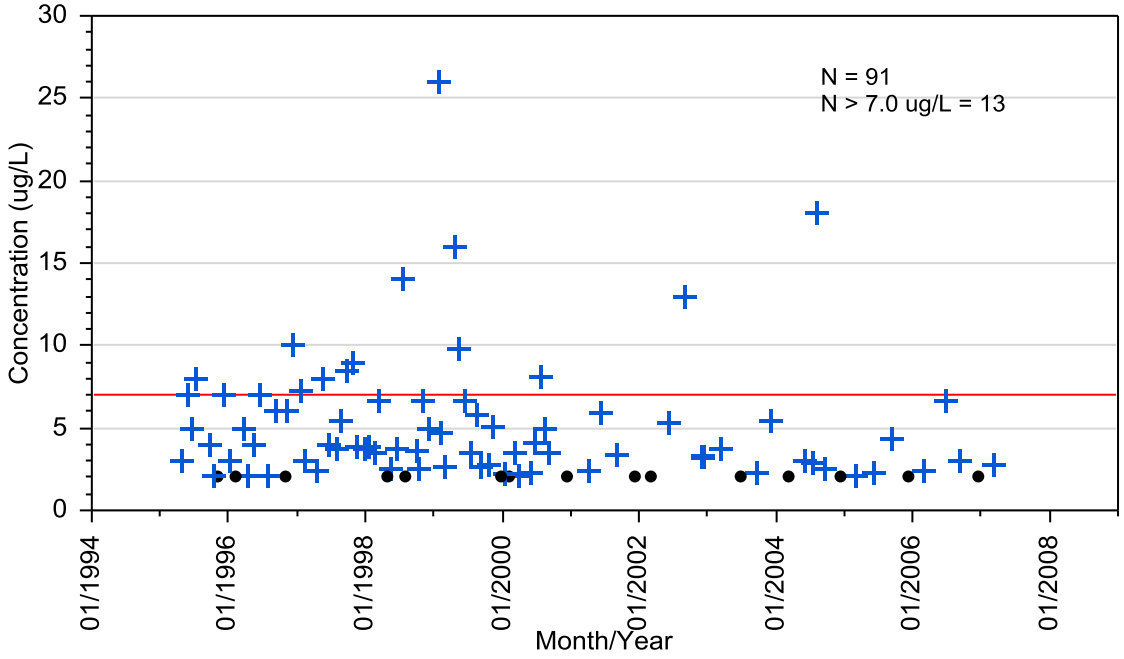


Figure 7. Copper concentrations measured from the NCDWQ ambient monitoring system station Goose Creek at SR 1524 near Mint Hill (Q8360000). The solid red line represents the NC action level of 7 µg/L. Black dots (.) are values below the PQL of 2 µg/L; blue + signs represent copper concentrations above the PQL. (There is no distinction among samples collected under different flow regimes.

CONCLUSIONS

1. Data collected for the BLM study, for the two related projects on Goose Creek, and the AMS data indicated that most copper concentrations were below the 7.0 µg/L NC action level. These data also suggested that most copper concentrations exceeding the action level probably were associated with suspended sediments during high flow.
2. Successful completion of this study was contingent upon sampling under multiple flow regimes. Stream flows that were sampled in Goose Creek for this study did not include any really high flow storm events.
3. Water temperatures during the minor stormflow events in December, January, and February sampling dates also were lower than a 10^{o} C criterion for calculation of copper toxicity using the BLM. WAT personnel were unaware of this criterion until after sampling these events.
4. Additional sampling under stormflow conditions may be needed to complete the dataset needed by the USFWS to use the BLM. Any further sampling on this project, however, probably will have to be approved by agreement between the NC Department of Transportation (NCDOT) and the NC Ecosystem Enhancement Program (NCEEP).
5. Assistance will be needed from the USFWS to determine the suitability of the existing data for use in the BLM as well as to provide interpretation of the results for the Goose Creek watershed.

RECOMMENDATIONS

1. Depending on the review by the USFWS, it may be necessary to collect additional samples under high flows, as would be expected to occur following a significant storm event.
2. WAT will provide the data to the USFWS for implementation and interpretation of the BLM model to evaluate copper toxicity in Goose Creek.

REFERENCES

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APPENDIX

Raw Data Collected by WAT for the BLM Study at Goose Creek, 2009-2010

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	12/2/2009 15:30	Specific Conductance	176		uS/cm	Stormflow	
4	US 601	12/2/2009 15:30	pH	7.2		SU	Stormflow	
4	US 601	12/2/2009 15:30	Temperature	9.5		oC	Stormflow	
4	US 601	12/2/2009 15:30	Dissolved Oxygen Saturation	93		%	Stormflow	
4	US 601	12/2/2009 15:30	Dissolved Oxygen	10.6		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Residue-Suspended Total	12	U	mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Turbidity	7.9		NTU	Stormflow	
4	US 601	12/2/2009 15:30	Nitrogen-Ammonia	0.02		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Nitrogen-Nitrite+Nitrate	2.2		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Nitrogen-Total Kjeldahl	0.53		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Phosphorus - Total	0.22		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Copper (Cu)	3.1		ug/L	Stormflow	
4	US 601	12/2/2009 15:30	Potassium (K)	4.6		mg/L	Stormflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	12/2/2009 15:30	Calcium (Ca)	13		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Magnesium (Mg)	5.1		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Hardness	53	Calculated	mg/L as CaCO3	Stormflow	
4	US 601	12/2/2009 15:30	Sodium (Na)	14		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Alkalinity	37		mg/L as CaCO3	Stormflow	
4	US 601	12/2/2009 15:30	Chloride (Cl)	16		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Sulfate (SO4)	10		mg/L	Stormflow	
4	US 601	12/2/2009 15:30	Sulfide (HS)	0.1	U	mg/L	Stormflow	
4	US 601	12/2/2009 15:35	Copper (Cu)	2.3		ug/L	Stormflow	Filtered
4	US 601	12/2/2009 15:35	Potassium (K)	4.8		mg/L	Stormflow	Filtered
4	US 601	12/2/2009 15:35	Calcium (Ca)	13		mg/L	Stormflow	Filtered
4	US 601	12/2/2009 15:35	Magnesium (Mg)	5.3		mg/L	Stormflow	Filtered
4	US 601	12/2/2009 15:35	Sodium (Na)	14		mg/L	Stormflow	Filtered
4	US 601	12/2/2009 15:35	Dissolved Organic Carbon (DOC)	5.5		mg/L	Stormflow	Filtered
1	Country Woods Dr.	1/20/2010 11:30	Specific Conductance	104		uS/cm	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	pH	7		SU	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
1	Country Woods Dr.	1/20/2010 11:30	Temperature	9.1		oC	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Dissolved Oxygen Saturation	97		%	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Dissolved Oxygen	11.2		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Turbidity	14		NTU	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Nitrogen-Ammonia	0.02	U	mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Nitrogen-Nitrite+Nitrate	0.7		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Nitrogen-Total Kjeldahl	0.2	U	mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Phosphorus - Total	0.03		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Copper (Cu)	2	U	ug/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Potassium (K)	1.5		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Calcium (Ca)	10		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Magnesium (Mg)	3.7		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Hardness	40	Calculated	mg/L as CaCO3	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Sodium (Na)	6.5		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Alkalinity	31		mg/L as CaCO3	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
1	Country Woods Dr.	1/20/2010 11:30	Chloride (Cl)	9.9		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Sulfate (SO4)	5		mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:30	Sulfide (HS)	0.1	U	mg/L	Baseflow	
1	Country Woods Dr.	1/20/2010 11:35	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
1	Country Woods Dr.	1/20/2010 11:35	Potassium (K)	1.4		mg/L	Baseflow	Filtered
1	Country Woods Dr.	1/20/2010 11:35	Calcium (Ca)	10		mg/L	Baseflow	Filtered
1	Country Woods Dr.	1/20/2010 11:35	Magnesium (Mg)	3.6		mg/L	Baseflow	Filtered
1	Country Woods Dr.	1/20/2010 11:35	Sodium (Na)	6.4		mg/L	Baseflow	Filtered
1	Country Woods Dr.	1/20/2010 11:35	Dissolved Organic Carbon (DOC)	2.8		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Specific Conductance	117		uS/cm	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	pH	7.2		SU	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Temperature	10		oC	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Dissolved Oxygen Saturation	104		%	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Dissolved Oxygen	11.7		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Turbidity	16		NTU	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Nitrogen-Ammonia	0.02	U	mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Nitrogen-Nitrite+Nitrate	0.64		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Nitrogen-Total Kjeldahl	0.22		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Phosphorus - Total	0.08		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Copper (Cu)	2	U	ug/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Potassium (K)	1.6		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Calcium (Ca)	11		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Magnesium (Mg)	3.9		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Hardness	44	Calculated	mg/L as CaCO3	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Sodium (Na)	7.4		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Alkalinity	34		mg/L as CaCO3	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Chloride (Cl)	11		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Sulfate (SO4)	5.9		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:40	Sulfide (HS)	0.1	U	mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:45	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:45	Potassium (K)	1.7		mg/L	Baseflow	Filtered

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:45	Calcium (Ca)	11		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:45	Magnesium (Mg)	4		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:45	Sodium (Na)	7.6		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	1/20/2010 12:45	Dissolved Organic Carbon (DOC)	3.3		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Specific Conductance	129		uS/cm	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	pH	7.3		SU	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Temperature	9.7		oC	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Dissolved Oxygen Saturation	102		%	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Dissolved Oxygen	11.6		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Turbidity	16		NTU	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Nitrogen-Ammonia	0.04		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Nitrogen-Nitrite+Nitrate	1		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Nitrogen-Total Kjeldahl	0.51		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Phosphorus - Total	0.18		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Copper (Cu)	2.1		ug/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Potassium (K)	2		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Calcium (Ca)	10		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Magnesium (Mg)	3.9		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Hardness	41	Calculated	mg/L as CaCO3	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Sodium (Na)	9.4		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Alkalinity	32		mg/L as CaCO3	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Chloride (Cl)	14		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Sulfate (SO4)	8		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:10	Sulfide (HS)	0.1	U	mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:15	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:15	Potassium (K)	2		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:15	Calcium (Ca)	11		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:15	Magnesium (Mg)	4		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:15	Sodium (Na)	9.7		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	1/20/2010 13:15	Dissolved Organic Carbon (DOC)	4		mg/L	Baseflow	Filtered
4	US 601	1/20/2010 14:35	Specific Conductance	146		uS/cm	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	1/20/2010 14:35	pH	7.3		SU	Baseflow	
4	US 601	1/20/2010 14:35	Temperature	8.6		oC	Baseflow	
4	US 601	1/20/2010 14:35	Dissolved Oxygen Saturation	90		%	Baseflow	
4	US 601	1/20/2010 14:35	Dissolved Oxygen	10.5		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Turbidity	15		NTU	Baseflow	
4	US 601	1/20/2010 14:35	Nitrogen-Ammonia	0.03		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Nitrogen-Nitrite+Nitrate	2.5		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Nitrogen-Total Kjeldahl	0.67		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Phosphorus - Total	0.18		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Copper (Cu)	2.8		ug/L	Baseflow	
4	US 601	1/20/2010 14:35	Potassium (K)	3.5		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Calcium (Ca)	10		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Magnesium (Mg)	4.8		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Hardness	45	Calculated	mg/L as CaCO3	Baseflow	
4	US 601	1/20/2010 14:35	Sodium (Na)	10		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	1/20/2010 14:35	Alkalinity	23		mg/L as CaCO3	Baseflow	
4	US 601	1/20/2010 14:35	Chloride (Cl)	16		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Sulfate (SO4)	12		mg/L	Baseflow	
4	US 601	1/20/2010 14:35	Sulfide (HS)	0.1	U	mg/L	Baseflow	
4	US 601	1/20/2010 14:40	Copper (Cu)	2.6		ug/L	Baseflow	Filtered
4	US 601	1/20/2010 14:40	Potassium (K)	3.5		mg/L	Baseflow	Filtered
4	US 601	1/20/2010 14:40	Calcium (Ca)	10		mg/L	Baseflow	Filtered
4	US 601	1/20/2010 14:40	Magnesium (Mg)	4.7		mg/L	Baseflow	Filtered
4	US 601	1/20/2010 14:40	Sodium (Na)	9.9		mg/L	Baseflow	Filtered
4	US 601	1/20/2010 14:40	Dissolved Organic Carbon (DOC)	5.6		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Specific Conductance	140		uS/cm	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	pH	7.3		SU	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Temperature	9.5		oC	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Dissolved Oxygen Saturation	96		%	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Dissolved Oxygen	11		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Residue-Suspended Total	6.2	U	mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Turbidity	15		NTU	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Nitrogen-Ammonia	0.02		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Nitrogen-Nitrite+Nitrate	2.5		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Nitrogen-Total Kjeldahl	0.53		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Phosphorus - Total	0.16		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Copper (Cu)	2.7		ug/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Potassium (K)	3.2		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Calcium (Ca)	9.3		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Magnesium (Mg)	4.5		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Hardness	42	Calculated	mg/L as CaCO3	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Sodium (Na)	9.6		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Alkalinity	20		mg/L as CaCO3	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Chloride (Cl)	16		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Sulfate (SO4)	11		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 13:55	Sulfide (HS)	0.1	U	mg/L	Baseflow	
5	Brief Rd. (SR 1547)	1/20/2010 14:00	Copper (Cu)	2.4		ug/L	Baseflow	Filtered

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
5	Brief Rd. (SR 1547)	1/20/2010 14:00	Potassium (K)	3.3		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	1/20/2010 14:00	Calcium (Ca)	9.3		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	1/20/2010 14:00	Magnesium (Mg)	4.6		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	1/20/2010 14:00	Sodium (Na)	9.7		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	1/20/2010 14:00	Dissolved Organic Carbon (DOC)	5.8		mg/L	Baseflow	Filtered
1	Country Woods Dr.	2/4/2010 13:20	Specific Conductance	94		uS/cm	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	pH	7		SU	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Temperature	6.6		oC	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Dissolved Oxygen Saturation	91		%	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Dissolved Oxygen	11.1		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Turbidity	20		NTU	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Nitrogen-Ammonia	0.02	U	mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Nitrogen-Nitrite+Nitrate	0.52		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Nitrogen-Total Kjeldahl	0.28		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Phosphorus - Total	0.04		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
1	Country Woods Dr.	2/4/2010 13:20	Copper (Cu)	2.6		ug/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Potassium (K)	1.5		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Calcium (Ca)	7.6		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Magnesium (Mg)	2.9		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Hardness	31	Calculated	mg/L as CaCO3	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Sodium (Na)	6.4		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Alkalinity	28		mg/L as CaCO3	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Chloride (Cl)	12		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:20	Sulfate (SO4)	5.2		mg/L	Baseflow	
1	Country Woods Dr.	2/4/2010 13:25	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
1	Country Woods Dr.	2/4/2010 13:25	Potassium (K)	1.6		mg/L	Baseflow	Filtered
1	Country Woods Dr.	2/4/2010 13:25	Calcium (Ca)	7.9		mg/L	Baseflow	Filtered
1	Country Woods Dr.	2/4/2010 13:25	Magnesium (Mg)	3		mg/L	Baseflow	Filtered
1	Country Woods Dr.	2/4/2010 13:25	Sodium (Na)	6.6		mg/L	Baseflow	Filtered
1	Country Woods Dr.	2/4/2010 13:25	Dissolved Organic Carbon (DOC)	4.3		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Specific Conductance	99		uS/cm	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	pH	7		SU	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Temperature	6.5		oC	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Dissolved Oxygen Saturation	94		%	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Dissolved Oxygen	11.5		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Turbidity	23		NTU	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Nitrogen-Ammonia	0.02		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Nitrogen-Nitrite+Nitrate	0.5		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Nitrogen-Total Kjeldahl	0.32		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Phosphorus - Total	0.06		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Copper (Cu)	2.8		ug/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Potassium (K)	1.8		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Calcium (Ca)	8.4		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Magnesium (Mg)	3.1		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Hardness	34	Calculated	mg/L as CaCO3	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Sodium (Na)	6.8		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Alkalinity	24		mg/L as CaCO3	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Chloride (Cl)	12		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 12:55	Sulfate (SO4)	5.7		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	2/4/2010 13:00	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	2/4/2010 13:00	Potassium (K)	1.7		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	2/4/2010 13:00	Calcium (Ca)	8.1		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	2/4/2010 13:00	Magnesium (Mg)	3		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	2/4/2010 13:00	Sodium (Na)	6.7		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	2/4/2010 13:00	Dissolved Organic Carbon (DOC)	4.9		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Specific Conductance	111		uS/cm	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	pH	6.9		SU	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Temperature	6.4		oC	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Dissolved Oxygen Saturation	92		%	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Dissolved Oxygen	11.4		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Turbidity	22		NTU	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Nitrogen-Ammonia	0.08		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Nitrogen-Nitrite+Nitrate	0.84		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Nitrogen-Total Kjeldahl	0.63		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Phosphorus - Total	0.14		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Copper (Cu)	3.6		ug/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Potassium (K)	2		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Calcium (Ca)	8.3		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Magnesium (Mg)	3.2		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Hardness	34	Calculated	mg/L as CaCO3	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Sodium (Na)	8.7		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Alkalinity	23		mg/L as CaCO3	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Chloride (Cl)	14		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:20	Sulfate (SO4)	7.4		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:25	Copper (Cu)	2.4		ug/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:25	Potassium (K)	1.9		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:25	Calcium (Ca)	8.4		mg/L	Baseflow	Filtered

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:25	Magnesium (Mg)	3.2		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:25	Sodium (Na)	8.7		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	2/4/2010 12:25	Dissolved Organic Carbon (DOC)	5.6		mg/L	Baseflow	Filtered
4	US 601	2/4/2010 10:55	Specific Conductance	117		uS/cm	Baseflow	
4	US 601	2/4/2010 10:55	pH	6.8		SU	Baseflow	
4	US 601	2/4/2010 10:55	Temperature	5.2		oC	Baseflow	
4	US 601	2/4/2010 10:55	Dissolved Oxygen Saturation	92		%	Baseflow	
4	US 601	2/4/2010 10:55	Dissolved Oxygen	11.7		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Residue-Suspended Total	7.8		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Turbidity	18		NTU	Baseflow	
4	US 601	2/4/2010 10:55	Nitrogen-Ammonia	0.04		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Nitrogen-Nitrite+Nitrate	1.6		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Nitrogen-Total Kjeldahl	0.58		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Phosphorus - Total	0.14		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Copper (Cu)	3.5		ug/L	Baseflow	
4	US 601	2/4/2010 10:55	Potassium (K)	2.7		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	2/4/2010 10:55	Calcium (Ca)	8.2		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Magnesium (Mg)	3.8		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Hardness	36	Calculated	mg/L as CaCO3	Baseflow	
4	US 601	2/4/2010 10:55	Sodium (Na)	8		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Alkalinity	17		mg/L as CaCO3	Baseflow	
4	US 601	2/4/2010 10:55	Chloride (Cl)	15		mg/L	Baseflow	
4	US 601	2/4/2010 10:55	Sulfate (SO4)	9.3		mg/L	Baseflow	
4	US 601	2/4/2010 11:00	Copper (Cu)	2.8		ug/L	Baseflow	Filtered
4	US 601	2/4/2010 11:00	Potassium (K)	2.6		mg/L	Baseflow	Filtered
4	US 601	2/4/2010 11:00	Calcium (Ca)	8		mg/L	Baseflow	Filtered
4	US 601	2/4/2010 11:00	Magnesium (Mg)	3.7		mg/L	Baseflow	Filtered
4	US 601	2/4/2010 11:00	Sodium (Na)	8.1		mg/L	Baseflow	Filtered
4	US 601	2/4/2010 11:00	Dissolved Organic Carbon (DOC)	6.9		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Specific Conductance	113		uS/cm	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	pH	6.8		SU	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Temperature	5		oC	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Dissolved Oxygen Saturation	97		%	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Dissolved Oxygen	12.4		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Residue-Suspended Total	12	U	mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Turbidity	17		NTU	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Nitrogen-Ammonia	0.03		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Nitrogen-Nitrite+Nitrate	1.5		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Nitrogen-Total Kjeldahl	0.51		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Phosphorus - Total	0.13		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Copper (Cu)	3.2		ug/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Potassium (K)	2.5		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Calcium (Ca)	7.6		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Magnesium (Mg)	3.7		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Hardness	34	Calculated	mg/L as CaCO3	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Sodium (Na)	7.9		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Alkalinity	16		mg/L as CaCO3	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Chloride (Cl)	14		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
5	Brief Rd. (SR 1547)	2/4/2010 10:15	Sulfate (SO4)	8.8		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	2/4/2010 10:20	Copper (Cu)	2.6		ug/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	2/4/2010 10:20	Potassium (K)	2.5		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	2/4/2010 10:20	Calcium (Ca)	7.6		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	2/4/2010 10:20	Magnesium (Mg)	3.7		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	2/4/2010 10:20	Sodium (Na)	8		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	2/4/2010 10:20	Dissolved Organic Carbon (DOC)	7.1		mg/L	Baseflow	Filtered
1	Country Woods Dr.	4/7/2010 10:50	Specific Conductance	130		uS/cm	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	pH	6.9		SU	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Temperature	17.7		oC	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Dissolved Oxygen Saturation	104		%	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Dissolved Oxygen	9.8		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Turbidity	3.2		NTU	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Nitrogen-Ammonia	0.02	U	mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Nitrogen-Nitrite+Nitrate	0.53		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
1	Country Woods Dr.	4/7/2010 10:50	Nitrogen-Total Kjeldahl	0.28		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Phosphorus - Total	0.02		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Copper (Cu)	2	U	ug/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Potassium (K)	1.5		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Calcium (Ca)	13		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Magnesium (Mg)	4.8		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Hardness	52	Calculated	mg/L as CaCO3	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Sodium (Na)	7.8		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Alkalinity	46		mg/L as CaCO3	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Chloride (Cl)	8		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Sulfate (SO4)	2.3		mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:50	Sulfide (HS)	0.1	U	mg/L	Baseflow	
1	Country Woods Dr.	4/7/2010 10:45	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
1	Country Woods Dr.	4/7/2010 10:45	Potassium (K)	1.5		mg/L	Baseflow	Filtered
1	Country Woods Dr.	4/7/2010 10:45	Calcium (Ca)	13		mg/L	Baseflow	Filtered
1	Country Woods Dr.	4/7/2010 10:45	Magnesium (Mg)	4.7		mg/L	Baseflow	Filtered

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
1	Country Woods Dr.	4/7/2010 10:45	Sodium (Na)	7.7		mg/L	Baseflow	Filtered
1	Country Woods Dr.	4/7/2010 10:45	Dissolved Organic Carbon (DOC)	2.9		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Specific Conductance	140		uS/cm	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	pH	7.4		SU	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Temperature	18.9		oC	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Dissolved Oxygen Saturation	109		%	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Dissolved Oxygen	10.1		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Turbidity	2.8		NTU	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Nitrogen-Ammonia	0.02		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Nitrogen-Nitrite+Nitrate	0.4		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Nitrogen-Total Kjeldahl	0.29		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Phosphorus - Total	0.04		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Copper (Cu)	2	U	ug/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Potassium (K)	1.8		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Calcium (Ca)	14		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Magnesium (Mg)	5.1		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Hardness	56	Calculated	mg/L as CaCO3	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Sodium (Na)	8.7		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Alkalinity	49		mg/L as CaCO3	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Chloride (Cl)	9.8		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Sulfate (SO4)	2.9		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:15	Sulfide (HS)	0.1	U	mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:10	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:10	Potassium (K)	1.7		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:10	Calcium (Ca)	14		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:10	Magnesium (Mg)	5.1		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:10	Sodium (Na)	8.9		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	4/7/2010 11:10	Dissolved Organic Carbon (DOC)	3.2		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Specific Conductance	176		uS/cm	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	pH	7.8		SU	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Temperature	21.2		oC	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Dissolved Oxygen Saturation	141		%	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Dissolved Oxygen	12.5		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Turbidity	2.6		NTU	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Nitrogen-Ammonia	0.12		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Nitrogen-Nitrite+Nitrate	1.3		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Nitrogen-Total Kjeldahl	0.6		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Phosphorus - Total	0.5		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Copper (Cu)	3.8		ug/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Potassium (K)	3		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Calcium (Ca)	15		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Magnesium (Mg)	5.2		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Hardness	59	Calculated	mg/L as CaCO3	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Sodium (Na)	14		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Alkalinity	49		mg/L as CaCO3	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Chloride (Cl)	16		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Sulfate (SO4)	6.7		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:45	Sulfide (HS)	0.1	U	mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:40	Copper (Cu)	3.5		ug/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:40	Potassium (K)	3		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:40	Calcium (Ca)	15		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:40	Magnesium (Mg)	5.3		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:40	Sodium (Na)	15		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	4/7/2010 13:40	Dissolved Organic Carbon (DOC)	4.4		mg/L	Baseflow	Filtered
4	US 601	4/7/2010 13:10	Specific Conductance	164		uS/cm	Baseflow	
4	US 601	4/7/2010 13:10	pH	7.3		SU	Baseflow	
4	US 601	4/7/2010 13:10	Temperature	21		oC	Baseflow	
4	US 601	4/7/2010 13:10	Dissolved Oxygen Saturation	82		%	Baseflow	
4	US 601	4/7/2010 13:10	Dissolved Oxygen	7.3		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Turbidity	2.3		NTU	Baseflow	
4	US 601	4/7/2010 13:10	Nitrogen-Ammonia	0.04		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	4/7/2010 13:10	Nitrogen-Nitrite+Nitrate	0.3		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Nitrogen-Total Kjeldahl	0.43		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Phosphorus - Total	0.16		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Copper (Cu)	2.5		ug/L	Baseflow	
4	US 601	4/7/2010 13:10	Potassium (K)	3		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Calcium (Ca)	13		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Magnesium (Mg)	5.2		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Hardness	54	Calculated	mg/L as CaCO3	Baseflow	
4	US 601	4/7/2010 13:10	Sodium (Na)	13		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Alkalinity	47		mg/L as CaCO3	Baseflow	
4	US 601	4/7/2010 13:10	Chloride (Cl)	16		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Sulfate (SO4)	6.9		mg/L	Baseflow	
4	US 601	4/7/2010 13:10	Sulfide (HS)	0.1	U	mg/L	Baseflow	
4	US 601	4/7/2010 13:05	Copper (Cu)	2.4		ug/L	Baseflow	Filtered
4	US 601	4/7/2010 13:05	Potassium (K)	3.1		mg/L	Baseflow	Filtered
4	US 601	4/7/2010 13:05	Calcium (Ca)	14		mg/L	Baseflow	Filtered

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	4/7/2010 13:05	Magnesium (Mg)	5.3		mg/L	Baseflow	Filtered
4	US 601	4/7/2010 13:05	Sodium (Na)	13		mg/L	Baseflow	Filtered
4	US 601	4/7/2010 13:05	Dissolved Organic Carbon (DOC)	5.3		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Specific Conductance	163		uS/cm	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	pH	7.3		SU	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Temperature	20		oC	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Dissolved Oxygen Saturation	105		%	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Dissolved Oxygen	9.5		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Turbidity	2.5		NTU	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Nitrogen-Ammonia	0.02		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Nitrogen-Nitrite+Nitrate	0.36		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Nitrogen-Total Kjeldahl	0.42		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Phosphorus - Total	0.1		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Copper (Cu)	2.1		ug/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Potassium (K)	3		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Calcium (Ca)	13		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Magnesium (Mg)	5.3		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Hardness	54	Calculated	mg/L as CaCO3	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Sodium (Na)	13		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Alkalinity	44		mg/L as CaCO3	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Chloride (Cl)	17		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Sulfate (SO4)	7.3		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:40	Sulfide (HS)	0.1	U	mg/L	Baseflow	
5	Brief Rd. (SR 1547)	4/7/2010 12:35	Copper (Cu)	2.1		ug/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	4/7/2010 12:35	Potassium (K)	2.9		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	4/7/2010 12:35	Calcium (Ca)	13		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	4/7/2010 12:35	Magnesium (Mg)	5.2		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	4/7/2010 12:35	Sodium (Na)	13		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	4/7/2010 12:35	Dissolved Organic Carbon (DOC)	5.4		mg/L	Baseflow	Filtered
1	Country Woods Dr.	8/10/2010 9:15	Specific Conductance	122		uS/cm	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	pH	6.7		SU	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
1	Country Woods Dr.	8/10/2010 9:15	Temperature	23.1		oC	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Dissolved Oxygen Saturation	84		%	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Dissolved Oxygen	7.2		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Turbidity	7.5		NTU	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Nitrogen-Ammonia	0.02		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Nitrogen-Nitrite+Nitrate	1		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Nitrogen-Total Kjeldahl	0.4		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Phosphorus - Total	0.04		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Copper (Cu)	2		ug/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Potassium (K)	2.5		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Calcium (Ca)	12		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Magnesium (Mg)	4.3		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Hardness	48	Calculated	mg/L as CaCO3	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Sodium (Na)	6.8		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Alkalinity	39		mg/L as CaCO3	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
1	Country Woods Dr.	8/10/2010 9:15	Chloride (Cl)	6.9		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:15	Sulfate (SO4)	2.8		mg/L	Baseflow	
1	Country Woods Dr.	8/10/2010 9:10	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
1	Country Woods Dr.	8/10/2010 9:10	Potassium (K)	2.4		mg/L	Baseflow	Filtered
1	Country Woods Dr.	8/10/2010 9:10	Calcium (Ca)	12		mg/L	Baseflow	Filtered
1	Country Woods Dr.	8/10/2010 9:10	Magnesium (Mg)	4.4		mg/L	Baseflow	Filtered
1	Country Woods Dr.	8/10/2010 9:10	Sodium (Na)	6.8		mg/L	Baseflow	Filtered
1	Country Woods Dr.	8/10/2010 9:10	Dissolved Organic Carbon (DOC)	2.8		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Specific Conductance	120		uS/cm	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	pH	6.7		SU	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Temperature	23.7		oC	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Dissolved Oxygen Saturation	87		%	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Dissolved Oxygen	7.4		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Residue-Suspended Total	12	U	mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Turbidity	80		NTU	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Nitrogen-Ammonia	0.02		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Nitrogen-Nitrite+Nitrate	0.75		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Nitrogen-Total Kjeldahl	0.36		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Phosphorus - Total	0.13		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Copper (Cu)	5.5		ug/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Potassium (K)	2.2		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Calcium (Ca)	11		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Magnesium (Mg)	4.2		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Hardness	45	Calculated	mg/L as CaCO3	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Sodium (Na)	7.2		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Alkalinity	39		mg/L as CaCO3	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Chloride (Cl)	7.6		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:35	Sulfate (SO4)	2.7		mg/L	Baseflow	
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:30	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:30	Potassium (K)	2.1		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:30	Calcium (Ca)	11		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:30	Magnesium (Mg)	4		mg/L	Baseflow	Filtered

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:30	Sodium (Na)	7.4		mg/L	Baseflow	Filtered
2	Stevens Mill Rd. (SR 1524)	8/10/2010 9:30	Dissolved Organic Carbon (DOC)	4.2		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Specific Conductance	163		uS/cm	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	pH	7		SU	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Temperature	24.6		oC	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Dissolved Oxygen Saturation	88		%	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Dissolved Oxygen	7.3		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Turbidity	65		NTU	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Nitrogen-Ammonia	0.02		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Nitrogen-Nitrite+Nitrate	2.5		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Nitrogen-Total Kjeldahl	0.55		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Phosphorus - Total	0.54		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Copper (Cu)	5.5		ug/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Potassium (K)	3.6		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Calcium (Ca)	12		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Magnesium (Mg)	4.4		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Hardness	48	Calculated	mg/L as CaCO3	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Sodium (Na)	13		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Alkalinity	39		mg/L as CaCO3	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Chloride (Cl)	13		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:20	Sulfate (SO4)	6.8		mg/L	Baseflow	
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:15	Copper (Cu)	3.3		ug/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:15	Potassium (K)	3.7		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:15	Calcium (Ca)	13		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:15	Magnesium (Mg)	4.4		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:15	Sodium (Na)	13		mg/L	Baseflow	Filtered
3	Mill Grove Rd. (SR 1525)	8/10/2010 10:15	Dissolved Organic Carbon (DOC)	4.4		mg/L	Baseflow	Filtered
4	US 601	8/11/2010 8:55	Specific Conductance	149		uS/cm	Baseflow	
4	US 601	8/11/2010 8:55	pH	7.1		SU	Baseflow	
4	US 601	8/11/2010 8:55	Temperature	25.8		oC	Baseflow	
4	US 601	8/11/2010 8:55	Dissolved Oxygen Saturation	63		%	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	8/11/2010 8:55	Dissolved Oxygen	5.2		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Residue-Suspended Total	6.5		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Turbidity	17		NTU	Baseflow	
4	US 601	8/11/2010 8:55	Nitrogen-Ammonia	0.04		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Nitrogen-Nitrite+Nitrate	0.91		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Nitrogen-Total Kjeldahl	0.49		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Phosphorus - Total	0.21		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Copper (Cu)	2.3		ug/L	Baseflow	
4	US 601	8/11/2010 8:55	Potassium (K)	4.2		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Calcium (Ca)	12		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Magnesium (Mg)	4.5		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Hardness	48	Calculated	mg/L as CaCO3	Baseflow	
4	US 601	8/11/2010 8:55	Sodium (Na)	10		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Alkalinity	41		mg/L as CaCO3	Baseflow	
4	US 601	8/11/2010 8:55	Chloride (Cl)	10		mg/L	Baseflow	
4	US 601	8/11/2010 8:55	Sulfate (SO4)	6.7		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
4	US 601	8/11/2010 8:50	Copper (Cu)	2	U	ug/L	Baseflow	Filtered
4	US 601	8/11/2010 8:50	Potassium (K)	4.1		mg/L	Baseflow	Filtered
4	US 601	8/11/2010 8:50	Calcium (Ca)	12		mg/L	Baseflow	Filtered
4	US 601	8/11/2010 8:50	Magnesium (Mg)	4.4		mg/L	Baseflow	Filtered
4	US 601	8/11/2010 8:50	Sodium (Na)	10		mg/L	Baseflow	Filtered
4	US 601	8/11/2010 8:50	Dissolved Organic Carbon (DOC)	6		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Specific Conductance	139		uS/cm	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	pH	7.1		SU	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Temperature	25.4		oC	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Dissolved Oxygen Saturation	80		%	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Dissolved Oxygen	6.5		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Residue-Suspended Total	6.2	U	mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Turbidity	11		NTU	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Nitrogen-Ammonia	0.02	U	mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Nitrogen-Nitrite+Nitrate	0.73		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Nitrogen-Total Kjeldahl	0.44		mg/L	Baseflow	

BLM Map Code	BLM Location	Date+Time	Parameter	Result	Remarks	Units	Flow Condition	Filtered?
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Phosphorus - Total	0.16		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Copper (Cu)	2.5		ug/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Potassium (K)	4.1		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Calcium (Ca)	11		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Magnesium (Mg)	4.3		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Hardness	45	Calculated	mg/L as CaCO3	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Sodium (Na)	9		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Alkalinity	38		mg/L as CaCO3	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Chloride (Cl)	9.5		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:45	Sulfate (SO4)	6.3		mg/L	Baseflow	
5	Brief Rd. (SR 1547)	8/11/2010 9:40	Copper (Cu)	2		ug/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	8/11/2010 9:40	Potassium (K)	4.2		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	8/11/2010 9:40	Calcium (Ca)	11		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	8/11/2010 9:40	Magnesium (Mg)	4.3		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	8/11/2010 9:40	Sodium (Na)	11		mg/L	Baseflow	Filtered
5	Brief Rd. (SR 1547)	8/11/2010 9:40	Dissolved Organic Carbon (DOC)	6.3		mg/L	Baseflow	Filtered

Nutrients (Nitrogen-Ammonia, Nitrogen-Nitrite+Nitrate, Nitrogen-Total Kjeldahl, Phosphorus – Total) were collected to address other questions about water quality within the Goose Creek watershed.)

Remarks:

A designation of “U” is a data qualifier code which “Indicates that the analyte was analyzed but not detected above the reported practical quantitation limit. The number value reported with the "U" qualifier is equal to the laboratory's practical quantitation limit.” The Practical Quantitation Limit (PQL) is defined and proposed as "the lowest level achievable among laboratories within specified limits during routine laboratory operation". The PQL is about three to five times the calculated Method Detection Limit (MDL) and represents a practical and routinely achievable detection limit with a relatively good certainty that any reported value is reliable". See: http://portal.ncdenr.org/web/wq/lab/staffinfo/techassist#Practical_Quantitation_Limits for more information.

Appendix G:

Evaluation of Copper Concentrations in Goose Creek with Regard to Conservation of Freshwater Mussels

Evaluation of Copper Concentrations in Goose Creek with regard to Conservation of Freshwater Mussels

Executive Summary

The Raleigh Field Office of the U.S. Fish and Wildlife Service is assisting the North Carolina Ecosystem Enhancement Program in an evaluation of copper as a limiting factor for the endangered Carolina heelsplitter (*Lasmigona decorata*) in Goose Creek, Mecklenburg and Union Counties, North Carolina. The 2009 and 2010 copper data for Goose Creek do not exceed biotic ligand model (BLM)-derived water quality criteria for the protection of aquatic life. These data, if representative of the system, indicate copper is not currently of toxicological concern. Estimation of historical dissolved copper concentrations indicated few exceedences of the BLM criteria, and the few exceedences appear to be associated with higher flows when suspended forms of copper (which are of lesser toxicological concern) would be anticipated. From a watershed management standpoint, attention to nonpoint source controls of sediment would further reduce copper loadings, but no special attention would be needed to address copper. A sensitivity analyses indicated that measured variations in Goose Creek water temperature, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity do not appreciably affect the BLM's predictions of safe dissolved copper concentrations for this stream. Stream pH and dissolved organic carbon (DOC) are important drivers of the BLM's predictions in this system. Stream pH is well-characterized and the recent data are consistent with historic data. There are few data for DOC so this parameter should be added to future monitoring efforts to help determine if our inference that copper is not a limiting factor is accurate. Comments and questions on this draft are encouraged and feedback will be used in preparing a final version.

Background

Goose Creek, in Mecklenburg and Union Counties, is critical habitat for the federally-listed as endangered and state critically-endangered Carolina heelsplitter (*Lasmigona decorata*), a freshwater mussel. Goose Creek is on the North Carolina Division of Water Quality's (DWQ) list of impaired waters because of excess fecal coliform (a recreational use concern) and an altered biological community (an ecological integrity concern). To address the bacteria contamination, a total maximum daily load was derived and approved for the watershed to set targets for achieving water quality standards (Mecklenburg County Water Quality Program 2005). To address sources of water quality impairment, management rules were adopted by the North Carolina Environmental Management Commission (2009; see also NCDENR 2008) which specify requirements for wastewater discharges, stormwater management, streamside buffer protection, and control of toxic substances including ammonia.

Among the water quality concerns identified in Goose Creek over the past 15 years is total copper in surface waters at concentrations exceeding the State's water quality action level of 7 µg/L (parts per billion) (NCDENR 2007). Copper concentrations exceeding this action level have been documented by the State (Chen et al. 2001, NCDWQ 2002 and 2007), university researchers (Allan 2004), and federal natural resource management agencies (Ward et al. 2007). While copper is referenced as a water quality concern in summaries of exiting data and to support management (USFWS, NCWRC, NCNHP 2005, NCENR 2008), the significance of

elevated copper has been questioned because of uncertainty in how much of the total copper exists in a form that would be readily bioavailable and toxic (Ward et al. 2007), particularly to mussels that have been a focus of natural resource management in Goose Creek.

The aquatic bioavailability and toxicity of metals including copper is known to be a function of water chemistry (Adams and Chapman 2007). Experimental data indicate sorption on particle surfaces and formation of inorganic and organic metal complexes can reduce metal toxicity by keeping copper sequestered away from the sites of toxic action in organisms. Hardness cations (Ca^{2+}, Mg^{2+}) can reduce copper toxicity by competing for binding sites at gill or cell membranes, and dissolved organic carbon (DOC) and alkalinity can decrease copper bioavailability and thus copper toxicity by complexation. This is important to regulation of metals and interpreting ambient concentrations because the toxicity of a given quantity of metal can be quite variable and dependent on these and other water chemistry variables when expressed as total recoverable metal or even the dissolved metal fraction (Bergman and Dorward-King 1997).

The North Carolina Ecosystem Enhancement Program (EEP) has taken a leadership role in identification of stream and wetland restoration, enhancement, and preservation projects within the Goose Creek basin. Part of their effort is aimed at resolving uncertainties over which water quality parameters are limiting factors to the streams' aquatic fauna so restoration can be effectively targeted. The EEP lead a cooperative effort by DWQ and the US Fish and Wildlife Service (FWS) to address this issue. The DWQ collected data to support a biotic ligand model (BLM)-based approach to evaluation of instream copper concentrations (DWQ 2011), and in this draft document, FWS reports on the application of those data in the BLM.

Biotic ligand models have been developed to enable mechanistic modeling of copper bioavailability and acute toxicity as a function of metal speciation and the protective effects of competing cations. The theoretical basis for the model is concisely explained in a users' manual for one popular version (HydroQual Inc. 2007):

> Metal toxicity is simulated as the accumulation of metal at a biologically sensitive receptor, the "biotic ligand", which represents the site of action of acute metal toxicity. Inorganic and organic ligands can also bind metal; however, thereby reducing accumulation at the biotic ligand. By incorporating the biotic ligand into a chemical equilibrium framework that includes aqueous metal complexation, the relation between free metal ion concentrations and toxicity is an inherent feature of the model. The BLM framework also incorporates the competitive effects of other cations that interact with the biotic ligand to mitigate toxicity. For example, at a fixed free metal concentration, as hardness increases, the increased Ca^{2+} competes with the free metal for binding sites at the biotic ligand. A higher free metal concentration is therefore required to achieve the same toxic effect in the presence of elevated Ca^{2+} concentration. The BLM uses this competitive mechanism to simulate the reduction in metal toxicity due to elevated hardness concentrations. Thus, the BLM can effectively account for reduction in metal toxicity due to elevated levels of hardness cations.

Because of the BLM's increased accuracy in defining safe versus hazardous concentrations of copper to aquatic organisms, it has been used by the U.S. Environmental Protection Agency

(EPA) as the basis for the revised water quality criteria for protection of aquatic life (EPA 2007). For our application, it is important to add that the BLM for copper reliably predicts acute copper toxicity to juvenile mussels (assumed to be among the most sensitive lifestages) across diverse water sources (Wang et al. 2009). The concentration of DOC is important in explaining copper toxicity to mussels, and while those data are not typically available in historic datasets for North Carolina streams, DOC was among the parameters in DWQ's recent sampling of Goose Creek. With the BLM (HydroQual, Inc. 2007), the data to populate the model (DWQ 2011), and acute and chronic copper toxicity data for mussels (March et al. 2007, Wang et al. 2007 and 2009), it is practical to evaluate the significance of instream copper concentrations in a manner not previously available for Goose Creek.

The FWS's objectives in this draft report are to 1) evaluate the most recent copper data for Goose Creek via the BLM; 2) address the adequacy of the 2009-2010 Goose Creek water chemistry database which populates the BLM; and 3) offer recommendation to Goose Creek water quality managers. For the second objective, we make special emphasis on two questions posed by DWQ following their data collection to support the modeling: 2a) the implications of having data derived from mostly winter sampling (when water temperatures were lower than a 10^{o}C recommended limit for the BLM), and 2b) the implications of the dataset which captured low and moderate storm flows but did not include sampling in substantial storm flows.

Methods

Significance of current copper data

Data collected by NCDWQ (2011) were evaluated with BLM Windows Interface, Version 2.2.3 (HydroQual Inc. 2007) in Water Quality Criteria Calculation mode. This use of the model takes input data on water temperature, pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity to tailor the EPA acute and chronic water quality criteria for protection of aquatic life to local water chemistry conditions. The modeled-predicted criteria are then compared to dissolved copper concentrations measured at the same time as the DOC, alkalinity, pH, cations, and anions used in the BLM.

Adequacy of existing data

To evaluate the adequacy of the 2009-2010 Goose Creek water chemistry database which populates the BLM, summary statistics for DWQ's sampling of Goose Creek were calculated to compare to historical data (when available) and to support a sensitivity analyses of the water quality variables' influence on BLM outputs. For the sensitivity analyses, medians (50th percentile values) for each BLM input parameter were used to model an "average" BLM application for the creek. Twenty successive model runs were then performed which changed one parameter at a time (water temperature, pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity) to its maximum then minimum to determine the influence of each variable on model output.

Because dissolved copper measurements during substantial storm flows were not part of the 2009-2010 dataset, we applied the BLM to historic copper data for the creek at SR 1524 (Steven Mill Road, station ID Q8360000) which we retrieved from STORET. Those data are all total

copper and the BLM evaluates the significance of dissolved copper. We estimated a dissolved fraction for the historic total copper concentrations by using the ratio of dissolved to total copper from the 2009-2010 dataset which included both measures (DWQ 2011). For the 11 measures of both forms of copper which exceeded method detection limits, 0.8 was the median fraction of total copper represented by the dissolved fraction (range = 0.6 to 1.0). Using median values for most parameters (for the variables with minimal influence on the BLM) and median and low values (10^{th} percentile) for DOC and pH that drive the BLM's site-specific derivation of safe copper values, the estimated dissolved copper concentrations from the historic dataset were evaluated.

Results and Discussion

Significance of current copper data

Data were available from DWQ (2011) for 21 sampling events covering five locations (Figure 1) in Goose Creek with sufficient data for populating the BLM. Table 1 lists the total copper (and compares those concentrations to the current 7 µg/L action level). None of the 2009-2010 total copper concentrations exceed the action level.

Table 1 also compares the measured dissolved copper concentrations to the BLM-derived criteria. National water quality criteria in the U.S. generally consist of two estimated values designed to protect aquatic organisms; these are commonly referred to as the acute and chronic water quality criteria, but more specifically, they are the criteria maximum concentration (CMC) and criteria continuous concentration (CCC), respectively. The CMC is an estimate of the highest one-hour average concentration that should not result in unacceptable adverse effects to aquatic organisms. The CCC is an estimate of the highest four-day average concentration that should not result in unacceptable adverse effects. The EPA typically advises that CMC and CCC are protective if not exceeded more than once every three years. The 2009 and 2010 dissolved copper data for Goose Creek do not exceed BLM-derived CMCs and CCCs (Table 1).

While the BLM reliably predicts acute copper toxicity to juvenile mussels (Wang et al. 2009), the dataset used to derive the EPA's application of the BLM for criteria derivation did not include several species of mussel known to be sensitive to copper (Wang et al. 2009 and 2011). Incorporating recent data into a recalculation of the criteria could be done to support a mussel-specific toxicological screening value, but examination of the available data indicates the magnitude of that screening value would be only slightly lower than the criteria (not different enough to affect interpretation of the low dissolved copper concentrations measured for Goose Creek in 2009-2010). Our first objective was to evaluate the most recent copper data for Goose Creek via the BLM; if representative of the system, these data indicate copper is not currently of toxicological concern.

Adequacy of existing data

The second objective was to assess the adequacy of the 2009-2010 Goose Creek water chemistry database which populates the BLM. Table 2 provides summary statistics for the DWQ's sampling of Goose Creek to support the BLM. There is not much available data to compare to the recently collected values. The pH vales are consistent with those collected at the SR1524

crossing of Goose Creek since 1995. A retrieval of all data from this station provides one DOC value for comparison (6 mg/L on June 6, 2001), two calcium values (both 12 mg/L, on March 9, and June 3, 2010), and ten alkalinity measures (median 28 mg/L and range of 28 to 48 mg/L between 1969 and 1972). All of these are similar to the values recently measured (Table 2).

For the sensitivity analyses, medians for each BLM input parameter were used to model an "average" BLM application for the creek. Twenty successive model runs were then performed which changed one parameter at a time to its maximum then minimum (Table 3) to determine the influence of each variable on model output. Table 4 provides the output of this sensitivity analysis; it is apparent that pH and DOC (and to a lesser extent sodium) are important drivers of the BLM's predictions in this system. Varying the concentrations of other cations and anions does not appreciably affect the model predictions of safe concentrations, so available data for these parameters should be adequate. As mentioned in the previous paragraph, the pH of the system has been well-characterized and the recent data are consistent with historic data. The EPA conducted a preliminary analysis of data needed to run the BLM from thirteen river and stream segments over ten years. At these sites, pH typically varied temporally by one unit (USEPA 2009); that is similar to the range of Goose Creek pH (Table 2).

The model is highly sensitive to changes in DOC and there are few data for that parameter. We examined the lab's method precision and accuracy to determine the degree of analytical variability for DOC (which would help in interpreting the environmental variability). Repeated measures of DOC differed by only about 3% (well-within accepted ranges of ± 20%) and performance on check samples was well-within accepted ranges of about ± 15%. The variation in the 21 DOC measures from Goose Creek can be assumed to mostly reflect normal environmental variability. In the EPA's analysis of DOC for thirteen river and stream segments, DOC values varied by a factor of two (USEPA 2009). That range is similar to the range of Goose Creek DOC (Table 2) and supports an inference that available data are adequate for BLM modeling, but this parameter should be included in future monitoring programs.

With regard to concern of having data derived from mostly winter sampling (when water temperatures were lower than a 10^{o}C recommendation for calculation of copper toxicity using the BLM), it is apparent from Table 4 that temperature is a minor variable in the BLM. In addition to that empirical demonstration, EPA (2009) notes that the BLM can be used when the parameters, particularly temperature, fall outside the specified ranges.

Because the study design called for some sampling in substantial storm flows, there was a question on the implications of 2009-2010 data with regard to the range of stream conditions. Previous work has alluded to elevated total copper following storm events (Ward et al. 2007). Figure 2 illustrates a relationship between total copper and turbidity for the creek at SR 1524 in which the highest concentrations of total copper are associated with sampling events during which turbidity was also elevated. The three highest copper concentrations for which there are corresponding data for total suspended solids (July 21, 1998 total copper = 14 µg/L and TSS = 130 mg/L; January 25, 1999 total copper = 26 µg/L and TSS = 130 mg/L; April 28, 1999 total copper = 16 µg/L and TSS = 130 mg/L) indicate total copper is high when suspended sediments are near their maximum for this system. Simulated storm flow samples also documented high total copper; concentrations from less than the action level to 27 µg/L were reported (DWQ 2011) which mirror the highest concentration in the long-term record of 26 µg/L (NCDWQ

2002, 2007). While storm events were not rigorously sampled in the 2009-2010 effort to measure dissolved copper directly, the historic database was used to examine this issue further.

Table 5 provides summary statistics for total copper concentrations in Goose Creek. From that database, the dissolved fraction was approximated by using the ratio of dissolved copper to total copper from the 2009-2010 dataset which included both measures (DWQ 2011). The resulting database of estimated dissolved copper was evaluated with the BLM using median values for most parameters (for the variables with minimal influence on the BLM) and low (10^{th} percentile) values for DOC and pH that drive the BLM's site-specific derivation of safe copper values. Since bioavailability and toxicity increase as pH and DOC increase, using low values for these drivers of the BLM should be a conservative (protective) application of existing data. Table 6 provides a comparison of estimated historic dissolved copper concentrations to BLM-predicted safe concentrations of dissolved copper under average conditions and conditions of either low pH or low DOC. The CMC (which is probably the best basis for comparison for grab samples in the dataset) is rarely exceeded. Because no high copper values were in the side-by-side comparison of total versus dissolved copper, it is likely that our 0.8 median dissolved fraction is biased high. We note that a previous estimation of the dissolved copper fraction for Goose Creek (before any side-by-side measurements were available), using EPA estimation methods, yielded a dissolved fraction of 0.38 (Ward et al. 2007). Accordingly, our review of the historic data is likely conservative (protective) with regard to evaluating effects on aquatic life.

Recommendations

Current Goose Creek copper concentrations are less than levels defined previously (Chen et al. 2001, DWQ 2002, Allan 2004, Ward et al. 2007). The most recent basinwide assessment report notes much lower concentrations with a median of 3 µg/L between 2002 and 2006 (DWQ 2007). The DWQ's 2011 special sampling report includes a review of historic data and notes that there have been no exceedences of the action level since 2004 (although sampling has been relatively infrequent since then). Estimation of historical dissolved copper concentrations indicated few exceedences of the BLM criteria, and the few exceedences appear to be associated with higher flows when suspended forms of copper (which are of lesser toxicological concern) would be anticipated. From a watershed management standpoint, attention to nonpoint source controls of sediment would reduce copper loadings, but no special attention would be needed to address copper.

A sensitivity analyses indicated that measured variations in Goose Creek water temperature, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity do not appreciably affect BLM's predictions of safe dissolved copper concentrations. Stream pH and DOC are important drivers of the BLM's predictions in this system. Stream pH is well-characterized and the recent data are consistent with historic data. There are few data for DOC so this parameter should be added to future monitoring efforts to help determine if our inference that copper is not a limiting factor is accurate.

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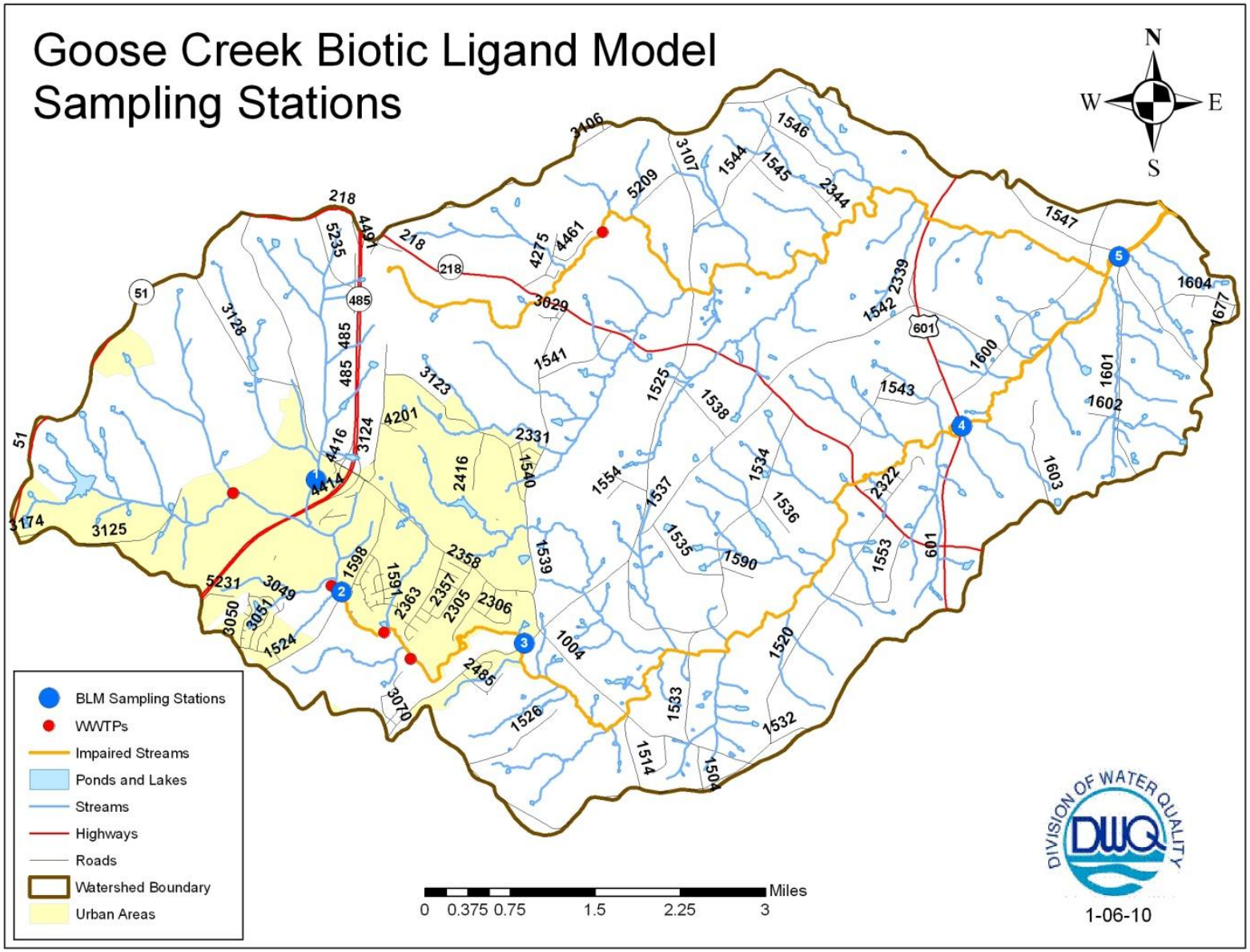


Figure 1. Location of sampling sites in the Goose Creek watershed sampled by DWQ (from DWQ 2011)

Table 1. Goose Creek total copper and dissolved copper concentrations compared to water quality action levels and criteria for the protection of aquatic life (data are µg/L)

Map Code	Location	Sampling Date	Total Copper	Dissolved Copper	Event-specific BLM Criteria[a]	
					CMC[b]	CCC[c]
1	Country Woods Dr.	01/20/10	< 2	< 2	5.2	3.2
		02/04/10	2.6	< 2	8.0	5.0
		04/07/10	< 2	< 2	4.8	3.0
		08/10/10	2.0	< 2	3.3	2.0
2	Stevens Mill Rd. (SR 1524)	01/20/10	< 2	< 2	8.2	5.1
		02/04/10	2.8	< 2	9.2	5.7
		04/07/10	< 2	< 2	10.9	6.8
		08/10/10	5.5	< 2	4.9	3.0
3	Mill Grove Rd. (SR 1525)	01/20/10	2.1	< 2	11.7	7.3
		02/04/10	3.6	2.4	9.2	5.7
		04/07/10	3.8	3.5	26.4	16.4
		08/10/10	5.5	3.3	8.9	5.5
4	US 601	12/02/09	3.1	2.3	14.7	9.1
		01/20/10	2.8	2.6	16.5	10.3
		02/04/10	3.5	2.8	9.6	6.0
		04/07/10	2.5	2.4	16.5	10.3
		08/11/10	2.3	< 2	13.9	8.6
5	Brief Rd. (SR 1547)	01/20/10	2.7	2.4	17.2	10.7
		02/04/10	3.2	2.6	10.0	6.2
		04/07/10	2.1	2.1	16.8	10.4
		08/11/10	2.5	2.0	14.8	9.2
% of samples exceeding 7 µg/L Action Level[d] = 0						
% of samples exceeding event-specific BLM-based water quality criteria[a] = 0						

[a] USEPA 2007
[b] CMC = Criteria Maximum Concentration
[c] CCC = Criteria Continuous Concentration
[d] NCDENR 2007

Table 2. Summary statistics for DWQ's 2009-2010 sampling of Goose Creek to support biotic ligand model application to interpretation of copper concentrations (n=21 for all analytes)

	T (^oC)	pH	DOC (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO_4 (mg/L)	Cl (mg/L)	ALK (mg/L as $CaCO_3$)
Median	10.0	7.1	4.9	11.0	4.4	8.9	2.5	6.7	13.0	37.0
Max	25.8	7.8	7.1	15.0	5.3	15.0	4.8	12.0	17.0	49.0
Min	5.0	6.7	2.8	7.6	3.0	6.4	1.4	2.3	6.9	16.0
10th percentile	6.4	6.8	2.9	8.0	3.2	6.7	1.6	2.8	8.0	20.0
90th percentile	24.6	7.3	6.3	14.0	5.3	13.0	4.1	10.0	16.0	47.0

Table 3. Biotic ligand model input data for a sensitivity analysis of Goose Creek data. Median concentrations of each parameter were used for a baseline in the model, then input data were changed, one parameter at a time, to the maximum then minimum to see the influence of each variable on model output (results are in Table 4).

	T (^oC)	pH	DOC (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO_4 (mg/L)	Cl (mg/L)	ALK (mg/L as $CaCO_3$)
All medians	**10.0**	**7.1**	**4.9**	**11**	**4.4**	**8.9**	**2.5**	**6.7**	**13**	**37**
Max T	25.8									
Min T	5.0									
Max pH		7.8								
Min pH		6.7								
Max DOC			7.1							
Min DOC			2.8							
Max Ca				15						
Min Ca				7.6						
Max Mg					5.3					
Min Mg					3.0					
Max Na						15				
Min Na						6.4				
Max K							4.8			
Min K							1.4			
Max SO_4								12		
Min SO_4								2.3		
Max Cl									17	
Min Cl									6.9	
Max ALK										49
Min ALK										16

Table 4. Results of a sensitivity analysis of Goose Creek water chemistry data in the biotic ligand model's derivation of event-specific water quality criteria for copper. Data from Table 3 were used to assess the influence of maximizing or minimizing each variable on model output. Dissolved organic carbon, pH, and to a lesser extent sodium are the only parameters (shaded) with an appreciable influence on the model over the ranges evaluated.

	CMC[a] (µg/L)	CCC[b] (µg/L)	% Deviation from Median CCC
All medians	**10.9**	**6.7**	**0**
Max T	11.2	6.9	2.9
Min T	10.8	6.7	-0.4
Max pH	25.9	16.1	140
Min pH	5.7	3.6	-47
Max DOC	15.9	9.9	46
Min DOC	6.1	3.8	-43
Max Ca	10.9	6.8	0.2
Min Ca	10.9	6.8	0.5
Max Mg	10.9	6.8	0.8
Min Mg	10.8	6.7	-0.9
Max Na	11.5	7.1	6.0
Min Na	10.6	6.6	-2.5
Max K	10.8	6.7	-0.1
Min K	10.9	6.7	0.1
Max SO_4	10.8	6.7	-0.6
Min SO_4	10.9	6.8	0.6
Max Cl	10.8	6.7	-0.3
Min Cl	10.9	6.8	0.6
Max ALK	10.8	6.7	-0.5
Min ALK	11.0	6.8	1.1

[b] CMC = Criteria Maximum Concentration

[c] CCC = Criteria Continuous Concentration

Table 5. Historic record for total recoverable copper in Goose Creek and estimated dissolved fraction. Dissolved fraction approximated by using the ratio of dissolved copper to total copper from the 2009-2010 dataset which included both measures (DWQ 2011). For the 11 measures of both forms of copper which exceeded method detection limits, 0.8 was the median fraction of total copper represented by the dissolved fraction (range = 0.6 to 1.0) and was used to create third column (all data are µg/L).

	Total copper[a]	Simulated dissolved copper concentration[b]
Minimum	< 2	< 2
10th percentile	< 2	< 2
25th percentile	2.7	2.2
50th percentile	3.7	3.0
75th percentile	5.8	4.6
90th percentile	8.1	6.5
95th percentile	11.2	9.0
Maximum	26.0	20.8

[a] Summarized available data from the ambient monitoring station at Steven Mill Road (SR 1524) (n = 95 values from 1995 to 2010)
[b] Estimated as total recoverable copper x 0.8 for this assessment

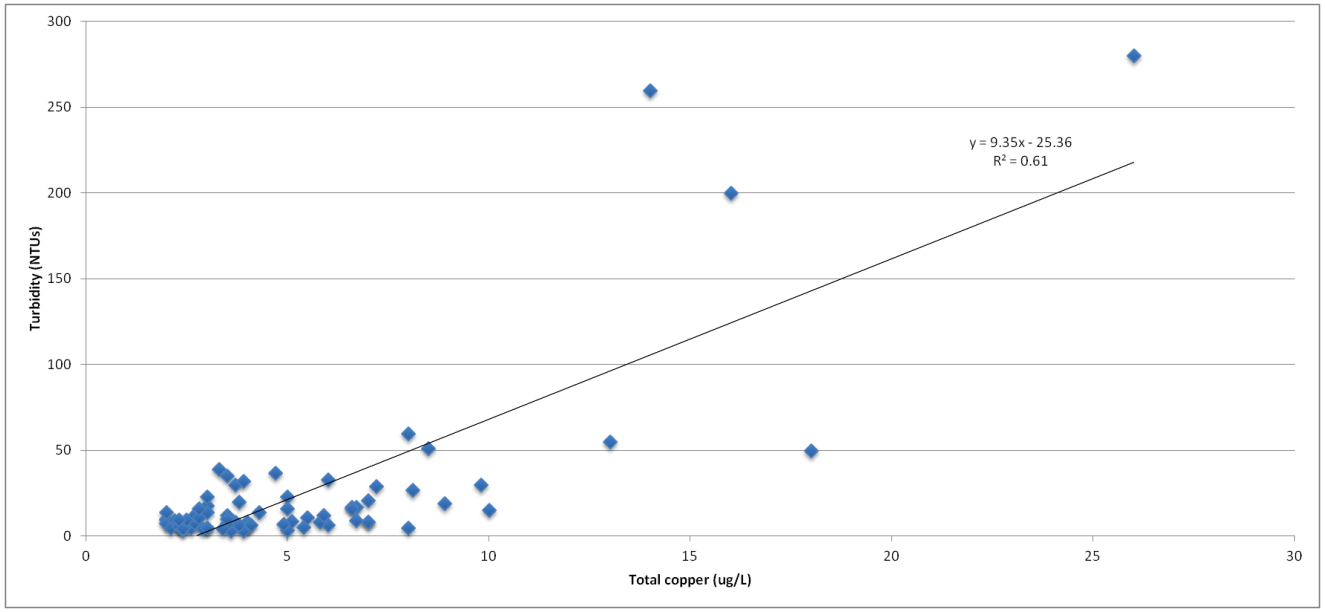


Figure 2. Comparison of total recoverable copper from Goose Creek ambient monitoring station at Steven Mill Road (SR 1524) to corresponding measures of turbidity. In general the highest concentrations of copper are associated with sampling events in which turbidity was also elevated.

Table 6. Comparison of Goose Creek's estimated historic dissolved copper concentrations[a] to BLM-predicted safe concentrations of dissolved copper under average conditions and conditions of either low pH or low DOC.

	CMC[b] (µg/L)	Historic exceedences (%)	CCC[c] (µg/L)
Median pH (7.1) and DOC (4.9 mg/L)	10.9	4	6.7
Medians with low pH (6.8)	6.9	7	4.3
Medians with low DOC (2.9 mg/L)	6.5	8	4.0

[a] Dissolved fraction approximated by using the median ratio (0.8) of dissolved copper to total copper from the 2009-2010 dataset which included both measures (DWQ 2011) and applying that to the data for total copper from 1995 to the present (n=112)
[b] CMC = Criteria Maximum Concentration
[c] CCC = Criteria Continuous Concentration

Appendix H:

Goose Creek and Crooked Creek LWP

Phase II-III Stream Restoration Planning

TETRA TECH

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Technical Memorandum

To:	**Anjie Ackerman** **NC Ecosystem Enhancement Program**	**Date:**	**December 6, 2010**
From:	**J. Todd Kennedy and Peter Cada**	**Subject:**	**Goose Creek & Crooked Creek LWP Phase II- III Stream Restoration Planning**
Cc:	**Trevor Clements, Nick Jokay**	**Proj. No.**	**100-RTP-T25954**

In 2008, the North Carolina Ecosystem Enhancement Program (NCEEP) initiated development of a local watershed plan (LWP) for Goose Creek and Crooked Creek. The two watersheds, encompassing parts of northern Union County and southeastern Mecklenburg County, are located in the Yadkin Pee Dee River Basin (14-digit hydrologic units 03040105030020 and 03040105040010) and drain to the Rocky River.

The primary objectives of the LWP are:

- To identify major causes of degradation to watershed functions and future threats to watershed assets.
- To develop strategies addressing the problems that are consistent with local priorities.
- To identify optimal sites for the implementation of watershed improvement projects, many of which may be used for compensatory mitigation.

The LWP process is typically divided into four phases: watershed characterization and preliminary findings (Phase I), detailed watershed assessment (Phase II), implementation plan development (targeting of management, Phase III), and implementation (Phase IV). Phase I was completed in spring 2009.

The Phase I preliminary findings suggested that the Goose Creek and Crooked Creek watersheds have experienced widespread channel impacts most notably in the upper reaches draining headwater-based development (Tetra Tech, 2008). The current work involved screening potential stream management opportunities for further field assessment based on the results from Phase I, NCEEP minimum criteria for stream restoration, existing Hydrologic Engineering Center's River Analysis System (HEC-RAS) models, and available Geographic Information System (GIS) data and aerial imagery. Geomorphic data, instream habitat, and other data items were then collected in the field to support more in depth analysis of stream management opportunities. This memorandum provides a summary of the field assessment and preliminary management recommendations for streams in the Goose Creek and Crooked Creek watersheds as part of the next phase of plan development.

1 Stream Reach Eligibility and Screening

Desktop analysis was conducted to determine stream reaches that meet NCEEP eligibility criteria for stream restoration, to target reaches in the most need of management, and to screen out reaches with significant constraints discernable with available GIS and aerial imagery.

Data resources used for the effort included a variety of GIS data, aerial imagery, available HEC-RAS models, and results from the previous field and desktop analyses performed for Phase I.

1.1 ELIGIBILITY CRITERIA

The minimum criteria used to identify eligible reaches were based on site selection criteria for stream restoration projects approved by NCEEP (2008):

- Streams proposed for restoration should be greater than 2,000 linear feet.[1]
- Proposed stream reaches must be perennial as indicated on United States Geological Survey (USGS) 24K Quadrangle Maps and/or in the National Resources Conservation Service (NRCS) Soil Surveys.
- A proposed stream reach will typically have a contributing drainage area under 20 square miles.

In addition, it was assumed that reaches identified as existing, critical habitat for the federally endangered Carolina heelsplitter mussel should be excluded from consideration for active restoration. However, these areas will be considered in a companion analysis of preservation opportunities

The Hydro24k GIS coverage that represents perennial streams, as seen on the USGS 24K Quadrangle Maps, was created by the North Carolina Center for Geographic Information and Analysis in February 2006. Tetra Tech obtained this GIS coverage from the NC One Map website in February 2010. Tetra Tech confirmed that the extent of perennial streams identified in the Hydro24k GIS coverage in these watersheds was generally consistent with those observed in the paper copy of the Soil Survey of Union County, North Carolina (issued January 1996).

Stream reaches meeting these initial criteria are shown in Figure 1. These represent 33 and 34 miles of stream in the Goose Creek and Crooked Creek watersheds, respectively.

[1] This is a change from the 1,500 linear feet minimum requirement as originally approved by NCEEP in February 2008 (A. Ackerman, NCEEP, personal communication to T. Kennedy, December 3, 2008).

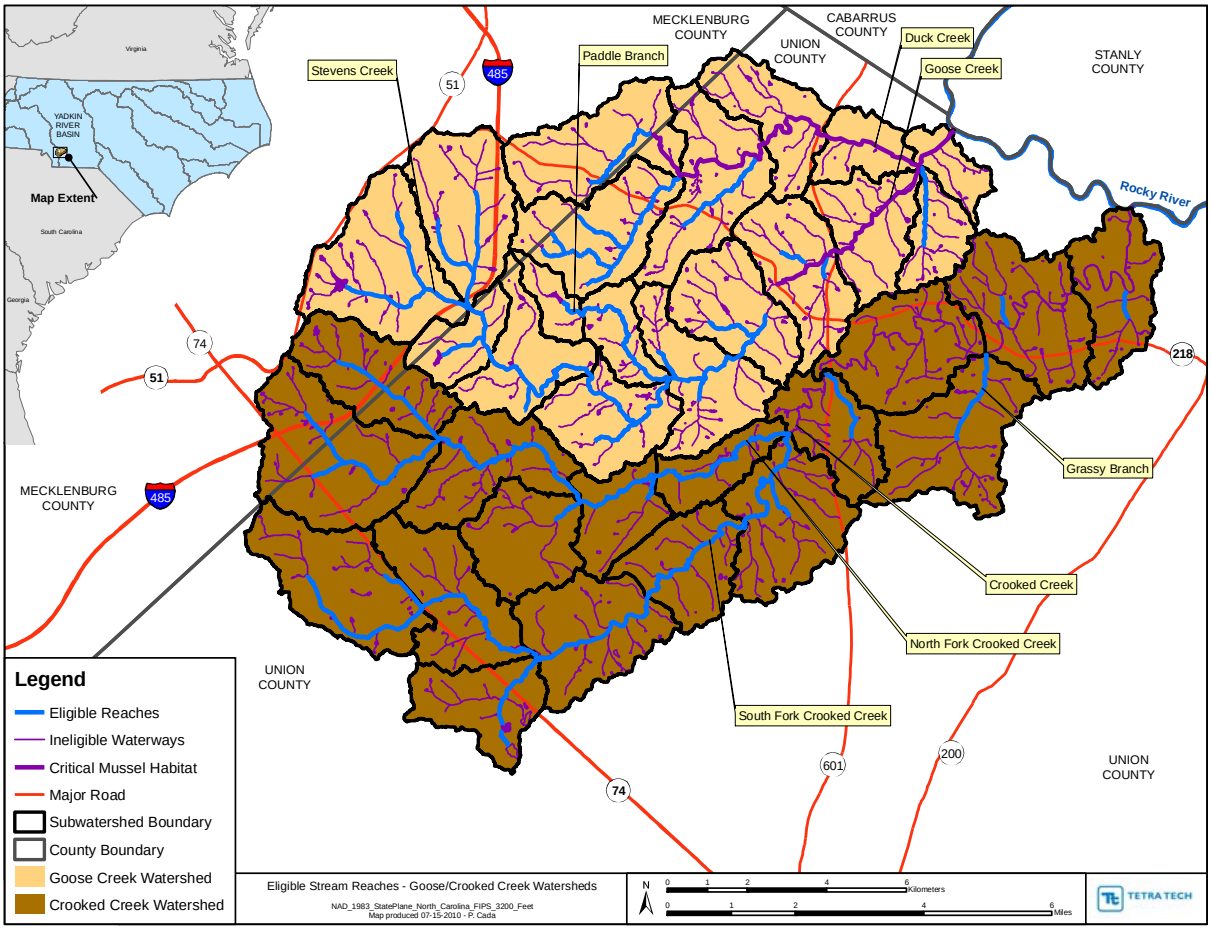


Figure 1. Reaches Eligible for Stream Restoration Considerations

1.2 HEC-RAS MODELS

HEC-RAS, a one-dimensional hydraulic model for simulating flow in open channels, was used as one of several lines of evidence to target stream reaches in most need of management. HEC-RAS models were available for many of the eligible reaches throughout both watersheds (Figure 2). While HEC-RAS is often used for floodplain management, output also includes a number of hydraulic variables related to channel stability and in-stream erosion potential.

HEC-RAS models were obtained from the NC Floodplain Mapping Program, Union County, and the City of Charlotte's Stormwater Services. Models were assembled and analyzed to determine their extents and connectivity. The available models covered all of the mainstem and major tributaries in the Crooked Creek watershed, and most of the Goose Creek watershed except for approximately seven miles along the middle of the mainstem.

HEC-RAS simulations of bankfull storm events, discharges that fills the channel to the elevation of the active floodplain, can be used to identify reaches with a greater risk for geomorphological instability based on the assumption that bankfull discharge is approximately equal to the discharge that transports the largest percentage of the sediment load over time (i.e., effective discharge). Although HEC-RAS models for these watersheds were constructed for floodway studies describing larger flow events (i.e., 100-year event), inputs for a bankfull storm event (e.g., 2-year, 24-hour storm event) can be developed

using Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). However, HEC-HMS models covering all of Goose and Crooked Creek watersheds were not available.

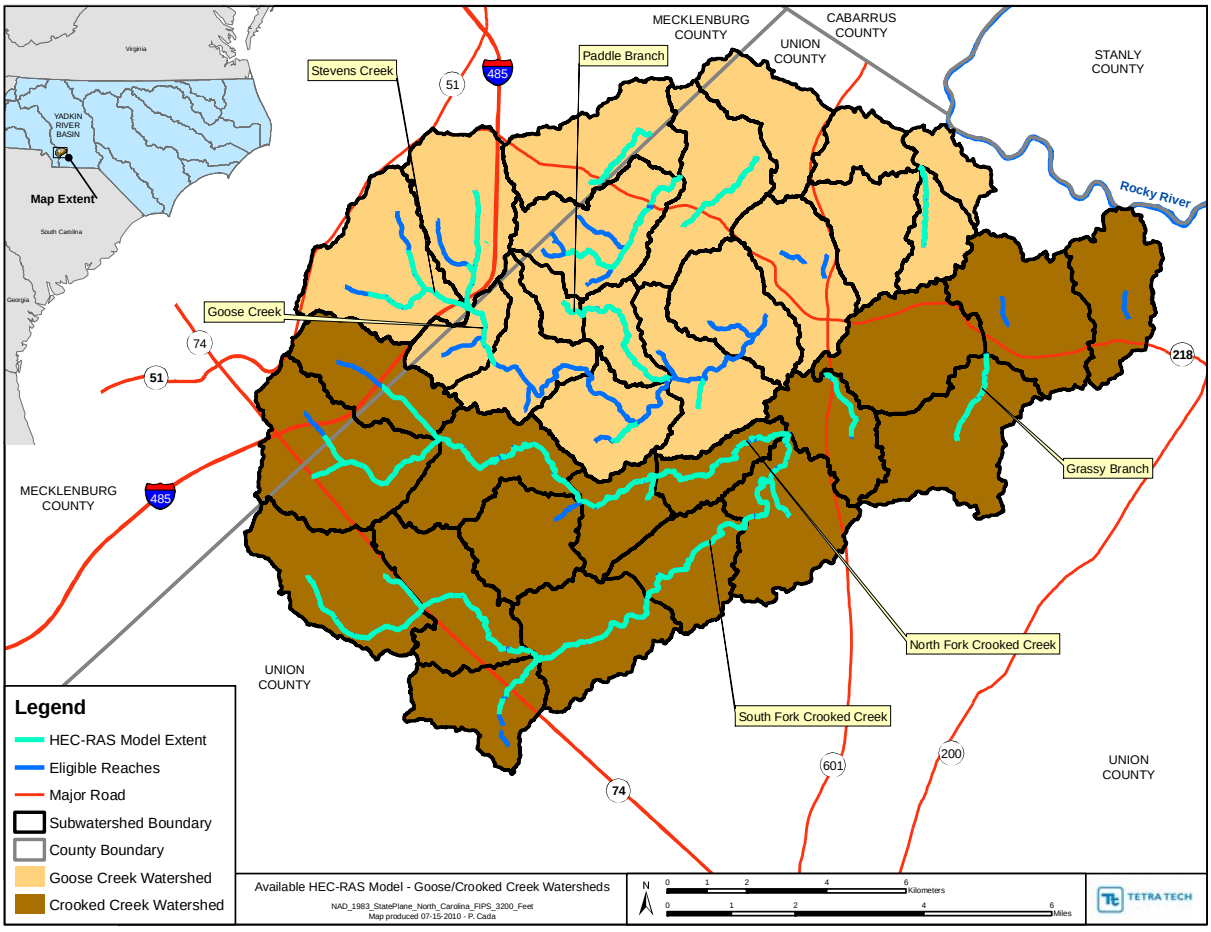


Figure 2. HEC-RAS Model Coverage of Eligible Reaches

In the absence of HEC-HMS models, Tetra Tech utilized an alternative method to estimate bankfull flows and simulate channel velocities. First, Tetra Tech evaluated a range of flows for a sample of HEC-RAS models to select the flow profile that approximates bankfull flow according to the cross-section. Since all of the HEC-RAS models included a 100-year floodway value, a bankfull/100-year flow ratio was calculated and averaged. The average ratio was subsequently used to calculate a bankfull flow value for each model and cross-section using the provided 100-year peak flow value. Bankfull flow profiles were then developed for every model and used to simulate channel velocities.

Reach segments with cross-sections having an average velocity above the 85th percentile ranking were highlighted as priority areas (Note: the percentile analyses were done separately for the two watersheds). A 1000-foot reach was selected at locations where HEC-RAS velocity output exceeded the 85th percentile ranking, shown within the yellow areas in Figure 3. Reaches where two consecutive cross-sections exceeded the 85th percentile were considered to have the highest potential for degradation. These segments, shown within the purple areas in Figure 3, were given more weight in subsequent screening steps.

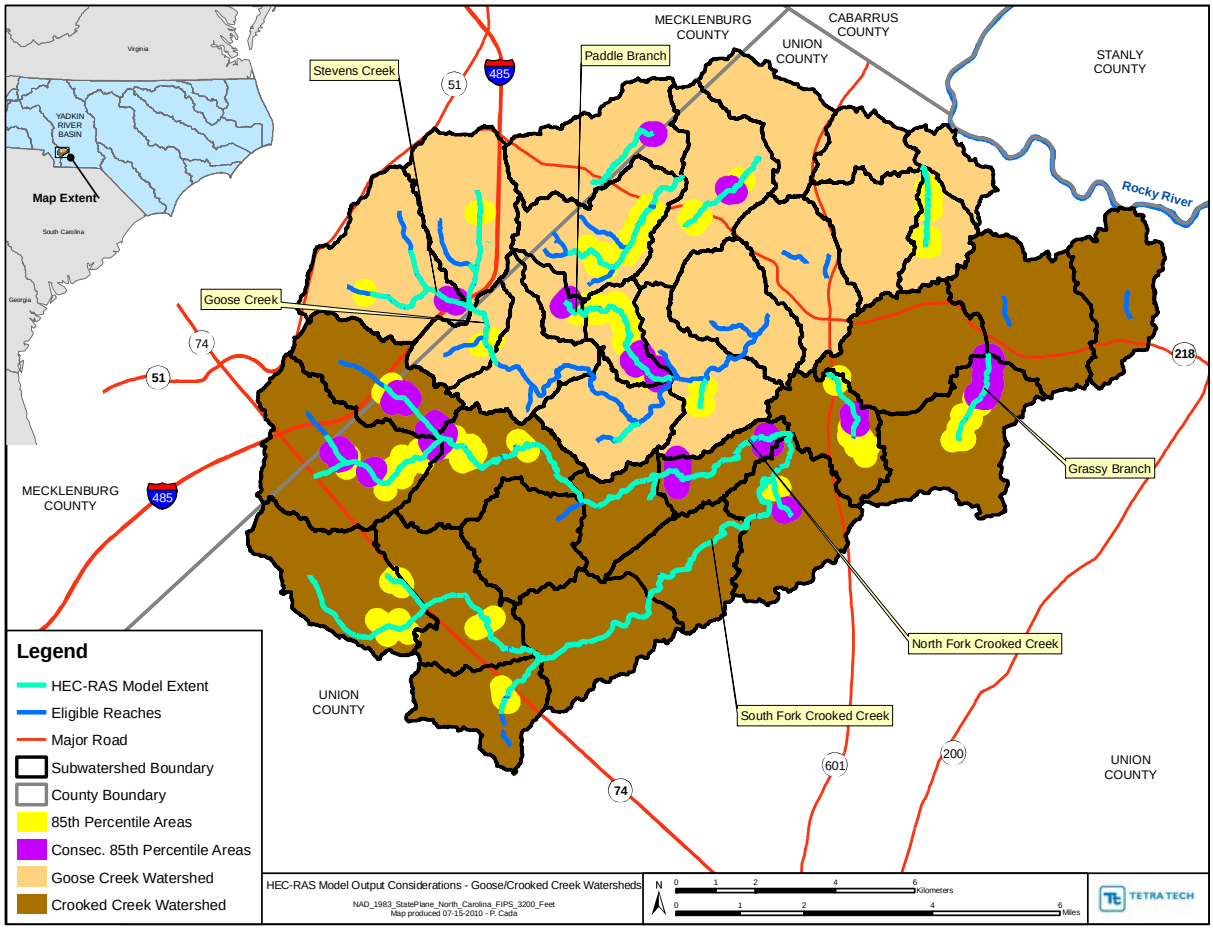


Figure 3. High Velocity Reaches Determined Using HEC-RAS Models

1.3 PHASE I RESULTS

Higher priority areas for management were also identified by averaging and applying several site-specific field and geospatial measures from the Phase I work (Tetra Tech, 2008) at the subwatershed scale. The measures considered from the previous analysis were:

- Cumulative percent impervious surface
- Riparian buffer deficiency (less 30 percent canopy)
- Stream habitat score
- Bank Erosion Hazard Index (BEHI)
- Channel stability rating

Each of these measures assisted in identifying stream reaches to target for management. Special attention was given to subwatersheds with low stream habitat scores, less stable streambanks, and a higher BEHI. Taking all measures into consideration subwatersheds were classified as higher or lower priority (Figure 4). Subwatersheds labeled as "Not Considered" were removed from the screening process because they did not contain any eligible reaches.

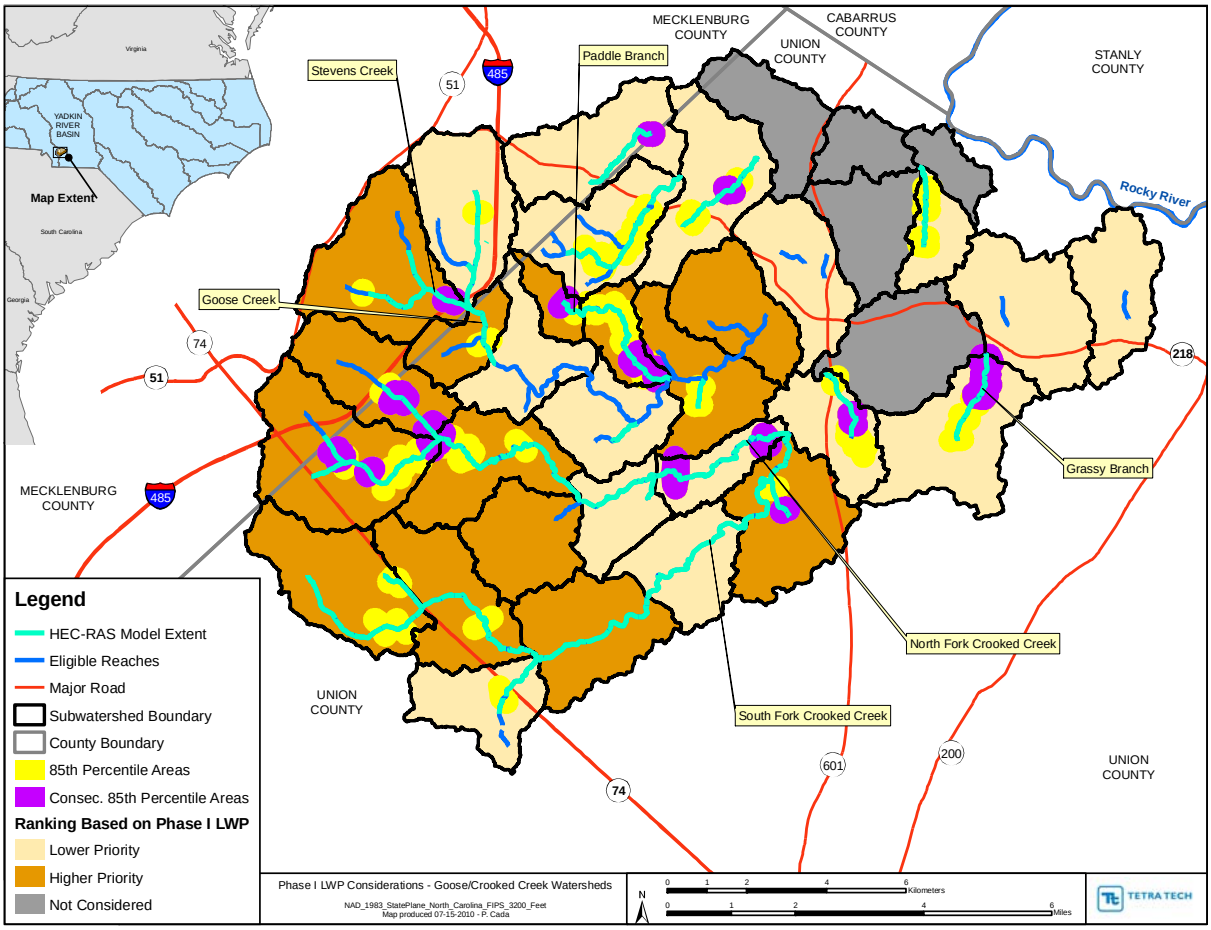


Figure 4. Subwatershed-based Reach Priorities Derived from Phase I Results

1.4 OTHER SCREENING FACTORS

Several potential constraints on restoration activities identified by NCEEP (2008) were considered during reach screening:

- Stream crossings by utilities and infrastructure, roads, bridges, culverts, etc.
- Number of private landowners
- Impediments to construction staging and access
- Utilities running parallel and within close proximity to the stream reach

To address these factors, GIS layers created during Phase I, parcel data from 2006, and 2007 high-resolution aerial imagery were used to evaluate reaches. For example, aerial imagery and available GIS coverages of utilities and infrastructure were used to remove reaches from consideration when any utility or infrastructure directly crossed the reach or ran proximately parallel for a significant length to the selected reach. Parcel boundaries were employed to remove reaches that had a significant number of landowners along the reach. Additionally, aerial imagery and available GIS coverages were used to remove reaches that had significant forested areas, buildings, roads, and other potential obstructions to construction staging and access.

Stream reaches adjacent to existing easements and potential wetland and/or riparian buffer restoration opportunities, as identified in Phase I, were noted. In addition, modified channels in agricultural settings were also considered.

1.5 SELECTED REACHES

The stream reach screening process resulted in a selection of 38 reaches of varying lengths for field assessment. to evaluate conditions and management needs. The total length of selected reaches was ~136,000 linear feet throughout both watersheds (58,600' in Goose; 77,600' in Crooked) (Figure 5).

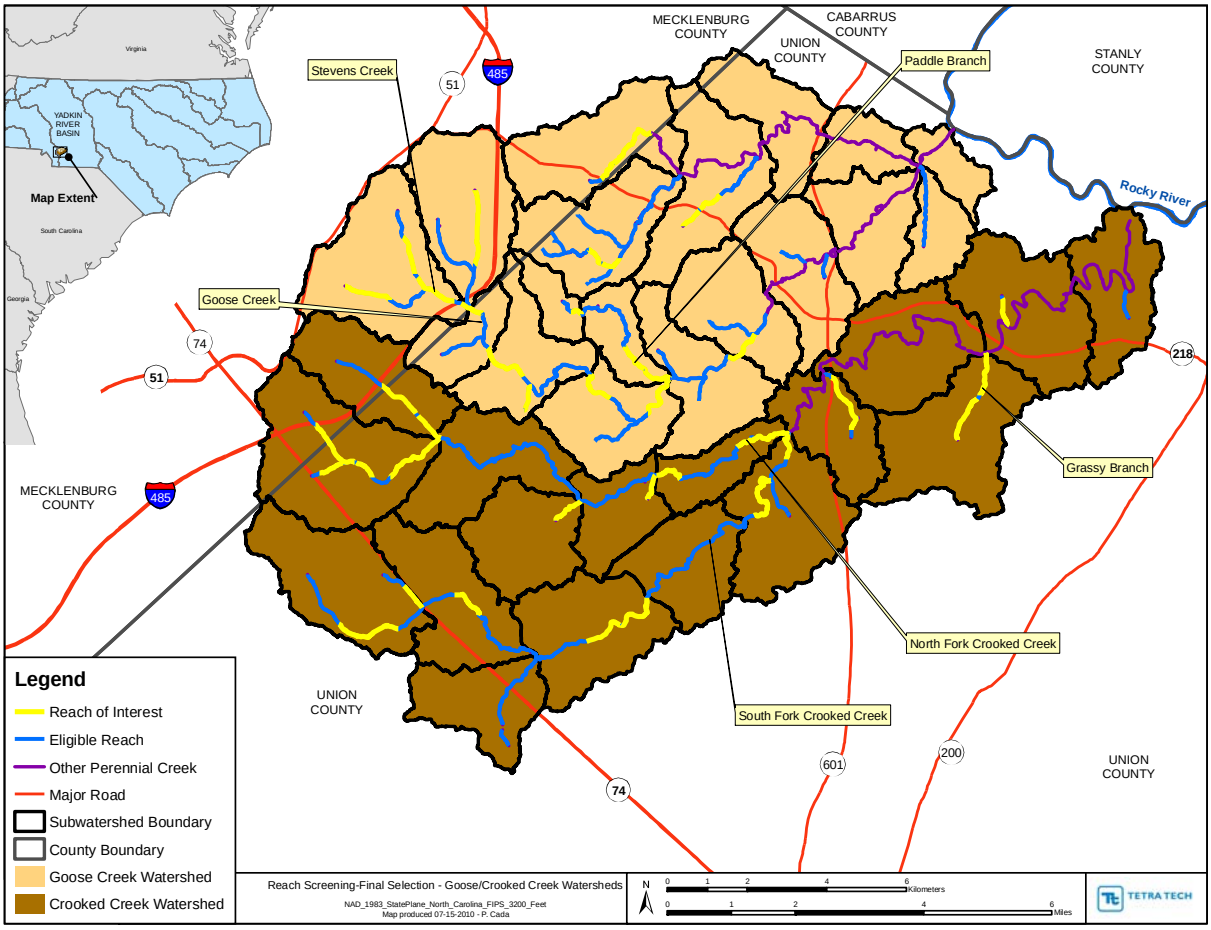


Figure 5. Reaches Selected for Subsequent Field Assessment

2 Field Assessment

During Phase I, the team conducted an assessment to document existing conditions of reaches and to identify gaps in knowledge. Building on that preliminary watershed characterization, the objective of the Phase II field assessment is to identify and prioritize stream enhancement and restoration opportunities. Phase II assessment consisted of a more comprehensive survey that includes a geomorphic assessment, a Stream Habitat Evaluation (SHE) (NCDENR, 2001), supporting field observations (e.g., evidence of beavers, migration barriers, debris dams, floodplain disconnection, livestock access), and reach management information (e.g., reach accessibility, constraints, and restoration type).

Field assessments were conducted on reaches selected during the screening process starting from 38 access points (near stream crossings) throughout the two watersheds (Figure 6). To reduce influence the crossing may have on channel form and aquatic habitat, starting points were selected to accommodate a reasonable distance (e.g., 50 meters) from the crossings. The reach was then walked for approximately 20 minutes, while field data were collected. Field forms are provided in Appendix A and Appendix B. Eight of the 38 assessed sites (Sites 5, 6, 9, 16, 17, 22, 23, and 37) were part of the Phase I effort and selected to evaluate management options.

In total, the team evaluated 29 parameters for the field assessment. These include both geomorphic and stream habitat parameters, which are discussed in more detail below. Tabular results are provided in Appendix C.

2.1 GEOMORPHIC ASSESSMENT

Parameters collected during the geomorphic assessment were used to calculate a Bank Erosion Hazard Index (Rosgen, 2001b) and stream stability index, and to classify the reaches according to stages of the Channel Evolution Model (Simon, 1989). Sketches of stream plan forms and cross sections were also collected.

2.1.1 Bank Erosion Hazard Index

BEHI is an empirically derived, process-integrated streambank erosion assessment methodology that is used for evaluating risk of streambank erosion. BEHI allows for rapid field observations and measurements of key streambank characteristics to be converted to a normalized index of erosion risk (Rosgen, 2001a). In addition, one of the evaluated components of the BEHI, the bank height ratio, is a measure of channel incision and can be translated to a stability rating as described in Rosgen (2001b). Of note, the BEHI methodology accounts only for the resistive properties of the streambank, not for erosive forces associated with hydrology and it is a static observation that does not consider changes over time (change over time could be considered when measurements are repeated over various time intervals). For the purposes of this study, the benefits of the BEHI are considered to outweigh these limitations.

Employing the BEHI requires collecting field data used to generate six parameters. The measured and/or calculated values for the first five parameters are converted to index scores ranging from 0 to 10 and the total is summed (Table 1). The total score may be adjusted using the sixth parameter – bank materials – which is based on whether the materials are more highly or less highly erodible. The six parameters include: (1) Banktop Height to Bankfull Height Ratio, (2) Rooting Depth to Bank Height Ratio, (3) Rooting Density, (4) Bank Angle, (5) Surface Protection, and (6) Bank Materials.

The risk of streambank erosion for field assessed stream reaches was categorized using thresholds provided in Table 1. Visual examples of the three classes identified in the study area are presented in Figure 7 through Figure 9. Watershed-wide results are illustrated in Figure 10.

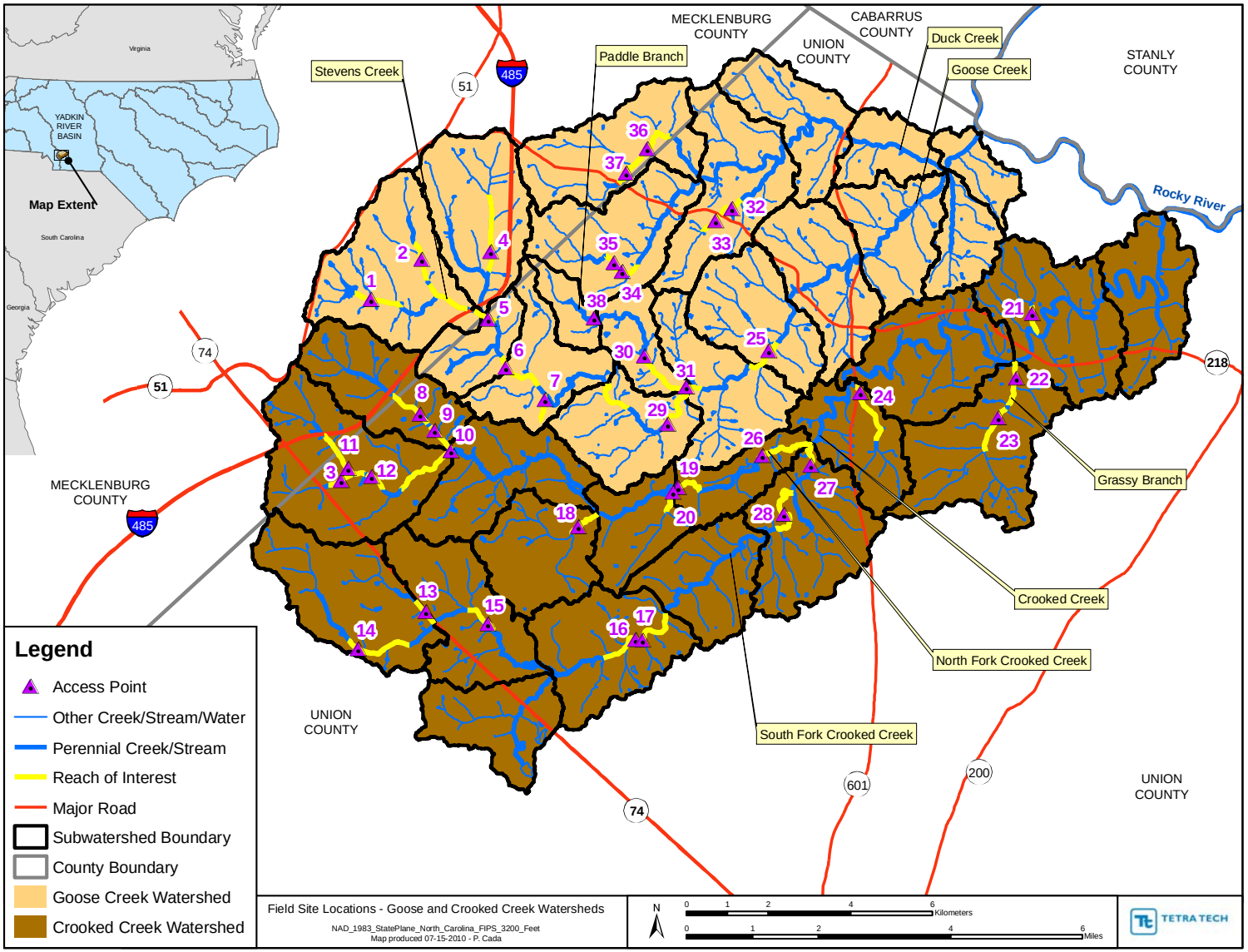


Figure 6. Locations of Field Assessments in Goose Creek and Crooked Creek Watersheds (July 2010)

Table 1. BEHI Index Scores and Risk Rating Categories (Rosgen, 2001a)

Adjective Hazard or Risk Rating Categories		Bank Height/ Bankfull Height	Root Depth/ Bank Height	Root Density %	Bank Angle (Degrees)	Surface Protection %	Totals
VERY LOW	Value	1.0-1.1	1.0-0.9	100-80	0-21	100-80	
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	5-9.5
LOW	Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55	
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	10-19.5
MODERATE	Value	1.2-1.5	0.49-0.3	54-30	61-80	54-30	
	Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	20-29.5
HIGH	Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15	
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	30-39.5
VERY HIGH	Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10	
	Index	8.0-9.0	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	40-45
EXTREME	Value	>2.8	<0.05	<5	>119	<10	
	Index	10	10	10	10	10	46-50



Figure 7. Low Stream Bank Erosion Risk Category – Unnamed Tributary (Site #7)



Figure 8. Moderate Stream Bank Erosion Risk Category – Unnamed Tributary (Site #3)



Figure 9. High Stream Bank Erosion Risk Category – Unnamed Tributary of North Fork Crooked Creek (Site #20)

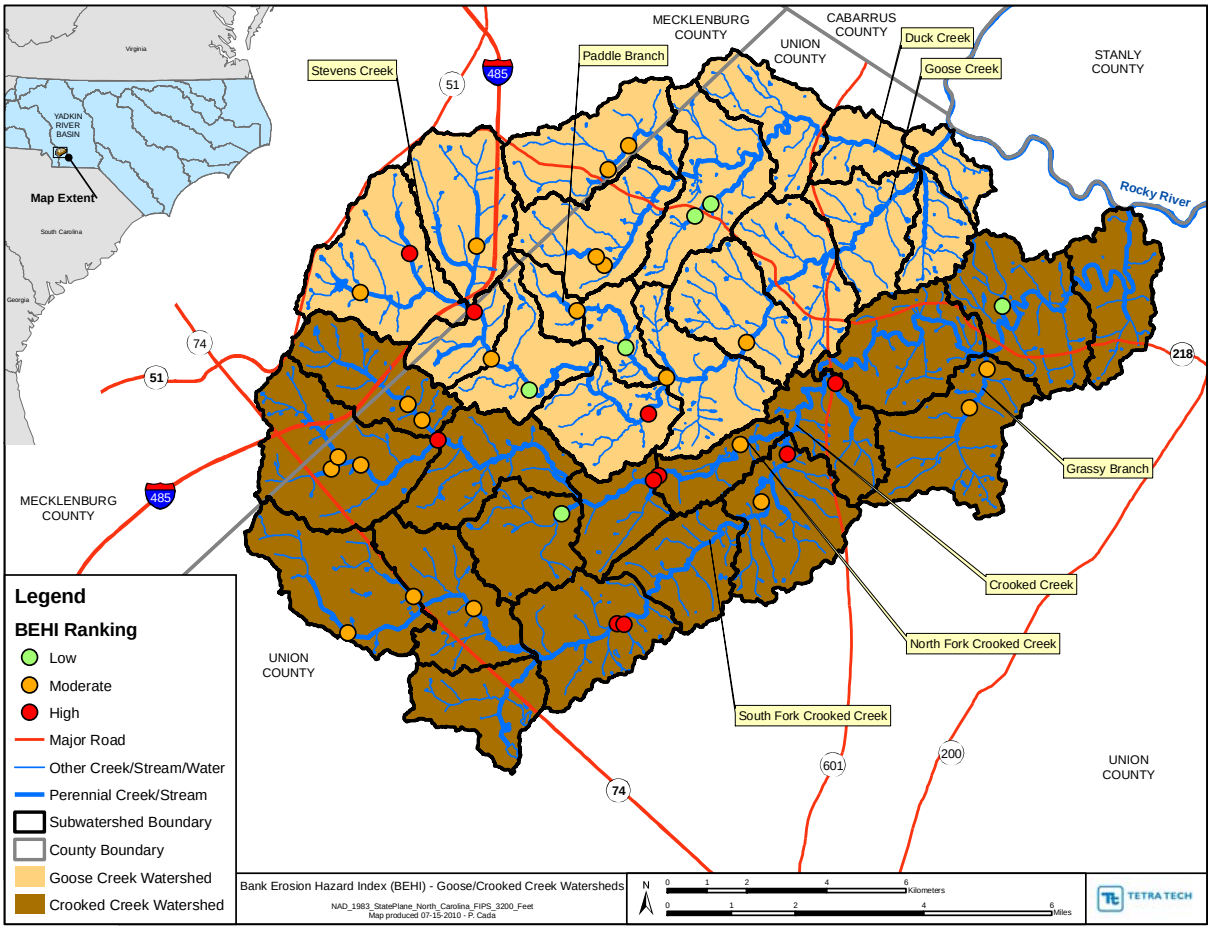


Figure 10. Categories of Stream Bank Erosion Risk as Defined by the BEHI

Streambank erosion can be the dominant sediment source in watersheds having deeply incised and actively eroding channels. Incised channels can impact sediment load two ways: 1) large bankface surface areas may be exposed to scouring flows, and 2) increased streambank mass wasting events. The bank height to bankfull ratio indicates the degree of channel incision; that is the extent which the bed has recently downcut below a prior equilibrium elevation. Ideally, the bankfull height coincides with the top of the streambank, such that the height ratio is one. As a channel incises, the height of the streambanks increase, whereas the bankfull height typically stays nearly constant as it follows relative to the downcutting streambed. Therefore, continued channel incision increases the bank height to bankfull height ratio. If this ratio exceeds a certain critical threshold, determined by the geotechnical properties of the streambank soils, the streambanks will become unstable and will begin to fail by mass wasting. The conversion of the degree of channel incision (Rosgen, 2001b), as quantified through the bank height ratio to a qualitative rating of channel stability, is shown in Table 2. It is important to note that a "Highly Unstable" classification does not necessarily mean that the assessed channel is actively unstable. It means that the channel has characteristics similar to those of highly unstable channels. If the channel is not presently unstable, it either has the potential to become unstable in the near future, or there are other characteristics not included in the stability rating that are keeping the channel stable. Results illustrating the risk to channel stability due to incision are presented in Figure 11.

Table 2. Conversion of Bank Height to Bankfull Ratio to Stability Ratings (Rosgen, 2001b)

Bank Height to Bankfull Ratio	Stability Rating
1.0 – 1.05	Stable (low risk of degradation)
1.06 – 1.3	Moderately Stable
1.3 – 1.5	Unstable (high risk of degradation)
Greater than 1.5	Highly Unstable

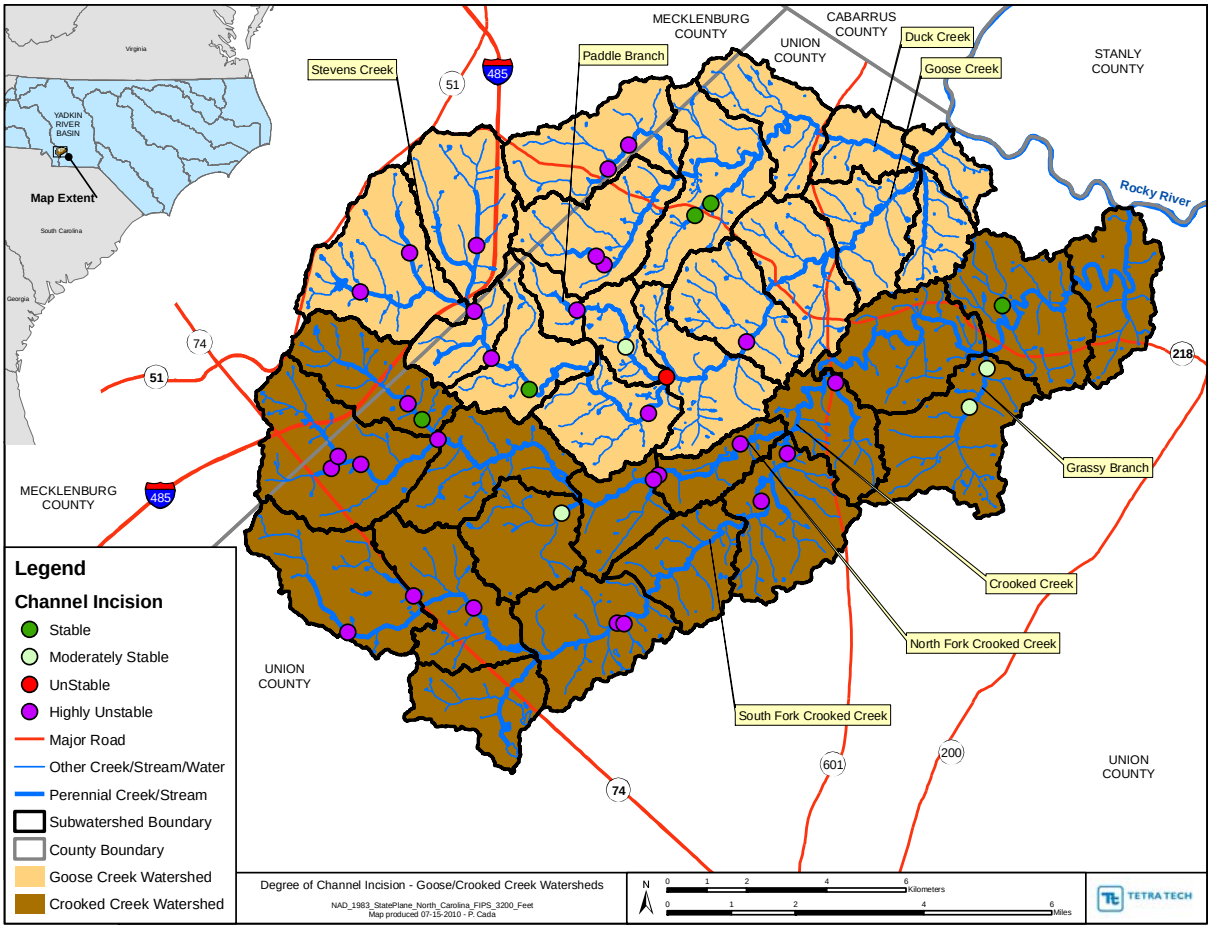


Figure 11. Categories of Channel Stability Due to Degree of Incision

Particular stream reaches that exhibit moderate- to high-risk characteristics with a higher potential for contribution of sediment to the streams in the study area, through both bank erosion and incision, are represented in Figure 12. Reaches considered a moderate risk are classified as having *Moderate* BEHI values and either *Unstable* or *Highly Unstable* morphologies, due to the degree of incision. High risk reaches have *High* BEHI values and *Highly Unstable* morphologies.

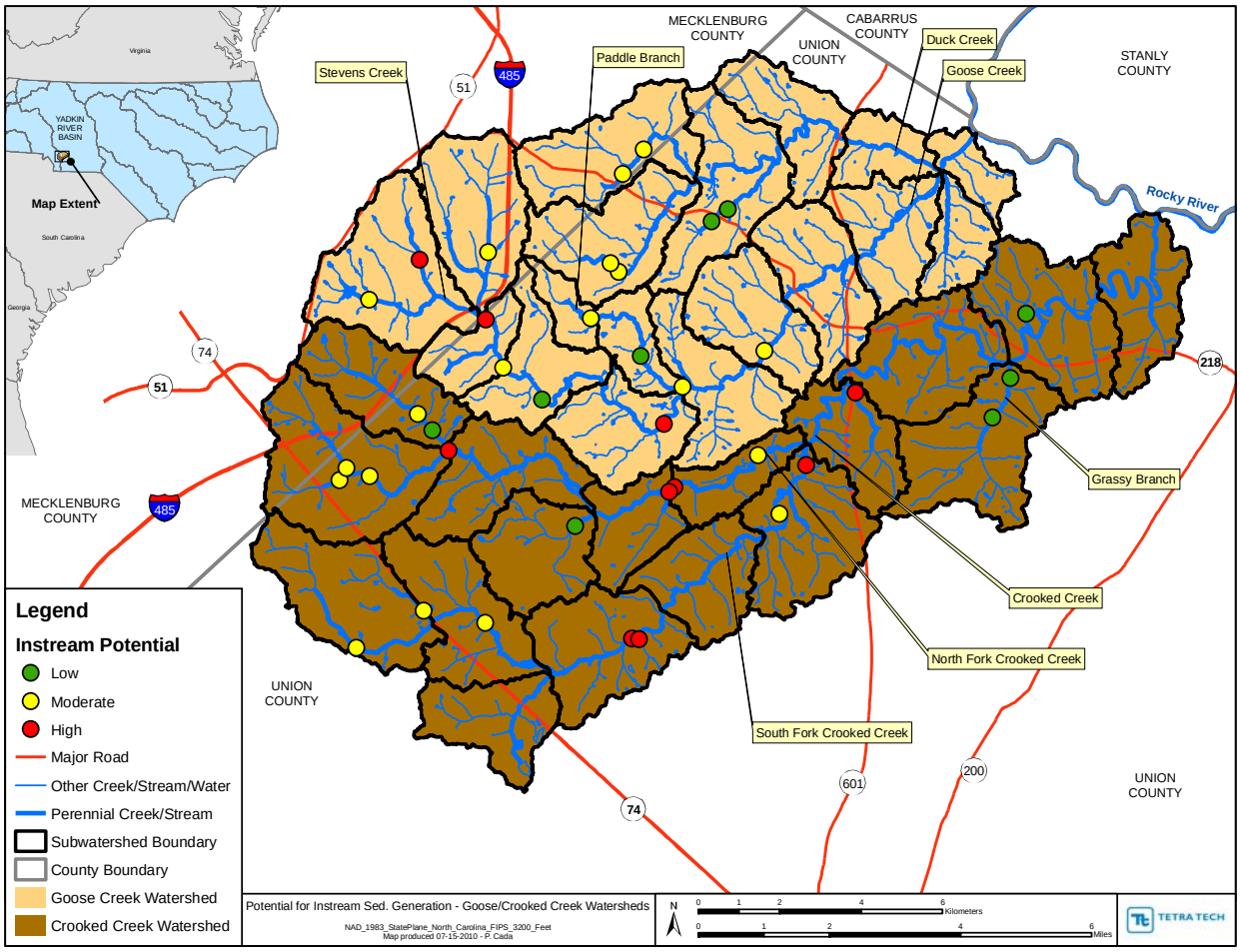


Figure 12. Stream Reaches Exhibiting Highest Potential for Generation of Instream Sediment

2.1.2 Channel Evolution Model

The Channel Evolution Model (CEM) was originally developed with five distinct stages by Schumm, Harvey and Watson (1984) and later modified by Simon (1989) who added a sixth stage: (stage II in Figure 13) representing constructed and channelized reaches. This conceptual model has been used widely to classify stream reaches in the field, for a wide variety of flow regimes and regions throughout the country. The six channel form stages represent different points in a time series. This is often in response to upstream drainage area development and/or changes in land use and land cover. While this conceptual model does not represent all forms a stream reach may be found in during its evolution through time, it can serve as a proxy for the degree of stream ecosystem degradation in impacted watersheds. The CEM is used for this purpose in the Goose Creek and Crooked Creek watersheds. Visual examples of the six different CEM classes identified in the study area are presented in Figure 14 through Figure 19. The results across the watersheds from Phase II are illustrated in Figure 20.

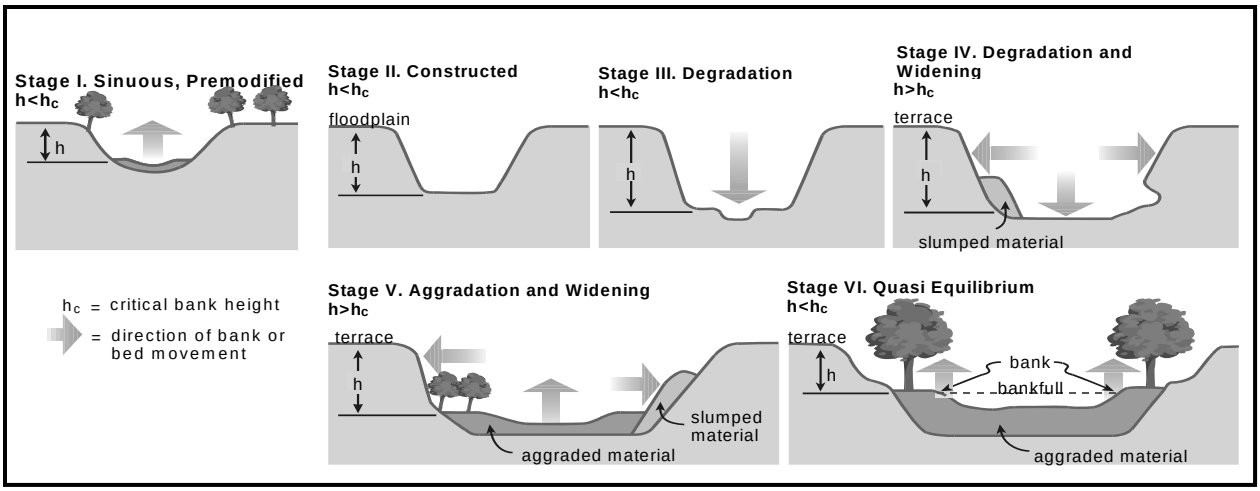


Figure 13. Six Stages of the Channel Evolution Model (from Alonso et al., 2002)



Figure 14. CEM Stage 1 Stream Reach – Unnamed Tributary of Goose Creek (Site #7)



Figure 15. CEM Stage 2 Stream Reach – North Fork Crooked Creek – Headwaters (Site #9)



Figure 16. Example of CEM Stage 3 Stream Reach – Unnamed Tributary of North Fork Crooked Creek (Site #20)



Figure 17. Example of CEM Stage 4 Stream Reach – South Fork Crooked Creek (Site #17)



Figure 18. Example of CEM Stage 5 Stream Reach – S. Fork Crooked Creek (Site #14)



Figure 19. Example of CEM Stage 6 Stream Reach – N. Fork Crooked Creek (Site #12)

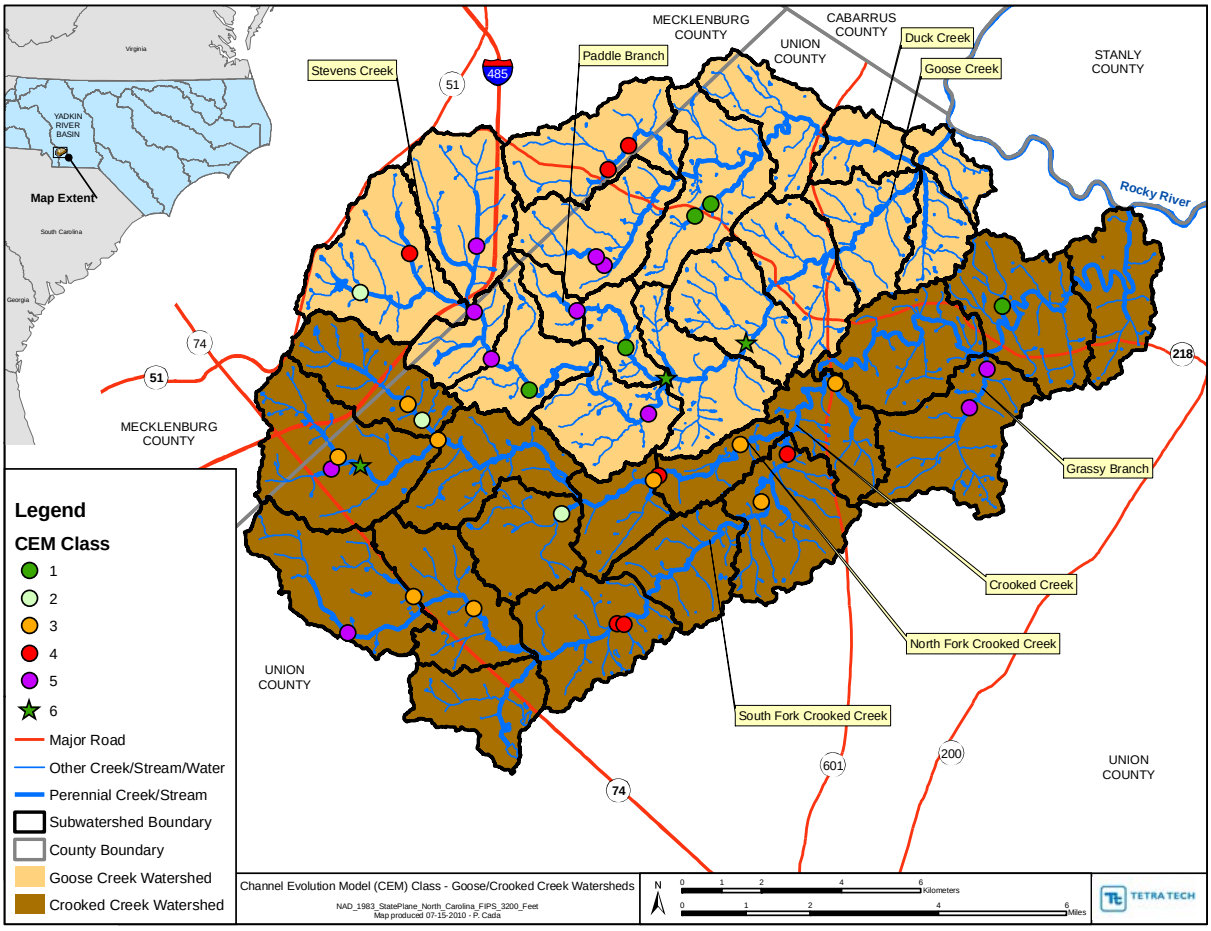


Figure 20. Channel Form Categories (CEM) – Goose Creek and Crooked Creek Watersheds

2.2 STREAM HABITAT EVALUATION

The SHE used in the field follows the guidelines set out in Appendix E of the NC Department of Environment and Natural Resources (DENR) Internal Technical Guide for Stream Work in North Carolina (NCDENR, 2001). The SHE is composed of eight questions which require field personnel to make scaled, qualitative observations, including:

- Channel Modification (0 to 5)
- Instream Habitat (0 to 20)
- Bottom Substrate (1 to 15)
- Pool Variety (0 to 10)
- Riffle Habitat (0 to 16)
- Bank Stability and Vegetation (0 to 14)
- Light Penetration (0 to 10)
- Riparian Vegetative Zone Width (0 to 10)

Scores for each item are totaled, resulting in a Habitat Evaluation score for the reach. The maximum possible score (100) represents the highest quality stream habitat. However, since the SHE scoring is not linked to bioclassification ratings, there are no specific thresholds or breakpoints available to classify SHE scores into categories describing aquatic habitat health other than higher overall scores represent better aquatic habitat than lower overall scores. General habitat health of reaches assessed throughout the two watersheds can be viewed spatially in Figure 21.

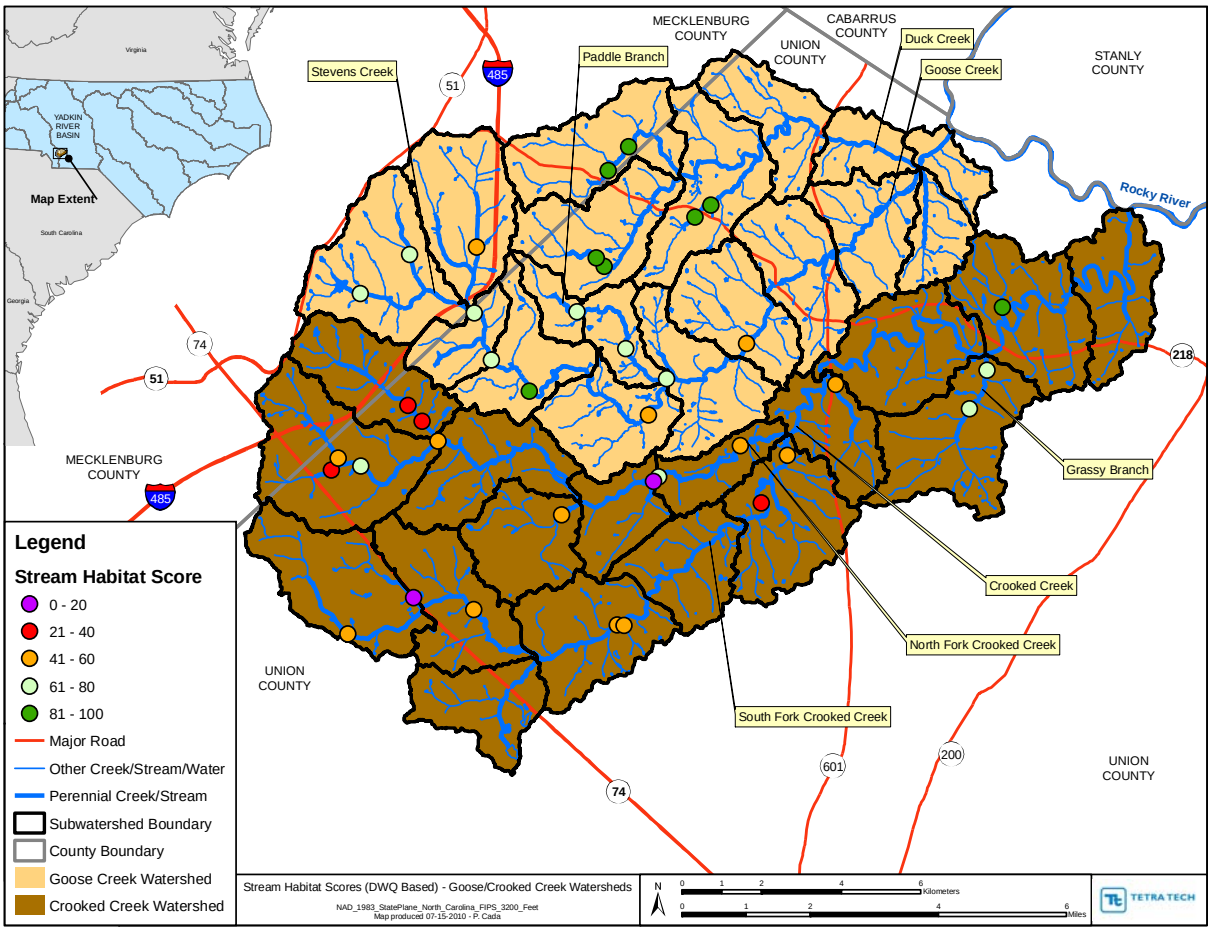


Figure 21. Stream Habitat Scores in the Goose Creek and Crooked Creek Watersheds

2.3 SUMMARY OF STREAM ASSESSMENT

Building upon the screening-level findings of channel impacts during Phase I, the more detailed recent field assessment of stream reaches throughout the Goose Creek and Crooked Creek watersheds revealed widespread stream channel impacts. Most reaches evaluated in the current study have a moderate-to-high risk of bank erosion, with characteristics similar to highly unstable channels. This indicates that some reaches may be actively unstable or could become unstable if peak flows and runoff volumes were to increase.

Evidence of undercutting, incision to bed rock, and widening of stream channels was observed. In many reaches incision has disconnected streams from the floodplain. Mass wasting of streambanks was also observed in both watersheds, which results in streambanks failing and large quantities of sediment entering the stream.

Stream habitat evaluation results varied widely among the observed reaches. Only a small minority of sites scored above 80. Many of these were in the Duck Creek subwatershed of Goose Creek. Habitat scores in the Crooked Creek watershed were generally lower than in the Goose Creek watershed. The features that had the strongest influence on the lower scoring sites (<60) were deficiencies in the substrate (e.g., great amount of embeddedness) and riffle habitat.

A compilation of key indices collected in the Phase II assessment is provided below (Table 3). There was some correlation between indices. Sites with low BEHI were either categorized as CEM stage 1 or 2, were stable (or moderately stable) and had an average habitat score of 79. Those sites found to have a high BEHI were all highly unstable and produced an average habitat score of 51. CEM stages were 3 through 5. The moderate BEHI category, which made up 60 percent of sites, showed greater variability in CEM, stability rating, and habitat score (average of 59).

Table 3. Summary Key Assessment Indices

Watershed	Site ID	BEHI Category	Stability Rating	Habitat Score	CEM Category
Goose	1	Moderate	Highly Unstable	74	2
Goose	2	High	Highly Unstable	66	4
Goose	4	Moderate	Highly Unstable	58	5
Goose	5	High	Highly Unstable	61	5
Goose	6	Moderate	Highly Unstable	73	5
Goose	7	Low	Stable	93	1
Goose	25	Moderate	Highly Unstable	46	6
Goose	29	High	Highly Unstable	51	5
Goose	30	Low	Moderately Stable	74	1
Goose	31	Moderate	Unstable	70	6
Goose	32	Low	Stable	84	1
Goose	33	Low	Stable	84	1
Goose	34	Moderate	Highly Unstable	87	5
Goose	35	Moderate	Highly Unstable	87	5
Goose	36	Moderate	Highly Unstable	83	4
Goose	37	Moderate	Highly Unstable	87	4
Goose	38	Moderate	Highly Unstable	76	5
Crooked	3	Moderate	Highly Unstable	29	5

Watershed	Site ID	BEHI Category	Stability Rating	Habitat Score	CEM Category
Crooked	8	Moderate	Highly Unstable	30	3
Crooked	9	Moderate	Stable	40	2
Crooked	10	High	Highly Unstable	46	3
Crooked	11	Moderate	Highly Unstable	51	3
Crooked	12	Moderate	Highly Unstable	64	6
Crooked	13	Moderate	Highly Unstable	19	3
Crooked	14	Moderate	Highly Unstable	46	5
Crooked	15	Moderate	Highly Unstable	49	3
Crooked	16	High	Highly Unstable	50	4
Crooked	17	High	Highly Unstable	54	4
Crooked	18	Low	Moderately Stable	41	2
Crooked	19	High	Highly Unstable	71	4
Crooked	20	High	Highly Unstable	14	3
Crooked	21	Low	Stable	95	1
Crooked	22	Moderate	Moderately Stable	70	5
Crooked	23	Moderate	Moderately Stable	70	5
Crooked	24	High	Highly Unstable	58	3
Crooked	26	Moderate	Highly Unstable	55	3
Crooked	27	High	Highly Unstable	42	4
Crooked	28	Moderate	Highly Unstable	33	3

3 Reach Management Opportunities

Information on channel and riparian area condition collected in the field was used to develop management recommendations for each stream reach. Each recommendation was site specific and took into account constraints on the ground. Costs and benefits were estimated for sites with higher level management recommendations (e.g., restoration, enhancement). The resulting cost-effectiveness information is combined with additional information to support project prioritization and selection.

3.1 MANAGEMENT RECOMMENDATIONS

3.1.1 Restoration Categories

The restoration potential recommendation for a reach is based on categories developed by USACE and contained within the stream mitigation guidelines for North Carolina (USACE, 2003).

Restoration

Restoration entails reestablishing the unstable, altered, or degraded stream corridor (including adjacent riparian buffers and floodplain) to its natural stable condition. This would include restoring the reach to stable physical dimensions (i.e., dimension, pattern, and profile), as well as restoring biological and water quality functions. This typically includes a change in channel location or improved sinuosity and the re-establishment of habitat conditions generally through stream channel longitudinal slope and streambank changes, which may include streambed changes. This is the most intensive and involved management activity.

Enhancement Level I

Enhancement Level I includes improvements to the stream channel and riparian zone to restore channel stability, water quality, and stream ecology. Channel dimension (streambanks) and profile (streambed's longitudinal slope) are typically addressed; however, restoration to a more natural channel pattern through movement of the existing channel location is typically not feasible. This category may include other practices that provide improved water quality and ecological benefits.

Enhancement Level II

Enhancement Level II category includes activities that augment channel stability, water quality, and stream ecology, but fall short of restoring both dimension and profile. This category may include other practices that provide improved water quality and ecological benefits.

Stabilization

Stabilization is the in-place stabilization of an eroding streambank. Stabilization techniques include: (1) the use of materials like root wads and log crib structures, (2) sloping streambanks, and (3) re-vegetating the riparian zone.

Buffer Restoration

Buffer Restoration refers to any activities in the area within at least 50 feet of the active stream channel that would restore the riparian buffer area to a more natural, vegetated state. Restoration is often, but may not be limited to, a combination of tree planting, invasive plant species control/removal, and/or removal of human infrastructure (e.g., fences, buildings, roads) if feasible.

Preservation

Preservation is the protection of ecologically important streams and is generally implemented in perpetuity through the implementation of appropriate legal and physical mechanisms. Preservation can

include the protection of upland buffer areas adjacent to the stream necessary to ensure protection or enhancement of the overall stream.

Note: The presence of habitat for federal or state endangered mussels in the Goose Creek and Crooked Creek watersheds provides a reason to consider the streams as "ecologically important" based on the stream mitigation guidelines. However, mitigation credits for preservation in the Goose Creek watershed may not be allowed given the current protections provided by the Site Specific Management Strategy developed by the state. Therefore, recommendations (for both watersheds for consistency) are categorized as *Preservation/Protection* to signify that the channel should be protected but that the appropriate mechanism is undetermined.

Constraints observed in the field were used to score both reach accessibility and restoration potential metrics during field reconnaissance. For example, the proximity of a particular reach to a sanitary sewer line running parallel to the reach will affect the scoring for both the reach accessibility (advantage) and restoration potential (constraint). The reach accessibility rating descriptions are provided in Table 4 (CWP, 2004).

Table 4. Reach Accessibility

Reach Accessibility		
Good:	Fair:	Difficult:
Open area in public ownership, sufficient room to stockpile materials, easy stream channel access.	Forested or developed area adjacent to stream. Access limited.	Must cross wetland, steep slope, or sensitive areas to get to stream. Access difficult.

3.1.2 Management Recommendations

Management recommendations are provided in Figure 22 and Table 5 and Table 6. Based on the information collected to date, all reaches were considered feasible for some degree of management. During plan implementation, more detailed, site-specific feasibility assessments and contact with landowners will be required.

The analysis of management opportunities in the study area yielded six stream reaches considered to be in good to excellent condition and that should be protected through some form of preservation or protection. Eight reaches are recommended for riparian buffer restoration, either because that was the only identified need or the constraints of a particular reach would limit management efforts to the riparian zone. Many of these reaches were classified as CEM stage I, where major stream degradation has not occurred.

The remaining 24 reaches are recommended for some degree of active or higher-level management (e.g., Restoration, Enhancement-1, Enhancement-2, or Stabilization). These included two of three reaches in stage II, all nine reaches in stage III, and six of seven reaches in stage IV. Half of the stage V reaches would benefit from higher levels of management to address widening and aggrading field observations.

Three reaches were observed in the quasi-equilibrium of CEM stage VI, where a new bankfull bench has established within the active channel area. Two of these reaches are recommended for Enhancement-2. The third reach observed in CEM stage VI has a stable active channel area but is in need of riparian buffer restoration.

In seven reaches, the team identified alternative options where further site investigation is needed to determine which, if any, of the management recommendations should be pursued. For example, Site #13 has three possible recommendations ordered "Buffer Restoration," "Enhancement-2," and then "Restoration." Buffer restoration at Site #13 could be accomplished with minimal investigation of infrastructure. However, the stream would benefit from grade control measures and depending on the

location of underground utilities and infrastructure, and the availability of large, undeveloped parcels on the opposite side of East Independence Boulevard, this reach could be re-routed into a newly created stream channel. While any or all of these three recommendations could improve the stream, more information is needed to determine the most appropriate option.

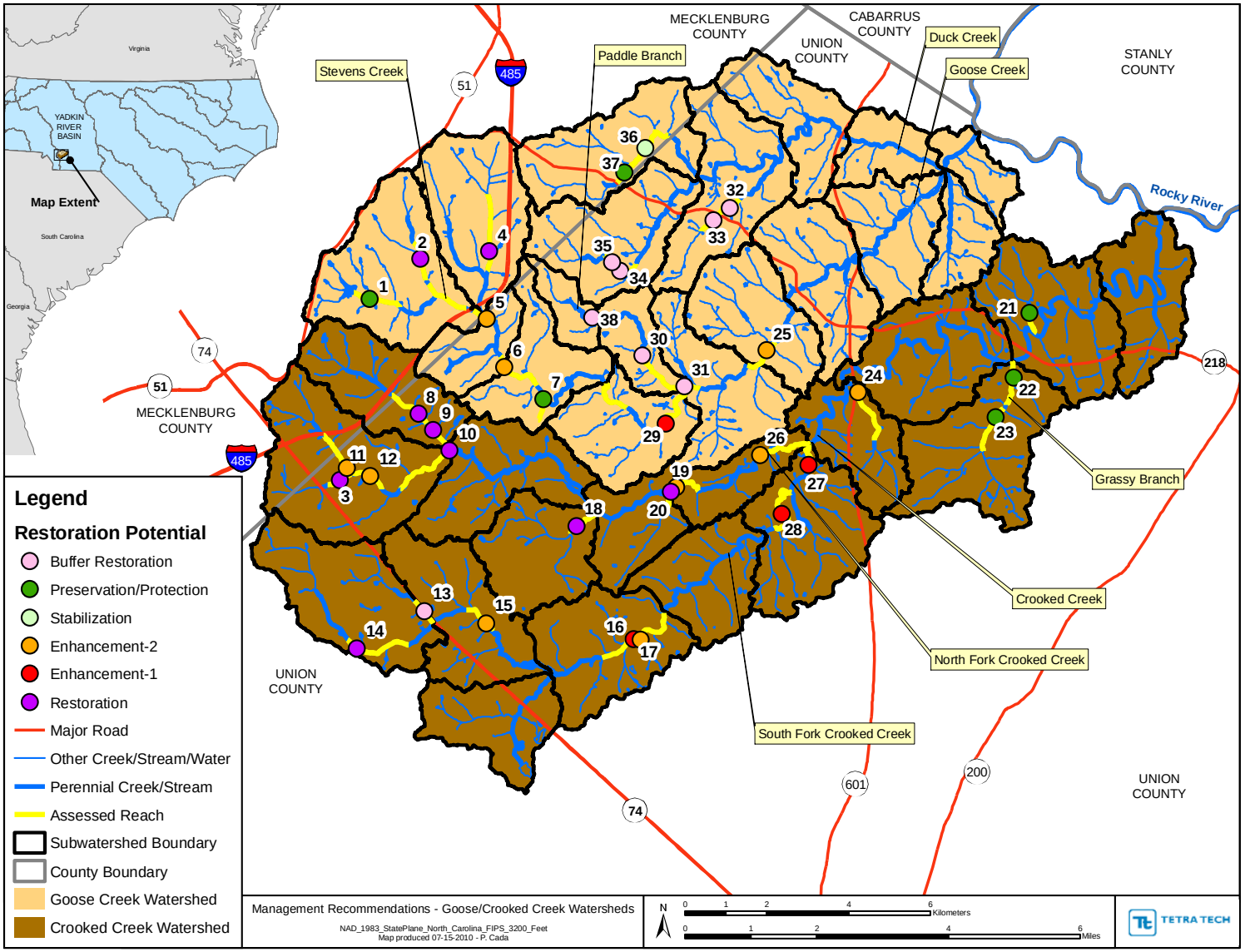


Figure 22. Recommended (Primary) Management Strategies for Selected Reaches

Table 5. Reach Accessibility and Management Recommendation Results – Goose Creek Watershed

Site ID	Reach Accessibility	Management Recommendation (Primary)	Management Recommendation (Secondary)
1	Fair	Preservation/Protection	--
2	Good	Restoration	--
4	Good	Restoration	--
5	Good	Enhancement-2	--
6	Good to Fair	Enhancement-2	--
7	Difficult	Preservation/Protection	--
25	Fair	Enhancement-2	Buffer Restoration
29	Fair	Enhancement-1	--
30	Fair	Buffer Restoration	--
31	Fair to Difficult	Buffer Restoration	--
32	Fair	Buffer Restoration	--
33	Fair	Buffer Restoration	--
34	Fair	Buffer Restoration	--
35	Fair to Difficult	Buffer Restoration	Preservation/Protection
36	Fair	Stabilization	Buffer Restoration
37	Fair	Preservation/Protection	--
38	Good to Fair	Buffer Restoration	--

Table 6. Reach Accessibility and Management Recommendation Results – Crooked Creek Watershed

Site ID	Reach Accessibility	Management Recommendation (Primary)	Management Recommendation (Secondary)
3	Good to Fair	Restoration	--
8	Good	Restoration	--
9	Good	Restoration	--
10	Good to Fair	Restoration	--
11	Good	Enhancement-2	--
12	Good	Enhancement-2	Enhancement-1 or Restoration
13	Good	Buffer Restoration	Enhancement-2 or Restoration
14	Good to Fair	Restoration	Buffer Restoration
15	Fair	Enhancement-2	--
16	Good to Fair	Enhancement-1	--
17	Good to Fair	Enhancement-2	--
18	Fair	Restoration	--
19	Good to Fair	Enhancement-2	--
20	Good	Restoration	--
21	Difficult	Preservation/Protection	--

Site ID	Reach Accessibility	Management Recommendation (Primary)	Management Recommendation (Secondary)
22	Good to Fair	Preservation/Protection	--
23	Good to Fair	Preservation/Protection	--
24	Fair	Enhancement-2	--
26	Good to Fair	Enhancement-2	--
27	Fair	Enhancement-1	--
28	Good to Fair	Enhancement-1	--

3.2 COST-EFFECTIVENESS

Higher level management opportunities include reaches recommended for Restoration, Enhancement-1, Enhancement-2, or Stabilization (USACE, 2003). Although all higher level management opportunities were considered feasible based on the information collected to date, the costs and benefits are not expected to be the same. Stream restoration costs include a variety of factors, but are not limited to, the intensity of restoration measures, project length, reach setting (e.g., urban versus rural), land acquisition, and infrastructure constraints. Generally, restoration projects have a lower cost per unit length restored if they require less intensive restoration measures, span longer distances, are located in rural settings, are situated on publicly-owned land, and have minimal infrastructure constraints. Various factors influence the benefits derived from a stream restoration project including, but not limited to, the intensity of the restoration measures, the severity of degradation existing in the reach prior to management, the location of the reach in the watershed, conditions in the contributing watershed, the size of the stream, and the timeframe over which benefits are measured. Benefits within the restored reach and benefits provided to the receiving watershed are typically greater when the restoration measures are more intense, the existing degradation is severe, the reach is located in the headwaters, the contributing watershed is less developed, the stream is lower order, and the timeframe over which benefits are measured is longer. Regardless of the methodology used to quantify the costs and benefits of stream restoration projects, the ratio of costs to benefits serves as a useful indicator of the cost-effectiveness of a proposed project.

3.2.1 Costs

The NCEEP in-lieu fee program assesses a charge of $338 per foot of impacted stream based on the current fee schedule for higher fee cataloging units (effective July 1, 2010; NCEEP, 2010). The rate represents the average cost for stream restoration projects and includes planning, design, construction, land acquisition, maintenance, and monitoring. However, the cost of restoration efforts at a particular location is dependent on the intensity of management measures recommended and the level of degradation. NCEEP has addressed this dependence by applying the mitigation credit ratios by management type to the $338 per foot rate to differentiate the approximate costs (Robin Hoffman, NCEEP, personal communication to P. Cada, July 26, 2010; Table 7).

Project costs for buffer restoration projects are typically based on the square feet to be restored and the fee schedule of $0.96 per square foot. Cost determinations for reaches recommended for only buffer restoration will require more detailed onsite assessments to more accurately determine areas of needed restoration; therefore, they were not considered in the cost/benefit analysis. Preservation/protection sites were also excluded from the analysis.

Table 7. Stream Restoration Mitigation Ratios

Management Category	Mitigation Ratio
Restoration	1:1
Enhancement-1	1.5:1
Enhancement-2	2.5:1
Stabilization	N/A[1]
Preservation	5:1

[1] In absence of a mitigation ratio, a best professional judgment estimate of 4:1 was used.

3.2.2 Benefits

The benefits of stream restoration are quantified herein through sediment reduction. Excessive instream sedimentation is one of the primary stressors in the study area. By reducing instream sources of sediment, water quality is expected to improve, aquatic habitat will be enhanced, and morphologic instabilities will stabilize, with the ultimate goal of restoring diversity and abundance of aquatic communities.

The reduction of instream sources of sediment due to restoration measures was estimated using a methodology previously employed by Tetra Tech in the Swift Creek LWP (Tetra Tech, 2005) – originally developed by Rosgen (2001a) and locally adapted for North Carolina ((Jessup, 2004; NCSRI, 2003). The methodology relates BEHI, near-bank stress, and streambank erosion. Near-bank stress (NBS) is an indicator of hydraulic force in the near bank region, defined as one-third of the channel cross-section associated with the bank being evaluated. Curves developed for streams in North Carolina provide a way to translate the BEHI for a reach to an average annual erosion rate.

The BEHI was determined for each of the proposed project reaches in the Goose Creek and Crooked Creek watersheds as described in Section 2. However, NBS was not calculated. The Rosgen methodology identifies six classes of NBS, which when coupled with the six BEHI classes, yield 36 possible erosion rates (Rosgen, 2001a). In this study area, only three BEHI classes were represented – *Low*, *Moderate*, and *High*. Erosion rates for various NBS classes for specific BEHI categories were averaged to produce a single estimate for average annual streambank erosion. The estimates of average annual erosion rates are shown in Table 8.

Table 8. Estimates of Average Annual Streambank Erosion Rates (Tetra Tech, 2005)

BEHI Class	Erosion Rate (feet/year)
High	0.20
Moderate	0.10
Low	0.05[a]
Stabilized	0.05[a]

The erosion rate for stabilized stream reaches and reaches with low potential for bank erosion (low BEHI class) was set to half of the moderate rate, because some degree of bank erosion is expected along reaches with low potentials for bank erosion, or sections of restored reaches. Because this rate is also applied to

the restored condition of all potential projects, changing the rate would have no effect on the relative comparisons of cost and benefit.

With the erosion rate for a particular streambank estimated using BEHI, the area of streambank exposed to erosional forces was used to estimate an average volume of sediment generated per year. A bulk density factor was used to convert volume to mass: 1.3 tons per cubic yard (Rosgen, 2010).

The calculation, illustrated in Equation 3-1, provides a consistent method that can be applied uniformly to stream reaches for generating relative sediment loading values. These values help estimate how much erosion can be prevented when reaches are stabilized and morphologic instabilities are controlled. The difference in sediment loading between the degraded and potentially stabilized conditions represents the benefit afforded to the restoration measures. The load values derived by these methods are considered relative values appropriate for use in comparing assessment reaches for management prioritization.

$$L = r * \ell * h * \gamma \quad (3\text{-}1)$$

Where:

L = average annual sediment load [tons per year]

r = average annual streambank erosion rate [feet per year]

ℓ = length of eroding streambank [feet] [1]

h = height of eroding streambank [feet]

γ = unit weight of bank material [tons per cubic foot]

[1] Length of eroding streambank is set equal to the length of the reach. This assumes that only one side of the stream is eroding at any given cross-section.

3.2.3 Cost-effectiveness Results

Cost-effectiveness of proposed stream restoration projects was used to help differentiate between the various types of recommended restoration projects that are considered feasible. Projects that are most cost-effective have the potential to provide the greatest benefit (i.e., tons of sediment reduced on an annual basis) for the lowest cost. The cost of each stream restoration project is divided by the average annual reduction in sediment loading (Equation 3-2).

$$CE_i = \frac{TotalCost}{(SL_e - SL_r)} \quad (3\text{-}2)$$

Where:

CE_i = cost-effectiveness [FY-10 dollars per ton of sediment reduced]

$TotalCost$ = cost based mitigation ratio applied to fee schedule [FY-10 dollars]

SL_e = existing sediment loading rate over the project length [tons per year]

SL_r = restored sediment loading rate [tons per year]

The cost-effectiveness for the potential stream restoration opportunities, along with supporting information, are shown in Table 10 and Table 11, separately for each watershed, ordered from least to highest cost/ton of sediment removed. A cost-effectiveness normalized by project length is also provided.

Observations from the field combined with aerial imagery were used to determine the relative amounts of proximate utilities and forested riparian areas (Low, Moderate or High). Though many of these constraints were considered during screening, in some cases the constraints were not readily apparent

from the data used in the desktop analysis, the conditions on the ground had changed from the time the aerial imagery was collected, or the location and extent of the original reach selection was altered slightly.

Using the data described above, a scoring system was developed to prioritize stream mitigation opportunities based on cost-effectiveness and potential constraints (Table 10). The scores are composited and used to provide a preliminary prioritization for stream mitigation projects. The results are provided in Table 10 and Table 11.

Table 9. Scoring System for Stream Mitigation

Cost Effectiveness ($/ton)	Values	Ranking
0 to 25th percentile	$0 – $16,004	10
>25th percentile – 50th percentile	>$16,004 – $27,496	7.5
>50th percentile – 75th percentile	>$27,946 - $46,944	5
>75th percentile	>$46,944	2.5

Number of Landowners	Ranking
1 - 3	10
4 - 6	7.5
7 - 10	5
>10	2.5

Proximity to Utilities; Forested Riparian Area	Ranking
Low	10
Medium	6.7
High	3.3

In the next stages of Phase II and III, the results presented here will be combined with information on other watershed opportunities (e.g., stormwater retrofits, wetland restoration) and subwatershed-based source, stressor, and condition data. Additional prioritization and management recommendations will incorporate cumulative and complimentary benefits and tie the planning process to functional losses in the watershed.

Table 10. Stream Restoration Cost-Effectiveness (CE) and Other Supportive Information – Goose Creek Watershed

Site ID	Management Recommendation	BEHI Rank	Estimated Length (ft)	Cost ($)	Benefit (ton/yr)	CE ($/ton)	CE / Length	Estimated No. of Adjacent Landowners	Proximity to Utility	Amount of Forested Riparian Area	Composite Score
29	Enhancement-1	High	4,386	988,421	85	11,591	2.6	3	Low	Moderate	9.2
5	Enhancement-2	High	1,957	264,584	39	6,706	3.4	4	Low	Moderate	8.6
2	Restoration	High	3,300	1,115,533	37	30,287	9.2	5	Low	Low	8.1
25	Enhancement-2	Moderate	3,478	470,169	19	24,493	7.0	10	Low	Moderate	7.3
6	Enhancement-2	Moderate	4,506	609,197	22	28,167	6.3	5	Low	High	7.1
4	Restoration	Moderate	6,308	2,132,261	29	74,123	11.7	6	Low	Moderate	6.7
36	Stabilization	Moderate	5,159	435,949	24	18,531	3.6	17	High	High	5.0

Table 11. Stream Restoration Cost-Effectiveness (CE) and Other Supportive Information – Crooked Creek Watershed

Site ID	Management Recommendation	BEHI Rank	Estimated Length (ft)	Cost ($)	Benefit (ton/yr)	CE ($/ton)	CE / Length	Estimated No. of Adjacent Landowners	Proximity to Utility	Amount of Forested Riparian Area	Composite Score
27	Enhancement-1	High	2,473	557,251	43	13,040	5.3	5	Low	Low	9.4
16	Enhancement-1	High	3,603	811,878	52	15,648	4.3	6	Low	Low	9.4
17	Enhancement-2	High	4,339	586,684	69	8,535	2.0	10	Low	Moderate	7.9
20	Restoration	High	2,336	789,516	17	46,944	20.1	3	Moderate	Low	7.9
15	Enhancement-2	Moderate	2,970	401,535	13	31,296	10.5	1	Moderate	Low	7.9

Site ID	Management Recommendation	BEHI Rank	Estimated Length (ft)	Cost ($)	Benefit (ton/yr)	CE ($/ton)	CE / Length	Estimated No. of Adjacent Landowners	Proximity to Utility	Amount of Forested Riparian Area	Composite Score
19	Enhancement-2	High	2,758	372,887	46	8,164	3.0	6	Moderate	Moderate	7.7
3	Restoration	Moderate	2,222	751,188	8	90,860	40.9	5	Low	Low	7.5
24	Enhancement-2	High	5,258	710,852	42	17,071	3.2	10	Low	Moderate	7.3
10	Restoration	High	5,629	1,902,714	81	23,472	4.2	9	Moderate	Low	7.3
18	Restoration	Low	2,859	966,424	- [1]	- [1]	- [1]	2	Moderate	Low	7.3
12	Enhancement-2	Moderate	1,904	257,359	7	37,556	19.7	1	High	Low	7.1
14	Restoration	Moderate	5,654	1,910,952	11	176,042	31.1	7	Low	Low	6.9
28	Enhancement-1	Moderate	6,477	1,459,497	31	46,944	7.2	10	Low	Moderate	6.7
26	Enhancement-2	Moderate	5,275	713,172	27	26,825	5.1	12	Moderate	Moderate	5.9
9	Restoration	Moderate	2,651	896,178	4	201,190	75.9	6	Moderate	Moderate	5.9
8	Restoration	Moderate	3,795	1,282,722	19	67,063	17.7	10	High	Moderate	4.4
11	Enhancement-2	Moderate	4,878	659,558	19	35,208	7.2	14	High	High	3.5

[1] This reach is channelized stream that received a Low BEHI rating in the field. The rating prevented the reach from demonstrating a quantifiable sediment benefit using the methodology selected for use in this analysis. However, it may present an opportunity using other measures of benefits and is therefore retained in the prioritization.

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Appendix A. Stream Habitat Evaluation Form

Channel Modification (Use topo map as an additional aid for this parameter)

A. channel natural, frequent bends (good diversity of bends or falls) 5
B. channel natural, infrequent bends.....4
C. some channelization present.....3
D. more extensive channelization, >40% of stream disrupted 2
E. no bends, completely channelized or rip rapped or gabioned, etc. 0

Instream Habitat: Consider the percentage of reach that is favorable for benthos colonization/fish cover.

Circle the habitats which occur-
(rocks) (macrophytes) (sticks and leaf packs) (snags and logs) (undercut banks or root mats)

EXAMPLE: If >70% of the reach is rocks, 1 type is present, circle the score of 17.

AMOUNT OF REACH FAVORABLE FOR COLONIZATION OR COVER

	>70% Score	40-70% Score	20-40% Score	<20% Score
4 or 5 types present.....	20	16	12	8
3 types present.....	19	15	11	7
2 types present.....	18	14	10	6
1 type present.....	17	13	9	5
No types present.....	0			

Bottom Substrate (silt, sand, detritus, gravel, cobble, boulder) entire reach for scoring, but only riffle for embeddedness.

A. substrate with good mix of gravel cobble and boulders **Score**
1. embeddedness <20% (very little sand, usually only behind large boulders) 15
2. embeddedness 20-40%.....12
3. embeddedness 40-80%.....8
4. embeddedness >80%.....3

B. substrate gravel and cobble
1. embeddedness <20%.....14
2. embeddedness 20-40%.....11
3. embeddedness 40-80%.....6
4. embeddedness >80%.....2

C. substrate mostly gravel
1. embeddedness <50%.....8
2. embeddedness >50%.....2

D. substrate homogeneous
1. substrate nearly all bedrock 3
2. substrate nearly all sand.....3
3. substrate nearly all detritus 2
4. substrate nearly all silt/ clay.....1

Dominant Substrate_____

Pool Variety (Pools are areas of deeper than average maximum depths with little or no surface turbulence)

A. Pools present	**Score**
1. Pools Frequent (>30% of 100m area surveyed)	
a. variety of pool sizes	10
b. pools same size	8
2. Pools Infrequent (<30% of the 100m area surveyed)	
a. variety of pool sizes	6
b. pools same size	4
B. Pools absent	
1. Runs present	3
2. Runs absent	0

Riffle Habitats

	Riffles Freq.	**Riffles Infreq.**
A. well defined riffle and run, riffle as wide as stream and extends 2X width of stream	16	12
B. riffle as wide as stream but riffle length is not 2X stream width	14	7
C. riffle not as wide as stream and riffle length is not 2X stream width	10	3
D. riffles absent	0	

Bank Stability and Vegetation

A. Banks stable	Left Bank	Rt. Bank
1. no evidence of erosion or bank failure, little potential for erosion	7	7
B. Erosion areas present		
1. diverse trees, shrubs, grass; plants healthy with good root systems	6	6
2. few trees or small trees and shrubs; vegetation appears generally healthy	5	5
3. sparse vegetation; plant types and conditions suggest poorer soil binding	3	3
4. mostly grass, few/no trees/shrubs, high erosion & failure pot. at high flow	2	2
5. no bank vegetation, mass erosion and bank failure evident	0	0

Light Penetration (Canopy is tree/veg. cover directly above stream that would block out sunlight when directly overhead).

A. Stream with **good** shading with some breaks for light penetration.....10
B. Stream with **full canopy** - breaks for light penetration absent.....8
C. Stream with **partial** shading - sunlight and shading are essentially equa.....7
D. Stream with **minimal** shading - full sun in all but a few areas.....2
E. **No shading**.....0

Riparian Vegetative Zone Width

Definition: A break in the riparian zone is any area which allows sediment to enter the stream. Breaks refer to the near-stream portion of the riparian zone (banks); places where pollutants can directly enter the stream.

	Lft. Bank	Rt. Bank
A. Riparian zone **intact** (no breaks)		
1. zone width > 18 meters	5	5
2. zone width 12-18 meters	4	4
3. zone width 6-12 meters	3	3
4. zone width < 6 meters	2	2
B. Riparian zone **not intact** (breaks)		
1. breaks rare		
a. zone width > 18 meters	4	4
b. zone width 12-18 meters	3	3
c. zone width 6-12 meters	2	2
d. zone width < 6 meters	1	1
2. breaks common		
a. zone width > 18 meters	3	3
b. zone width 12-18 meters	2	2
c. zone width 6-12 meters	1	1

Appendix B. Field Evaluation Form

General Notes

Site ID_____ Weather/Conditions_____ Date_____ Time_____ Observer(s)_____

Location/Road_____

Stream_____ Distance Up/Downstream from Rd(m)_____ Distance Surveyed(m)_____

Latitude (downstream)_____ Longitude (downstream)_____ GPS(ds)#_____

Latitude (upstream)_____ Longitude (upstream)_____ GPS(us)#_____

Turbidity: (circle one) Clear/Slightly Turbid/Turbid/Tannic Flow (circle one): High /Normal /Low

Remarks: _____

_____

Habitat Scoring

Channel Modification	_____
Instream Habitat Type(not scored)	_____
Instream Habitat Score	_____
Bottom Substrate	_____
Pool Variety	_____
Riffle Habitats	_____
Bank Stability & Veg. (L)	_____
Bank Stability & Veg. (R)	_____
Light Penetration	_____
Rip. Veg. Zone Width (L)	_____
Rip. Veg. Zone Width (R)	_____
TOTAL SCORE……	
Bed Material (6 - 0)	_____
Bank Material (6 - 0)	_____
Beaver Evidence (1=yes / 0=No)	_____
Corbicula spp. (1=yes / 0=No)	_____

Other Field Assessments

Bank Height	_____(m)	_____(m)
BFH	_____(m)	_____(m)
BFW	_____(m)	_____(m)
Root Depth	_____(m)	_____(m)
Root Density	_____(%)	_____(%)
Bank Angle	_____(degs)	_____(degs)
Surface Protection	_____(%)	_____(%)
CEM (0 to 6)	_____	
Mass Wasting	_____(%)	
Migration Barriers	_____(count)	
Debris Dams	_____(count)	
Valley Confinement	_____(%)	
Floodplain Connectivity	_____(%)	
Livestock Access	_____(%)	
Reach Accessibility	_____(5 – 0)	
Restoration Potential	_____(6 – 0)	

Recent Land Use Changes/Active Construction_____

_____

_____

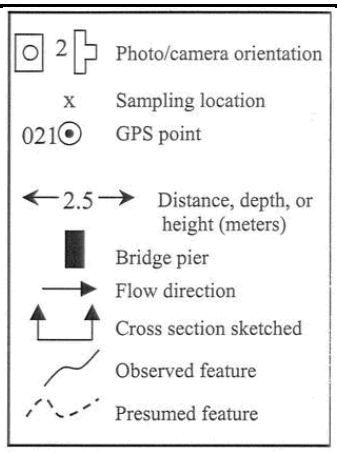
Other Notes_____

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Site Sketch Site ID_____



Appendix C. Field Assessment Results

Site	Number of Habitats	Channel Modification	Instream Habitat	Bottom Substrate	Pool Variety	Riffle Habitats	Bank Stability (Left)	Bank Stability (Right)	Light Penetration	Riparian Veg. Zone Width (Left)	Riparian Veg. Zone Width (Right)	Total Stream Habitat Score	Beaver Presence (1=yes, 0=no)	Corbicula spp. Pres. (1=yes, 0=no)	Bank Height (m)	Bankfull Height (m)	Bankfull Width (m)	Root Depth (m)	Root Density (% of bank)	Bank Angle (degrees)	Surface Protection (% of bank)	CEM Class	Mass Wasting (% of reach)	Mitigation Barrier (count)	Debris Dam (count)	Valley Confinement (% of reach)	Floodplain Connectivity (% of reach)	Livestock Access (% of reach)	Reach Accessibility	Recommended Management
1	3	4	19	9	4	6	6	6	10	5	5	74	0	1	2.2	0.5	2.9	1.0	70	85	45	0	0	0	2	0	0	0	3	0
2	5	4	14	10	6	10	4	5	8	1	4	66	0	0	1.6	0.4	4.0	1.3	30	90	20	4	10	0	0	10	0	0	5	6
3	3	1	7	3	6	0	4	4	2	0	2	29	0	0	1.6	0.5	2.9	1.4	85	75	30	5	0	0	1	40	0	0	4	6
4	5	3	16	2	9	5	4	4	10	5	0	58	0	0	1.9	0.6	4.2	1.8	60	80	35	5	0	0	5	0	0	0	5	6
5	5	4	16	8	4	12	3	0	10	2	2	61	0	1	2.8	0.5	9.0	1.5	20	70	20	5	30	0	0	20	0	0	5	4
6	5	4	18	11	6	14	3	3	10	2	2	73	0	1	2.0	0.7	9.5	2.0	30	70	40	5	0	0	0	0	10	0	4	4
7	5	5	20	14	10	12	6	6	10	5	5	93	0	0	1.1	1.1	1.4	1.1	100	45	60	1	0	0	3	10	60	0	1	2
8	3	1	7	2	4	3	3	3	7	0	0	30	0	0	2.1	0.6	3.3	2.1	100	90	50	3	10	0	1	0	0	0	5	6
9	5	0	8	3	1	0	4	4	10	5	5	40	0	1	0.7	0.7	5.0	0.7	30	70	20	0	0	0	1	0	100	0	5	6
10	3	1	11	4	8	7	2	2	7	2	2	46	0	0	2.0	0.7	3.3	1.8	80	95	20	3	10	0	2	0	0	0	4	6
11	4	1	14	8	5	5	4	4	7	1	2	51	0	0	1.6	0.4	3.2	1.5	60	85	25	3	10	2	1	0	0	0	5	4
12	5	3	16	8	6	7	6	6	10	1	1	64	0	0	1.5	0.5	3.7	1.5	90	60	60	6	0	1	0	0	0	0	5	4, 5, 6

Site	Number of Habitats	Channel Modification	Instream Habitat	Bottom Substrate	Pool Variety	Riffle Habitats	Bank Stability (Left)	Bank Stability (Right)	Light Penetration	Riparian Veg. Zone Width (Left)	Riparian Veg. Zone Width (Right)	Total Stream Habitat Score	Beaver Presence (1=yes, 0=no)	Corbicula spp. Pres. (1=yes, 0=no)	Bank Height (m)	Bankfull Height (m)	Bankfull Width (m)	Root Depth (m)	Root Density (% of bank)	Bank Angle (degrees)	Surface Protection (% of bank)	CEM Class	Mass Wasting (% of reach)	Mitigation Barrier (count)	Debris Dam (count)	Valley Confinement (% of reach)	Floodplain Connectivity (% of reach)	Livestock Access (% of reach)	Reach Accessibility	Recommended Management
13	1	0	5	3	3	0	4	4	0	0	0	19	0	0	2.2	0.6	2.7	2.2	60	90	70	3	0	1	0	0	0	0	5	4, 6
14	3	4	7	3	8	2	6	6	10	0	0	46	0	0	0.8	0.4	3.4	0.8	80	65	35	5	0	0	10	5	95	0	4	6, 1
15	3	1	7	3	8	3	6	6	10	2	3	49	0	1	1.8	0.4	3.8	1.8	90	85	40	3	0	0	2	0	0	0	3	4
16	5	2	16	2	4	0	3	3	10	5	5	50	0	1	2.0	0.1	7.5	1.0	20	90	10	4	20	0	0	10	0	0	4	5
17	5	3	16	11	8	0	1	1	10	2	2	54	0	0	2.2	0.1	6.5	2.2	50	90	20	4	20	1	1	0	0	0	4	4
18	3	3	7	1	8	0	6	6	7	1	2	41	1	0	0.8	0.7	3.1	0.8	90	70	70	2	0	0	2	0	30	0	3	6
19	5	2	16	11	10	12	1	1	9	5	4	71	0	1	2.3	0.8	6.0	2.3	30	80	20	4	30	0	2	0	10	0	4	4
20	1	1	2	1	3	0	2	2	2	1	0	14	0	0	1.0	0.4	0.8	1.0	20	90	30	3	10	0	0	0	10	0	5	6
21	4	5	20	15	9	14	6	6	10	5	5	95	0	0	0.5	0.5	0.1	0.5	95	70	40	1	0	0	0	0	100	0	1	2
22	5	4	18	12	3	3	5	5	10	5	5	70	0	0	1.3	1.0	10	1.3	30	80	30	5	0	1	1	0	100	0	4	2
23	5	4	18	12	3	3	5	5	10	5	5	70	0	0	1.3	1.0	10	1.3	30	80	30	5	0	1	1	0	100	0	4	2
24	5	4	14	5	6	3	4	4	10	4	4	58	0	0	1.1	0.5	3.3	1.1	30	85	10	3	0	0	1	0	0	0	3	4
25	2	4	14	3	4	0	6	6	5	2	2	46	0	1	2.3	1.0	12	2.3	70	75	30	6	10	0	0	10	0	0	3	4, 1
26	3	4	13	8	8	0	4	4	10	2	2	55	0	1	2.1	1.2	6.5	2.1	80	85	50	3	0	0	1	0	0	0	4	4

Site	Number of Habitats	Channel Modification	Instream Habitat	Bottom Substrate	Pool Variety	Riffle Habitats	Bank Stability (Left)	Bank Stability (Right)	Light Penetration	Riparian Veg. Zone Width (Left)	Riparian Veg. Zone Width (Right)	Total Stream Habitat Score	Beaver Presence (1=yes, 0=no)	Corbicula spp. Pres. (1=yes, 0=no)	Bank Height (m)	Bankfull Height (m)	Bankfull Width (m)	Root Depth (m)	Root Density (% of bank)	Bank Angle (degrees)	Surface Protection (% of bank)	CEM Class	Mass Wasting (% of reach)	Mitigation Barrier (count)	Debris Dam (count)	Valley Confinement (% of reach)	Floodplain Connectivity (% of reach)	Livestock Access (% of reach)	Reach Accessibility	Recommended Management
27	4	3	8	3	8	0	4	4	10	1	1	42	1	1	2.4	1.0	5.3	1.5	80	90	30	4	10	0	4	0	0	0	3	5
28	4	3	8	3	4	0	3	3	5	4	0	33	0	0	2.0	1.0	5.0	1.2	40	60	20	3	0	0	2	0	10	0	4	5
29	5	3	12	3	8	5	4	4	10	0	2	51	0	1	2.7	0.9	8.3	1.3	40	80	25	5	0	0	0	0	0	0	3	5
30	5	3	20	13	9	2	7	7	10	1	2	74	0	0	0.7	0.6	3.3	0.7	70	85	40	1	0	0	2	0	20	0	3	1
31	4	4	16	6	9	5	6	6	10	4	4	70	0	0	1.5	1.0	4.1	1.5	70	110	50	6	0	0	2	0	0	0	2	1
32	5	5	18	8	9	14	6	6	10	3	5	84	0	0	1.0	1.0	2.0	1.0	80	80	60	1	0	0	4	0	30	0	3	1
33	5	5	18	8	9	14	6	6	10	3	5	84	0	0	1.0	1.0	2.0	1.0	80	80	60	1	0	0	4	0	30	0	3	1
34	5	4	20	11	9	14	6	6	10	2	5	87	0	0	1.2	0.4	3.8	1.2	60	90	50	5	0	0	2	0	40	0	3	1
35	5	4	20	11	9	14	6	6	10	2	5	87	0	0	1.2	0.4	3.8	1.2	60	90	50	5	0	0	2	0	40	0	2	1, 2
36	4	4	20	15	9	14	3	3	10	0	5	83	0	0	1.9	0.3	4.3	1.9	40	80	20	4	10	0	1	0	0	0	3	3, 1
37	5	5	20	14	10	12	3	3	10	5	5	87	0	0	1.4	0.8	4.0	1.0	40	70	30	0	10	1	0	0	10	0	3	2
38	5	5	16	14	6	12	6	6	5	3	3	76	0	0	0.8	0.2	1.9	0.8	90	90	20	5	10	0	1	0	30	0	4	1

Appendix I:

Revised Goose Creek and Crooked Creek LWP Model Scenario Summary

TETRA TECH

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Memorandum

To:	Anjie Ackerman NC Ecosystem Enhancement Program	**Date:**	January 27, 2012
From:	Scott Job	**Subject:**	Revised Goose Creek and Crooked Creek LWP Model Scenario Summary
Cc:	Trevor Clements, J. Todd Kennedy	**Proj. No.**	100-RTP-T25954

The purpose of this memorandum is to provide a summary of existing and future baseline modeling results for the Goose Creek and Crooked Creek Local Watershed Plan (LWP) Watershed Assessment Report. More detailed presentation of results and discussion are provided in two modeling reports: Goose Creek and Crooked Creek Watersheds Model Development and Calibration report (Tetra Tech, 2011a) and Goose Creek and Crooked Creek Watersheds Scenario report (Tetra Tech, 2011b).

1 Summary of Watershed Model

The EPA-approved Loading Simulation Program C++ (LSPC) model was selected for the Goose Creek and Crooked Creek watersheds (http://www.epa.gov/athens/wwqtsc/html/lspc.html). LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land, as well as a stream fate and transport model (Tetra Tech, 2009). LSPC model configuration for the Goose Creek and Crooked Creek watersheds relied on a variety of local data sources. The data included detailed elevation data, meteorological time series of rainfall and ET, point source discharges, land cover/land use, soils, existing HEC models, field data from detailed stream surveys, and stream monitoring from several sources. Model setup was discussed in greater detail in Tetra Tech (2011a).

Sediment and increased peak flows/runoff volumes are considered the most important and pervasive stressors to watershed function in the Goose Creek and Crooked Creek watersheds (Tetra Tech, 2008). These stressors, resulting primarily from the lack of historical pre- and post-construction stormwater control, have resulted in impairments to aquatic habitat in both watersheds. Nutrient loading is also important as an indicator and surrogate for the remaining stressors of oxygen-demanding substances, bacteria, and toxic pollutants. To address the parameters of concern, the LSPC model was configured to simulate the following:

- Continuous hydrology
- Sediment, including upland loading, in-stream transport, and bed and bank behavior
- Nutrients (as total phosphorus and total nitrogen), including upland loading and in-stream reduction and transport

The model simulation spans January 1, 1999 through May 31, 2010. The time period reflects the availability of data needed to calibrate the model and use it in a decision support role. LSPC was configured to simulate the Goose Creek and Crooked Creek watersheds as a series of hydrologically connected subbasins. The spatial subdivision of the watersheds allowed for a more refined representation

of pollutant sources, and a more realistic description of hydrologic factors. Each subbasin was modeled as a defined land area draining to a single stream, with land area made up of model Hydrologic Response Units (HRUs), discussed below in Section 2. Output from LSPC is for the most downstream point of each subbasin. The model simulates continuous hydrology from the land surface HRUs, including runoff, interflow, groundwater, and the pollutants carried by each. Flow and pollutants become inputs to the streams in the model, represented as a series of interconnected "reaches." The reach simulation incorporates additional processes affecting pollutant fate and transport, including deposition or erosion in the bed, nutrient uptake, and bank erosion. The model also simulates the influence of stormwater best management practices (BMPs) on hydrology and pollutant reduction.

Tetra Tech (2011a) provides detailed information on model calibration. A brief summary is provided here. Calibration data included flow measurements from U.S. Geological Survey (USGS) gages, water quality monitoring data from several different entities, and field data from stream surveys.

For hydrology, the model performs well, predicting flow within specified tolerances across a range of flows and seasons/months. Both storm events and low flows are well represented in terms of the distribution of observed flows. The timing and magnitude of individual storm events often varies from observed conditions, largely due to limitations of rainfall data from remote locations representing local, intense thunderstorms. Low flows are over-predicted somewhat during extreme drought conditions.

Upland sediment loading is consistent with the lower end of ranges reported in land use monitoring studies. The model also replicates, to a large extent, the bed and bank dynamics observed in the field during 2008 and 2010. Model predictions of long-term sediment loading are sound, although there is some scatter in storm event comparisons between the model and observed data. Bank erosion events are stochastic by nature, so while the model cannot predict all eroding events, it does replicate the distribution as indicated by storm event loads and concentrations.

Upland nutrient loading is consistent with ranges reported in land use monitoring studies. However, model predictions of nutrient concentrations at lower flows for locations downstream of wastewater treatment plants (WWTPs) reflect limitations of the point source effluent monitoring data.

2 Development of Scenarios

Tetra Tech developed a framework for the stressor-based prioritization based directly on the Goose Creek and Crooked Creek LWP goals adopted by the Watershed Technical Team. The goals provide general statements regarding the desired outcomes for the watershed plan, and the objectives identify actions to take to achieve the goals. Goals 1 and 2 are most relevant to the stressor based analysis:

- Goal 1: Restore, protect, and enhance watershed functions such as hydrology, water quality, and aquatic and terrestrial habitat.
- Goal 2: To minimize impacts on water quality, aquatic and terrestrial habitat, and hydrology in the watershed by supporting balanced, sustainable, and diverse land use and development, in accordance with existing and future policies.

Goal 1 generally seeks to protect or improve existing watershed functions, while Goal 2 seeks to address future impacts to watershed functions. The LSPC scenarios address Goals 1 and 2 respectively by providing targeting performance measures for current conditions in the watersheds (Existing Baseline) and anticipated conditions in the future (Future Baseline). The performance measures were tied into the scoring system discussed in the Phase II-III Stressor-Based Subwatershed Prioritization (Tetra Tech, 2011c).

For Existing and Future Baseline results to be comparable and meaningful, it is critical to represent the most important aspects of the watershed projected to change between current and future conditions. The Future Baseline scenario differs from the Existing Baseline scenario by applying areal changes to the land

use and land cover, and by the addition of stormwater BMPs for the treatment of new development according to current regulations.

The hydrologic response unit (HRU) concept provides a way to capture landscape variability into discrete units. An HRU is defined as a unit of land with relatively homogenous hydrologic properties. The model HRUs are based on differences in land cover and hydrologic soil group (HSG), both of which influence long-term and storm event hydrology, as well as pollutant washoff processes. In this report, *land cover* refers to the type of vegetated or impervious surface present on the land (e.g., impervious surface, lawn vegetation, forest cover), while *land use* refers to how a piece of land is used or managed by its owner (e.g., commercial, residential). Current land use data and future development projections invariably rely on *land use* descriptions. This memo briefly discusses the translation of *land use* into model *land cover* HRUs; more details are provided in Tetra Tech (2011b).

LSPC does not explicitly represent the spatial location of land covers beyond the subbasin scale. By extension, stormwater BMP locations and specific drainage areas are also not spatially explicit, but rather are lumped on a subbasin scale. LSPC accounts for BMP treatment using stage-storage-discharge relationships and pollutant reduction processes scaled to the total acreage of treated land area. Runoff from land area designated for treatment is routed to the scaled BMP, and is released to the reach (via outflow) or to subbasin groundwater (via infiltration). The BMP simulation occurs on a continuous basis.

2.1 EXISTING BASELINE

Existing Baseline scenario land covers were developed from the following sources:

- The National Land Cover Dataset (NLCD) from 2001, which is based on interpretation of multi-seasonal Landsat satellite images into 30-meter grid cells. The land use/land cover and impervious surface data products were both utilized.
- Local cadastral (parcel) data, which provided land use classification in developed areas (a weak point for NLCD).
- Building footprints, planimetric impervious surfaces, and roadways to represent the majority of impervious surface; NLCD impervious data were used to supplement impervious surface classification.
- Forest cover data from the U.S. Forest Service (USFS)/DOI LANDFIRE Existing Vegetation Cover dataset.

The developed *land uses* were split into pervious and impervious *land covers* via post-processing calculations. Pervious land areas were then further divided into HSG B and C subcategories.

Location and influence of existing stormwater BMPs were estimated to reflect conditions during and prior to the year 2007. Exact location and treatment area data were not readily available in an electronic format from local municipalities for existing BMPs, so treatment areas were defined based on parcel year-built data. Stormwater requirements through 2007 reflect primarily peak flow control, typically specified as reducing post-development peak flows to pre-development levels for a set of design storm events (e.g., the 2-year 24-hour event and the 10-year 24-hour event). Only about 400 developed acres of land were estimated to be treated by peak-control BMPs, spread between Mint Hill/Matthews (subject to Mecklenburg County peak-control regulations since 1979), and Indian Trail/Stallings (local requirements beginning circa 2005). Pollutant removal was not explicitly included since peak control devices release stored water quickly; however, some removal was allowed to occur via minimal infiltration within the basins.

2.2 FUTURE BASELINE

For the Future Baseline model scenario, land use was based on 2030 future conditions projected by Michael Baker Engineering for the Monroe Bypass (MB) study (Michael Baker Engineering, 2010). The MB study land use data could not be used directly in LSPC, since different land use classes were utilized compared to the Existing Baseline land use. In addition, the MB study provided semi-spatial land use assignment for both current and future 2030 conditions, making a direct change-analysis to Existing Baseline land use unusable. Instead, the increase in development area and type was calculated for MB existing versus future land use, separately within each LSPC subbasin. A translation methodology was developed for relating MB study existing land use to LSPC existing land use, and the *change* in MB study existing to future land use was applied within each subbasin, using the same translation methods, to estimate equivalent growth for the Tetra Tech land use classes. Undeveloped land covers were reduced within each subbasin, according to relative proportions of both land cover and HSG.

There are several new or modified stormwater management regulations for new development throughout the two watersheds, originating from both state and local authorities. Many of the regulated areas overlap, so the most stringent requirement was assumed. Pertinent details are summarized below:

- Goose Creek Rule – applies to all areas in the Goose Creek watershed, enforced by NC DENR outside of municipalities that have adopted it to their stormwater ordinances. Applies to any project affecting one or more acres that increases impervious area (no threshold). Provides water quality detention and treatment (85 percent TSS load reduction required) for increase in runoff volume between pre-developed and post-developed conditions for the 1-year 24-hour storm. Also provide peak control for the 1-year 24-hour storm matching pre-developed peak flow. In addition, the stormwater management measures are required to promote infiltration for the purpose of maintaining stream base flow, though no specific performance criteria are provided for infiltration volume.
- Phase II – applies to all of Union County. Currently enforced by NC DENR outside of municipalities listed below. For development densities greater than 24 percent impervious area, the runoff from the first inch of rainfall must be detained and treated for water quality (85 percent TSS load reduction required), and peak flow control for the 1-year 24-hour storm to match pre-development conditions.
- In addition to Phase II requirements, Indian Trail and Stallings adopted the Goose Creek Rule water quality volume and treatment requirements within their entire jurisdictional boundaries. However, a density threshold was included in the Crooked Creek watershed, so the rules apply only to development greater than 24 percent impervious area. In addition, there is a requirement to match pre-developed peak flows for the 2-year, 10-year, 25-year, 50-year, and 100-year storm events, invoked at 24 percent impervious area in the Crooked Creek watershed and 10 percent impervious area in the Goose Creek watershed.
- In addition to Phase II requirements, Mint Hill adopted the Goose Creek Rule within the Goose Creek watershed. Matthews and require peak matching to pre-developed conditions for the 10-year and 25-year storm events.
- In addition to adopting Phase II, Matthews requires peak matching to pre-developed conditions for the 10-year and 25-year storm events. In the Crooked Creek watershed for developments exceeding 10 percent impervious area, Matthews requires 24 hour minimum detention for the 1-year storm event, and that stormwater management facilities reduce total phosphorus loading by 70 percent.

- In addition to Phase II, Monroe requires peak matching to pre-developed conditions is required for non-residential development creating a new impervious footprint exceeding 20,000 ft^2, applied to the 2-year and 10-year storm events. Exemptions are provided for existing impervious surface, and for sites that discharge to the 100-year floodplain.

There are also stream-buffer protection requirements included in the regulations. The Monroe Bypass study took all of these into account and explicitly excluded buffered lands from their future land use projection.

The Future BMPs selected represented likely candidates given their utility in meeting multiple, layered regulations. All meet the 85 percent TSS load reduction requirement. Three general BMP applications were chosen: wet ponds meeting minimum stormwater requirements (Phase II), bioretention in rural areas meeting more stringent requirements (Goose Creek Rule), and wet ponds in urban areas meeting more stringent requirements (Indian Trail and Stallings). Bioretention was selected for low density development in Goose Creek because it supports infiltration (a requirement of the Goose Creek Rule) and its footprint could more easily be integrated with site landscaping. Wet ponds are a more likely candidate when space is at a premium; in addition, they can be used to meet all the multiple, layered regulations, and designers have a lot of experience implementing them. Details on the BMP configurations, translation of stormwater requirements to BMP types, and the application of the BMPs to developing land use are provided in Tetra Tech (2011b). Note that these selections represent a generalization and in reality other BMP types and combinations of BMPs could be used depending on the specific site requirements and conditions.

2.3 MEASURES DEVELOPED TO SUPPORT SCORING FRAMEWORK

The selected indicators highlight management gaps and achievement of watershed goals. The greatest management gaps are likely to occur where extreme stormwater flows and volumes and high pollutant loading are occurring or will occur in the future. Since the watershed modeling reflects much of the data and knowledge gathered to date in support of the LWP, the model output provides the best available measure of stressor levels. Another advantage of the watershed model is that it provides output across all subwatersheds throughout an extended continuous period (e.g., annually or seasonally) as opposed to monitoring, which is limited to data at sampling locations reflecting only a few discrete points in time and space. Listed by stressor category, the following indicators were selected for model output:

- **Hydrology:** Percent increase in the time duration of bankfull events compared to undisturbed (forest) conditions based on hourly simulated flow. The bankfull event was defined as the 1.44 year return interval storm event for rural areas in the NC piedmont (Doll et al., 2002). Many researchers have investigated the role of increased duration of near-bankfull events due to urbanization and the risk of increased scour and bank erosion (MacRae, 1992; MacRae, 1993; Bledsoe and Watson, 2001).
- **Sediment:** Upland Sediment (tons/acre/year) and Streambank and Bed Sediment (tons/mile/year) based on simulated loading occurring within subwatershed boundaries.
- **Oxygen Demanding Substances/Nutrients:** Total nitrogen (TN; lbs/acre/year) and total phosphorus (TP; lbs/acre/year) based on simulated loading from within subwatershed boundaries.
- **Bacteria** and **Toxicity-related Pollutants:** considered qualitatively.

The simulation of bacteria and toxicity-related pollutants was beyond the scope of the watershed modeling, so adjustments to the subwatershed priorities were made based on a qualitative assessment of potential bacteria or toxicity-related pollutant loading.

Using the LSPC model output, the hydrology indicator was calculated using hourly simulated flow. The upland sediment and nutrient loading rates reflect annual average loading from within each subwatershed and are not cumulative loading rates. LSPC in-stream sediment loading output was also used to calculate the bank and bed sediment indicator. To the extent possible, this indicator reflects loading generated from within a particular subwatershed. Bank erosion is derived for each individual reach. Bed sediment could not be calculated independently of contributions from upstream subwatersheds, but the LSPC calibration did take field data into account to represent the streambed as degrading, stable, or aggrading. It should be noted that point sources were not considered in this assessment because these sources are not related to the management opportunities being considered in the project prioritization. Therefore, the simulated loading reflects nonpoint sources only.

The results include an additional scenario, termed "Future, no BMPs." The scenario provides a benchmark demonstrating what the impacts of development would be without stormwater management requirements and BMP treatment. It also helps distinguish which changes in measures are brought about solely by development. Note that this scenario is not projected to take place, but it does show the importance of current regulations for mitigating future development impacts.

3 Results and Discussion

Results are summarized in Figure 1 through Figure 5, and provided in detail in Appendix A. The graphical summary results are grouped separately by Goose Creek and Crooked Creek, which are both split further into *Upper* and *Lower* designations. Upper sections of both watersheds tend to correspond to more urbanized/developed areas, while the Lower sections are more rural and agricultural. The distinctions are helpful for understanding trends in the results. Figure A-1 in Appendix A shows how the subbasins are grouped.

For percent increase in bankfull time duration, two additional subgroups were added – Upper Goose non-Charlotte Belt, and Upper Crooked non-Charlotte Belt. As shown in Figure A-1, the Charlotte Belt geological zone is associated with the westernmost subbasins, largely within Mecklenburg County. Charlotte Belt soils are fairly impermeable, but the Slate Belt soils in the remainder of both watersheds are highly impermeable even in an undeveloped state. For the very largest storm events which contribute to this measure, undeveloped forested Slate Belt soils react with runoff rates somewhat analogous to impervious surfaces. The Charlotte Belt soils differ for large storm event runoff due to higher infiltration rates – the jump from forested to developed conditions creates a significantly larger increase in the duration of bankfull events.

While the magnitude difference is large between the zones, it does not necessarily mean there is little risk of channel geomorphologic change in the Slate Belt areas. Streams adjust to local conditions, and an alteration in peak flow and duration still may translate to increased risk of channel erosion. A relative comparison of the results shows that new development increases bankfull event duration across the board, more so in areas with larger increases in impervious surfaces. However, the stormwater management requirements appear to be effective at mitigating the risk and managing increased volume. The Bed+Bank Sediment Erosion measure shows a similar trend; unmitigated runoff from new development increases bed and bank erosion, but stormwater management requirements mitigate the increase by holding back the increase in erosive flows.

The Annual Upland Loading Rate measures show some trends that might not be expected; new development does not necessarily raise overall loading much, even if treatment BMPs are not used. This outcome is due chiefly to relatively high loading rates originating from agricultural land; when development with low or medium housing densities replaces agricultural land, overall rates may decrease. BMPs provide an additional reduction in loading rates.

Upland sediment loading and bed+bank erosion are not directly comparable in the figures below and the tables in Appendix A, since upland loading is areal (per acre) while bed+bank erosion are linear (per mile) and confined to the streams. When the rates are scaled back to loads, the Existing Baseline scenario indicates that about 31,800 and 47,500 tons of sediment are washed from upland areas to streams in Goose and Crooked creeks respectively, while an additional 43,500 and 56,800 tons are eroded from the banks and the beds from Goose and Crooked creeks respectively. Upland sediment does contribute to modeled aggradation in the stream (in a few reaches), so the total load leaving the two watersheds is slightly lower than the sum of the two contributions.

Additional details and discussion are provided in Tetra Tech (2011b).

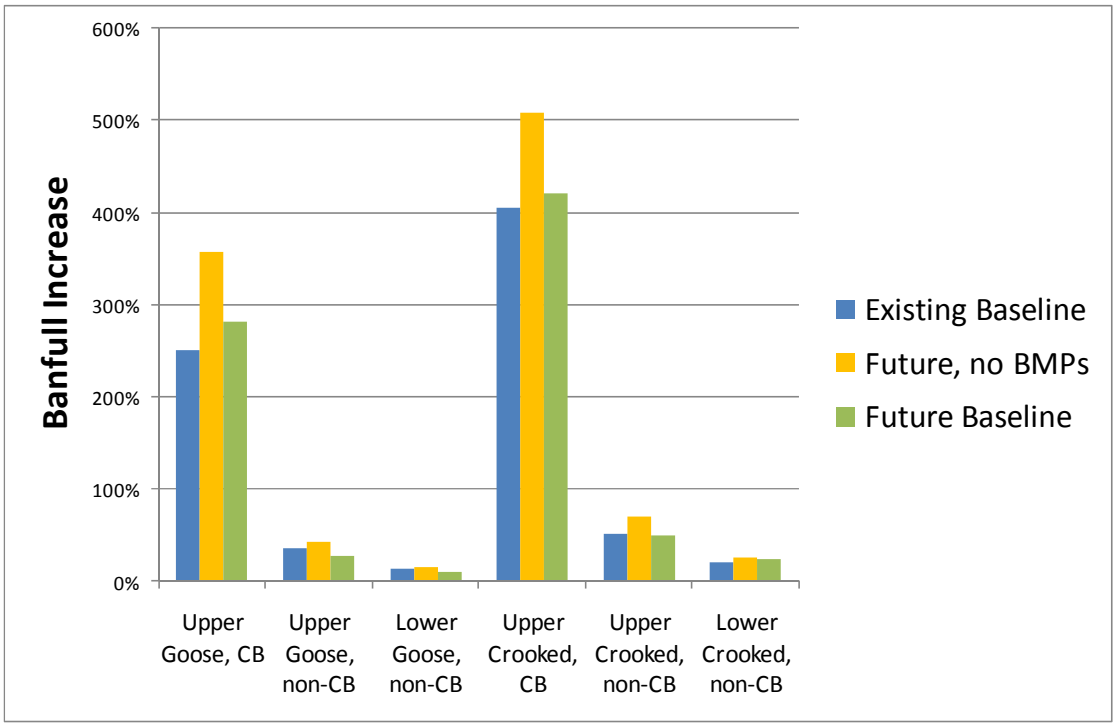


Figure 1. Scenario Results for Percent Increase in Bankfull Time Duration (CB=Charlotte Belt)

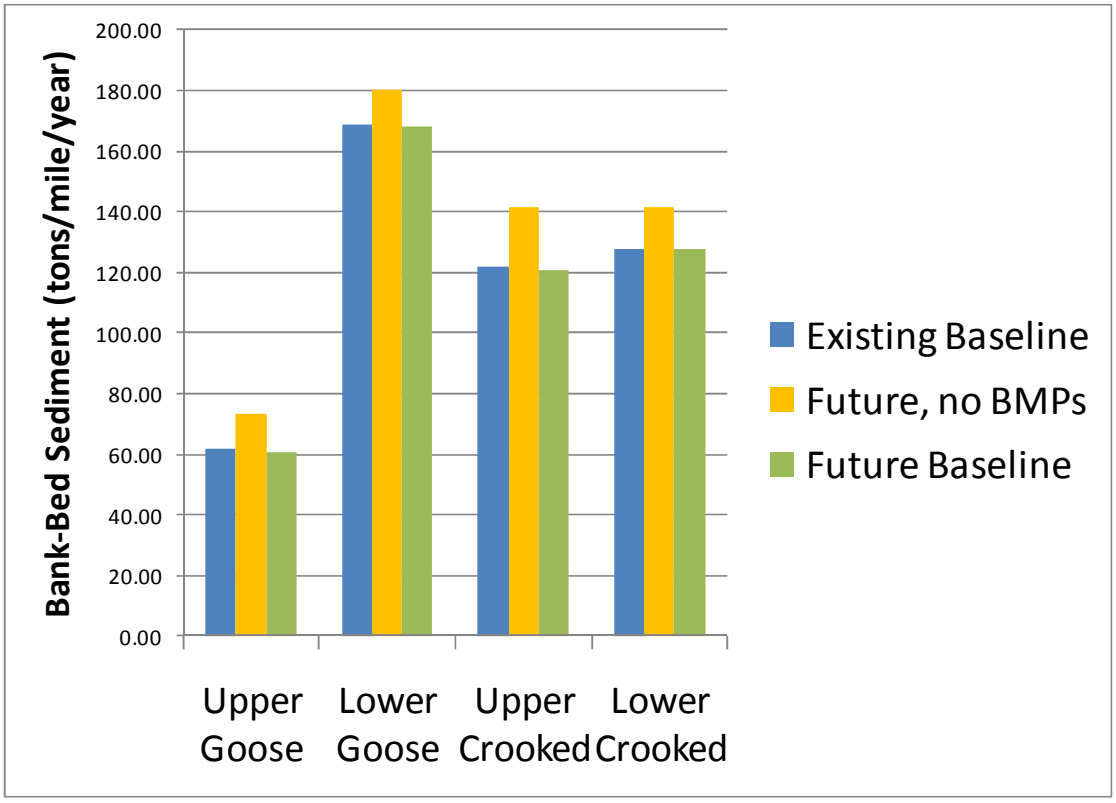


Figure 2. Scenario Results for Bed+Bank Sediment Erosion

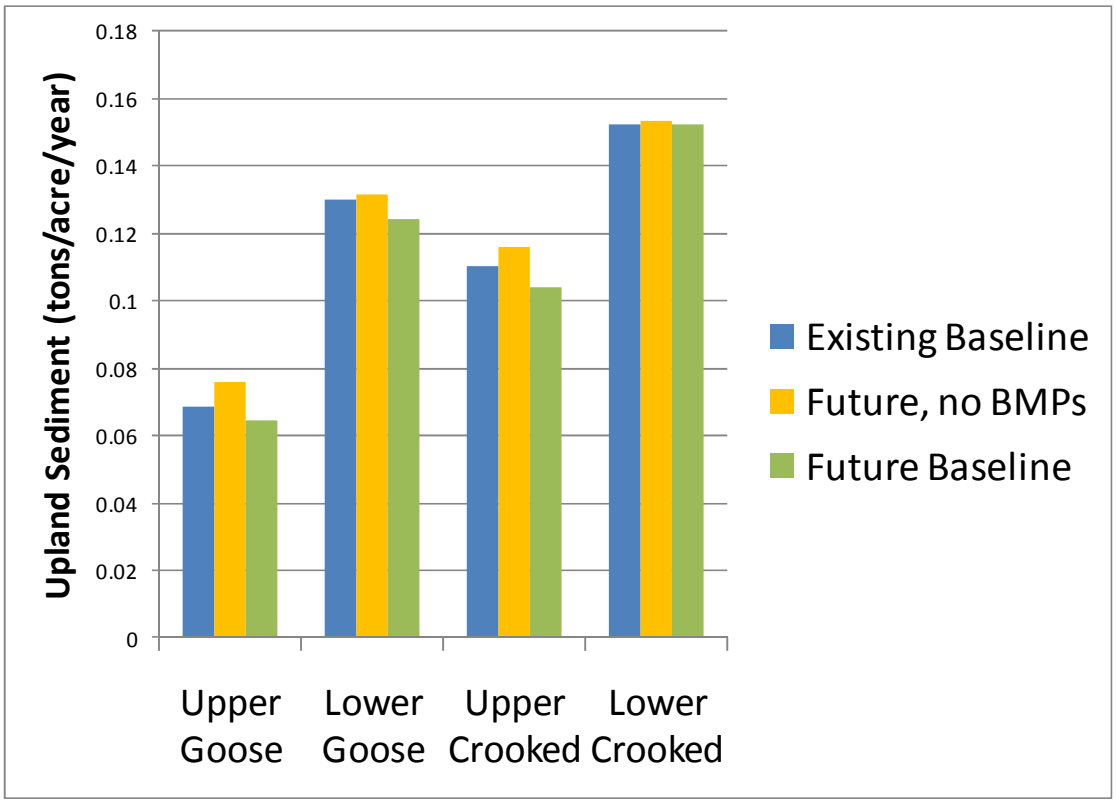


Figure 3. Scenario Results for Annual Upland TSS Loading Rates

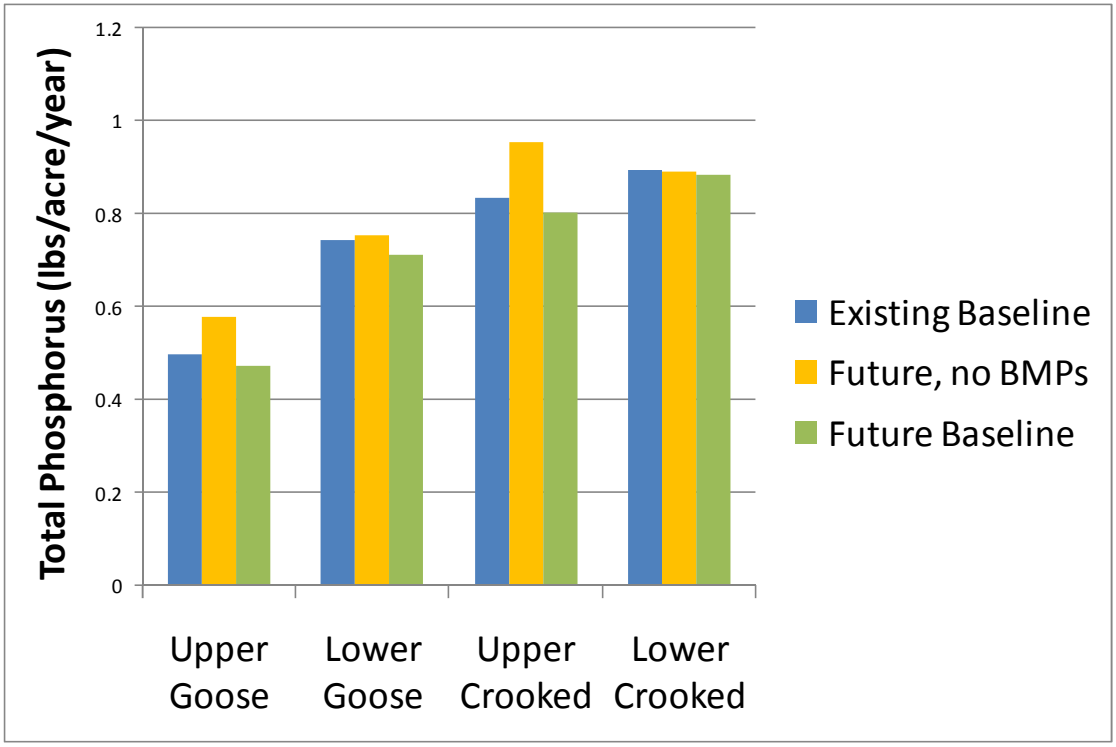


Figure 4. Scenario Results for Annual Upland TP Loading Rates

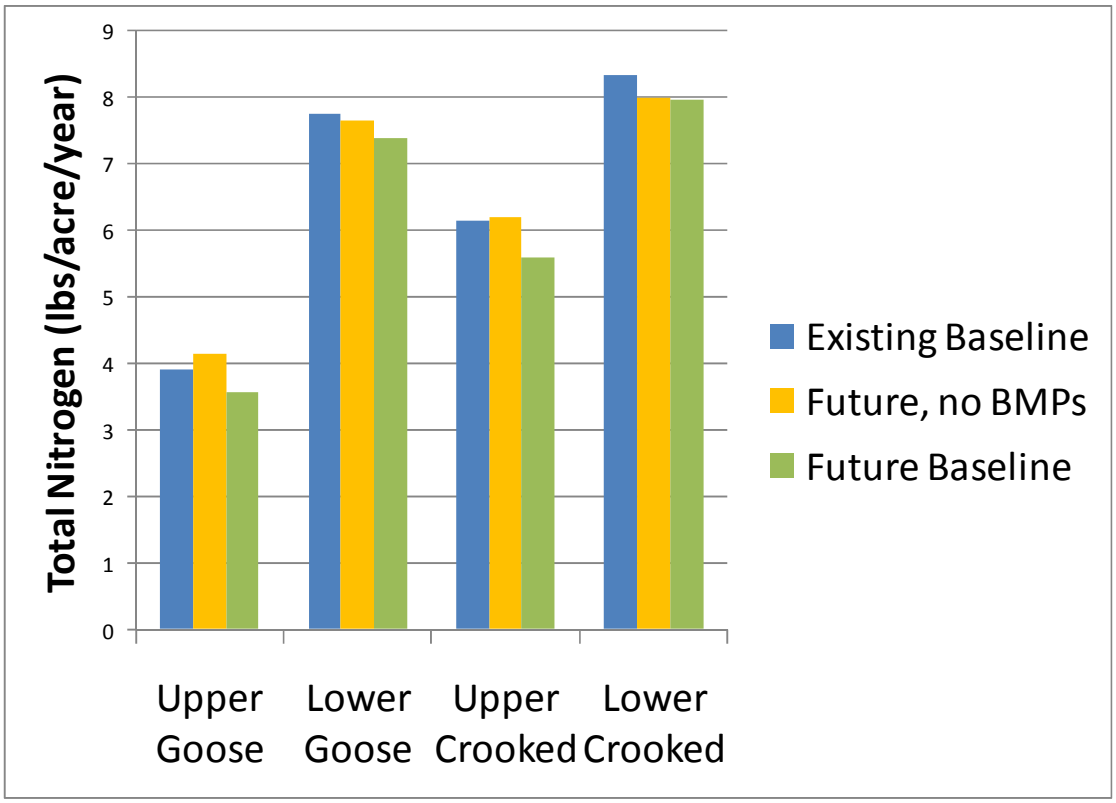


Figure 5. Scenario Results for Annual Upland TN Loading Rates

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Appendix A.

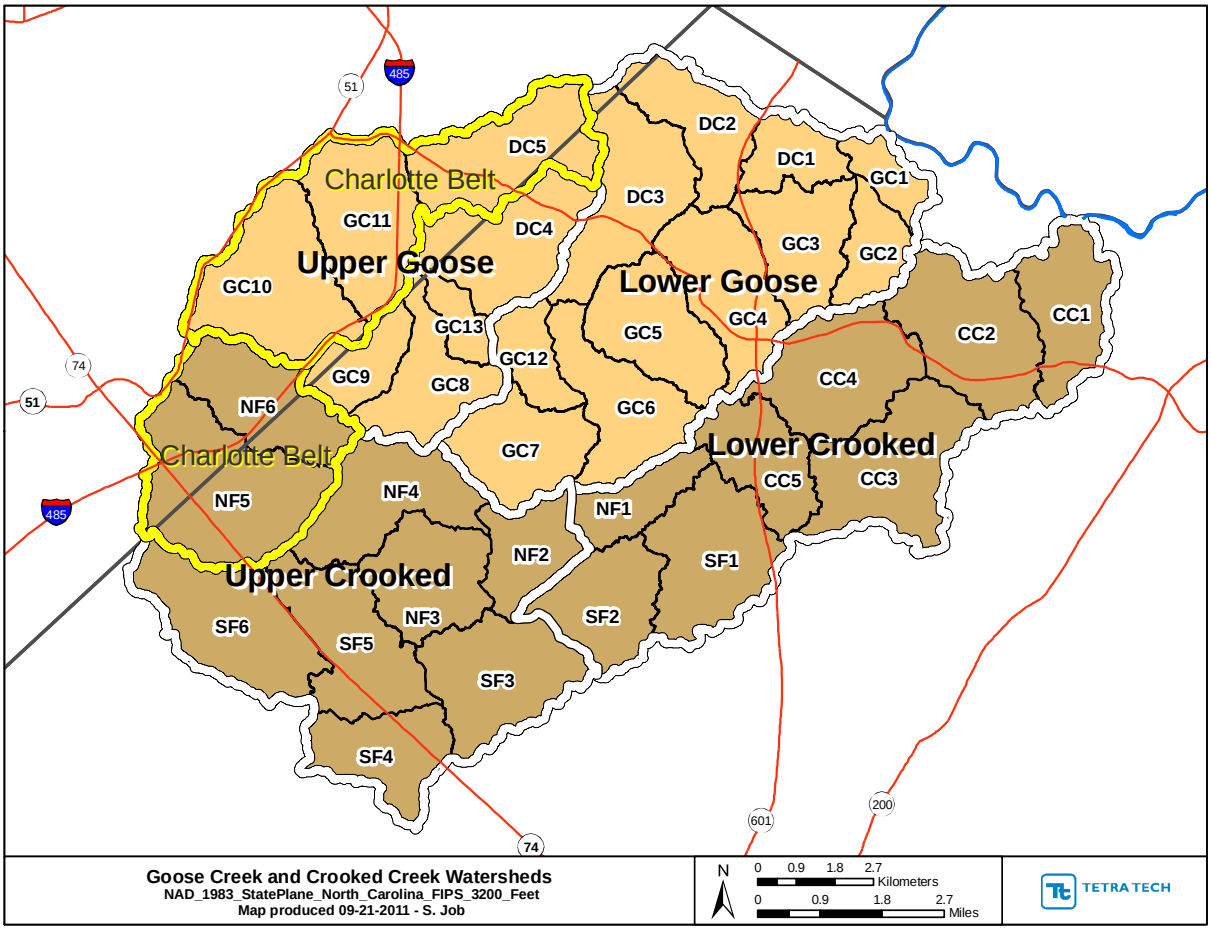


Figure A-1. Location Map for Subbasin IDs and Reporting Zones

Table A-1. Results by Subbasin, Existing Baseline Scenario

Subwatershed	Hydrology (% increase bankfull time duration)	Upland Sediment (tons/acre/year)	Bank and Bed Sediment (tons/mi/year)	Total Phosphorus (lbs/acre/year)	Total Nitrogen (lbs/acre/year)
GC1	13%	0.160	271	0.88	7.9
GC2	12%	0.160	22	0.92	8.1
GC3	14%	0.158	245	0.91	8.5
GC4	28%	0.185	261	1.11	9.4
GC5	13%	0.158	165	0.97	10.3
GC6	15%	0.086	66	0.49	6.0
GC7	7%	0.076	133	0.41	5.4
GC8	21%	0.075	62	0.45	4.3
GC9	82%	0.122	29	0.89	5.2
GC10	296%	0.053	74	0.45	3.1
GC11	279%	0.060	26	0.53	3.6
GC12	14%	0.087	31	0.50	6.4
GC13	63%	0.113	81	0.77	5.3
DC1	11%	0.138	246	0.81	9.2
DC2	8%	0.115	210	0.61	7.0
DC3	8%	0.122	230	0.66	7.6
DC4	18%	0.075	36	0.43	4.8
DC5	164%	0.051	121	0.40	3.1
CC1	9%	0.159	27	0.90	8.3
CC2	14%	0.165	35	0.96	8.3
CC3	21%	0.184	83	1.09	9.1
CC4	14%	0.161	179	0.94	8.5
CC5	17%	0.165	152	0.98	9.3
SF1	29%	0.120	236	0.72	7.4
SF2	36%	0.126	144	0.76	7.8
SF3	35%	0.106	226	0.66	6.8
SF4	42%	0.128	41	0.90	7.1
SF5	84%	0.126	75	0.98	6.3
SF6	74%	0.141	32	1.13	7.3
NF1	16%	0.110	180	0.63	7.4
NF2	20%	0.104	274	0.62	7.1
NF3	40%	0.108	34	0.76	6.4
NF4	46%	0.105	205	0.70	5.7
NF5	434%	0.096	31	0.91	5.2
NF6	357%	0.076	99	0.67	4.2

Table A-2. Results by Subbasin, Future Baseline Scenario

Subwatershed	Hydrology (% increase bankfull time duration)	Upland Sediment (tons/acre/year)	Bank and Bed Sediment (tons/mi/year)	Total Phosphorus (lbs/acre/year)	Total Nitrogen (lbs/acre/year)
GC1	11%	0.151	307	0.83	7.5
GC2	9%	0.156	21	0.90	7.9
GC3	8%	0.149	243	0.86	8.0
GC4	24%	0.177	261	1.06	8.9
GC5	9%	0.148	164	0.91	9.7
GC6	10%	0.084	66	0.48	5.8
GC7	4%	0.071	133	0.39	4.9
GC8	11%	0.070	62	0.43	3.8
GC9	80%	0.120	25	0.88	5.0
GC10	326%	0.050	74	0.43	2.9
GC11	329%	0.053	21	0.48	3.1
GC12	12%	0.085	30	0.49	6.2
GC13	63%	0.113	81	0.77	5.3
DC1	6%	0.131	241	0.77	8.7
DC2	6%	0.111	206	0.59	6.7
DC3	6%	0.116	225	0.63	7.2
DC4	7%	0.071	34	0.41	4.5
DC5	180%	0.048	120	0.37	2.8
CC1	14%	0.158	24	0.89	8.0
CC2	18%	0.165	35	0.95	8.0
CC3	26%	0.183	87	1.06	8.8
CC4	18%	0.163	176	0.93	8.2
CC5	20%	0.165	149	0.98	9.1
SF1	41%	0.122	243	0.71	6.8
SF2	32%	0.120	146	0.73	7.2
SF3	30%	0.096	229	0.61	5.9
SF4	38%	0.123	40	0.88	6.6
SF5	83%	0.125	76	0.98	6.1
SF6	77%	0.140	32	1.12	7.0
NF1	17%	0.111	181	0.63	7.3
NF2	18%	0.095	281	0.58	6.4
NF3	40%	0.102	31	0.73	5.6
NF4	41%	0.095	202	0.66	4.8
NF5	453%	0.089	26	0.85	4.7
NF6	367%	0.071	95	0.63	3.8

Table A-3. Results by Subbasin, Future No BMPs Scenario

Subwatershed	Hydrology (% increase bankfull time duration)	Upland Sediment (tons/acre/year)	Bank and Bed Sediment (tons/mi/year)	Total Phosphorus (lbs/acre/year)	Total Nitrogen (lbs/acre/year)
GC1	16%	0.160	294	0.88	7.7
GC2	13%	0.160	22	0.92	8.0
GC3	14%	0.159	261	0.91	8.3
GC4	30%	0.185	281	1.10	9.2
GC5	14%	0.159	184	0.97	10.0
GC6	17%	0.088	77	0.50	5.9
GC7	13%	0.081	157	0.44	5.3
GC8	34%	0.086	74	0.52	4.5
GC9	96%	0.125	41	0.96	5.3
GC10	357%	0.060	90	0.51	3.4
GC11	497%	0.070	38	0.73	4.1
GC12	16%	0.088	31	0.51	6.3
GC13	63%	0.114	81	0.78	5.3
DC1	13%	0.139	255	0.82	9.0
DC2	11%	0.118	219	0.63	6.9
DC3	10%	0.124	232	0.67	7.5
DC4	23%	0.080	37	0.46	4.8
DC5	212%	0.059	143	0.45	3.4
CC1	14%	0.158	29	0.89	8.0
CC2	18%	0.165	35	0.95	8.0
CC3	26%	0.183	87	1.06	8.8
CC4	18%	0.163	199	0.93	8.2
CC5	20%	0.165	175	0.98	9.1
SF1	41%	0.122	255	0.71	6.8
SF2	42%	0.130	155	0.80	7.5
SF3	53%	0.111	248	0.82	6.7
SF4	54%	0.132	45	1.02	7.1
SF5	90%	0.127	79	1.03	6.3
SF6	84%	0.143	34	1.17	7.2
NF1	17%	0.111	214	0.63	7.3
NF2	32%	0.109	328	0.70	6.9
NF3	64%	0.116	39	0.92	6.3
NF4	93%	0.121	255	0.94	5.9
NF5	548%	0.103	40	1.05	5.5
NF6	445%	0.083	117	0.74	4.4

Appendix J:

Goose Creek and Crooked Creek LWP

Phase II-III Wetland Mitigation Planning

TETRA TECH

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Memorandum

To:	Anjie Ackerman NC Ecosystem Enhancement Program	**Date:**	February 16, 2012 Revised
From:	Heather Fisher and Catherine Carter	**Subject:**	Goose Creek and Crooked Creek LWP Phase II-III Wetland Mitigation Planning
Cc:	J. Todd Kennedy, Trevor Clements	**Proj. No.**	100-RTP-T25954

In 2008, the North Carolina Ecosystem Enhancement Program (NCEEP) initiated development of a local watershed plan (LWP) for Goose Creek and Crooked Creek. The two watersheds, encompassing parts of northern Union County and southeastern Mecklenburg County, are located in the Yadkin Pee Dee River Basin (14-digit hydrologic units 03040105030020 and 03040105040010) and drain to the Rocky River.

The primary objectives of the LWP process are:

- To identify major causes of degradation to watershed functions and future threats to watershed assets.
- To develop strategies addressing the problems which are consistent with local priorities.
- To identify optimal sites for the implementation of watershed improvement projects, many of which may be used for compensatory mitigation.

The LWP process is typically divided into four phases: watershed characterization and preliminary findings (Phase I), detailed watershed assessment (Phase II), implementation plan development (targeting of management, Phase III), and implementation (Phase IV). Phase I was completed in spring 2009.

The Phase I preliminary findings hypothesized that sediment and increased peak flows/runoff volumes are the most important and pervasive stressors to watershed function in the Goose Creek and Crooked Creek watersheds (Tetra Tech, 2008a). Other stressors include pollutant loading from urban and agricultural sources. Riparian wetlands restoration or enhancement would address these stressors by reducing the velocity and volume of stormwater runoff and stream flows that are hydrologically connected to the restoration site. The type of wetlands enhancement provided would determine to what extent these stressors are addressed, but enhancement activities such as planting or minor improvements in hydrologic storage would slow runoff which would encourage settling within the enhanced wetland, leading to reduced turbidity and TSS in streams. Beyond enhancement, wetlands restoration could provide a much greater increase in these functions. Riparian wetlands enhancement or restoration may help reduce nutrients and other pollutants in these flows as well. In addition, enhancing or restoring wetland habitat would support the protection or restoration of critical aquatic habitat for sensitive mussel species through ecological pathways, like enhanced food web interactions and improved habitat through reduction in sediment loading, control of storm flows, and regulation of temperature through shading, among other benefits. Protection of sensitive mussel species is a key consideration for the LWP. Wetlands preservation would protect the water quality, hydrology, and habitat functions provided by existing wetlands. Non-riparian wetlands mitigation would restore or preserve the unique ecological functions of non-riparian wetlands, including habitat for rare, threatened, and endangered species.

As part of Phases II-III, wetlands mitigation opportunity identification and prioritization was a collaborative effort between NCEEP and Tetra Tech. NCEEP identified the candidate wetlands for restoration projects and conducted initial landowner outreach and field verification, and Tetra Tech developed a prioritization using NCEEP's results and available watershed data. This memorandum provides a summary of these efforts and preliminary management recommendations for wetlands mitigation opportunities in the Goose Creek and Crooked Creek watersheds as part of the next phase of plan development.

1 Site Identification

NCEEP identified candidate wetlands mitigation opportunities based on presence of hydric soils and national wetland inventory (NWI) GIS layers and if aerial photographs were indicative of land alteration, such as ditching. Following this identification, NCEEP developed an initial viability rating based on available information and GIS data. The factors in this rating were:

- Presence of hydric soils and/or NWI layer
  - Sites that did not exhibit hydric soils but where associated with an isolated NWI layer were considered but not ranked as highly viable.
- Number of landowners
  - NCEEP prefers to identify sites with three landowners or fewer. Those sites with three or more landowners received a lower prioritization.
- Ease of access for construction/monitoring/stewardship
  - Mitigation sites should have a logical ingress/egress for construction, monitoring, and stewardship purposes. Sites that appeared on aerial photography as potentially difficult to access received a lower prioritization.
- Evidence of land alteration
  - For sites identified for potential restoration/enhancement activities, the search included, but was not limited to, sites that exhibit ditching in areas of hydric soils/NWI layers, straightening of adjacent streams, land clearing activities and lack of stream buffer.
- Presence of utility or other structural constraints
  - Sites that exhibit obvious impacts from utility easements, structures, and other infrastructure received a lower prioritization.
- Opportunity area available for wetlands mitigation
  - NCEEP prefers to identify sites where a large wetland area is available on the smallest number of parcels however for this assessment smaller isolated wetlands were not excluded due to the need to identify non-riparian wetlands.

The criteria used to rate the sites is explained in more detail in Appendix A, which contains NCEEP's memorandum on site identification. The initial ratings were used to select 15 sites for landowner outreach and field verification. NCEEP was not able to access most sites during the initial field verification, either because a landowner denied or delayed permission or because the landowner could not be contacted. Appendix A provides more details on the landowner outreach results and describes the sites selected for field verification. NCEEP provided Tetra Tech with 32 sites to evaluate (23 riparian and 9 non-riparian), which represent the initial sites identified through GIS and additional sites identified after the field verification. Tetra Tech found site 31 to be located outside of the Crooked Creek watershed boundary delineated for the LWP, but decided to retain this site for analysis because it was included in NCEEP's site identification. NCEEP intends to continue landowner outreach efforts, and the evaluation described in this memorandum will help prioritize sites for additional landowner outreach and field verification.

2 Goals, Objectives, and Indicators

Following the site identification, NCEEP and Tetra Tech used Tetra Tech's Phase II-III recommendations memorandum (Tetra Tech, 2008b) as a foundation for discussing criteria for the wetlands mitigation prioritization. The following steps summarize the recommended approach for Phase II of the project:

- Select management strategies that address watershed functional deficits and associated stressors identified in the detailed assessment.
- Protect high quality resources from future degradation.
- Consider both local and contributing drainage area conditions to ensure successful restoration.
- Identify cost-effective opportunities for restoration and retrofit.
- Consider implementation timeframes where a variety of stressors are at play.
- Consider NCEEP criteria associated with mitigation.

As a guide to following the recommended Phase II-III approach, Tetra Tech developed the following overarching goal for the wetland mitigation prioritization:

- Prioritize sites that would provide the greatest potential benefit related to watershed stressors and are feasible and cost-effective.

When reviewing this goal, NCEEP and Tetra Tech discussed how the wetland mitigation opportunities could be evaluated in terms of watershed stressors, critical habitat considerations, and support for broader management efforts, including stream restoration and stormwater best management practice (BMP) implementation. It was determined that the wetlands prioritization would focus on the direct benefits provided by each site with some consideration of how the sites would support other management activities. Task 4 will involve a prioritization of subwatersheds based on watershed-wide management needs and stressors, and this latter analysis will provide an opportunity to consider which wetland opportunities provide the greatest functional benefits from a whole-watershed perspective. The subwatershed prioritization will also provide an opportunity to consider appropriate implementation timeframes for wetland opportunities in relation to other management opportunities.

With the above goal and objectives in mind, data were selected that would measure how well a wetland mitigation opportunity would provide functional benefits, feasibility, and mitigation value. Tetra Tech prioritized riparian and non-riparian wetlands separately and selected "major focus indicators" on which to base the prioritization. The following list outlines how the major focus indicators are related to benefits, feasibility and mitigation value.

- Benefits
    - Water Quality/Hydrology Benefits
    - Supports a Stream Restoration Opportunity
    - Supports or is Supported by a BMP Opportunity
    - Supports Existing Wildlife Habitat or Endangered/Threatened Species
    - Development Pressure
- Feasibility
    - Constraints – Landowners
    - Constraints – Utilities/Access

- Mitigation Value
    - Potential Wetlands Mitigation Units (WMUs)

Section 3 provides an explanation of each major focus indicator. The discussion includes reasons for indicator selection, data sources used, and trends among the wetland opportunities. Following this discussion, a prioritization scoring system is presented that provides insight into which wetland opportunities best meet the overarching goal for wetland mitigation.

3 Benefits, Feasibility, and Mitigation Value

Tetra Tech developed a comprehensive evaluation of wetland mitigation priorities that considered the available information and data as well as NCEEP's priorities and implementation strategy. The sites identified by NCEEP all provide potential management opportunities for the Goose Creek and Crooked Creek watersheds. Even those sites with limited viability at the present time may have potential in the future as conditions change (e.g., land ownership). For this reason, all sites identified were considered in the indicator and prioritization analysis. For the purposes of the LWP, Tetra Tech developed methods for measuring priorities based on current conditions as well as some consideration of future development pressure. For the major focus indicators presented in Section 2, Tetra Tech selected single or multiple indicators that provided the best information. Where multiple indicators are discussed, the term "supporting indicators" is used. Following indicator selection, Tetra Tech developed a scoring system using the selected indicators. The scoring system can be used as a tool to prioritize implementation of the wetland opportunities. The indicators used are discussed separately by the major categories of benefits, feasibility, and mitigation value below. Following this discussion, the scoring system methods and results are presented.

3.1 BENEFITS

Tetra Tech selected five major focus indicators to measure the relative benefit provided by each wetland mitigation opportunity:

1) Provides potential water quality/hydrology benefits to hydrologically connected waters
2) Supports a stream restoration opportunity
3) Supports or is supported by a BMP opportunity
4) Supports existing wildlife habitat or endangered/threatened species
5) Future availability is affected by development pressure

The first indicator provides a measure of the quality and quantity of water that would potentially flow into the wetland (using impervious surface and disturbed land cover) as well as the status of waters receiving flow from the wetland (using supporting or impaired stream status). This information provides an estimate of the potential water quality and hydrologic benefits of each wetland in its surrounding landscape. These were the most appropriate measures at the time of this analysis, and simulated pollutant loading and flow will be available for a more detailed evaluation during the Task 4 stressor-based prioritization.

Tetra Tech also prioritized the sites based on their proximity to stream restoration opportunities identified during Phase II-III of the LWP (Tetra Tech, 2010). Wetlands located either upstream from or adjacent to stream restoration sites are able to provide flow regulation and sediment removal to protect the restored stream habitat. For similar reasons (flow regulation and sediment removal), sites were also prioritized based on site proximity to proposed BMP locations with the understanding that a wetland mitigation opportunity could either support or be supported by a BMP. For example, a BMP that controls peak flows

upstream of a wetlands restoration site would help protect the functions of that site and prevent damage from erosive flows. In turn, a BMP and wetland opportunity could provide a treatment train if hydrologically connected, the more upstream site providing initial pollutant removal, while the downstream site providing additional treatment and pollutant removal.

In addition to flow regulation and sediment removal, wetlands provide valuable wildlife habitat for a multitude of species. Sites were prioritized based on their proximity to existing wildlife habitat and their potential to develop effective habitat for the protection of endangered and/or threatened species. This prioritization accounted for the ecological principle that adjacent natural habitats can support each other through multiple ecological pathways, including food web interactions and regulation of physical and chemical environmental process (hydrology, nutrient cycling. temperature variation, etc.). The supporting indicators were protected natural areas and occurrence of sensitive aquatic species.

NCEEP values restoration sites that have the greatest potential for ecological effectiveness and improvement of watershed functions and concludes that the majority of these sites are located within places that have been or may be impacted by transportation and/or economic-development improvements. For these purposes, spatial relationships between wetland mitigation opportunities and existing and future development within the Goose Creek and Crooked Creek watersheds were analyzed. Sites were prioritized based on their proximity to current or potential environmental impacts due to development. If priority is not placed on these sites and implementation planned in the near term, the opportunities could be permanently destroyed by development. These concepts are explained in more detail in the following sections.

Water Quality/Hydrology

Tetra Tech analyzed functional benefits relating to water quality and hydrology for each wetland mitigation opportunity on a drainage area basis. Assessment at this level accounted for each site's position within the greater landscape. Four supporting indicators were used to assess functional benefits.

1) The percent of cumulative drainage area as impervious surface
2) The percent of cumulative drainage area as forest/wetland/shrub
3) The cumulative drainage area in acres
4) The 303(d) stream status downstream from each site

Although these indicators are related to other functions, such as habitat, they were chosen to provide measures of water quality and hydrologic function benefits. It is important to note that the stressor-based subwatershed prioritization, to occur in a later task, will use simulated loading and flow data from the watershed model and will provide additional management priority information at the subwatershed scale. The indicators used in this analysis were selected as approximate indicators of functional benefits. Although potentially less accurate than simulated data, they provide a sufficient comparison of wetland mitigation benefits for the purposes of comparing the 32 wetland sites, of which 23 sites are riparian and 9 sites are non-riparian; site 17 includes both mitigation types and is counted twice.

Subwatershed boundaries generated during Phase I of the LWP (Tetra Tech, 2008a) were used as a starting point for delineating drainage areas for each wetland mitigation opportunity. Modifications to the LWP model subwatersheds were guided by site locations (points provided by NCEEP) and the use of a digital elevation model (DEM) representing elevation at 3-meter resolution (Gesch, 2007). Cumulative drainage areas were delineated as if the wetland would receive all water draining to the adjacent stream location, which accounts for potential benefits from receiving direct runoff and overbank flow. Cumulative drainage area boundaries for the 23 riparian sites ranged from 13 to approximately 30,000 acres, with a mean of about 10,000 acres. The 9 sites identified as non-riparian wetlands had drainage areas less than 50 acres, with a mean of approximately 22 acres. Even though sites 8 and 25 were

identified as potential riparian wetlands, their drainage areas were significantly less than other riparian wetlands because they were located on unnamed upland tributaries to Crooked Creek.

The impervious surface data layer generated during Phase 1 of the LWP (Tetra Tech, 2008a) was used to determine the percent of cumulative drainage area as impervious surface for each site. The percent impervious surface for riparian sites ranged from zero to 23 percent, with a mean of 11 percent and for non-riparian sites ranged from zero to 12 percent, with a mean of 4 percent (Table 1).

The amount of forest, wetland, or shrub land cover, was tabulated for each site's cumulative drainage area using the land cover data layer generated during Phase 1 of the LWP (Tetra Tech, 2008a). The percent forest, wetland, or shrub ranged from zero to 60 percent, with a mean of 32 percent for riparian sites and ranged from 1 percent to 88 percent, with a mean of 35 percent for non-riparian sites (Table 1).

The 2010 NC Final 305(b)-303(d) coverage was used to determine the 303(d) stream status as supporting or impaired downstream from each site (NCDWQ, 2010). If the immediate downstream stream section was identified as impaired for either aquatic life or recreation, the site received a "yes" to indicate that its waters would be flowing to an impaired stream. Twenty riparian sites were draining to impaired streams. Stream status downstream from each site was not incorporated into the prioritization of non-riparian sites because flow at these sites was isolated from classified streams (Table 1).

Table 1. Water Quality/Hydrology Metric Values for the Wetland Mitigation Opportunity Sites

Wetland ID	Water Quality/Hydrology			
	Cumulative Drainage Area (acres)	% of Cumulative Drainage Area as Impervious Surface	% of Cumulative Drainage Area as Forest/Wetland/Shrub	Stream Status - drains to a 303d impaired stream
Riparian				
1	2,911	18	22	yes
3	13,600	7	43	yes
4	1,766	22	22	yes
5	4,430	23	17	yes
6	8,583	17	23	yes
8	13	0	1	yes
9	24,730	12	28	yes
10	30,308	10	29	yes
11	4,899	15	28	yes
13	9,562	14	30	yes
14	22,599	13	27	yes
15	10,922	14	24	yes
16	25,746	12	28	yes

Wetland ID	Water Quality/Hydrology			
	Cumulative Drainage Area (acres)	% of Cumulative Drainage Area as Impervious Surface	% of Cumulative Drainage Area as Forest/Wetland/Shrub	Stream Status - drains to a 303d impaired stream
17	24,316	12	28	yes
18	15,954	7	40	yes
19	4,435	5	55	yes
20	8,765	9	47	yes
21	8,423	9	47	yes
22	8,306	4	54	yes
23	1,879	21	32	yes
25	13	7	0	no
29	375	6	60	no
32	941	8	42	no
Non-Riparian				
2	5	2	1	NA
12	48	3	88	NA
17	5	12	28	NA
24	27	0	22	NA
26	48	1	52	NA
27	25	0	81	NA
28	21	2	20	NA
30	12	10	20	NA
31	8	1	4	NA

Supports a Stream Restoration Opportunity

Tetra Tech evaluated riparian and non-riparian wetland mitigation opportunities based on their proximity to stream restoration opportunities identified during Phase II-III of the LWP (Tetra Tech, 2010). Any sites located within a 500-foot distance from either side of the stream were considered as supporting a stream restoration opportunity. This buffer distance was selected because a majority of the riparian sites were within 500 feet of the stream and riparian sites are expected to have potential for a connection to an adjacent stream channel. Six riparian sites intersected the 500-foot stream buffer along potential stream

restoration reaches, while 17 sites did not, and all non-riparian sites were found outside of the 500-foot stream buffer (Table 2).

Supports or is Supported by a BMP Opportunity

The NCEEP identified potential locations for implementing best management practices (BMPs) within the Goose Creek and Crooked Creek watersheds as part of Phases II-III (W. Ross, NCEEP, personal communication to H. Fisher, October 2010). Based on a visual inspection of the orientation between BMP locations and sites, it was apparent that no candidate wetland mitigation sites were located directly upstream or downstream from a BMP opportunity. Further assessment was performed by creating a 500-foot buffer around each BMP location to identify mitigation sites that may not have been hydrologically connected to BMPs, but were near BMP locations. The 500-foot buffer distance was chosen to remain consistent with the analysis of stream restoration opportunities. As a result of this analysis, no wetland mitigation sites were found within the 500-foot buffer; therefore, it was concluded that zero candidate wetland mitigation sites either support or are supported by a BMP opportunity (Table 2).

Supports Existing Wildlife Habitat or Endangered/Threatened Species

Tetra Tech selected two supporting indicators to assess how each wetland mitigation opportunity would support existing wildlife habitat or endangered/threatened species.

1) The site's adjacency to publicly-owned protected natural areas
2) The proximity of each site to a NC Natural Heritage Element Occurrence (NHEO)

To determine a site's adjacency to protected natural areas, Tetra Tech used the protected natural areas layer generated during Phase 1 of the LWP (Tetra Tech, 2008a), which includes protected areas reported by Mecklenburg County, Union County, the Town of Mint Hill, and the NC Wildlife Resource Commission. The parcels containing each of the sites were identified by NCEEP and, based on visual inspection, any site located in a parcel that was adjacent to one of the protected natural areas was classified as a "yes." Of the riparian and non-riparian opportunities, three riparian sites were on parcels adjacent to protected natural areas (Table 2).

The NC Natural Heritage Program produces and maintains data containing locations of sensitive species and habitat. As a part of this program, the NHEOs provide the approximate location where rare species, habitats, or ecosystems have been observed, including threatened and endangered species (NCNHP, 2010). Although restored wetlands are expected to provide habitat benefits to terrestrial species, the effect on aquatic species is likely to be more pronounced and was determined to represent a priority for the LWP, specifically for sensitive mussel species. To indicate priority relating to support of aquatic NHEOs, Tetra Tech selected all extant aquatic NHEO's within the Goose Creek and Crooked Creek watersheds, which included both fish and mussel species, and created a 2,000-foot buffer along streams for all NHEO locations. The 2,000-foot buffer distance was selected because sites within this distance were thought to provide a greater benefit to sensitive aquatic species, and it appeared that most sites were either within 2,000 feet or significantly farther away from the NHEOs and this threshold represented a natural break in the locations. Twenty riparian sites and four non-riparian sites were found to intersect the NHEO buffer, while eight sites were located outside of this buffer (Table 2).

Development Pressure

Several data layers were compiled in GIS to determine each site's proximity to existing or future development. Existing development was defined by the NC Statewide Municipal Boundary data layer. This layer was developed by the NC Department of Transportation's GIS Unit; it includes boundaries for all NC incorporated cities and towns and was last updated in March of 2009. Future development was defined by data layers obtained from the Centralina Council of Governments (N. Bennett, CCOG,

personal communication to P. Cada, June 2010) which included future land use boundaries for Stallings, Indian Trail, Monroe, Mint Hill, and Unionville. The to-be constructed Monroe Bypass was also included in this analysis. The bypass right-of-way (ROW) data layer was obtained from the NC Turnpike Authority and the PBS & J Corporation (C. Shumate, NCTA, and C. Gibilaro, PBS & J, personal communication to P. Cada, August 2010).

Wetland opportunities under development pressure would provide a greater functional benefit, considering the summation of all available wetland opportunities, compared to less-threatened opportunities because the summation of potential functional benefits will be less once these sites are developed. Sites were classified into one of five potential priority categories. The priorities reflect that development is more likely to occur within existing municipal boundaries compared to future municipal boundaries. Development is also more likely to occur within or near future municipal boundaries compared to areas outside and farther away. Development considered here is not specific to density or amount of imperviousness, but simply the potential of a site to be destroyed by any type of development. Areas near the Monroe Bypass were also given priority to account for increased development pressure near the future roadway. The categories are listed below in order of importance with the first category of highest priority relating to development pressure:

1) Within existing municipal boundaries (existing)
2) Within 10,000 feet of Monroe Bypass and within future municipal boundaries but outside of existing municipal boundaries (future; <10,000)
3) Within future municipal boundaries, but outside of existing municipal boundaries and greater than 10,000 feet from Monroe Bypass (future)
4) Less than 2,000 feet from future municipal boundaries (<2,000)
5) Greater than 2,000 feet from future municipal boundaries (>2,000)

Eighteen riparian sites and eight non-riparian sites were found to be located within existing municipal boundaries, one site was less than 2,000 feet from future municipal boundaries, one site was greater than 2,000 feet from future municipal boundaries, and four sites were within 10,000 feet of the Monroe Bypass and outside of existing municipal boundaries (all four sites were within future municipal boundaries (Table 2). No sites were found within future municipal boundaries (category 3) that were farther than 10,000 feet from the Monroe Bypass ROW. The 2,000-foot and 10,000-foot distances were selected based on natural breaks in the data and allowed for effective separation of sites for evaluation.

Table 2. Other Benefit-Related Metrics

Wetland ID	Supports a Stream Restoration Opportunity	Supports or is Supported by a BMP Opportunity	Supports Existing Wildlife Habitat or Endangered/Threatened Species		Future Availability based on Development Pressure
			Adjacent Public Natural Area	Near Aquatic NHEO	
Riparian					
1	yes	no	no	yes	1) existing
3	no	no	yes	yes	1) existing
4	yes	no	no	yes	1) existing

Wetland ID	Supports a Stream Restoration Opportunity	Supports or is Supported by a BMP Opportunity	Supports Existing Wildlife Habitat or Endangered/Threatened Species		Future Availability based on Development Pressure
			Adjacent Public Natural Area	Near Aquatic NHEO	
5	no	no	no	yes	1) existing
6	no	no	no	yes	2) future; <10,000
8	no	no	no	yes	1) existing
9	no	no	no	yes	1) existing
10	no	no	no	yes	5) >2,000
11	no	no	no	no	2) future; <10,000
13	yes	no	no	no	2) future; <10,000
14	no	no	no	yes	1) existing
15	yes	no	no	yes	1) existing
16	no	no	no	yes	1) existing
17	no	no	no	yes	1) existing
18	no	no	yes	yes	1) existing
19	no	no	no	yes	1) existing
20	yes	no	no	yes	4) <2,000
21	no	no	no	yes	1) existing
22	no	no	no	yes	1) existing
23	no	no	no	yes	1) existing
25	no	no	no	yes	1) existing
29	no	no	yes	no	1) existing
32	yes	no	no	yes	1) existing
Non-Riparian					
2	no	no	no	yes	2) future; <10,000
12	no	no	no	no	1) existing
17	no	no	no	yes	1) existing

Wetland ID	Supports a Stream Restoration Opportunity	Supports or is Supported by a BMP Opportunity	Supports Existing Wildlife Habitat or Endangered/Threatened Species		Future Availability based on Development Pressure
			Adjacent Public Natural Area	Near Aquatic NHEO	
24	no	no	no	no	1) existing
26	no	no	no	no	1) existing
27	no	no	no	no	1) existing
28	no	no	no	yes	1) existing
30	no	no	no	no	1) existing
31	no	no	no	yes	1) existing

3.2 FEASIBILITY

Tetra Tech identified two major focus indicators to measure the feasibility of constructing each site within the Goose Creek and Crooked Creek watersheds.

1) Constraints related to landowners
2) Constraints related to existing utilities and obstacles for access

All of the sites included in this analysis are located on private land. Often, a major hurdle with the development of wetland mitigation projects is landowner consent to access their land and their interest in allowing a permanent conservation easement. In addition, when the wetland project extends into several properties, multiple landowners become involved in the process and acquiring landowner consent can become an even greater obstacle. In general, less restricted wetland projects are coupled with fewer landowners and landowners that are willing to cooperate with the needs of the wetland project.

Aside from constraints related to landowners, additional constraints for wetland projects arise from the presence of utility easements or restricted access to the site. Access to a site could be limited for a number of reasons including the surrounding land use or natural landscape features.

Constraints – Landowners

During the site identification process, NCEEP reported landowner willingness and the number of owners for each site (Appendix A). Based on these records, sites were classified by the number of owners and each site was classified into one of four potential categories for landowner willingness ordered from highest to lowest priority:

1) Landowners allowed NCEEP access to their property (yes)
2) A potential willingness from the landowner is evident and NCEEP was allowed access to the sites after harvesting was completed (potential)
3) Willingness is unknown because contact was not yet attempted by NCEEP or NCEEP had not yet received a response from the landowner (unknown)
4) Landowners denied NCEEP access to their property (no)

Of the 32 sites analyzed, landowner willingness for 21 sites was unknown (a majority of these had been contacted by NCEEP, but they had not yet responded), 4 sites were classified as having the potential for landowner willingness, 4 sites resided on properties where landowners denied access to NCEEP, and 3 sites were located on properties where landowners were willing to cooperate with NCEEP and future wetland projects (in these counts, site 17 was counted as two sites, once for the riparian and once for the non-riparian portion) (Table 3). The number of landowners for riparian sites ranged from 1 to 25 landowners, with an average of approximately 4 landowners per site (Table 3). Two non-riparian sites had two owners, while 7 non-riparian sites had a single owner (Table 3).

Constraints – Utilities/Access

The presence of utilities was assessed based on visual inspection in GIS using a multitude of utility data layers. Within Mecklenburg County, the location of stormwater infrastructure and outfalls, wastewater infrastructure, and utility ROWs were inspected. Within Union County, the location of stormwater infrastructure was inspected; other utility layers were not available. The presence of utilities on each site was additionally inspected using aerial imagery. As a result, 1 site was found adjacent to an existing power line easement and 31 sites were found free of constraints due to the presence of utilities (Table 3).

Access constraints were reported for sites by NCEEP during the site identification process (Appendix A). For sites where access constraints were noted as difficult or moderately difficult to access, that site was classified as a "yes." If a site had no indication of access constraints, it received a "no." In all, 19 riparian sites were classified as having unconstrained access while the remaining 4 sites had constrained access (Table 3) and 5 non-riparian sites were classified as having unconstrained access while 4 sites had constrained access.

Table 3. Feasibility-Related Metrics

Wetland ID	Constraints - Landowners		Constraints - Utilities/Access	
	Landowner Willingness	Number of Landowners	Presence of Utilities	Constrained Access
Riparian				
1	unknown	9	no	no
3	unknown	1	no	no
4	unknown	6	no	no
5	unknown	1	no	yes
6	unknown	5	no	no
8	potential	1	no	no
9	unknown	1	no	no
10	unknown	2	no	yes
11	unknown	25	no	yes
13	unknown	19	yes	no
14	potential	1	no	no
15	unknown	1	no	no
16	unknown	4	no	no
17	yes	1	no	no
18	unknown	2	no	no
19	no	1	no	no
20	unknown	2	no	no
21	unknown	1	no	no
22	unknown	1	no	no
23	unknown	6	no	yes
25	unknown	1	no	no
29	no	1	no	no
32	yes	1	no	no

Wetland ID	Constraints - Landowners		Constraints - Utilities/Access	
	Landowner Willingness	Number of Landowners	Presence of Utilities	Constrained Access
Non-Riparian				
2	potential	1	no	yes
12	potential	1	no	yes
17	yes	1	no	no
24	unknown	1	no	no
26	no	1	no	yes
27	unknown	2	no	yes
28	no	1	no	no
30	unknown	1	no	no
31	unknown	2	no	no

3.3 MITIGATION VALUE

The mitigation value of a project is the amount of mitigation credit NCEEP receives from the regulatory agencies for implementing a watershed project multiplied by the NCEEP In-Lieu Fee Program fee schedule for a particular mitigation type (for fees see http://portal.ncdenr.org/web/eep/mitigation-applicants). The fee includes all program costs (watershed planning, project development and construction, monitoring, maintenance, administration, overhead…) per credit. Individual projects may cost less or more than the fee schedule to implement based on many factors (e.g. land cost, site constraints, construction cost, etc.) and therefore mitigation value is not a measure of construction cost or cost efficiency. However, approximate mitigation values of projects are an important consideration for mitigation providers in project selection.

Another important consideration is cost efficiency which includes all the costs to implement a watershed project, the mitigation value of the project, and the carrying cost of a project. In areas where mitigation demand is high, and therefore credits will be consumed more quickly, credits developed in addition to current needs will be consumed quickly, the carrying cost will be low, and, as a result, larger projects are usually more cost-effective. In areas where mitigation demand is low and credits are consumed more slowly, carrying costs are higher and larger projects may not be as cost-effective.

For each site, NCEEP estimated the wetland opportunity acres available in terms of restoration, enhancement, and preservation. These estimates were based on a review of available GIS data, including NWI and hydric soils. The actual opportunity area is uncertain, and these estimates may change once NCEEP has the opportunity to visit the sites.

To estimate potential Wetland Mitigation Units (WMUs), Tetra Tech applied the approximate opportunity areas to the current mitigation ratios used by NCEEP. The standard ratios of mitigation acres to impact acres are: 1:1 for restoration, 2:1 for enhancement, and 5:1 for preservation (R. Hoffman, NCEEP, personal communication to H. Fisher, November 2010). These ratios generally represent the amount of

mitigation provided, but the actual credit award may vary based on site conditions. Potential WMUs estimated for the wetland opportunities ranged widely from 0.1 to 30 units, with a mean of 5.5 units (Table 4).

Cost estimates were developed for reference purposes but were not included in the formal prioritization since this Cataloging Unit is expected to continue to have high mitigation demand and therefore the cost estimates represent the same trends as the WMU estimates (i.e., larger sites are preferred to smaller sites due to cost-effectiveness). The in-lieu fees, at the time of this analysis, for wetland impacts were $62,210 per acre for riparian and $44,883 for non-riparian wetlands in High Fee Cataloging Units, including 03040105, where this LWP is located (NCEEP, 2010). These fees represent the average cost per acre for wetlands restoration in High Fee Cataloging Units. To estimate the cost for each potential watershed project, the wetland acres were divided by the mitigation ratios (1:1 for restoration, 2:1 for enhancement and 5:1 for preservation) and then multiplied by the fee schedule. Similar to the WMUs, cost estimates ranged widely from $4,000 to $1.9 million, with a mean of $340,000 (Table 4).

Table 4. Mitigation Value Metrics

Wetland ID	Mitigation Type	WMUs	Cost
Riparian			
1	enhancement/preservation	2.4	$149,000
3	restoration/enhancement	18.5	$1,151,000
4	preservation	1.8	$112,000
5	preservation	5.8	$361,000
6	preservation	2.8	$174,000
8	enhancement/preservation	5.1	$317,000
9	restoration/enhancement	5.5	$342,000
10	preservation	8.4	$523,000
11	preservation	4.8	$299,000
13	preservation	1.8	$112,000
14	preservation	11.5	$715,000
15	restoration/enhancement	2.5	$156,000
16	preservation	4.0	$249,000
17	restoration	30.0	$1,866,000
18	preservation	6.0	$373,000
19	restoration	11.0	$684,000

Wetland ID	Mitigation Type	WMUs	Cost
20	preservation	6.0	$373,000
21	enhancement/preservation	1.6	$96,000
22	enhancement/preservation	5.5	$342,000
23	preservation	4.4	$274,000
25	restoration	20.0	$1,244,000
29	restoration	3.0	$187,000
32	enhancement	5.0	$311,000
Non-Riparian			
2	restoration/enhancement	4.0	$180,000
12	preservation	1.4	$63,000
17	enhancement	0.2	$7,000
24	enhancement/preservation	0.4	$18,000
26	enhancement	0.1	$4,000
27	preservation	0.1	$4,000
28	restoration	0.8	$36,000
30	restoration	0.7	$31,000
31	restoration	0.3	$13,000

3.4 PRIORITIZATION

Using the data described above, Tetra Tech developed a scoring system to prioritize wetland mitigation opportunities based on functional benefits, feasibility, and mitigation value. Scoring methods and results are discussed in the following sections.

Scoring Methods

Data resulting from GIS analyses and collected by NCEEP during the site identification process were used to prioritize sites by assigning scores to each site based on scoring thresholds or breaks within the data. Two forms of data were generally recorded; either continuous data (e.g., cumulative drainage area) or categorical data (e.g., supports a stream restoration opportunity). For continuous data, scoring thresholds were set using equal intervals or obvious natural breaks within the data. Equal intervals were calculated as quartiles, which are statistical ranges that divide the data into four sets, each representing 25 percent of the range. When the continuous data for a supporting indicator was not divided into quartiles, it was divided into 2, 3, or 4 groups using obvious natural breaks, or spaces in the data where

values are clustered. For supporting indicators with categorical data, Tetra Tech established qualitative categories or predefined categories for scoring thresholds. The scoring criteria are listed in Appendix B, organized by category and major focus indicator. If scoring criteria depended on the metrics data, different criteria were used for riparian versus non-riparian sites, as indicated in Appendix B.

Scores ranged from 1 to 10, with a score of 10 assigned to characteristics of highest priority (Appendix B). When more than one supporting indicator was identified for a major focus indicator, the scores for each supporting indicator were averaged to calculate a composite score for the major focus indicator (e.g., scores for landowner willingness and number of landowners were averaged to calculate the score for the constraints associated with landowners). As a result, each wetland had one score for each of the major focus indicators. Overall composite scores were then calculated for each site by averaging scores across the major focus indicators to ensure each indicator received equal weight in the overall composite score. Appendix C reports the scores for each major focus indicator as well as the overall composite score.

Scoring Results

Total riparian wetland scores ranged from 4.2 to 7.1, with an average score of 5.9. Of the 23 riparian sites prioritized, 11 of the sites had overall composite scores greater than 6.0. Based on these results, the 3 riparian sites of highest priority were sites 15, 17, and 3 with scores of 7.1, 7.0, and 7.0, respectively. Total non-riparian wetland scores ranged from 3.3 to 5.8, with an average score of 4.8. Of the 9 non-riparian sites prioritized, site 2 was the highest scoring site having a score of 5.8. Site locations and total scores for riparian and non-riparian sites are displayed in Figure 1and Figure 2. The higher priority sites appear to be spread evenly throughout the watershed, and neither high nor low priority sites are concentrated in a particular location.

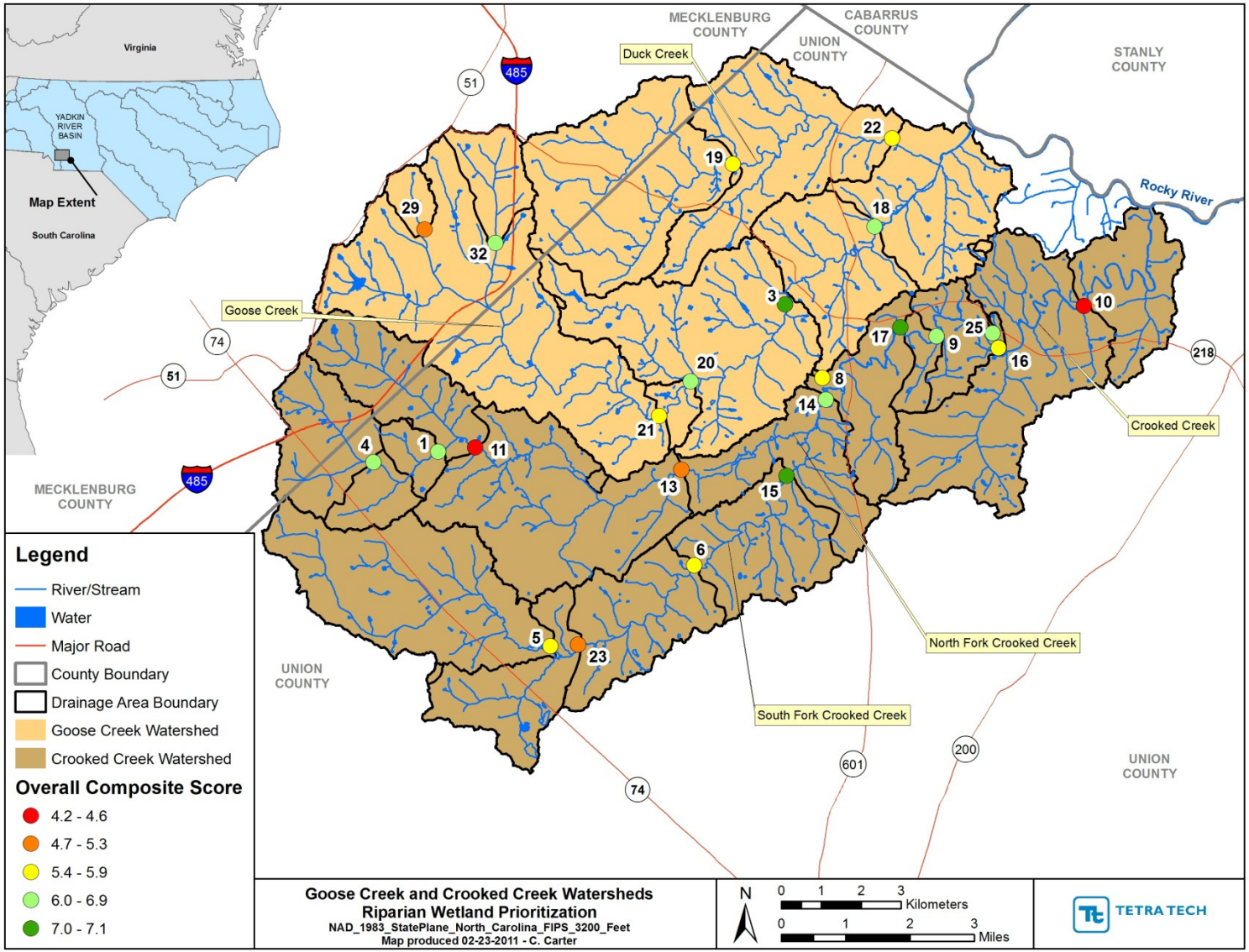


Figure 1. Potential Riparian Wetland Mitigation Sites Varying by Overall Composite Score

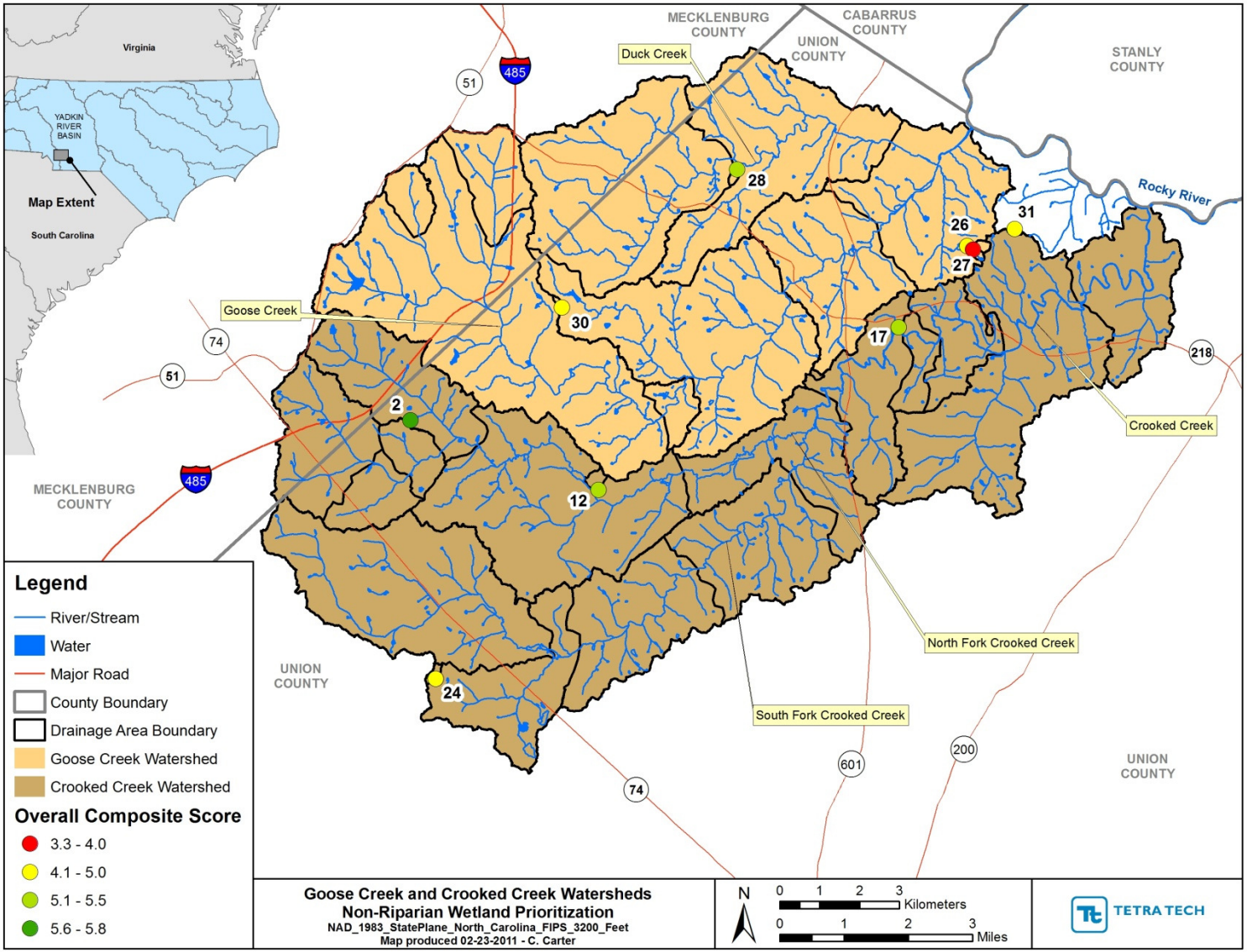


Figure 2. Potential Non-riparian Wetland Mitigation Sites Varying by Overall Composite Score

4 Discussion and Recommendations

The wetlands prioritization provides a tool for comparing benefits, feasibility, and mitigation value across the 32 wetland mitigation opportunities identified by NCEEP. To assess whether the composite scores adequately reflected the overall goal of the analysis, Tetra Tech reviewed the characteristics of the three top riparian and the top non-riparian scoring sites (15, 17, 3, and 2). All four sites appeared to provide promising opportunities, and their unique characteristics are described in more detail below:

- **Site 15** is a high priority riparian site based on several major focus indicators. Of all sites inspected, site 15 is one of four sites with the third highest score (8.1 out of 10) for its potential to provide local water quality and hydrologic benefits. Site 15 is located within an existing municipal boundary, supports a stream restoration opportunity, and does not have observable constraints related to utilities or access. Landowner consent at this time is unknown. The landowners have been contacted and NCEEP is anticipating a response from them. Site 15 consists of 5 acres with the potential for riparian enhancement.
- **Site 17** is a site of high priority based on several major focus indicators. The site is located within an existing municipal boundary, consists of both riparian and non-riparian opportunities, and has a high potential for WMUs. The site has no observable constraints and the landowners have shown interest in establishing a conservation easement for the wetland project. In addition, NCEEP has obtained an option for purchase from the landowners. The site supports wildlife habitat and endangered or threatened species and may provide a stream enhancement opportunity in addition to the opportunities identified in Tetra Tech's stream restoration planning report (Tetra Tech, 2010).
- **Site 3** is a high priority riparian site based on several major focus indicators. The site is located within an existing municipal boundary, has high potential for WMUs, has no record of utility or access constraints, and appears to support wildlife habitat and endangered or threatened species. Site 3 has only one landowner of unknown interest. NCEEP left information regarding participation in wetland restoration efforts at the landowner's residence during the site identification process and anticipates further communication efforts if the landowner does not respond.
- **Site 2** was the highest scoring non-riparian wetland site. Even though site 2 did not score the highest across all major focus indicators, it consistently scored within the higher range for almost all major focus indicators. Site 2 has highest potential WMUs across all non-riparian opportunities, and one of four non-riparian sites having the highest potential to support endangered or threatened aquatic species. NCEEP reported potential interest for participation from landowners after speaking with the landowners in person on August 4, 2010.

For additional insight into priorities, Table 5 compares the overall composite score to the NCEEP viability rating (methods described in Appendix A). The sites with high viability all fall within an overall composite score range of 5.2 to 7 points. This range includes both riparian and non-riparian sites, and provides opportunities for restoration, enhancement, and preservation. Tetra Tech recommends that NCEEP consider placing higher priority on this subset, with more attention to those sites with higher viability ratings. As NCEEP continues to pursue landowner outreach and field verification, this priority subset may change to reflect updates on landowner interest, opportunity area, and other indicators.

The stressor-based subwatershed prioritization in Task 4 will provide a more detailed, holistic review of management priorities. This subsequent prioritization may provide insight into how particular wetland opportunities address priority stressors and how well they would support other priority opportunities within recommended implementation timeframes.

Table 5. Summary of Wetland Mitigation Opportunities in the Goose and Crooked Creek

Wetland ID	Opportunity Area (acres) R / E / P[1]	Total Score	NCEEP Viability
Riparian			
15	0 / 5 / 0	7.1	medium
17	30 Riparian / 0 / 0.75 Non-Riparian	7.0	high
3	17 / 3 / 0	7.0	high
1	0 / 4 / 2	6.9	low
32	0 / 10 / 0	6.9	high
14	0 / 19 / 10	6.6	medium
4	0 / 0 / 9	6.5	low
18	0 / 0 / 30	6.3	medium
20	0 / 0 / 30	6.1	low
25	20 / 0 / 0	6.1	high
9	0 / 11 / 0	6.1	medium
8	0 / 7 / 8	5.9	medium
19	11 / 0 / 0	5.8	high
16	0 / 0 / 20	5.7	medium
6	0 / 0 / 14	5.7	low
22	0 / 3 / 20	5.6	medium
5	0 / 0 / 29	5.5	low
21	0 / 2.5 / 1.5	5.4	low
29	3 / 0 / 0	5.1	low
23	0 / 0 / 22	5.0	low
13	0 / 0 / 9	5.0	low
10	7 / 0 / 7	4.6	medium
11	0 / 0 / 24	4.2	low

Wetland ID	Opportunity Area (acres) R / E / P[1]	Total Score	NCEEP Viability
Non-Riparian			
2	4 / 0 / 0	5.8	medium
17	30 Riparian / 0 / 0.75 Non-Riparian	5.5	high
12	0 / 0 / 7	5.5	medium
28	0.8 / 0 / 0	5.2	high
30	0.7 / 0 / 0	5.0	low
24	0 / 0 / 2	4.7	medium
31	0.3 / 0 / 0	4.6	low
26	0 / 0.17 / 0	4.1	low
27	0 / 0.19 / 0	3.3	low

[1]Acres of opportunity for wetlands restoration (R), enhancement (E), and preservation (P).

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Appendix A. NCEEP Site Identification

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To: Heather Fisher, Todd Kennedy Tetra Tech, Inc.
From: Robin Hoffman, NC EEP
Re: Goose and Crooked Creek wetland opportunities field work

As part of the development of the Goose and Crooked Creek Local Watershed Plan, the NC EEP performed a search for wetland opportunities in the planning area. This memo contains the results of that site search, and includes search methodology and photos of the site that was accessed. An Excel spreadsheet of all potential opportunities identified during the GIS site search that provides ranking explanation and other pertinent site information is attached.

Search methodology:

The site search methodology for this task was a combination of desktop Arcview 9.3 GIS analysis and field observation of sites. GIS criteria used were 24K USGS contours, hydric soils data, National Wetlands Inventory (NWI) layers, LIDAR contour data for the Goose and Crooked Creek watersheds, and 2008 aerial photography. EEP staff assessed potential wetland sites on GIS based on presence of hydric soils, NWI wetland layers, and if aerial photos showed obvious signs of alteration of the land, such as ditching. Thirty-seven sites were initially chosen for assessment.

Criteria for GIS and initial field ranking (no particular order):

Site exhibits hydric soils and/or is associated with an NWI (National Wetlands Inventory) layer – sites that did not exhibit hydric soils but were associated with an isolated NWI layer were considered but not ranked as highly viable.

Number of landowners – EEP prefers to identify sites with three landowners or fewer. Those sites with three or more landowners received a lower prioritization.

Ease of access for construction/monitoring/stewardship – Mitigation sites should have a logical ingress/egress for construction, monitoring, and stewardship purposes. This includes access off of a public road, utility ROW, private road contained entirely within subject property, or other easy access point. Sites that appeared on aerial photography as potentially difficult to access for either construction, monitoring, and/or stewardship purposes received a lower prioritization.

Evidence of land alteration – For sites that were chosen for restoration/enhancement, the search included, but was not limited to, sites that exhibited ditching in areas of hydric soils/NWI layers, straightening of adjacent streams, land clearing activities and lack of stream buffer.

Constraints – EEP prefers to identify sites with minimal impact from utility easements, structures, and other infrastructure. Those that exhibited obvious impacts from such constraints received a lower prioritization.

Size – EEP prefers to identify sites where a large wetland area was available on the smallest number of parcels possible. However, for the inital screening, smaller isolated wetlands were not excluded due to need to identify non-riparian wetlands.

Results:

Six sites were deemed to be highly viable based on GIS analysis and the applied criteria, eleven sites were deemed to have medium viability, and the remaining fourteen sites were deemed to have low viability. Attempts were made to the contact landowners of fifteen sites for the first round of ground truthing site visits. Due to limited staff time, landowners of sites considered to be preservation only were not contacted during the round of site searches that occurred on 8/3 and 8/4/2010.

Two landowners denied permission to their properties; one requested on the phone that we wait until after crops on the property are harvested in late fall, and another asked that we send an email requesting permission, which was never granted. The other eleven landowners did not respond to phone calls requesting permission to access their property. On August 3 and 4, 2010, EEP personnel visited eleven potential wetland sites in an attempt to gain permission in person from landowners to access the sites. Two landowners gave permission to visit their sites, two denied permission (one asked that we come back after crops are harvested in Oct.), and the other seven were not available. Packets of information were left for those landowners who were not home, but none of those landowners have contacted EEP. Those sites where a visit was made or attempted are noted in the table below. The other sites have not yet been visited due to staff time, previous site visits, or they were identified after the initial round of site visits.

Sites:

EEP staff visited or attempted to visit the following sites on 8/3 and 8/4 2010. They are identified by their corresponding site ID number in the attached Excel spreadsheet entitled “Goose & Crooked Ck. LWP wetland opportunity memo_REH_10.7.2010”.

Site ID 2:

This potential headwater wetland site or spring is located on the property of Bobby and Doris Helms (Union County PIN 07078007). It appears that the potential headwater wetland or spring could be ditched before it drains into a pond. EEP spoke with the landowner in person on 8/4/2010, but the site was not visited because he would not give permission for EEP personnel to access the site until after his soybean crops are harvested in October/November.

Site ID 3:

This potential riparian wetland and stream site is located on the property of Kathleen Haigler (Union County PIN 08222010), on the main stem of Goose Creek. From GIS aerial photography, it appears that there are several ditches in the floodplain that may be draining the wetlands and the stream has minimal buffer and appears to have been straightened in some areas. This site was not visited because permission could not be obtained from the landowner as she was not at home when EEP personnel arrived at the site. A packet of information was left at the residence, with a request to contact EEP for a site visit. The landowner has not contacted EEP to this date.

Site ID 7:

This potential riparian wetland and stream restoration site is located on the properties of Marvin and Martha Forbis (Union County PIN 50866) and Ronald and Gladys Porter (Union County PIN 25944). EEP staff received permission from the Forbis' to visit their property on Aug. 3, 2010 and a site visit revealed that the stream on their property has an intact wooded buffer and while GIS NWI layers indicated the presence of wetlands, redoximorphic soil features were not present and neither were hydrologic or vegetative features indicate a presence of wetlands. The Porters denied permission to access their property.

Site ID 8:

This potential riparian wetland and stream site is located on the property of Beta Investments, LLC (Union County PIN 08192001), on the main stem of Crooked Creek and on an unnamed tributary of Crooked Creek. The unnamed tributary flows through open row crop and is unbuffered and appears to have been straightened. There may also be ditches draining wetlands in the floodplain of the UT. The main stem of Crooked Creek appears to be wooded, with large areas of NWI wetlands (as identified through GIS). The site was not visited because the landowner would not give permission for EEP personnel to access the site until after soybean crops are harvested in October or November.

Site ID 12:

This potential riparian and non-riparian wetland site is located on the property of the Estate of Carroll Edwards (Union County PIN 07021001), on the North Fork of Crooked Creek. From the GIS search, it appears that there are large areas on the property of NWI

wetlands, which have not been field verified. The site is heavily wooded and is slated for development at some point in the future. The executor of the estate, Jeff Edwards, has given EEP personnel permission to visit the site, but the site has not yet been visited.

Site ID 17:

This riparian wetland, non-riparian wetland, and stream enhancement site is located on the property of Logan and Mildred Tucker (Union County PIN 08153002), on the main stem of Crooked Creek. The site has several ditches in the floodplain of Crooked Creek, draining approximately 30 acres of riparian wetlands. A hillside seep yields about 0.75 acres of non-riparian wetland enhancement, and about 1800 linear feet of Crooked Creek occurs on the property that could be enhanced. If the landowners are amenable, there are about 5 acres of riparian wetland preservation and 1800 linear feet of stream preservation on an adjacent parcel. EEP personnel visited this site on Aug. 3, 2010 and the landowners indicated that they are interested in learning more about the EEP and possibly putting on conservation easement on the wetlands and stream. The site was approved by EEP's internal project review committee on Sept. 3, 2010 and EEP has contacted the landowners to follow up confirm continued interest. EEP is currently working with the State Property Office to generate a purchase offer for the landowners.

Photos of Site ID 17:


08.03.2010 14:31


08.03.2010 14:42


08.03.2010 14:30


08.03.2010 14:47

Site ID 19 and 28:

This potential riparian wetland site is located on the property of the Robert Pittenger Company (Union County PIN 08249001), on the main stem of Duck Creek. There appear to be several ditches draining wetlands in the floodplain of Duck Creek. The floodplain appears to be partially in row crop or pasture and partially wooded, with areas of NWI wetlands (as identified through GIS). The site is eventually slated to be sold for development. The site was not visited because the landowner denied permission to EEP staff.

Site ID 24:

This potential non-riparian wetland site is located on the property of Indian Trail Associates (Union County PIN 07087008), in the headwaters of an unnamed tributary of the South Fork of Crooked Creek. The site appears to be partially in row crop or pasture and partially wooded. GIS searches revealed large areas of NWI wetlands on the property, possibly indicating the presence of wetlands. No ditches or disturbance other than clearing could be seen on aerial photography. The landowner was contacted to ask permission to visit the site; they requested that EEP staff send an email detailing the request, which was done. However, the landowner never responded to the email.

Site ID 25:

This potential riparian wetland and stream restoration site is located on the property of the Freeman Heirs (Union County PIN 08120011), on an unnamed tributary of Crooked Creek. Both forks of the UT on the property flow throw row crop or pasture and are completely unbuffered. There also appear to be several ditches in the floodplain of both forks. Approximately 4,200 linear feet of stream occurs on the property, although the east fork of the UT flows off of the property for a while and forms a property boundary with an adjacent landowner in its downstream portion. This site was not visited because permission could not be obtained from the executor of the estate, as he was not at home when EEP personnel arrived at the site. A packet of information was left at the residence, with a request to contact EEP for a site visit. The landowner has not contacted EEP to this date.

Site ID 26 and 27:

This potential non-riparian wetland site is located on the property of Frances and Douglas McCoy (Union County PIN 08117005), in the headwaters of an unnamed tributary of Goose Creek. GIS searches indicate that there are small areas of NWI wetlands on the property that appear to be isolated. There is also a small pond on the property that empties into the UT, which is unbuffered. Approximately 1,100 feet of the UT occurs on the subject property. This site was not visited because permission could not be obtained from the landowners. The residence on the site is a rental property and the tenant was unable to give EEP staff contact information for the landowner. The landowner's phone number is unlisted, so a packet of information will be sent to the landowner's PO Box.

Site ID 29:

This potential riparian wetland site is located on the property of Julius Kennedy (Mecklenburg County tax PID 19507103), in the floodplain of an unnamed tributary of Stevens Creek. It appears that the floodplain, which is in located in an equestrian housing development that is under construction, has a ditch running through it that may be draining riparian wetlands. This area is slated to be a homesite. This landowner was approached in February 2010 regarding a potential project on the UT and other adjacent wetlands and he declined to participate. The landowner was not contacted again.

Appendix B. Scoring Criteria

Table B-1. Scoring System for Indicators of Benefits

Water Quality/Hydrology		
% of Cumulative Drainage Area as Impervious Surface: Riparian	**Upper Limit**	**Ranking**
75 - 100%	23.47	10
50 - 75%	14.65	7.5
25 - 50%	11.59	5
0 - 25%	7.11	2.5
% of Cumulative Drainage Area as Impervious Surface: Non-riparian	**Upper Limit**	**Ranking**
75 - 100%	12.06	10
50 - 75%	2.84	7.5
25 - 50%	1.53	5
0 - 25%	1.12	2.5
% of Cumulative Drainage Area as Forest/Wetland/Shrub: Riparian	**Upper Limit**	**Ranking**
75 - 100%	59.89	2.5
50 - 75%	42.56	5
25 - 50%	28.32	7.5
0 - 25%	23.74	10
% of Cumulative Drainage Area as Forest/Wetland/Shrub: Non-riparian	**Upper Limit**	**Ranking**
75 - 100%	88.15	2.5
50 - 75%	51.57	5
25 - 50%	21.81	7.5
0 - 25%	19.79	10
Cumulative Drainage Area (acres): Riparian	**Upper Limit**	**Ranking**
75 - 100%	30,308	10
50 - 75%	14,777	7.5
25 - 50%	8,423	5

0 - 25%	2,395	2.5
Cumulative Drainage Area (acres): Non-riparian	**Upper Limit**	**Ranking**
75 - 100%	48	10
50 - 75%	27	7.5
25 - 50%	21	5
0 - 25%	8	2.5
Stream Status: Riparian	**Code**	**Ranking**
drains to a 303d impaired stream	yes	10
does not drain to a 303d impaired stream	no	1
Supports a Stream Restoration Opportunity		
Intersects Stream Restoration Buffer (500ft)	**Code**	**Ranking**
intersects	yes	10
does not intersect	no	1
Supports or is Supported by a BMP Opportunity		
Intersects BMP Buffer (500 ft) or is Directly Downstream from BMP	**Code**	**Ranking**
intersects or is directly downstream	yes	10
does not intersect or is not directly downstream	no	1
Supports Existing Wildlife Habitat or Endangered/Threatened Species		
On Parcel Adjacent to Public Property with Natural Area	**Code**	**Ranking**
parcel is adjacent to natural area	yes	10
parcel is not adjacent to natural area	no	1
Intersects NHEO Aquatic Buffer (2,000ft)	**Code**	**Ranking**
intersects	yes	10
does not intersect	no	1
Development Pressure		
Distance from Future Municipal Boundaries and Monroe Bypass	**Code**	**Ranking**
within existing municipal boundaries	existing	10
within future, outside existing municipal boundaries	future	7.5

<2,000ft from future municipal boundaries	<2,000	5
>2,000ft from future municipal boundaries	>2,000	2.5
within 10,000ft of Monroe Bypass and outside of existing municipal boundaries	future; <10,000	8.5

Table B-2. Scoring System for Indicators of Feasibility

Constraints - Landowners		
Landowner Willingness	**Code**	**Ranking**
interested	yes	10
potentially interested (delayed access)	potential	7.5
interest is unknown (no contact attempted or no response from owner)	unknown	5
not interested (denied access)	no	2.5
Number of Landowners: Riparian	**Upper Limit**	**Ranking**
>9	25	2.5
3 to 9	9	5
2	2	7.5
1	1	10
Number of Landowners: Non-riparian	**Upper Limit**	**Ranking**
2	2	1
1	1	10
Constraints - Utilities/Access		
Presence of Utilities	**Code**	**Ranking**
present	yes	1
not present	no	10
Constrained Access	**Code**	**Ranking**
constrained	yes	1
not constrained	no	10

Table B-3. Scoring System for the Mitigation Value Indicator

Potential WMU: Riparian		
Estimated WMUs	**Upper Limit**	**Ranking**
<2	2	2.5
2 to 6	6	5
6 to 12	12	7.5
>12	30	10
Potential WMU: Non-riparian		
Estimated WMUs	**Upper Limit**	**Ranking**
<1	1	1
>1	4	10

Appendix C. Individual Indicator Scores

Table C-1. Major Focus Indicator Scores for the Goose Creek and Crooked Creek Watersheds

Wetland ID	Water Quality/ Hydrology	Potential WMUs (Mitigation Value)	Constraints - Landowners	Constraints - Utilities/ Access	Supports a Stream Restoration Opp.	Supports or is Supported by a BMP Opp.	Supports Existing Wildlife Habitat or E/T Sp.	Dev. Pressure	Total Score
Riparian									
1	8.8	5.0	5.0	10.0	10.0	1.0	5.5	10.0	6.9
3	6.3	10.0	7.5	10.0	1.0	1.0	10.0	10.0	7.0
4	8.1	2.5	5.0	10.0	10.0	1.0	5.5	10.0	6.5
5	8.8	5.0	7.5	5.5	1.0	1.0	5.5	10.0	5.5
6	9.4	5.0	5.0	10.0	1.0	1.0	5.5	8.5	5.7
8	6.3	5.0	8.8	10.0	1.0	1.0	5.5	10.0	5.9
9	8.8	5.0	7.5	10.0	1.0	1.0	5.5	10.0	6.1
10	7.5	7.5	6.3	5.5	1.0	1.0	5.5	2.5	4.6
11	8.1	5.0	3.8	5.5	1.0	1.0	1.0	8.5	4.2
13	7.5	2.5	3.8	5.5	10.0	1.0	1.0	8.5	5.0
14	8.8	7.5	8.8	10.0	1.0	1.0	5.5	10.0	6.6
15	8.1	5.0	7.5	10.0	10.0	1.0	5.5	10.0	7.1
16	8.1	5.0	5.0	10.0	1.0	1.0	5.5	10.0	5.7
17	8.8	10.0	10.0	10.0	1.0	1.0	5.5	10.0	7.0
18	6.9	5.0	6.3	10.0	1.0	1.0	10.0	10.0	6.3
19	5.0	7.5	6.3	10.0	1.0	1.0	5.5	10.0	5.8
20	6.3	5.0	6.3	10.0	10.0	1.0	5.5	5.0	6.1
21	5.6	2.5	7.5	10.0	1.0	1.0	5.5	10.0	5.4
22	5.0	5.0	7.5	10.0	1.0	1.0	5.5	10.0	5.6
23	6.9	5.0	5.0	5.5	1.0	1.0	5.5	10.0	5.0

Wetland ID	Water Quality/ Hydrology	Potential WMUs (Mitigation Value)	Constraints - Landowners	Constraints - Utilities/ Access	Supports a Stream Restoration Opp.	Supports or is Supported by a BMP Opp.	Supports Existing Wildlife Habitat or E/T Sp.	Dev. Pressure	Total Score
25	4.0	10.0	7.5	10.0	1.0	1.0	5.5	10.0	6.1
29	2.1	5.0	6.3	10.0	1.0	1.0	5.5	10.0	5.1
32	3.4	5.0	10.0	10.0	10.0	1.0	5.5	10.0	6.9
Non-Riparian									
2	5.8	10.0	8.8	5.5	1.0	1.0	5.5	8.5	5.8
12	6.7	10.0	8.8	5.5	1.0	1.0	1.0	10.0	5.5
17	5.8	1.0	10.0	10.0	1.0	1.0	5.5	10.0	5.5
24	5.8	1.0	7.5	10.0	1.0	1.0	1.0	10.0	4.7
26	6.7	1.0	6.3	5.5	1.0	1.0	1.0	10.0	4.1
27	4.2	1.0	3.0	5.5	1.0	1.0	1.0	10.0	3.3
28	6.7	1.0	6.3	10.0	1.0	1.0	5.5	10.0	5.2
30	8.3	1.0	7.5	10.0	1.0	1.0	1.0	10.0	5.0
31	5.0	1.0	3.0	10.0	1.0	1.0	5.5	10.0	4.6

Appendix K:

Goose Creek and Crooked Creek LWP

Phase II-III Stressor Based Subwatershed Prioritization- Revised

TETRA TECH

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Memorandum

To:	Anjie Ackerman NC Ecosystem Enhancement Program	**Date:**	January 20, 2012
From:	Heather Fisher	**Subject:**	Goose Creek and Crooked Creek LWP Phase II-III Stressor-Based Subwatershed Prioritization - Revised
Cc:	J. Todd Kennedy, Trevor Clements, Scott Job	**Proj. No.**	100-RTP-T25954

In 2008, the North Carolina Ecosystem Enhancement Program (NCEEP) initiated development of a local watershed plan (LWP) for Goose Creek and Crooked Creek (Figure 1). The two watersheds, encompassing parts of northern Union County and southeastern Mecklenburg County, are located in the Yadkin Pee Dee River Basin (14-digit hydrologic units 03040105030020 and 03040105040010) and drain to the Rocky River. The Goose Creek watershed supports a population of the Carolina heelsplitter (*Lasmigona decorata*), which is listed as endangered at the federal level and critically endangered at the state level (WRC, 2005). In 2002, USFWS designated specific stream reaches as critical habitat for the Carolina heelsplitter along Goose and Duck creeks as shown in Figure 1.

The primary objectives of the LWP process are:

- To identify major causes of degradation to watershed functions and future threats to watershed assets
- To develop strategies addressing the problems which are consistent with local priorities
- To identify optimal sites for the implementation of watershed improvement projects, many of which may be used for compensatory mitigation

The LWP process is typically divided into four phases: watershed characterization and preliminary findings (Phase I), detailed watershed assessment (Phase II), implementation plan development (targeting of management, Phase III), and implementation (Phase IV). Phase I was completed in spring 2009.

The Phase I preliminary findings discussed the linkages between the major stressors, sources, impacts, and functional deficits (Table 1) and hypothesized that sediment and increased peak flows/runoff volumes are the most important and pervasive stressors to watershed function in the Goose Creek and Crooked Creek watersheds (Tetra Tech, 2008). The following were hypothesized as secondary stressors: bacteria, oxygen demanding substances/nutrients, and toxicity-related pollutants (i.e., ammonia, copper, and pesticides).

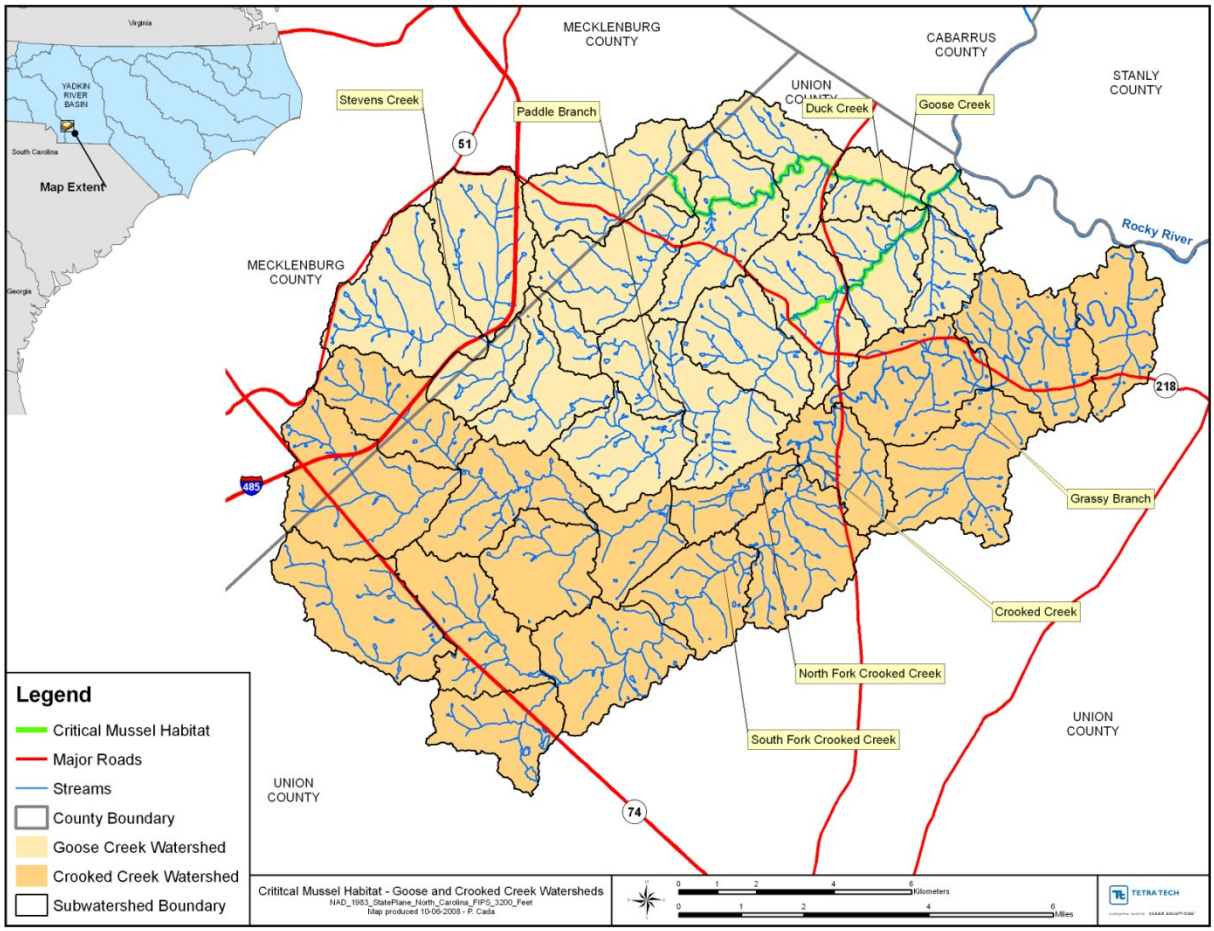


Figure 1. Goose and Crooked Creeks and USFWS Critical Mussel Habitat

Table 1. Linkage Between Stressors, Sources, Impacts and Functional Deficits in the Goose Creek and Crooked Creek Watersheds

Stressor	Source(s)	Impact(s)	Functional Deficit(s)
Increased Peak Flows and Runoff Volumes	Impervious surface, removal of vegetation, direct stormwater discharges	Decreased groundwater recharge and baseflows, channel modification, substrate disturbance; increased velocities, scour	Impaired aquatic habitat, loss of wetland hydrology/ habitat, Impaired aquatic organisms
Sediment	Erosion of construction sites, agricultural land, livestock access to streams, streambank and channel erosion, ATV use	Increased deposited sediment in stream channel, increased turbidity/suspended sediment	Impaired aquatic habitat and aquatic organisms
Bacteria	Pets, livestock, wastewater discharges, septic tanks, wildlife	Increased count of pathogens in surface and ground water	Increased risk to human health (and aquatic life)

Stressor	Source(s)	Impact(s)	Functional Deficit(s)
Oxygen Demanding Substances/ Nutrients	Nutrient loading from urban and agricultural runoff, temperature increase in runoff from impervious surfaces; natural sources; WWTP; septic systems; direct loading from livestock; other agricultural sources.	Excessive algal growth, depletion of dissolved oxygen	Aquatic organism stress and mortality
Ammonia, Copper, Pesticides (toxicity-related)	Wastewater discharges, runoff from lawns, golf courses, and agricultural land (manure and agrochemicals)	Increased concentration of toxic chemicals	Toxic effects on aquatic organisms

Phases II-III involve the identification of opportunities for stream enhancement and restoration, stormwater retrofits, and wetland enhancement, restoration, and preservation. A number of opportunities have been identified throughout the watersheds, and preliminarily assessment has indicated which opportunities are the most promising considering site-scale or subwatershed-scale benefits. The stressor-based prioritization provides a method for selecting opportunities in locations where the greatest magnitude of stressors exist or are likely to exist in the future based on conditions throughout the Goose Creek and Crooked Creek watersheds. This memorandum outlines the methods used to score subwatersheds based on stressor-related indicators and select subwatersheds as priorities for management.

1 Scoring Framework and Indicator Selection

Tetra Tech developed a general framework for the prioritization and then selected indicators, or datasets, that supported this framework and addressed the stressors identified during Phase I. The framework for the stressor-based prioritization was based directly on the Goose Creek and Crooked Creek LWP goals. In March 2011, as part of Phases II-III, the Watershed Technical Team (WTT) adopted the Goose Creek and Crooked Creek LWP goals and objectives (Appendix A). The goals provide general statements regarding the desired outcomes for the watershed plan, and the objectives identify actions to take to achieve the goals. Goals 1 and 2 are most relevant to the stressor based analysis:

- Goal 1: Restore, protect, and enhance watershed functions such as hydrology, water quality, and aquatic and terrestrial habitat.
- Goal 2: To minimize impacts on water quality, aquatic and terrestrial habitat, and hydrology in the watershed by supporting balanced, sustainable, and diverse land use and development, in accordance with existing and future policies.

Goal 1 generally seeks to protect or improve existing watershed functions, while Goal 2 seeks to address future impacts to watershed functions. To prioritize subwatersheds where management would best meet each of these goals, two scores were calculated for each subwatershed: one for existing conditions and one for future conditions. As part of the scoring, the subwatersheds with the greatest magnitude of stressors were considered the highest priority because addressing these areas would address the most extreme impacts to mussel habitat and other watershed functions.

Tetra Tech then selected indicators that would measure the gaps between existing and future conditions and achievement of these goals. The greatest management gaps are likely to occur where extreme stormwater flows and volumes and high pollutant loading are occurring or will be occurring in the future. Tetra Tech considered the available data gathered and developed for the LWP, including modeling, field-based assessment, and water quality monitoring data. Field assessments performed for previous tasks have directly contributed to opportunity identification (e.g., stream assessments led to stream enhancement and restoration opportunities). Water quality monitoring and stream assessment data also were used to develop watershed model input and calibration. Since these datasets have already been incorporated in the watershed modeling, the model output provides the best available measure of stressor levels. Another advantage of the watershed model is that it provides output across all subwatersheds throughout an extended continuous period (e.g., annually or seasonally) as opposed to monitoring, which is limited to data at sampling locations reflecting only a few discrete points in time and space. Listed by stressor category, the following indicators were selected to score the subwatersheds:

- **Hydrology:** Percent increase in the time duration of bankfull events compared to undisturbed (forest) conditions based on hourly simulated flow. The bankfull event was defined as the 1.44 year return interval storm event for rural areas in the NC piedmont (Doll et al., 2002). Many researchers have investigated the role of increased duration of near-bankfull events due to urbanization and the risk of increased scour and bank erosion (MacRae, 1992; MacRea, 1993; Bledsoe and Watson, 2001).
- **Sediment:** Upland Sediment (tons/acre/year) and Streambank and Bed Sediment (tons/mile/year) based on simulated loading occurring within subwatershed boundaries.
- **Bacteria:** No direct indicator for subwatershed scoring; considered qualitatively.
- **Oxygen Demanding Substances/Nutrients:** Total nitrogen (TN; lbs/acre/year) and total phosphorus (TP; lbs/acre/year) based on simulated loading from within subwatershed boundaries.
- **Toxicity-related Pollutants:** No direct indicator for subwatershed scoring; considered qualitatively.

The simulation of bacteria and toxicity-related pollutants was beyond the scope of the watershed modeling. In addition, limited monitoring data did not provide a means to compare the contribution of these stressors among all subwatersheds. To address these stressors, Tetra Tech has recommended adjustments to the subwatershed priority list based on a qualitative assessment of potential bacteria or toxicity-related pollutant loading. Further, the TN and TP indicators provided surrogate measures as these constituents tend to be related to bacteria and toxicity loading from nonpoint sources.

2 Scoring Methods

The data used for the scoring was developed as part of the 319 grant-funded watershed modeling developed by Tetra Tech for the Centralina Council of Governments. Loading Simulation Program C++ (LSPC), a continuous simulation watershed hydrology and water quality model, was calibrated and validated using available flow and water quality data. Development of the existing and future baseline scenarios are discussed below.

The Existing Baseline model scenario was developed starting with the 2001 National Land Cover Dataset and updating that coverage based on available parcel-based land use data, the US Forest Service LANDFIRE dataset, and recent aerial photographs. Location and effects of existing stormwater best management practices (BMPs) were estimated to reflect conditions during and prior to the year 2007. For the Future Baseline model scenario, land use/land cover was based on 2030 future conditions projected by Michael Baker Engineering (MBE) for the Monroe Bypass study (MBE, 2010). The Monroe Bypass

study land use data could not be used directly in LSPC, since different assumptions were used and the land use classes were not equivalent. The Monroe Bypass study provided semi-spatial land use assignment for both current and future 2030 conditions, so the increase in development area and type was calculated within each LSPC subbasin. A translation methodology was developed for relating Monroe Bypass study existing land use to LSPC existing land use, and the change in developed land use was applied within each subbasin using the same translation methods. Undeveloped land covers were reduced within each subbasin, according to relative proportions of both land cover and hydrologic soil group (HSG).

Future BMPs were reflected in the model using three general BMP applications: wet ponds meeting minimum stormwater requirements, bioretention in rural areas meeting more stringent requirements, and wet ponds in urban areas meeting more stringent requirements. The more stringent requirements reflect meeting stormwater requirements for the Goose Creek watershed and applicable areas within the Crooked Creek watershed. Bioretention was selected for low density development in Goose Creek because it supports infiltration (a requirement of the Goose Creek rules) and its relatively large footprint could more easily be integrated with site landscaping. Wet ponds are a more likely candidate when space is at a premium; in addition, they can be used to meet all the multiple, layered regulations, and designers have a lot of experience implementing them. Details on the model development, calibration, and validation are provided in a separate technical memorandum.

Using the LSPC model output, the hydrology indicator was calculated using hourly simulated flow. The upland sediment and nutrient loading rates reflect annual average loading from within each subwatershed and are not cumulative loading rates. LSPC instream sediment loading output was also used to calculate the bank and bed sediment indicator. To the extent possible, this indicator reflects loading generated from within a particular subwatershed. Bank erosion is derived for each individual reach. Bed sediment could not be calculated independently of contributions from upstream subwatersheds. The contributions from traditional point sources are not included in the loading values used for the prioritization. Management of point sources will be discussed in the final watershed management plan.

The Goose and Crooked Creek watersheds were scored separately to provide each watershed a similar number of priority subwatersheds and to ensure protection of the Carolina heelsplitter. For each indicator, the subwatersheds were scored from 2.5 to 10 points, with 2.5 representing the greatest contribution to stressors, or worst conditions, and 10 representing the least contribution to stressors, or best conditions. The scores were assigned based on statistical quartiles of the existing conditions data. For each indicator, subwatersheds within the first quartile (lowest 25 percent) received a score of 10, subwatersheds within the second quartile (between the lowest 25 and 50th percentiles) received a score of 7.5, and so on. Tables 2 and 3 display the quartile values used to assign scores for each indicator. Appendix B provides the data used to score the subwatersheds. The quartile upper limit indicates the highest value within each quartile. The same scoring criteria were used for existing and future conditions so that changes would be apparent and potential declines in conditions could be identified.

For the sediment and oxygen demanding substance categories, two indicators were used for each category. Under these categories, the individual scores were averaged to calculate a composite score for each category. The sediment and hydrology categories were given double weight because these stressors are considered of primary importance to watershed functions according to the preliminary findings. Once the weights were assigned, a weighted average was calculated across each category score to achieve an overall composite score across the indicators. Table 4 outlines this calculation process.

Table 2. Scoring Thresholds for the Goose Creek Watershed

Indicator	Thresholds by Level of Impact (Unweighted Score)			
	Very High (2.5)	High (5)	Medium (7.5)	Low (10)
Hydrology (%)	296%	54%	14%	12%
Sediment, Upland (ton/ac/yr)	0.19	0.15	0.11	0.08
Sediment, Bank and Bed (ton/mi/yr)	271	225	101	43
Oxygen-demanding Substances, Total Phosphorus (lb/ac/yr)	1.11	0.89	0.63	0.46
Oxygen-demanding Substances, Total Nitrogen (lb/ac/yr)	10.28	8.03	6.16	4.90

Table 3. Scoring Thresholds for the Crooked Creek Watershed

Indicator	Thresholds by Level of Impact (Unweighted Score)			
	Very High (2.5)	High (5)	Medium (7.5)	Low (10)
Hydrology (%)	434%	46%	35%	17%
Sediment, Upland (ton/ac/yr)	0.18	0.16	0.13	0.11
Sediment, Bank and Bed (ton/mi/yr)	274	180	99	35
Oxygen-demanding Substances, Total Phosphorus (lb/ac/yr)	1.13	0.96	0.90	0.70
Oxygen-demanding Substances, Total Nitrogen (lb/ac/yr)	9.27	8.33	7.26	6.37

Table 4. Weighted and Composite Score Calculations for the Goose and Crooked Creek Watersheds

Indicator	Calculation	Example (GC 1, Future)
Hydrology Weighted Score	2 X Hydrology Score	10 x 2 =20
Sediment, Composite Weighted Score	2 X Average of Upland and Bank and Bed scores	Avg(5, 2.5) x 2 = 7.6
Oxygen-demanding Substances, Composite Weighted Score	1 X Average of TP and TN scores	Avg(5, 5) = 5
Overall Composite	Sum of weighted scores divided by sum of indicator weights	Sum(20, 7.6, 5) / 5 = 6.5

3 Results and Discussion

Figure 2 and Figure 3 display the results of the stressor-based scoring for existing and future conditions, respectively, and the scoring results for each watershed are detailed in Appendix C. The subwatersheds are shaded according to natural breaks in the overall composite scores. Two tiers of priorities are recommended: Tier I represents primary management needs, and Tier II represents secondary management needs.

For Tier I priorities under existing conditions, the scoring results suggest that the ten lowest scoring subwatersheds, GC1, GC3, GC4, GC5, GC9, GC13, CC3, SF2, SF5, and SF6, exhibit a high level of stressors compared to the rest of the study area. Tetra Tech is recommending that these subwatersheds be considered Tier I priorities for managing existing stressors. In particular, the headwater subwatersheds SF5 and SF6 were given low scores under the hydrology and oxygen demanding substance indicators (particularly total phosphorus). These results are expected, as some of the densest commercial and industrial land use exists in this portion of the watershed, and these two subwatersheds straddle the NC-74 corridor where this development is concentrated.

Subwatershed SF2 also stands out as an area with significant management needs for stream erosion, hydrology, and pollutant loading. Reaches within this subwatershed were found to have high streambank erosion risk during field assessments (Tetra Tech, 2008; Tetra Tech, 2010). Low scores for the bed and bank indicators, as well as moderately low scores under the hydrology and nitrogen indicators, contributed to an overall Tier I priority recommendation for this subwatershed.

Subwatersheds CC3, GC1, GC3, GC4, and GC5 are recommended as Tier I priorities due to their low scores across most indicators. These subwatersheds contain a large percentage of agricultural land that contributes sediment and nutrient loading to runoff. In addition, the cumulative influence over time of upstream development likely contributes to poor bank and channel stability in subwatersheds GC1, GC3, and GC4.

Finally, subwatersheds GC9 and GC13 received low composite scores due to conditions relating to hydrology and total phosphorus loading. Although bank and bed sediment is not as great a concern in these subwatersheds, the relatively high duration of bankfull events could be affecting conditions in downstream subwatersheds.

As explained in Section 1, the TN and TP indicators provide surrogates for estimating potential trends in fecal coliform and toxicity loading since the limited data available for these constituents does not provide a means of comparing subwatersheds. Several subwatersheds exhibit high loading for both TN and TP due to a high percentage of agricultural land. DC1, CC4, and CC5 received low scores under TN and TP and relatively low overall composite scores while being among the subwatersheds with high percentages of agricultural land.

Although no streams near DC1, CC4, and CC5 were sampled for fecal coliform, it is possible that livestock operations or other agricultural activities may be contributing fecal coliform loading in these subwatersheds. Due to their high percentage of agricultural land and high simulated nutrient loading, these subwatersheds appear to have the greatest potential for contributing to bacteria loading in addition to the subwatersheds already selected as Tier I priorities. DC1, CC4, and CC5 were added to the list of recommended Tier I priority subwatersheds to ensure that management for bacteria loading is addressed. Regarding urban sources of fecal coliform, the urban subwatersheds already recommended for the priority list likely represent bacteria loading priorities for urban source management.

No additional subwatersheds are recommended as priority due to toxicity loading. The urban subwatersheds already recommended, especially SF5 and SF6 along NC-74, are likely among the greatest contributors of toxicity from urban sources. The greatest toxicity loading from agricultural sources is likely captured by prioritizing subwatersheds DC1, GC1, GC3, GC4, GC5, CC3, CC4, and CC5 under

Tier I. It should be noted that the priorities based on bacteria and toxicity are uncertain, and if data are available in the future on these constituents, the priority subwatersheds could be re-evaluated. A red border in Figure 2 indicates the 13 subwatersheds recommended as Tier I management priorities under the existing baseline.

Under future conditions, 10 of the 13 existing Tier I priorities remain priorities for management because they received the lowest overall scores under future conditions or had low scores (very high loading) under the TN and TP indicators (Figure 3). Conditions in SF2, GC1, and GC3 are estimated to improve in the future compared to existing conditions through conversion of agricultural land to development with water quality treatment, and therefore, these subwatersheds were not recommended as future management priorities (although enforcement of water quality treatment practices should be emphasized as being critical to improved conditions).

A yellow border indicates the subwatersheds recommended as Tier II management priorities under both the existing and future baselines in Figure 2 and Figure 3. These subwatersheds exhibit moderate to high level stressors across the indicators and/or low scores (very high loading) under the TN and TP indicators. Management focused only on the Tier I priority subwatersheds may miss opportunities to improve watershed conditions with management in these additional subwatersheds.

The Tier I and II priority subwatersheds are recommended as tools for selecting the most promising management opportunities for the Goose Creek and Crooked Creek LWP. During the development of the watershed management plan, these priorities will aid in identifying management opportunities that would best address the major stressors and help restore and protect watershed functions.

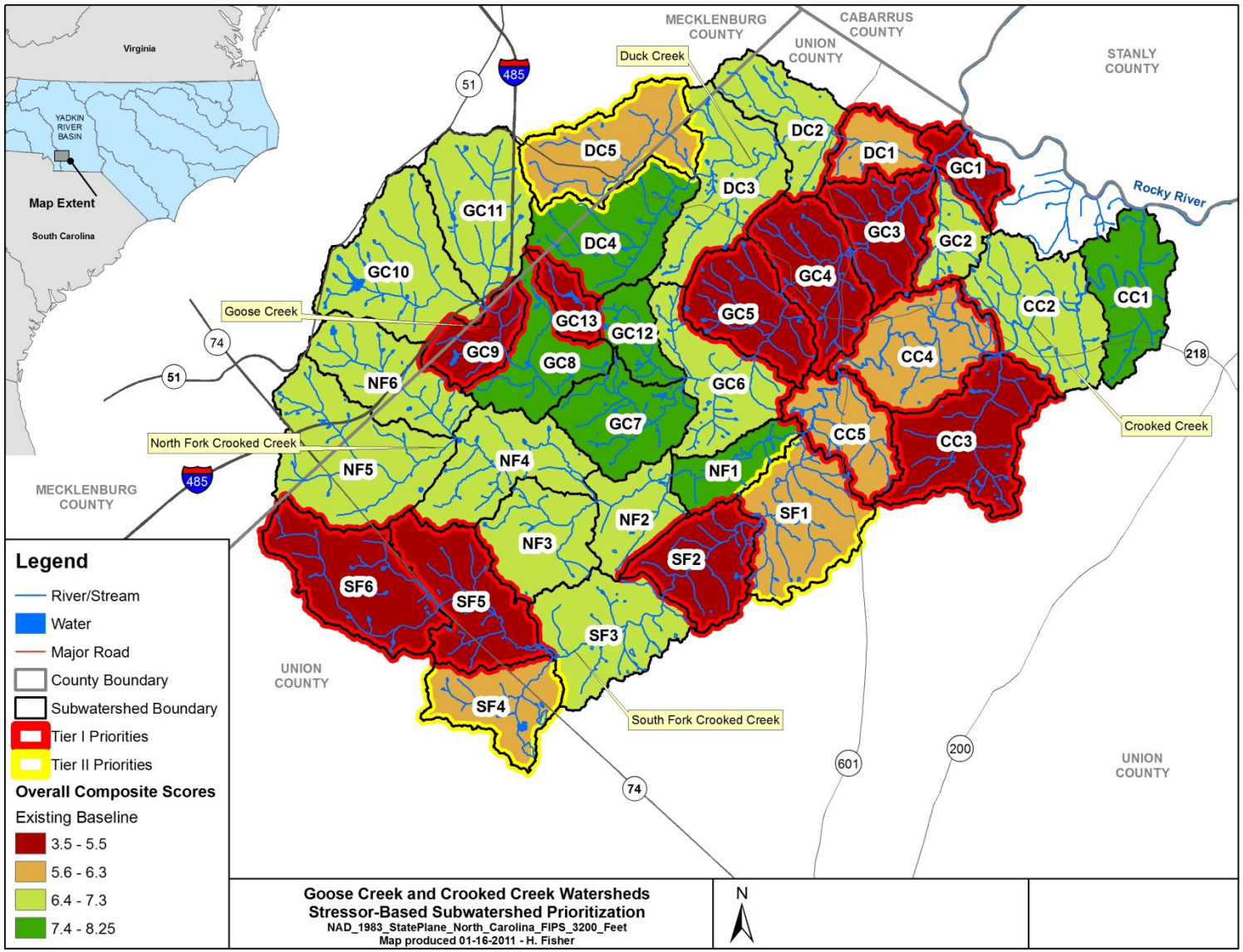


Figure 2. Existing Baseline Subwatershed Scoring Results and Priority Recommendations

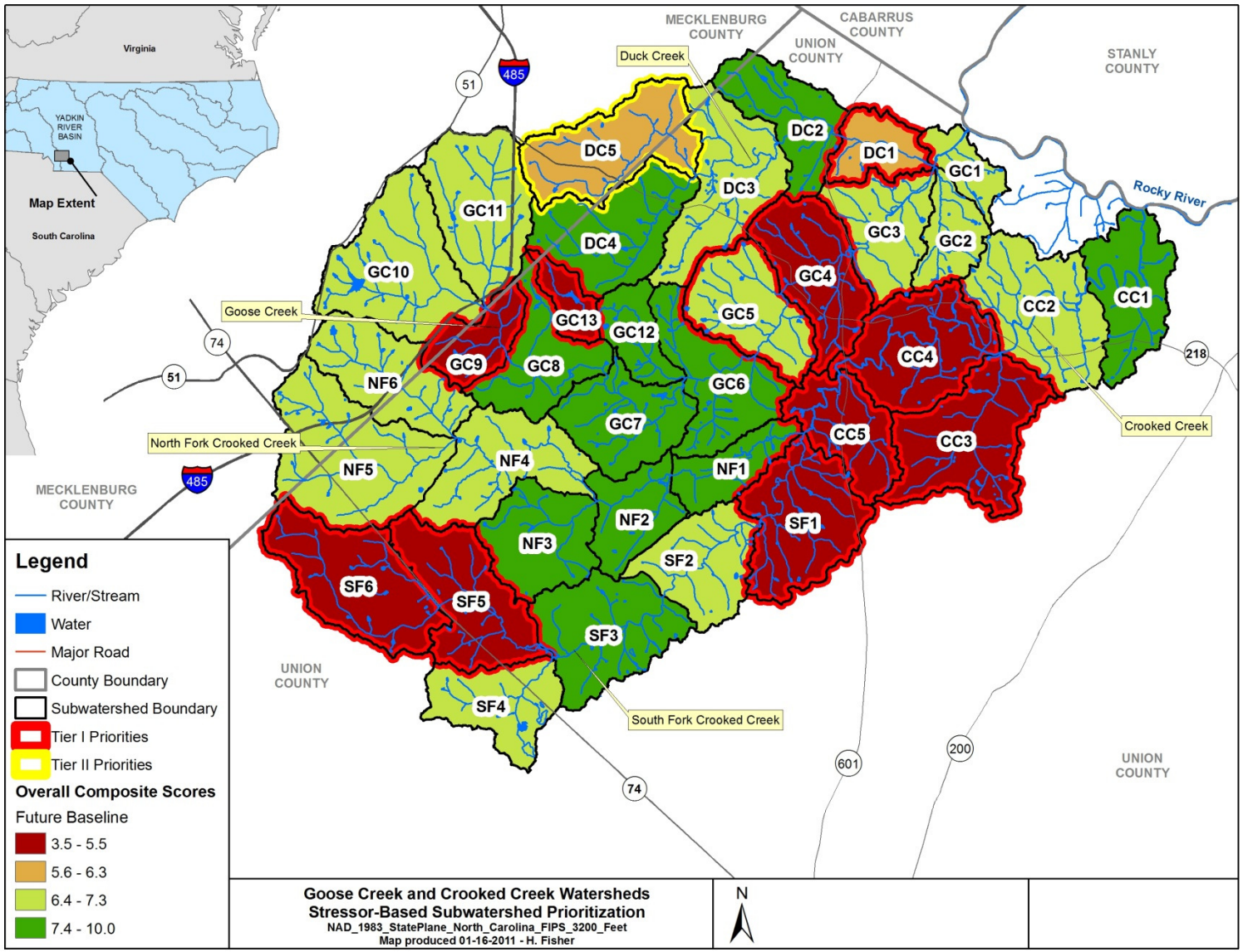


Figure 3. Future Baseline Subwatershed Scoring Results and Priority Recommendation

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Appendix A. LWP Goals and Objectives



NC Ecosystem Enhancement Program
Goose Creek & Crooked Creek Local Watershed Plan – Phases II & III
GOALS AND OBJECTIVES
Adopted 3/29/11

GOAL 1:
Restore, protect, and enhance watershed functions such as hydrology, water quality, and aquatic and terrestrial habitat

OBJECTIVES 1:

a) Restore, expand, support, and protect beneficial watershed functions and uses including:
   - Protect flood plain function
   - Terrestrial & aquatic habitat
     i. Environmentally sensitive and critical lands
        1. Undeveloped natural areas
        2. Natural area connectivity
     ii. Native vegetation
     iii. Native aquatic biology
     iv. In-stream habitat
   - Recreation
   - Wetland hydrology

b) Design and construct projects to restore, maintain, and enhance:
   - Stream banks
   - Riparian areas
   - Wildlife habitat areas
   - In-stream habitat
   - Riparian buffers
   - Wetlands

c) Minimize impacts of stormwater runoff and erosion on stream hydrology to promote stable stream morphology and protect aquatic habitat and native tree species

d) Minimize impacts on water quality by pathogens, nutrients, and other pollutants in stormwater runoff

e) Cooperate with property owners and permitting agencies to detect and eliminate illicit discharges, sanitary sewer overflows, and malfunctioning septic systems to protect human health, enhance water quality and aquatic habitat

f) Address impacts to stream water quality due to livestock access to streams

g) Address pollutant(s) of concern for state approved Total Maximum Daily Loads and water quality improvement plans

GOAL 2:
To minimize impacts on water quality, aquatic and terrestrial habitat, and hydrology in the watershed by supporting balanced, sustainable, and diverse land use and development, in accordance with existing and future policies

OBJECTIVES 2:

a) Promote site planning, design, construction and maintenance strategies to maintain or restore hydrology and water quality of the property

b) Identify strategies that strive to maximize effectiveness, minimize cost, and minimize impacts on businesses and residents where possible

c) Identify restoration and protection strategies that complement comprehensive plans and policies and provide multiple benefits such as recreation and protection of critical lands

d) Design and construct infrastructure projects (e.g., water/sewer lines, energy transmission lines, etc.) in manner that minimizes impacts on watershed functions (i.e., water quality, habitat, and hydrology)

e) Promote design and construct new developments, recreation areas, etc. in manner that minimizes impacts on watershed functions, including minimizing impervious areas

GOAL 3:
Build partnerships and involve stakeholders in the protection and restoration of the watersheds

OBJECTIVES 3:

a) Increase education, awareness, and stewardship within the watershed, including encouraging policy makers to develop policies that support a healthy watershed

b) Identify and recruit stakeholders and partners in protecting, maintaining, and restoring watersheds in Mecklenburg and Union counties

c) Report progress toward protection and restoration through monitoring and assessment

d) Identify funding for implementation

e) Seek adoption or endorsement of the local watershed plan by each local jurisdiction within the watersheds

Appendix B. Indicator Data

Table B-1. Indicator Data by Subwatershed, Existing Conditions

Subwatershed	Hydrology (% increase bankfull time duration compared to forested)	Upland Sediment (tons/acre/year)	Bank and Bed Sediment (tons/mi/year)	Total Phosphorus (lbs/acre/year)	Total Nitrogen (lbs/acre/year)
GC1	13%	0.16	271	0.88	7.9
GC2	12%	0.16	22	0.92	8.1
GC3	14%	0.16	245	0.91	8.5
GC4	28%	0.19	261	1.11	9.4
GC5	13%	0.16	165	0.97	10.3
GC6	15%	0.09	66	0.49	6.0
GC7	7%	0.08	133	0.41	5.4
GC8	21%	0.08	62	0.45	4.3
GC9	82%	0.12	29	0.89	5.2
GC10	296%	0.05	74	0.45	3.1
GC11	279%	0.06	26	0.53	3.6
GC12	14%	0.09	31	0.50	6.4
GC13	63%	0.11	81	0.77	5.3
DC1	11%	0.14	246	0.81	9.2
DC2	8%	0.12	210	0.61	7.0
DC3	8%	0.12	230	0.66	7.6
DC4	18%	0.08	36	0.43	4.8
DC5	164%	0.05	121	0.40	3.1
CC1	9%	0.16	27	0.90	8.3
CC2	14%	0.17	35	0.96	8.3
CC3	21%	0.18	83	1.09	9.1
CC4	14%	0.16	179	0.94	8.5
CC5	17%	0.16	152	0.98	9.3
SF1	29%	0.12	236	0.72	7.4
SF2	36%	0.13	144	0.76	7.8
SF3	35%	0.11	226	0.66	6.8
SF4	42%	0.13	41	0.90	7.1
SF5	84%	0.13	75	0.98	6.3
SF6	74%	0.14	32	1.13	7.3
NF1	16%	0.11	180	0.63	7.4

Subwatershed	Hydrology (% increase bankfull time duration compared to forested)	Upland Sediment (tons/acre/year)	Bank and Bed Sediment (tons/mi/year)	Total Phosphorus (lbs/acre/year)	Total Nitrogen (lbs/acre/year)
NF2	20%	0.10	274	0.62	7.1
NF3	40%	0.11	34	0.76	6.4
NF4	46%	0.10	205	0.70	5.7
NF5	434%	0.10	31	0.91	5.2
NF6	357%	0.08	99	0.67	4.2

Table B-2. Indicator Data by Subwatershed, Future Conditions

Subwatershed	Hydrology (% increase bankfull time duration compared to forested)	Upland Sediment (tons/acre/year)	Bank and Bed Sediment (tons/mi/year)	Total Phosphorus (lbs/acre/year)	Total Nitrogen (lbs/acre/year)
GC1	11%	0.15	307	0.83	7.5
GC2	9%	0.16	21	0.90	7.9
GC3	8%	0.15	243	0.86	8.0
GC4	24%	0.18	261	1.06	8.9
GC5	9%	0.15	164	0.91	9.7
GC6	10%	0.08	66	0.48	5.8
GC7	4%	0.07	133	0.39	4.9
GC8	11%	0.07	62	0.43	3.8
GC9	80%	0.12	25	0.88	5.0
GC10	326%	0.05	74	0.43	2.9
GC11	329%	0.05	21	0.48	3.1
GC12	12%	0.09	30	0.49	6.2
GC13	63%	0.11	81	0.77	5.3
DC1	6%	0.13	241	0.77	8.7
DC2	6%	0.11	206	0.59	6.7
DC3	6%	0.12	225	0.63	7.2
DC4	7%	0.07	34	0.41	4.5
DC5	180%	0.05	120	0.37	2.8
CC1	14%	0.16	24	0.89	8.0
CC2	18%	0.17	35	0.95	8.0
CC3	26%	0.18	87	1.06	8.8
CC4	18%	0.16	176	0.93	8.2
CC5	20%	0.17	149	0.98	9.1
SF1	41%	0.12	243	0.71	6.8
SF2	32%	0.12	146	0.73	7.2
SF3	30%	0.10	229	0.61	5.9
SF4	38%	0.12	40	0.88	6.6
SF5	83%	0.12	76	0.98	6.1
SF6	77%	0.14	32	1.12	7.0
NF1	17%	0.11	181	0.63	7.3
NF2	18%	0.09	281	0.58	6.4
NF3	40%	0.10	31	0.73	5.6
NF4	41%	0.09	202	0.66	4.8
NF5	453%	0.09	26	0.85	4.7
NF6	367%	0.07	95	0.63	3.8

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Appendix C. Scores

Table C-1. Subwatershed Scores, Existing (all scores shown are unweighted except overall composite, which is calculated by weighting the scores.)

Sub-watershed	Hydrology	Sediment			Oxygen-demanding Substances			Overall Composite
		Upland Sediment	Bank and Bed Sediment	Sediment Composite	Total Phosphorus	Total Nitrogen	Oxygen Demanding Composite	
Weight	**2**			**2**			**1**	
GC1	7.5	2.5	2.5	2.5	5.0	5.0	5.0	5.0
GC2	10.0	2.5	10.0	6.3	2.5	2.5	2.5	7.0
GC3	7.5	2.5	2.5	2.5	2.5	2.5	2.5	4.5
GC4	5.0	2.5	2.5	2.5	2.5	2.5	2.5	3.5
GC5	7.5	2.5	5.0	3.8	2.5	2.5	2.5	5.0
GC6	5.0	7.5	7.5	7.5	7.5	7.5	7.5	6.5
GC7	10.0	7.5	5.0	6.3	10.0	7.5	8.8	8.3
GC8	5.0	10.0	7.5	8.8	10.0	10.0	10.0	7.5
GC9	2.5	5.0	10.0	7.5	2.5	7.5	5.0	5.0
GC10	2.5	10.0	7.5	8.8	10.0	10.0	10.0	6.5
GC11	2.5	10.0	10.0	10.0	7.5	10.0	8.8	6.8
GC12	7.5	7.5	10.0	8.8	7.5	5.0	6.3	7.8
GC13	2.5	7.5	7.5	7.5	5.0	7.5	6.3	5.3
DC1	10.0	5.0	2.5	3.8	5.0	2.5	3.8	6.3
DC2	10.0	5.0	5.0	5.0	7.5	5.0	6.3	7.3
DC3	10.0	5.0	2.5	3.8	5.0	5.0	5.0	6.5
DC4	5.0	10.0	10.0	10.0	10.0	10.0	10.0	8.0
DC5	2.5	10.0	5.0	7.5	10.0	10.0	10.0	6.0
CC1	10.0	5.0	10.0	7.5	5.0	5.0	5.0	8.0
CC2	10.0	2.5	10.0	6.3	5.0	2.5	3.8	7.3
CC3	7.5	2.5	7.5	5.0	2.5	2.5	2.5	5.5
CC4	10.0	2.5	5.0	3.8	5.0	2.5	3.8	6.3
CC5	10.0	2.5	5.0	3.8	2.5	2.5	2.5	6.0
SF1	7.5	7.5	2.5	5.0	7.5	5.0	6.3	6.3
SF2	5.0	5.0	5.0	5.0	7.5	5.0	6.3	5.3
SF3	7.5	10.0	2.5	6.3	10.0	7.5	8.8	7.3
SF4	5.0	5.0	7.5	6.3	7.5	7.5	7.5	6.0
SF5	2.5	7.5	7.5	7.5	2.5	10.0	6.3	5.3
SF6	2.5	5.0	10.0	7.5	2.5	7.5	5.0	5.0
NF1	10.0	7.5	5.0	6.3	10.0	5.0	7.5	8.0

Sub-watershed	Hydrology	Sediment			Oxygen-demanding Substances			Overall Composite
		Upland Sediment	Bank and Bed Sediment	Sediment Composite	Total Phosphorus	Total Nitrogen	Oxygen Demanding Composite	
Weight	**2**			**2**			**1**	
NF2	7.5	10.0	2.5	6.3	10.0	7.5	8.8	7.3
NF3	5.0	7.5	10.0	8.8	7.5	10.0	8.8	7.3
NF4	5.0	10.0	2.5	6.3	10.0	10.0	10.0	6.5
NF5	2.5	10.0	10.0	10.0	5.0	10.0	7.5	6.5
NF6	2.5	10.0	7.5	8.8	10.0	10.0	10.0	6.5

Table C- 2. Subwatershed Scores, Future (all scores shown are unweighted except overall composite, which is calculated by weighting the scores.)

Sub-watershed	Hydrology	Sediment			Oxygen-demanding Substances			Overall Composite
		Upland Sediment	Bank and Bed Sediment	Sediment Composite	Total Phosphorus	Total Nitrogen	Oxygen Demanding Composite	
Weight	**2**			**2**			**1**	
GC1	10.0	5.0	2.5	3.8	5.0	5.0	5.0	6.5
GC2	10.0	2.5	10.0	6.3	2.5	5.0	3.8	7.3
GC3	10.0	5.0	2.5	3.8	5.0	5.0	5.0	6.5
GC4	5.0	2.5	2.5	2.5	2.5	2.5	2.5	3.5
GC5	10.0	5.0	5.0	5.0	2.5	2.5	2.5	6.5
GC6	10.0	7.5	7.5	7.5	7.5	7.5	7.5	8.5
GC7	10.0	10.0	5.0	7.5	10.0	7.5	8.8	8.8
GC8	10.0	10.0	7.5	8.8	10.0	10.0	10.0	9.5
GC9	2.5	5.0	10.0	7.5	5.0	7.5	6.3	5.3
GC10	2.5	10.0	7.5	8.8	10.0	10.0	10.0	6.5
GC11	2.5	10.0	10.0	10.0	7.5	10.0	8.8	6.8
GC12	10.0	7.5	10.0	8.8	7.5	5.0	6.3	8.8
GC13	2.5	7.5	7.5	7.5	5.0	7.5	6.3	5.3
DC1	10.0	5.0	2.5	3.8	5.0	2.5	3.8	6.3
DC2	10.0	7.5	5.0	6.3	7.5	5.0	6.3	7.8
DC3	10.0	5.0	5.0	5.0	7.5	5.0	6.3	7.3
DC4	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
DC5	2.5	10.0	5.0	7.5	10.0	10.0	10.0	6.0
CC1	10.0	5.0	10.0	7.5	7.5	5.0	6.3	8.3
CC2	7.5	2.5	10.0	6.3	5.0	5.0	5.0	6.5
CC3	7.5	2.5	7.5	5.0	2.5	2.5	2.5	5.5

Sub-watershed	Hydrology	Sediment			Oxygen-demanding Substances			Overall Composite
		Upland Sediment	Bank and Bed Sediment	Sediment Composite	Total Phosphorus	Total Nitrogen	Oxygen Demanding Composite	
CC4	7.5	2.5	5.0	3.8	5.0	5.0	5.0	5.5
CC5	7.5	2.5	5.0	3.8	2.5	2.5	2.5	5.0
SF1	5.0	7.5	2.5	5.0	7.5	7.5	7.5	5.5
SF2	7.5	7.5	5.0	6.3	7.5	7.5	7.5	7.0
SF3	7.5	10.0	2.5	6.3	10.0	10.0	10.0	7.5
SF4	5.0	7.5	7.5	7.5	7.5	7.5	7.5	6.5
SF5	2.5	7.5	7.5	7.5	2.5	10.0	6.3	5.3
SF6	2.5	5.0	10.0	7.5	2.5	7.5	5.0	5.0
NF1	10.0	7.5	2.5	5.0	10.0	5.0	7.5	7.5
NF2	7.5	10.0	2.5	6.3	10.0	10.0	10.0	7.5
NF3	5.0	10.0	10.0	10.0	7.5	10.0	8.8	7.8
NF4	5.0	10.0	2.5	6.3	10.0	10.0	10.0	6.5
NF5	2.5	10.0	10.0	10.0	7.5	10.0	8.8	6.8
NF6	2.5	10.0	7.5	8.8	10.0	10.0	10.0	6.5