Development of a Wetland Monitoring Program for Headwater Wetlands in North Carolina

Final Report of EPA Grant CD 974260-01

Department of Environment and Natural Resources
North Carolina Division of Water Quality

May 2008

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Acknowledgements

The project coordinators, Rick Savage and Virginia Baker, would like to first acknowledge and thank the U.S. Environmental Protection Agency (U.S. EPA) for their continual support of grant-funded projects awarded to the North Carolina Division of Water Quality (NC DWQ). This wetlands monitoring study would not have happened without the support of the EPA. We would also like to especially thank John Dorney, the NC DWQ Program Development Unit Supervisor. John's persistence and vision was the primary reason this wetland-monitoring project was initiated. John has continued to provide his professional expertise, insight, and direction throughout the completion of this project. We would like to thank our technicians that worked on this project, Alicia Duclos, Sonia Gregory, Caroline Reddy, and Mike Turner, who each contributed hours of hard work. They always had excellent work ethics no matter how difficult the field conditions or long and tedious the office assignment was. Additionally, Caroline Reddy and Mike Turner wrote much of the introductory background sections for the soils, hydrology, amphibians and macroinvertebrates. We would like to thank Larry Eaton, Steve Kroeger, and Susan Gale of NC DWQ Program Development Unit. Larry Eaton assisted with the development of the macroinvertebrate field methods and macroinvertebrate candidate metrics; Susan Gale trained us on water quality sampling and NC DWQ lab standards; and Steve Kroeger assisted us with the use of JMP statistical software. Additionally, we would like to thank Alvin Braswell, the deputy director of the NC Museum of Natural Sciences, who assisted with the identification of the amphibians collected and photographed specimens. Lastly, we would like to thank our contractors, Rhinthron Associates Inc., for their identification work of our macroinvertebrate specimens, and Alan Weakley, curator of the University of North Carolina Herbarium, for his assistance with identification of plant voucher specimens and with the development of the Plant Index of Biotic Integrity.

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ABBREVIATIONS

AMS: North Carolina Division of Water Quality Ambient Monitoring System

DN: Downstream

EPA : United States Environmental Protection Agency

DN-FD: Downstream to Further Downstream Water Quality Station Comparison

FD: Further Downstream

LDI: Land Development Index

NCDWQ: North Carolina Division of Water Quality

ORAM: Ohio Rapid Assessment Method

UP: Upstream

UP-DN: Upstream to Downstream Water Quality Station Comparison

UP-FD: Upstream to Further Downstream Water Quality Station Comparison

USGS: United States Geological Survey

IBI: Index of Biotic Integrity

C of C: Coefficient of Conservation

FQAI: Floristic Quality Assessment Index

FAQWet: Floristic Assessment Quotient for Wetland Plants Index

DBH: Diameter at Breast Height

AQAI: Amphibian Quality Assessment Index

EW-HW-SW: Ephemeral Wetland-Headwater Wetland-Seepage Wetland amphibian species

EPT: Ephemeroptera, Plecoptera, Trichoptera

OET: Odonata, Ephemeroptera, Trichoptera

POET: Plecoptera, Odonata, Ephemeroptera, Trichoptera

MBI: Macroinvertebrate Biotic Index

DTW: Distance to Water

AC: Exchangeable Acidity

CEC: Cation Exchange Capacity

Section 1.1 Executive Summary

North Carolina wetlands have been affected negatively by watershed development. Urbanization, agriculture and silviculture have altered the quality of stormwater runoff that flows into wetlands and impacts surrounding upland buffers and wildlife corridors. Wetlands can act as a natural filtering system for water quality by removing, reducing, or transforming pollutants. This natural filtering is especially important with headwater wetland systems since they are the primary water source for first order streams. These wetlands also reduce downstream erosion by retaining stormwater runoff and releasing it more slowly after a heavy rain. Headwater wetlands provide important habitat for macroinvertebrates and amphibians, both of which are sensitive to stressors in their environment such as impacts to water quality and wetland habitat, and deforestation of the surrounding upland buffer. Maintaining the ecological integrity of these headwater wetland systems is necessary not only to protect wildlife habitat but also to protect the water quality of the entire downstream watershed.

The original objective of this EPA Wetland Program Development Grant (CD 974260-01) was to "elucidate the differences and similarities among amphibians, macroinvertebrates and vegetation along a gradient of human disturbance within specific wetland types". To meet this objective, a NC wetland monitoring program was begun with a focus on the monitoring of physical, chemical, and biological parameters of one type of wetland- headwater wetlands. Headwater wetlands were chosen as the initial wetland type to monitor because these systems are a very important natural resource found in the highest reaches of watersheds across the entire state. The North Carolina Division of Water Quality (NC DWQ) conducted a monitoring effort on 11 Coastal Plain and 12 Piedmont headwater wetlands located along a disturbance gradient during a two year period. Two physiographic regions were chosen to examine any variation of headwater wetlands across these regions. Monitoring strategies were developed for wetland water quality, hydrology, soils, amphibians, macroinvertebrates, and plants. Disturbance measurements of each wetland were determined with the Ohio Rapid Assessment Method (ORAM is a wetland rapid assessment) and a Land Development Index in order to analyze the abiotic and biotic data.

This study showed that headwater wetlands located in the Piedmont tended to be small bowl-shaped wetlands that graded into narrow intermittent or perennial channels while headwater wetlands in the Coastal Plain were flatter wider systems. Headwater wetlands are often impacted by road crossings and ditches (especially in the Coastal Plain) that have the capacity to alter the hydrology, water quality, and habitat structure. Impacts to the watershed and headwater wetlands can be especially damaging since headwater wetlands affect downstream aquatic resources. Regional differences as well as the quality of the wetland can cause variability between the soils, topography, and vegetation, which can affect the water quality. In this study, water quality in the Coastal Plain was more acidic and had higher levels of calcium and magnesium most likely due to regional soil differences. Headwater wetlands that have maintained a natural condition are forested with mature trees, primarily hardwoods with red maple (*Acer rubrum*), sweet gum (*Liquadambar styraciflua*), and tulip poplar (*Liriodendron tulipifera*) dominating in both the Coastal Plain and Piedmont regions. Coastal Plain headwater wetlands tend to have a more dense coverage of shrubs and understory trees while Piedmont headwater wetlands have a more diverse and denser coverage of herbaceous plant species. A diverse array of amphibian and macroinvertebrate species is found in headwater wetlands. Many amphibian species require the fish-free conditions that undisturbed headwater wetlands provide. This study, found 26 species of amphibians (17 in the Coastal Plain and 19 species in the Piedmont), 5 of which require fish-free conditions, and 246 macroinvertebrate taxon (160 in the Coastal Plain and 175 in the Piedmont).

The water quality analysis showed that headwater wetlands effectively reduce pollutants in downstream waters, have a significant correlation between water quality and the condition of the wetland water quality and the condition of the watershed, and that headwater wetlands of lower quality actually have a better capacity for reducing pollutants than wetlands of higher quality. This last finding indicates that headwater wetlands still maintain the ability to filter pollutants even when impacted by human disturbance. The hydrological analysis showed that headwater wetlands located in more urban watersheds tended to have flashier hydroperiods than wetlands located in more natural watersheds. During the growing season, the water table remained within a foot of the ground level at least 46% of the time. The water table was within a foot of the surface 75% and 72% of the growing season for the Coastal Plain and Piedmont sites respectively. The water table for urban headwater wetlands sites was within a foot of the surface during the growing season 62% of the time whereas natural sites had a longer period of 84%. The soils analysis showed that magnesium, copper, and zinc soil content increased as the quality of the wetland and surrounding buffer decreased. Draft Indices of Biotic Integrity (IBIs), composed of five to ten metrics, were developed from the amphibian, macroinvertebrate, and plant monitoring survey results to measure how disturbance affects these biotic communities. Candidate metrics were identified through the examination of the monitoring results and a literature review of comparable studies. The amphibian and macroinvertebrate metrics responded more to the specific water quality and soil chemistry disturbance rather than ORAM and LDI, indicating these taxa are influenced more by water quality and soil chemistry than by wetland condition (ORAM) and surrounding land cover (LDI). The plant metrics, however, did have a strong correlation with LDI and ORAM. The biotic results of this study show there are significant differences between amphibian, macroinvertebrate, and plant communities located in headwater wetlands of variable quality.

Section 1.2 Purpose and Goals

The original objective of this Wetland Monitoring Grant (CD 974260-01) was to "elucidate the differences and similarities among amphibians, macroinvertebrates, and vegetation along a gradient of human disturbance within specific wetland types". In order to meet this objective the North Carolina wetland monitoring program was initiated with the physical, chemical, and biological monitoring of 23 headwater wetlands located in the Piedmont and Coastal Plain regions of North Carolina. Wetland sites located in urban, agricultural, and natural (i.e. primarily forested) watersheds were chosen to meet this goal. Physical and / or chemical monitoring of the abiotic headwater wetland characteristics was accomplished by surveying the water quality, hydrology, and soils while biological monitoring of the biotic headwater wetland characteristics was accomplished by surveying the amphibian, macroinvertebrate, and plant populations. A second objective was to characterize and gain a better understanding of the water quality, hydrology, soils, amphibians, macroinvertebrates, and plants of headwater wetlands in the Piedmont and Coastal Plain.

PHYSICAL AND CHEMICAL MONITORING

The water quality monitoring was a particularly important part of this headwater wetland study because states are required to protect the water quality of waters under Section 401 of the Clean Water Act (33 U.S.C. 1344, U.S. EPA 1989). Water that originates in headwater wetlands ultimately discharges into downstream navigable waters of the US. The primary goals of the water quality-monitoring plan were:

1. To determine how the water quality of headwater wetlands within more developed watersheds compared with the water quality of headwater wetlands within more natural watersheds.

2. To determine whether headwater wetlands are able to filter pollutants by comparing upstream station results to downstream station results.

3. To determine whether headwater wetlands located in a more natural watershed have a better filtering capacity for removing pollutants than wetlands located in a more developed watershed.

Secondary goals of the water quality monitoring included: 1) to compare Coastal Plain and Piedmont water quality to see what variations existed between regions; 2) to compare headwater wetland water quality to North Carolina stream water quality to see how headwater wetlands differed from small perennial streams; 3) to compare water quality results through the different seasons to see if there are any seasonal trends in water quality; and, 4) evaluate how individual sites compared to each other with a cluster analysis.

The goals of the hydrology monitoring were to develop hydroperiods for 12 of the sites, six in the Coastal Plain and six in the Piedmont. Sites located in urban, agricultural, and natural watersheds were chosen to see if watershed development had any effect on the headwater wetland hydroperiod. Seasonal trends were reviewed to see how hydrology changed across the season. Additionally, regional comparisons were made to see if region had any significant effects on hydrology.

The goals of the soil monitoring were to determine if the condition of the watershed or the wetland had any effect on the chemical and physical characteristics of the soil. The soil samples taken in the wetland, the downstream wetland corridor, and surrounding upland were also compared to see if there were any significant differences. Lastly, a regional comparison of the soil characteristics was completed to see how chemical and physical soil qualities compared within regions.

BIOTIC AND CHEMICAL MONITORING

The main goal for the biotic monitoring was to develop separate amphibian, macroinvertebrate, and plant IBIs that could be applied in the Coastal Plain and Piedmont regions of the state for headwater wetlands. The IBIs were composed of 5 to 10 metrics, derived from biological attributes such as species richness, percent predators, and percent tolerant species. Reviewing the monitoring results and literature written on similar IBI development studies identified candidate metrics.

A second goal was to gain a better understanding of the amphibian, macroinvertebrate, and plant populations found in headwater wetlands and how they varied across regions. Additionally, for the macroinvertebrates, we wanted to compare sampling methodologies; sweep, stove-pipe, and funnel trap to determine which was the most efficient for sampling abundant and diverse macroinvertebrates.

Section 1.3 Introduction and Background Information

Wetlands are a highly important feature of the landscape that provide ecological value at the population, ecosystem, regional, and global level. At the population level, wetlands provide ecological conditions that many species of plants need to survive, as well as habitat, refuge, and food for many species of fish, amphibians, reptiles, birds, mammals, and macroinvertebrates. A diverse array of macroinvertebrates such mayflies, stone flies and midges can be found in wetlands, many of which are important for species higher on the food chain. Of the fish and shellfish that are wetland dependent, 95% are harvested for human consumption (Mitsch and Gosselink 2003). Most frog and toad species plus many salamanders require wetlands in order to reproduce and therefore survive. Reptiles such as turtles need a mosaic of small wetlands in the landscape to maintain population numbers. Many mammals, like beavers and muskrats, live in or around wetlands, while other mammals utilize wetlands as a food source (e.g. raccoons) or a place to bed down (e.g. deer). Wetlands are extremely important to birds, 80% of the American breeding population and greater than 50% of the migratory bird population rely on wetlands. Although wetlands only cover 3.5% of the US land area, approximately 50% of the threatened and endangered federally listed species need the presence of wetlands to reproduce (Mitsch and Gosselink 2000, Niering 1997, U.S. EPA 2002a). At the ecosystem level, wetlands filter polluted waters, control floods, protect shorelines during storms, and recharge aquifers. These unique systems are also aesthetically pleasing and provide a place for recreation and education for many communities of people (Mitsch and Gosselink 2000, Niering 1997, Hansen 2006**,** Ohio EPA

2004). At the regional and global level, wetlands may play a significant role in the cycling of nitrogen, sulfur, methane, and carbon dioxide gases (Mitsch and Gosselink 2000, Hansen 2006).

Historically, the importance of preserving wetlands as a natural resource was not widely recognized. It has not been until more recent years that education and policy development have slowed the trend of wetland destruction. The US has seen a 53% loss of wetlands in the lower forty-eight states since the year 1700 (Mitsch and Gosselink 2000). The southeast has seen the greatest losses of wetlands, primarily in the Atlantic and Gulf Coastal Plain region (Hansen 2006, USDA 2006). The draining of wetlands for agricultural purposes has had the greatest impact on wetland loss. By 1930, 80 million acres of wetlands had been converted to agriculture. This trend slowed during the depression years and WWII. However, by 1954 another 10 to 11 million acres had been converted primarily to agriculture. Wetland conversion slowed again from 1954 to 1974, but during this time development and agricultural expansion shifted from the Midwest to the gulf region and the southeast. The increase of urban expansion, especially in Florida and North Carolina, were contributors to wetland drainage and fill (Hansen 2006, USDA 2006). In 1780 in North Carolina, there were an estimated 11,090,000 acres of wetlands that were reduced to 5,690,000 acres by the mid 1980s resulting in a 44% reduction in wetlands over 200 years (Mitsch and Gosselink 2000). Federal wetland policies started to change in the 1970s with growing public interest and awareness of the conservation of wetlands. The Clean Water Act's Section 404 established a program to regulate the discharge of dredged and fill materials in waters of the U.S., while Executive Order 11990 directed Federal agencies to minimize the loss and degradation of wetlands and to improve the health of wetlands (Hansen 2006). Other provisions, which occurred between 1982 and 2002, that contributed to the decrease in wetland conversion include "swampbuster" provisions of the 1985 Food Security Act, more stringent enforcement of 404/401 permitting, changes in income tax treatment of conversion investments, decreasing agricultural prices, and additional state regulations. For instance, in North Carolina a Pre-Construction Notification (PCN) is generally required for impacts to wetlands that are greater than 1/3 of an acre east of I-95, and greater than 1/10 of an acre west of I-95 (NC General Certification 3705), which allows tracking of larger impacts.

Wetlands are formed by the interaction of biological communities with their physical and chemical environment. This "interaction" has the capacity to be altered physically, chemically, or biologically (U.S. EPA 2002a). Examples of physical alterations include dredging, draining, filling, flooding, trampling with livestock, plowing, and the steepening of slopes. Wetlands can be altered chemically by the introductions of pollutants such as pesticides, herbicides, metals, and sewage. Biological alterations can come in the form of the removal of species through logging and mowing and the introduction of species such as exotic invasives and ruderal natives (U.S. EPA 2002a, 2002c). Minimal activities that impact watersheds and wetlands within those watersheds allow biological communities to stay intact and continue functioning. However at some threshold, these communities reach an unhealthy level which causes significant changes in the wetland system quality and the ability of the system to function properly (U.S. EPA 2002a, 2002b). Monitoring the biological health of wetland communities enables wetland managers to recognize these threshold points and the status and trends of wetlands within a region. Knowledge of threshold points and the status and condition of wetland within a region enables ecologically sound decisions to be made regarding wetland management (Hansen 2006). Monitoring of a wetland can also determine current ambient condition, whether the system is improving or degrading, and whether there are any seasonal patterns in wetland condition (U.S. EPA 2002b).

Often standards used for wetlands are not based on measures that were neither tested nor derived from empirical data that has been related to ecosystem processes or reference wetlands (Fennessy *et al*. 2004). Monitoring in the form of bioassessments is a useful way to identify and implement numerical wetland standards. Bioassessments are used to evaluate the health of a wetland by measuring the condition of one or more of the taxonomic assemblages within that wetland. It is believed that the community of plants and animals within a wetland system reflects the underlying health of where they live. Studies have shown that solely measuring the chemical and physical attributes is not always a direct indication of the health of the biological communities within a wetland and is therefore not a practical approach to evaluate wetland condition. Measuring chemical and physical attributes in conjunction with biological attributes is still useful and can be used to interpret biological data, understand stressors, or the variability between systems (U.S. EPA 2002a). Biological attributes are typically monitored in four categories: 1) species richness and composition; 2) tolerance and intolerance (sensitivity) to human activities; 3) trophic composition; and, 4) population characteristics (health and condition of individuals) (U.S. EPA 2002c).

The ability to interpret the results of multiple biological attributes from different taxa can be done with complex and extensive statistics or by the development of an Index of Biotic Integrity, or IBI. An IBI is an index that combines several (preferably 8-10) metrics derived from biological attributes and is used to represent a sites wetland condition (U.S. EPA 2002a). Unlike statistical analyses, an IBI provides results that are easily interpreted and presentable to the general public to understand. IBIs are a useful tool for understanding the condition of natural wetlands as well as wetlands that have been restored, enhanced, and created. Separate IBIs probably need to be developed for each wetland type as different wetland types have different assemblages of plant and animal communities. In addition, IBIs need to be developed separately for each taxon type as different taxon groups respond differently to stressors. In order to develop an IBI, wetland study sites in the same wetland class must be located along a disturbance gradient. Therefore the study sites chosen should contain wetlands that have been severely degraded at one end of the spectrum and wetlands with minimal disturbance to be used as reference sites at the other end of the spectrum. Biological attributes of the chosen taxon group that have the potential to be used as metrics in an IBI can be identified by reviewing data results. Some biological attributes within a taxon group will have an empirical and predictable response to human disturbance and can therefore be used as a metric, while other biological attributes will respond differently and therefore are not useable. Various measures of human disturbance such as surrounding land-use, buffer presence and width, and proximity to other natural habitats can be used to test biological attributes. Biological attributes (the dependent Y-axis variable) that correspond to human disturbance measurements (the independent X-axis variable) can then be considered as a metric and used in the final wetland class and taxon group IBI (U.S. EPA 2002a, 2002c).

The NC DWQ decided to use bioassessments and the development of headwater wetland IBIs for amphibians, macroinvertebrates, and plants to meet one of the goals of the "Development of a Wetland Monitoring Program in North Carolina" grant (CD 974260-01). Headwater wetlands, as stated in Section 1.2, were chosen as the type of wetland to monitor due to their location within watersheds and effect on down stream aquatic resources. Headwater wetlands are found at the highest areas of the watershed at the head of and in association with first order intermittent and perennial streams. These wetland areas tend to be bowl-shaped in the piedmont and mountains while being somewhat wider and flatter in the coastal plain. These NC forested wetland systems grade into first order intermittent and perennial streams through braided channels or seepage areas. Headwater wetland plant communities are diverse and vary from the Piedmont to the Coastal Plain. Headwater wetlands, though numerous within watersheds, are rarely if ever greater than one acre in size in the Piedmont and Mountains.

The following Section 2 describes how the headwater wetland study sites were chosen and provides maps and descriptions of the sites while Section 3 describes how human disturbance referred to as "disturbance measurements" were developed and measured at each site. Section 2 also describes the statistical analysis and procedure used to develop the IBIs and analyze the abiotic data. Sections 4, 5, and 6 provide details on the monitoring and results of the chemical and physical attributes of the wetland sites that were monitored (Section 4 – water quality, Section 5 – hydrology, Section 6 – soils). IBI development for the North Carolina wetland-monitoring program of headwater wetlands is discussed in Sections 7, 8, and 9 for amphibians, macroinvertebrates, and plants, respectively. Section 10 contains final conclusions and recommendations for the North Carolina Wetlands Monitoring Program with respect to headwater wetlands.

Section 2 Site Selection, Delineation and Descriptions

Section 2.1.1 Site Selection Methods

Twelve sites in the Piedmont and eleven sites in the Coastal Plain were chosen for this study (see Figure 2.1). The NC Division of Coastal Management's (DCM) NC Coastal Region of Evaluation of Wetland Significance (NC-CREWS) data (NC DENR DCM, 1999) was first used to locate headwater wetlands in the Coastal Plain. The DCM, NC-CREWS database had three categories: "natural" headwater wetlands (undisturbed), "partially drained" headwater wetlands, and "cutover" headwater wetlands. Thirty headwater wetlands were selected: ten each from the three categories previously mentioned. Of the 30 sites visited, 3 were deemed usable for the study. The rest of the Coastal Plain sites and the Piedmont sites were selected using a random selection method with the North Carolina Atlas and Gazetteer (DeLorme 2003) since there was low success of finding usable sites with NC CREWS. The latitude and longitude lines on the pages of the NC Gazetteer were used to create a grid for the Piedmont (Charlotte North to Virginia State line and east to I-95) and Coastal Plain (I-95 eastward) regions of the state. Grid cells were randomly chosen to represent focus areas to locate headwater wetlands. Cells that were to close to or overlapping regional boundaries were not chosen to insure a distinction between Piedmont and Coastal Plain sites would exist. Chosen grid cells that had potential areas with headwater streams located within 1/2 mile of a road were then examined in the field to see if a usable headwater wetland site existed. This method did have limitations since not enough headwater wetlands located in urban settings were found initially with the random approach as large swaths of NC land cover is located in rural areas. Urban areas within the Piedmont and Coastal Plain were then targeted in order to find more usable urban wetlands to represent sites affected more significantly by human disturbance. Aerial, soil, and topographic maps then were utilized to locate these urban sites prior to field truthing.

Most study sites were located in 2003-2004; additional urban sites were located in 2005. Some sites were abandoned and replaced due to landowner decisions, physical alterations of the site, or sites not meeting study site criteria. The sites chosen had various levels of disturbance from fairly pristine to highly disturbed and had at least 10-20% of the canopy with mature trees (approximately 30-years old or $\geq$12 inches DBH). Most sites were located at the origin of a stream. Sites in the Piedmont were typically bowl-shaped wetlands that graded into headwater streams. Some sites were similar in the Coastal Plain while others were flatter, wider and covered more area before a stream formed which was often well downstream of the study site boundary.

Section 2.1.2 Site Delineation Method and Features Recorded with GPS

Study site boundaries were determined by measuring approximately 200 ft downstream from the monitoring well location with measuring tape or a GPS unit. The 200 ft was measured along an approximate "centerline" of the headwater wetland or first order headwater stream. This 200 ft ending location was marked with flagging. An "ending site boundary" line was measured out perpendicular to the site centerline. Both ends of the "ending boundary line" were flagged at the edge of the wetland (usually in the Coastal Plain) or top of the headwater stream bank (usually in the Piedmont) (see Figure 2.2). The wetland was then delineated using methods described in the US Army Corps of Engineers Wetland Delineation Manual, 1987 (Environmental Laboratory 1987). Delineation points were marked in the field with flagging and recorded with GPS along with the boundary line in order to determine the study site acreage (See Figure 2.2). For situations where the 200 ft centerline crossed a road and or utility right-of-way with a non-forested section of wetland, the utility right-of-way and road right-of-way was flagged separately and notated in the GPS comments. The road right-of-way area was deleted from the overall study site area but the non-forested wetland in the utility right-of-way remained.

GPS points were collected at the monitoring well location, water quality sampling stations, vegetation plot boundary, macroinvertebrate sampling stations, and other areas of interest such as points of disturbance (e.g. sedimentation). Sampling methods for hydrology, water quality, vegetation and macroinvertebrates are described in later sections. GPS points were collected using the Trimble GeoXT unit. All GPS points were differentially corrected and loaded into a GIS database created for the headwater wetland monitoring sites. The GPS data collected followed the "North Carolina - Statewide Global Positioning System (GPS) Data Collection and Documentation Standards, Version 2" (http://www.richlandmaps.com/pdfdocs/ncgpstnd.pdf). Typically, 20 or more GPS waypoints were taken with each GPS location point. All points were recorded in state plane meters as the coordinate system.

Figure 2.1 Headwater Wetland Site Locations

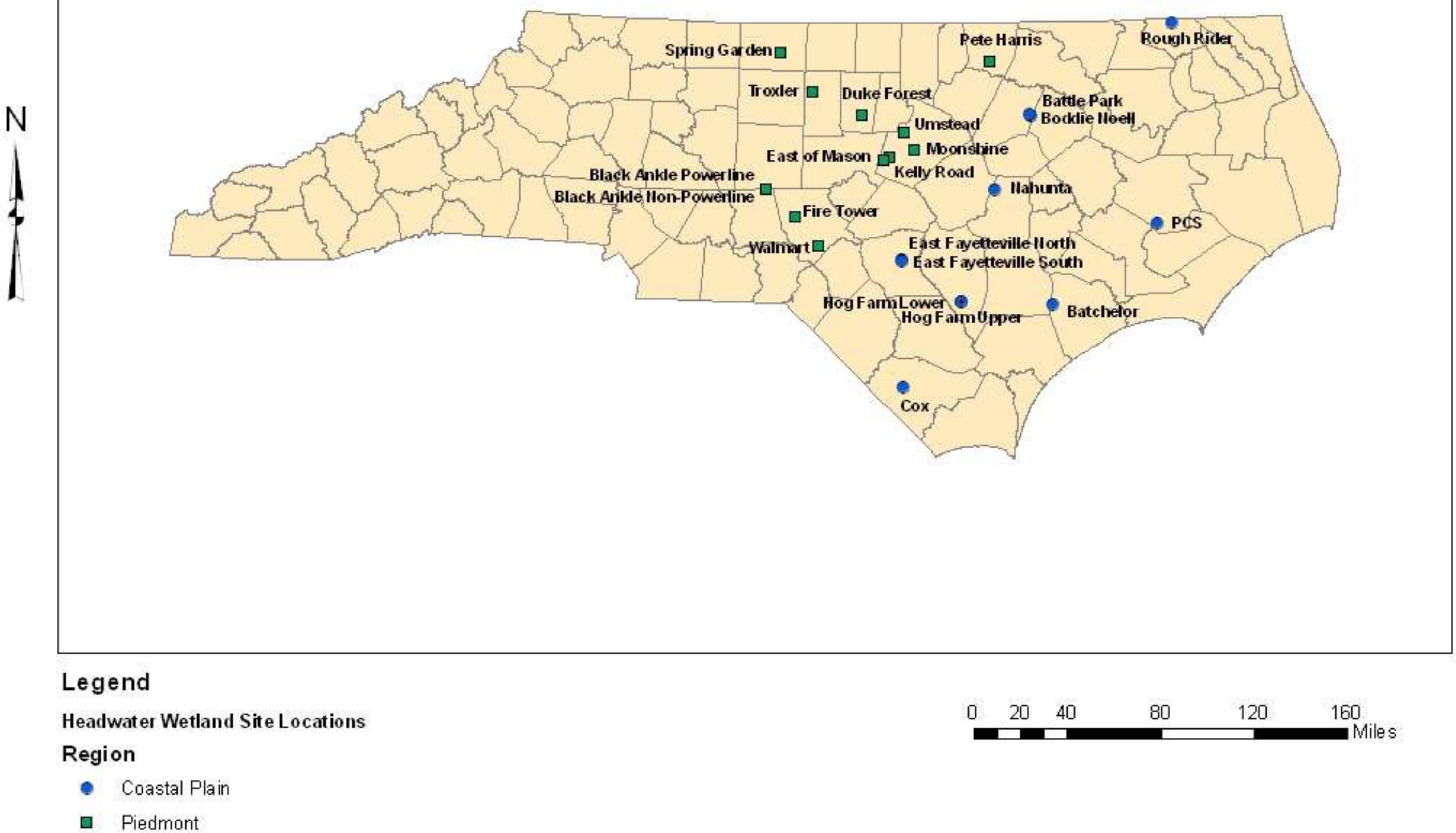
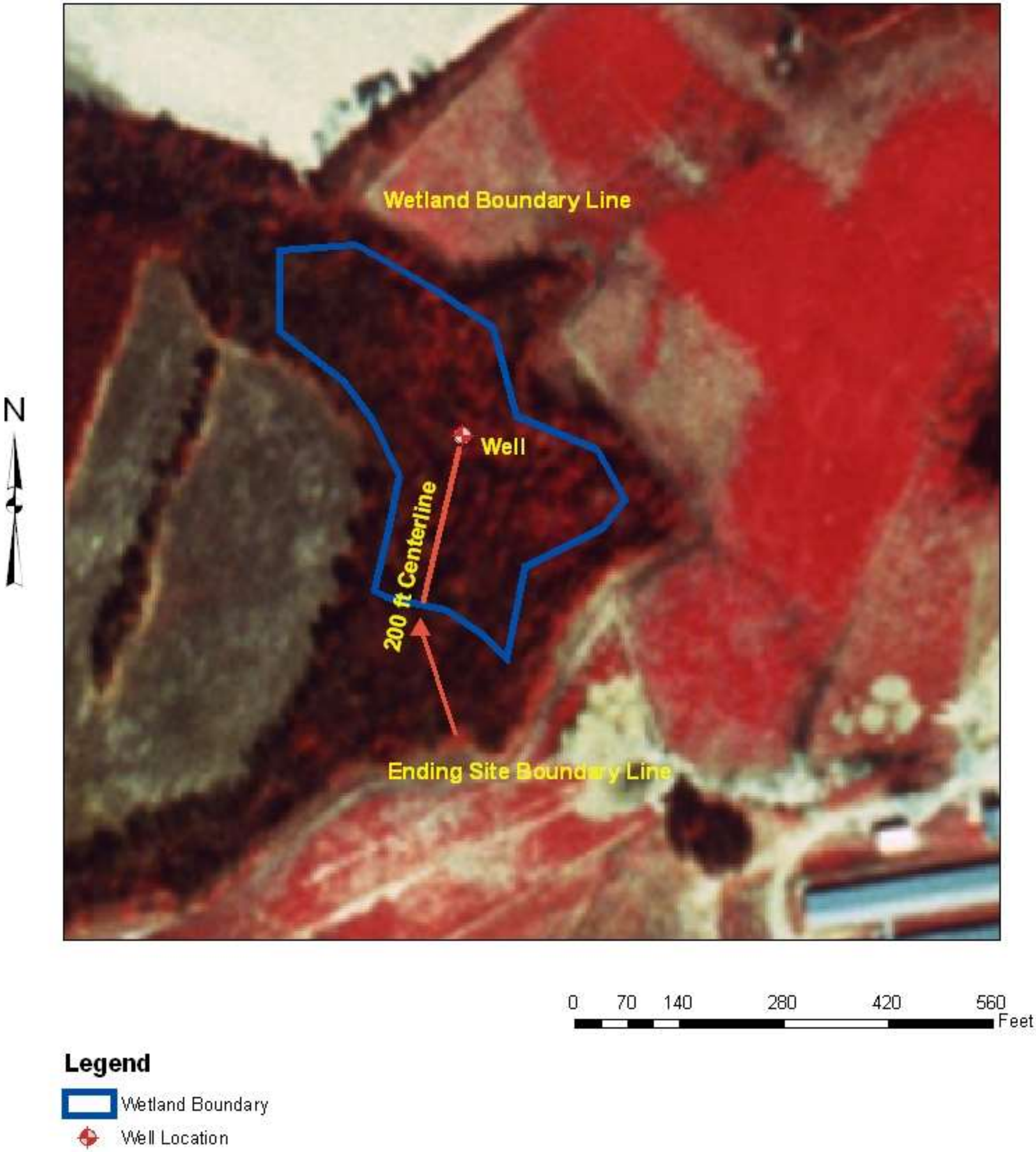


Figure 2.2 Hog Farm Upper Site Delineation Map



Section 2.2 Site Descriptions

Table 2.1 lists each wetland sites, region, county, acreage, and latitude and longitude coordinates. Appendix A also contains aerial maps of three Piedmont sites: one natural (Spring Garden), two rural agricultural (the Black Ankle sites), and one urban (Walmart), and three Coastal Plain sites: one natural (PCS), two rural agricultural (the Hog Farm Sites), and one urban (Boddie Noell). Of the twenty-three sites, eighteen were on private land, three are on public land, and the Nature Conservancy owned two sites. The 23 sites were located in 15 different counties throughout the NC Piedmont and Coastal Plain.

In order to have a visual comparison of the study sites, a set of photo points was taken at the well locations with a digital camera between 10 am and 3 pm. An 8-foot high vegetation range pole made out of 2-inch diameter PVC with the feet clearly marked was placed next to the well. Photos were taken from 10 meters away at 120º, 240º, and 0/360º from the vegetation range pole. The camera was placed on a 4.5 ft stand in a level position for all photos. Photo point locations were marked with flagging and recorded with GPS. All photos were taken without flash. Digital photos were labeled with the site, date, and direction and cataloged in electronic folders. Other photos taken were of wetland study site disturbance features (i.e. excessive sedimentation, erosion, or road and utility crossings), amphibians, plants, and water sampling stations. All digital photos from the study were labeled and categorized. Photo point photos for Spring Garden, Black Ankle Non-Powerline, Walmart, PCS, and Hog Farm Upper and a site photo for Boddie Noell are shown in Appendix A.

The following sections provide a brief description of each site. Information on the location, topography, stream type, 100-foot buffer and surrounding landscape, and vegetation including the dominant plant species, community type and presence of exotic invasives is provided.

PIEDMONT SITES

Black Ankle – Black Ankle is owned by the NC Chapter of The Nature Conservancy and is located at their Black Ankle Preserve in Montgomery County. Black Ankle contains two sites – Black Ankle Powerline, located immediately east of a powerline utility road, and Black Ankle Non-Powerline, located 250 feet east of the powerline utility road. The Black Ankle Powerline and Non-Powerline wetland sites both drain into the same small perennial stream which is an unnamed tributary of Suggs Creek. The Black Ankle Powerline stream is ephemeral to intermittent while the Black Ankle Non-Powerline stream is intermittent to perennial. The Black Ankle Powerline and Non-Powerline sites do not overlap, but their 100 foot buffer areas do. Black Ankle Non-Powerline has a fairly open canopy, shrub, and sub-canopy stratum while the ground vegetation is quite diverse. The Black Ankle Non-Powerline site has a more closed canopy with a dense herb and moderate shrub stratum. Agricultural farms exist to the north and west of the two Black ankle sites. The Black Ankle Powerline site is narrower and has a fairly open canopy while the Black Ankle Non-Powerline is more open and has a fairly closed canopy. Both sites have a moderate shrub stratum with a dense and diverse and herb layer. The Nature Conservancy regularly burns this preserve to enhance the herb layer. Some of the dominant tree species at the Black Ankle sites include red maple (*Acer rubrum*), southern red oak (*Quercus* *falcata*), tag alder (*Alnus serrulata*), white oak (*Quercus alba*), red oak (*Quercus rubra*), black gum (*Nyssa sylvatica*), and tulip poplar (*Liriodendron tulipifera*).

Duke Forest – The Duke forest site is located in Orange County on property owned by the Duke School of Forestry. This site, unlike most Piedmont headwaters, is fairly flat and wide. The headwater area drains into an ephemeral-intermittent stream that is an unnamed tributary of Mountain Creek. There is a two-lane paved road located within 80 feet of the site with a cutover area past that to the south. Otherwise the Duke forest site is colonized by and surrounded by mature forest. Duke forest is composed of red maple, sweet gum (*Liquidambar styraciflua*), dogwood (*Cornus florida*), willow oak (*Quercus phellos*), southern red oak, winged elm (*Ulmus alata*), and hickory (*Carya* spp). The shrub and sapling layer is fairly open with a moderate herb layer dominated with the invasive Nepalese browntop grass (*Microstegium vimineum*).

East of Mason – East of Mason is located adjacent to Old US 1 in Wake County. The historic head area of the wetland is cut off with fill used to construct Old US 1. There is also some trash near the road within 50 feet of the wetland study site. The site is bowl-shaped and has a nice seepage area with mossy covered tussocks and good salamander habitat. The East of Mason headwater wetland grades into an intermittent stream that is a tributary of Little Beaver Creek to the north. The site is forested with mature trees in the buffer and throughout the site including tulip tree, red maple, sweet gum, black gum, persimmon (*Diospyros virginiana*), and white oak.

Fire Tower – Fire Tower is another typical bowl-shaped headwater Piedmont wetland located in Moore County. This site has a fairly narrow buffer area (averaging 50-60 feet) with a rural residence to the southeast, abandoned mobile home park to the northeast and car junkyard to the northwest. The crossing of Bensalem Church Road has bisected the Fire Tower site. The construction of Bensalem Church Road filled a portion of the historic headwater that had graded slowly into a stream. Water draining off the Fire Tower site has been diverted through a culvert underneath Bensalem Church Road where it drains directly into an unnamed perennial tributary of McLendon’s Creek. Fire Tower has a dense canopy on both sides of Bensalem Church Rd, however the shrub layer is much more dense with a number of evergreen Ericaceae species located in the headwater area while there is a more open shrub layer on the south side of Bensalem Church Rd around the unnamed tributary. Some of the dominant species include sweet pepper bush (*Clethra alnifolia*), sweet bay (*Magnolia virginiana*), red maple, tulip poplar, and black gum.

Kelly Road – Kelly Road, similar to East of Mason, is located just to the northwest of Old US 1, approximately two miles from the East of Mason site in Wake County. Kelly road is also bowl-shaped and drains into an intermittent stream. At the northwestern side of the site the intermittent stream widens into a 40’ by 40’ ponded area that has flooded due to the berm of a farm pond located along the western site boundary. This ponded area is dominated with lizard’s tail (*Saururus cernuus*) and does have a hydrological connection to the fish-stocked farm pond to the east of the site. The west side of the farm pond drains into an unnamed tributary of Beaver Creek. The Kelly Road site is not as high quality a habitat for salamanders as the nearby East of Mason site. The moss-covered tussocks are absent and there is a large stand of golden bamboo (*Phyllostachys aurea*) plus some dense areas of *Smilax* spp. and muscadine grape (*Vitis rotundifolia*). Canopy trees are similar to the East of Mason site.

Moonshine – The Moonshine site is owned by NC State University and is located within the Raleigh city limits of Wake County. This site appears to be less bowl-shaped, but does drain down a slope into an unnamed ephemeral tributary that drains into a perennial and ditched tributary of Walnut Creek. The site and 100 foot buffer area is forested with mature hardwoods with a fairly urban setting located outside this buffer. To the south is I-40/440 and to the west and northwest are the neighborhoods associated with Trawick Road and Centennial Middle School, respectively. The Moonshine site has a fairly dense canopy and some dense sections of shrubs in the headwater area with a moderate herb layer. Some of the canopy trees include red maple, tulip poplar, sweet gum, white oak, and black gum.

Pete Harris – The Pete Harris site is more linear and less bowl-shaped than other Piedmont sites. This site contains a narrow headwater section that grades into an intermittent and then perennial stream, which is a tributary of Long Branch. To the east 150 feet is unused pasture, to the north and to the south 200 feet are low traffic dirt roads. The site and the buffer area to 100 feet are primarily forested with mature hardwoods, however closer to the woods boundary the buffer area is much more shrubby due to the edge effect. Also, the lower downstream portion of the Pete Harris site has dense sapling and shrub growth indicating the area was more recently cut over than the upstream portion of the site. The Pete Harris site is composed of red maple, tulip tree, hickory, ironwood (*Carpinus caroliniana*), sweet gum, black gum and some loblolly pine (*Pinus taeda*).

Spring Garden – The Spring Garden site is a fairly pristine bowl-shaped headwater wetland located near Reidsville in Rockingham County. Most of this site's 100-foot buffer is forested with mature trees. There is a power utility maintenance road to the west within 50 feet and a portion of a yard to the south within 100 feet. Spring Garden grades into an intermittent – perennial stream, which is an unnamed tributary of Hunt Lake. Spring Garden is forested with tulip poplar, red maple, spicebush (*Lindera benzoin*), sourwood (*Oxydendrum arboreum*), American hazelnut (*Corylus americana*), sweet bay, sweet gum, ironwood, black gum, and white oak. There is a moderate shrub and sub-canopy stratum. The herb layer is fairly diverse with various species of ferns and sedges.

Troxler – The Troxler site is located in a very urban setting in the northern part of Burlington in Alamance County. This site has some mature trees; however, the 100-foot buffer area has been impacted by a factory to the southeast and south, an unmanaged open grassy area to the southwest and northeast, and a recent clear-cut to the northwest that is both in the buffer and along the edge of the site. The factories are located upstream from the site. The headwater wetland grades into an ephemeral – intermittent stream that is an unnamed tributary of the Haw River. The site is forested with tulip trees, red maple, box elder (*Acer negundo*), willow oak, and sweet gum. Also present are a lot of poison ivy (*Toxicodendron radicans*), trumpet vine (*Campsis radicans*), and Japanese honeysuckle (*Lonicera japonica*) indicating past disturbances at this site.

Umstead – Umstead is located in the northern part of Umstead State Park in Wake County. The site, its buffer and beyond are completely forested with mature hardwoods and loblolly pine. Umstead is a typical bowl-shaped wetland that drains into an intermittent stream, which is an unnamed tributary of Crabtree Creek. Umstead is forested with green ash (*Fraxinus pennsylvanica)*, white oak, sweet gum, red maple and American elm (*Ulmus americana*).

Walmart – The Walmart site is located in a developed area of Aberdeen in Moore County. The Walmart 100-foot buffer has been highly impacted by a Walmart parking lot to the north and Staples to the east, to the south is a retention pond. Developed areas continue beyond the 100-foot buffer in all directions. Sediment and trash were noted in a few areas of this site. Walmart is a bowl-shaped headwater wetland that grades into a perennial unnamed tributary of Watson Lake. Walmart had a dense canopy of mature trees and a dense shrub area with sparse herbaceous vegetation. Some of the dominant species include tag alder (*Alnus serrulata*), black gum, tulip poplar, black cherry (*Prunus serotina*), red bay (*Persea borbonia*), sweet bay, green ash, black gum, red maple, large gallberry (*Ilex coriacea*), greenbriar (*Smilax* spp.), and titi (*Cyrilla racemiflora*).

COASTAL PLAIN SITES

Bachelor – Bachelor is located in rural Onslow County. The wetland itself is primarily dominated by pocosin-like vegetation with dense evergreen shrubs and scattered canopy trees. There is sheet flow from the wetland, which is located on flat topography, to an unnamed tributary of Nine-mile Creek. The Bachelor site has a wide area of forested buffer to the north, west and south that is primarily forested with loblolly pine. To the east is a farm retention pond and horse pastureland. There are pools of standing water in acidic loam and loamy sand soils that support matts of sphagnum moss heath family shrubs. Some of the dominant tree species include sweet bay, fetterbush (*Lyonia lucida*), swamp tupelo (*Nyssa biflora*), sweet gum, red maple, large gallberry, and coastal doghobble (*Leucothöe axillaris*).

Battle Park – Battle Park is located at Battle Park, a forested Rocky Mount city-owned park in Nash County. This site discharges water into the Tar River about 200 m to the east of SR43/48, a high traffic road in Rocky Mount. The Battle Park site has a small headwater area approximately 40 feet long that drains to the south into a basin wetland. The basin wetland drains underneath a walkway to the south into a retention area that overflows during storm events into the Tar River. Both the headwater section and basin wetland are considered part of the study site. Prominent tree species that are found in the Battle Park site include ironwood, red maple, hickory, pond cypress (*Taxodium ascendens*, found in the basin section), and over-hanging beech trees (*Fagus grandifolia*).

Boddie Noell – Boddie Noell is also located in Rocky Mount within Nash County in an urban area. Boddie Noell is a forested site with a forested buffer that is greater than 100 feet on the south and east sides. The buffer is forested for just less than 100 feet to the west while to the north abutting the site boundary is Jeffreys Road. Boddie Noell drains to the north (or northeast) through a culvert underneath Jeffreys Road to Goose Branch. To the west of the site is a business park and to the north are urban neighborhoods. Some of the dominant vegetation at Boddie Noell includes red maple, American elm, black gum, sweet gum, and poison ivy.

Cox – The Cox site is located some meters downstream of the exact headwater area. The upper headwater area was clear-cut in 2004 and this site was then located downstream along the intermittent – perennial first order stream, which is an unnamed tributary of Fivemile Branch. To the southeast of the site at the edge of the clear-cut area is a 3-4 foot deep ditch and dirt road. The depth of the ditch most likely had some effect on the hydrology of this site. The 100-foot buffer in other directions is completely intact and composed of mature hardwoods. The site is dominated with dense evergreen waxy shrubs and mature canopy trees including red maple, American holly (*Ilex opaca*), coastal doghobble, water oak (*Quercus nigra*), titi, and sweet pepperbush.

East Fayetteville North – The Fayetteville sites are located in Cumberland County within a half-mile of each other along Rock Hill Road. East Fayetteville North is located in a rural area with pastureland to the north, forest to the east, neighborhoods to the south and Rock Hill Road to the west. Most of the 100-foot buffer and site are forested with mature vegetation. The site is fairly bowl-shaped and drains to the west toward Rock Hill Road. Water has ponded at the west side of the site at the edge of Rock Hill Road due to clogged culverts. Ponding at the edge of roads that headwater wetlands drain toward seems to be a fairly common phenomenon. Water from both Fayetteville sites ultimately drains into a tributary of Locks Creek. Due to recent blowdowns, some of the East Fayetteville site has dense, shrubby, pocosin-like vegetation (and its accompanying organic-rich soils) with vines such as greenbriar and muscadine grape (*Vitis rotundifolia*) growing among the red bay, red maple, swamp tupelo, and horse sugar (*Symplocos tinctoria*).

East Fayetteville South – East Fayetteville South has a buffer that is primarily forested up to 100 feet wide on all sides. However directly outside the buffer is more pastureland and rural homes and lawns. East Fayetteville south is bisected by Rock Hill Road so approximately two-thirds of the site is to the east and one-third of the site is to the west of Rock Hill Road. Similar to East Fayetteville North, East Fayetteville South drains to the west with ponding adjacent to Rock Hill Road although it is less pronounced than the northern Fayetteville site. Vegetation is fairly similar to East Fayetteville North however the shrub stratum is not as dense and there are more ferns present. Species include sourwood, sweet gum, red maple, water tupelo, and netted chain fern (*Woodwardia areolata*). It should be noted that in January 2006, DWQ lost the use of the west side of this site near the headwater section due to landowner issues. Therefore the upstream water sample was not acquired in April and July of 2006, water level measurements were not taken at the well, and macroinvertebrates were only sampled in the downstream section of the site.

Hog Farm Lower – The Hog Farm sites are located on an active hog farm in Sampson County. Hog Farm Lower is located approximately a quarter mile to the northeast of Hog Farm Upper. Hog Farm Lower is forested with mature trees within the site and most of the 100-foot buffer. To the northwest, west, southwest, south, and southeast, primarily outside the 100-foot buffer, is pastureland. The pastureland to the southwest, south, and southeast receives effluent from the pig farm operation via broadcast spraying. These spray fields are located upstream of the site. Hog Farm Lower contains a perennial unnamed tributary that drains into Coharie Creek. The site has primarily mineral soil and is dominated by swamp tupelo, red maple, tulip tree, and some of the invasive Chinese privet (*Ligustrum sinense*).

Hog Farm Upper – The Hog Farm Upper site in Sampson County has a forested buffer that is only about 50 feet wide in most sections. This site also receives drainage from the same effluent-sprayed pasturelands located to the north and east of the headwater section of the site. Pastureland is also located to the south and west. Hog Farm Upper, unlike Hog Farm Lower, has organic soil and a fairly obvious wide wetland area in the headwater section that grades into an unnamed perennial tributary of Coharie Creek. Hog Farm Upper does have a mature canopy, however the shrub stratum of much of the wetland site and buffer area is dominated with invasive Chinese privet. Other dominant species include tulip poplar, American holly, coastal doghobble, red maple, and loblolly bay (*Gordonia lasianthus*).

Nahunta – The Nahunta site is located in Wayne County. The site itself is completely forested with mature trees, however only the buffer area to the south is forested to 100 feet and beyond. The site has a racecar track located to the southeast, pastureland to the north, and Old Kenly Road to the West. Nahunta is a flat headwater area located on organic soils with pools of water and pockets of saturation. This site drains to the west directly into the perennial stream flow of Dennis Branch. Nahunta is dominated with sweet gum, red maple, tulip poplar, tag alder, and also has a section (on the north side especially) that is dominated with the invasive Chinese privet.

PCS – PCS is located in Beaufort County on PCS Phosphate mining property. PCS is forested with mature hardwoods and also has a forested buffer that is at least 100 feet wide along most of the site. The buffer area and forested area that continues past the buffer contains numerous loblolly pine trees in addition to hardwoods. Homes are located directly to the northeast and southeast of the PCS site. PCS is a large, wide, flat headwater area with muck soil that drains to the east through a culvert under highway 306. PCS is vegetated with a number of evergreen trees and shrubs. Some of the dominant species include red bay, red maple, sweet bay, American holly, coastal doghobble, large-leaved gallberry, and swamp tupelo.

Rough Rider – The Rough Rider site is located in Gates County. The Rough Rider site and all but one section of the 100-foot buffer are forested with mature trees with a moderate shrub and more sparse herb stratum. There is an agricultural field located to the southeast that cuts into the buffer area as well. To the southeast and north are forested areas, and to the west are several rural homes located along a dirt road. This site has more of a slope than the typical headwater wetland. The seepage drains down-slope to the east into a section of narrow bottomland forest associated with a perennial second order stream that is an unnamed tributary of Duke Swamp. Some of the species that have colonized the Rough Rider site include sweet gum, water oak, red maple, tulip tree, loblolly pine, and sourwood.

Table 2.1 Site Descriptions

	Site Name	County	Acreage	Latitude	Longitude
Piedmont	Black Ankle Non-Powerline	MONTGOMERY	0.65	35 30 9.28	79 49 10.52
	Black Ankle Powerline	MONTGOMERY	0.25	35 30 7.69	79 55 45.12
	Duke Forest	ORANGE	0.70	35 58 3.51	79 05 50.68
	East of Mason	WAKE	0.50	36 35 13.11	78 55 32.97
	Fire Tower	MOORE	0.68	35 20 9.51	79 36 2.94
	Kelly Rd	WAKE	0.63	35 42 25.03	78 52 58.92
	Moonshine	WAKE	0.67	35 45 12.66	78 41 35.40
	Pete Harris	WARREN	0.59	36 17 42.52	78 06 24.27
	Spring Garden	ROCKINGHAM	0.55	36 21 11.00	79 43 21.46
	Troxler	ALAMANCE	1.16	36 06 54.27	79 28 25.99
	Umstead	WAKE	0.70	35 51 33.96	78 46 11.67
	Walmart	MOORE	1.21	35 09 32.81	79 25 18.93
Average			0.69		
Coastal Plain	Bachelor	ONSLOW	1.38	34 47 3.97	77 39 42.60
	Battle Park	NASH	0.60	35 57 42.53	77 48 16.41
	Boddie Noell	NASH	0.79	35 58 24.73	77 49 0.87
	Cox	COLUMBUS	0.81	34 16 49.49	78 47 3.62
	East Fayetteville North	CUMBERLAND	1.19	35 04 30.12	78 47 46.61
	East Fayetteville South	CUMBERLAND	0.75	35 04 9.82	78 47 49.02
	Hog Farm Lower	SAMPSON	4.02	34 48 57.19	78 20 40.20
	Hog Farm Upper	SAMPSON	2.70	34 48 44.78	78 20 50.67
	Nahunta	WAYNE	3.94	35 30 17.06	78 04 58.83
	PCS	BEAUFORT	6.14	35 16 58.65	76 51 18.38
	Rough Rider	GATES	1.85	36 31 29.19	76 42 28.39
Average			2.20		

Section 2.3 Field Survey Methodology Outline

Field data was collected on water quality (Section 4), hydrology (Section 5), soils (Section 6), amphibians (Section 7), macroinvertebrates (Section 8), and plants (Section 9). The following provides a brief description of the methods, which are described in detail in Sections 4-9.

1. **Water Quality** – Water quality was monitored quarterly for 18 months from April 2005 to July 2006 at two to three established "upstream", "downstream", and "further downstream" stations (three stations in Coastal Plain sites only). The pH, dissolved oxygen, specific conductivity, and temperature were taken each quarter and water samples were collected for total suspended solids, turbidity, fecal coliform, nutrients (NO_2+NO_3, phosphorous, ammonia, and total Kjeldahl), metals (lead, copper, zinc, calcium, and magnesium), total organic carbon, and dissolved organic carbon. Due to seasonal and specific site conditions, surface water samples were not always obtainable. In some of those situations soil pore water samples were obtained (see Section 4).

2. **Hydrology –** Data was collected at each site via a two foot deep, hand augered monitoring well. The water level depth in each monitoring well was taken by hand at 11 of the sites at least every three months, and 12 of the sites every half hour with In-Situ pressure transducers (Level Troll 500, c2005). Data from the pressure transducers was collected in the field and downloaded to a spreadsheet program every three months. Pressure transducer water level readings were always field proofed with measurements taken by hand every three months (see Section 5).

3. **Soils** – Samples were taken at 10 stations within each wetland: four in the wetland, two downstream and usually along the stream corridor, and four in the surrounding upland. Each soil sample was examined in the field for the number of horizons and color, texture and width of each identified horizon. Soil samples were collected for each horizon at each station for all sites and analyzed for nutrients (phosphorus, nitrate, nitrogen, potassium, calcium, magnesium, and sodium), metals (also called micronutrients-manganese, zinc, and copper), weight/volume, exchangeable acidity, sum of the cation, cation exchange capacity, base saturation, and humic matter. All samples were analyzed at the North Carolina Division of Agronomy, Soils Testing Lab I Raleigh, North Carolina (see Section 6).

4. **Amphibians** – Semi-qualitative amphibian survey of approximately three man hours per acre was performed in March and June of 2005. All visual and auditorial observations of amphibians were recorded. Voucher specimens and / or photographs were taken for identification and record purposes for all captured amphibians that were not identifiable in the field. Dip-nets for standing water areas, potato rakes for moving logs, funnel traps, and a tape recorder were used to aid with the amphibian survey work (see Section 7).

5. **Aquatic macrobenthos** – Up to five (depending on the specific site condition) macroinvertebrate sample stations were established at each site. Macroinvertebrate samples were collected with sweep nets, stove-pipe samples, and funnel traps in March and April of 2006 (see Section 8).

6. **Plants** – A qualitative presence / absence plant survey was performed at all sites in the fall of 2004 or spring of 2005. A quantitative survey was performed using methodology derived from the Carolina Vegetative Survey (Peet et. al. 1997). This methodology included surveying the presence and coverage of all plant species and diameter at breast height of the woody species (see Section 9).

Section 3 – Index of Biotic Integrity and Disturbance Measurements

Section 3.1 – Index of Biotic Integrity Development and Statistical Analyses of Biotic Data

Indices of Biotic Integrity (IBIs) were developed for the three biotic sections- amphibians, macroinvertebrates, and plants of the Wetlands Monitoring Grant (methods used to evaluate the abiotic sections of the grant are described in section 3.5). A set of biological attributes were identified and evaluated for use as candidate metrics in taxa specific IBIs (i.e. amphibians, macroinvertebrates, and plants). Different types of biological attributes were evaluated for each taxa group such as species richness, percent tolerant species, and percent sensitive species. The exact biological attributes that were evaluated and chosen as candidate metrics for each taxa group are described further in Sections 7, 8, and 9 for amphibians, macroinvertebrates, and plants, respectively.

Various wetland disturbance measurements were produced in order to test candidate metrics for each taxa group. The disturbance measurements used to test metrics include a Level 1 GIS assessment (LDI – Land Development Index), Level 2 wetland rapid assessment (ORAM – Ohio Rapid Assessment Method), and Level 3 summary of the intensive survey of each site's water quality, and soils. The development of the disturbance measurements are described in detail in the following sections 3.2 - 3.4 and summarized in Table 3.2 located at the end of Section 3.

The disturbance measurements (the independent X variable) and the candidate metrics (the dependent Y variable) for each taxon group were tested for normality by plotting normal quartile plots and using the Shapiro-Wilk W Goodness of Fit test (p-value < 0.05 indicated a normal distribution). Pairwise comparisons using correlation analyses, including Spearman's Rho (a non-parametric test) and Pearson's correlations, were run for the candidate metrics of each taxon group against the disturbance measurements. For the Pearson's correlation, disturbance measurement and candidate metrics that did not have a normal distribution were transformed using a log 10 transformation prior to running a Pearson's correlation. Correlations results of candidate metrics and disturbance measurements that had a p-value < 0.15 were considered significant and therefore potentially usable as a metric in the taxon group's IBI. Correlation tests were run using both sets of regional data together and using the Coastal Plain and Piedmont regional data separately (See Sections 7, 8, and 9).

Multiple regression was also used to evaluate candidate macroinvertebrate metrics against disturbance measurements. A stepwise regression technique was used in which various candidate metrics established for the macroinvertebrate IBI were used as predictor variables in the regression model and the various measures of disturbance were used as dependent variables. Therefore, the use of the macroinvertebrate candidate metrics was used to build a regression model to predict disturbance in the wetland.

Section 3.2 – Level 1 - Land Cover, Disturbance Score and Correlation Analysis

A Land Development Index (LDI) value was calculated for each site's watershed and 300m and 50m buffer using a method similar to that described in Brown and Vivas (2003), "A Landscape Development Intensity Index". An LDI value estimates the potential impacts from anthropomorphic influences on the land cover by evaluating the land cover in a designated area. LDI values are essentially a human-related disturbance score. US Geographical Survey topographical quad maps were used to determine the watershed boundaries for each site. Land cover parcels were delineated and assigned a land cover type value (see Table 3.1) with ArcGIS. A 2006 DOQQ aerial and on the ground observations were used to delineate the land parcel polygons for all land area located within each site's 300m buffer or watershed. Heads-up digitizing of hand drawn lines was used for the GIS analysis that was then used to determine the acreage of each digitized land parcel for each site's watershed, 300m buffer, and 50m buffer. A Land Development Index coefficient was then assigned to each Land Cover type (see Table 3.1 below). Lastly, the following equation was used to determine the Land Use Index value for the watershed of each site. LDI values were also calculated using the same methodology for a 300m and 50m buffer radius for each wetland site.

$LDI_{Total} = \sum \%Lu_i * LDI_i$

LDI_{Total} = LDI ranking for landscape unit
$\%Lu_i$ = percent of the total area of influence in the land use i
LDI_i = landscape development intensity coefficient for land use i

Table 3.1 Headwater Wetland Land Cover Type and Index Values

Land Cover Types for wetland study site watersheds and one-mile buffers	LDI Coefficient
Natural Areas	1
Water Bodies	1
Unmanaged Herbaceous Upland	2
Unmanaged Herbaceous Wetland	2
Managed Herbaceous Upland	3
Pine Plantation	3
Unconsolidated Sediment	4
Cultivated	5
Low Intensity Developed	6
High Intensity Developed	8

LDI values with a higher score indicated the land use for the watershed; 300m buffer and 50m buffer were more heavily impacted by human usage (see Table 3.2). LDI values for the site's watersheds, 300m buffer, and 50m buffer ranged from 107 to 595.5, 116.3 to 579.1, and 100 to 516.1 with an average of 242.7, 251.3, and 164.6 and medium 219.9, 213.2, and 120.4 respectively.

It should be noted that the assignment of cover types to land parcels surrounding each site was based primarily on photo interpretation and in the field ground-truthing. Originally, the 1996 LandSat Coverage was reviewed as an already existing dataset for the LDI calculation. However, a comparison of recent aerials and our on the ground knowledge indicated that the LandSat Coverage was 20-40% inaccurate and was deemed unusable. Some of the land coverages that were more similar on an aerial may have some inaccuracies such as Managed and Unmanaged herbaceous upland were differentiated by the presence of scattered trees and shrubs (indicating managed). High density and low density development was also a subjective judgement base on in the field observation. Generally neighborhoods were considered "low" density while strip malls and 4-lane roads were considered high density.

Section 3.3 – Level 2 – Ohio Rapid Assessment Method

The Ohio Rapid Assessment Method v. 5.0 (Mack, 2001, see Appendix B for copy of ORAM form) was used to calculate a disturbance score for each of the wetland sites. ORAM is an existing functional evaluation tool that was suggested for use by the EPA. ORAM contains six rapid assessment metrics: 1. wetland area, 2. upland buffers and surrounding land use, 3. hydrology, 4. habitat alteration and development, 5. special wetlands, 6. plant communities, interspersion, and microtopography. Metric 5, which was specific to Ohio wetlands, was not used in the assessment. Both project coordinators and a technician completed the assessments independently to avoid bias. The maximum score for a quality wetland in NC would be 90 without the use of metric 5. Headwater wetland site ORAM scores were normally distributed for both the Coastal Plain and Piedmont combined and ranged from 20.5 to 74.3 with an average score of 52.9 and median score of 55.8 (see Table 3.2). The North Carolina wetland rapid assessment method, NC Wetland Assessment Method (NCWAM), has been developed however the scoring calculator was being finalized when the analysis for the report was being completed. Additionally, NCWAM is a "functional" evaluation as opposed to a "conditional" evaluation like ORAM. ORAM contains some general metrics that appear to be usable for evaluating NC wetlands although ORAM has not been specifically calibrated for NC. Metrics 2, 3, and 4, are all completely applicable to describing NC headwater wetlands. Metric 1, acreage, would typically result in a lower score for smaller wetland types, like Piedmont headwater wetlands, therefore some of the Coastal Plain sites may have scored a point or 2 higher. Metric 6a, wetland vegetation communities, contains some answers that would not be appropriate for headwater wetlands like "mud flats" and "open water". In this study, headwater wetlands are not being compared to other types of wetlands that would have mudflats and open water. Headwater wetlands also typically have low or no horizontal dispersion as described in Metric 6b, but again headwater wetlands are not being compared to other wetland types in this study. Metric 6c, invasive plant cover, and 6d, microtopography, are applicable for headwater wetlands.

Section 3.4 – Disturbance Measurements Developed from Level III Intensive Surveys

Section 3.4.1 – Water Quality Disturbance Measures

Disturbance measurements for water quality parameters were developed with average site surface water quality results for 19 water quality parameters. These include ammonia, calcium, copper, dissolved organic carbon (DOC), dissolved oxygen (percent and mg/L), fecal coliform, lead, magnesium, nitrite + nitrate (NO_2+NO_3), phosphorous, specific conductivity, total kjeldahl (TKN), total organic carbon (TOC), total suspended solids (TSS), turbidity, and water temperature, zinc and pH. The soil pore water quality results (no dig results) were not included in the average calculation, see Section 4. Summing the relative averages of the surface water results was also used to develop combination water quality disturbance measurements for all the sites together and for each region separately. The combination disturbance measurements that were developed are a nutrient disturbance measurement (NO2+NO3, TKN, phosphorous, and ammonia); a metals disturbance measurement (copper, lead, zinc, calcium and magnesium); a copper-lead-zinc disturbance measurement; and a pollutant disturbance measurement that included the four nutrients, five metals, total suspended solids and specific conductivity. The different measurements, including the average surface water quality results and four different combination disturbance measurements were tested for normality by plotting normal quartile plots and using the Shapiro-Wilk W Test ($P > 0.05$ indicated a normal distribution). Normality tests were done with the data of 23 sites together and with the regional specific data separately. The combination disturbance measurement for each region (the average relative nutrients + relative metals + relative fecal coliform + relative TSS + relative specific conductivity) is displayed in Table 3.2. All other water quality disturbance measurements are found in Appendix C Tables C.3.1, C.3.2, and C.3.3.

Section 3.4.2 - Soil Disturbance Measures

At each wetland site, 10 soil samples were collected and analyzed for a number of parameters including pH, copper, lead, and zinc. As explained in Section 6, four samples were collected in the upland, four samples collected in the wetland, and two more samples collected in either the lower wetland or stream areas (bank of stream) of the site (collections adjacent to the stream along the bank were often done for Piedmont sites, especially). The average value for each site's four wetland samples, two stream samples, and six wetland plus stream samples in combination were calculated for pH, copper, lead, and zinc at each site. The average wetland, average stream, and overall average of wetland and stream results were used as disturbance measurements for soil pH, soil copper, soil lead and soil zinc (see Table 3.2). Upland soil samples were not used as disturbance measurements or in the disturbance measurement calculation as all macroinvertebrate samples were collected in the site's wetland or stream areas (See Section 8). In addition, many of the amphibians were observed in the wetland or stream areas of the study sites during the amphibian survey (see Section 7).

Section 3.5 – Statistical Analysis of Abiotic Data

Various statistical tests were used to analyze water quality, hydrology, and soils data. Similarly to the biotic indices, abiotic data sets were tested for normality by plotting normal quartile plots and using the Shapiro-Wilk W Goodness of Fit test ($p\text{-value} < 0.05$ indicated a normal distribution). The water quality analysis used the Analysis of Variance (ANOVA) and ranks sums tests to determine significant differences between regional data sets (Coastal Plain compared to Piedmont) and station location data sets (upstream compared to downstream stations) for the different parameters. Both the ANOVA and ranks sums test were used for the station comparison tests within region but only the ranks sum test was used for the station comparison tests within sites due to the small sample size. The ANOVA assumptions were also checked by performing a Goodness of Fit test ($p\text{-value} < 0.05$) on the error residuals. The Spearman's Rho correlation analysis was run on the water quality parameter data sets and the disturbance measurements, ORAM and LDI (see sections 3.2 and 3.3). An exploratory cluster analysis was also performed on the water quality data to see which sites were more similar or less similar based solely on water quality results (see Section 4). The data for the hydrology was presented in graphical form, showing the hydroperiods. Water level fluctuations in the headwater wetlands were recorded from about January 2006 to April 2007. No statistical tests were done on the hydrology data. The soils data were summarized using means for the soil parameters. Analysis of Variance was used to analyze the soil data along the variables of ecoregions (Coastal Plain and Piedmont), Sample location (Wetland area, Centerline, and upland), and topography. A p-value of <.06 was used for determining significance.

Section 3.6 – Statistical Concerns

The problem of the inflated alpha (p-value) was of concern. In any statistical analysis, the more tests that are performed, the higher the potential to commit a Type I error (i.e. a false significant result). Multiple correlations, regressions, ANOVA's, and rank's sums tests (Wilcoxon and Kruskal-Wallis) were performed, thereby increasing the likelihood that a Type I error may occur. DWQ is willing to accept that risk given the exploratory nature of this research. In other words, DWQ wants to discover all possibly significant results in order to guide future research and analysis, as this research will continue. During future monitoring studies, as more data are collected the statistical analysis will become more refined and the significant results will be less likely to be at risk of a Type I error.

In a similar manner, DWQ has chosen to accept a larger significance level for the same reasons stated above, plus the fact that field research by its very nature, is less likely to have the same level of control as a laboratory experiment. Therefore, a p-value ≤ 0.15 was considered significant for many of the statistical results. Due to these decisions to accept a greater risk of Type I statistical error, DWQ believes that the risk is not only acceptable given the stated reasons, but also that these results will show practical significance. For example, an important "practical" result for a downstream water quality parameter that showed improvement would be a statistically significant result of p-value ≤ 0.15 as opposed to the traditional p-value of ≤ 0.05. There is also more confidence in the "practical" significance of a p-value ≤ 0.15 for the downstream water parmameter that showed improvement if other downstream water quality parameters that show improvement have similar p-values of ≤ 0.15. There will then be greater confidence in not committing a Type 1 error as more water quality parameters show improvement with at least a practical significance level of a p-value ≤ 0.15. Finally, a number of statistical tests performed used a stricter p-value of ≤ 0.10 or ≤ 0.05 and are specified in the various method sections. Finally, the exact p-values for the significant results are always reported in each of the results and conclusion sections.

Table 3.2 Headwater Wetland Disturbance Scales Used to Test IBI Candidate Metrics

Region	Site Name	ORAM Score	LDI Watershed Value	LDI 300 m Buffer Value	LDI 50 m Buffer Value	Water Quality Pollutant Scale*	Ave Soils PH	Ave Soils Copper	Ave Soils Zinc
Coastal Plain	Batchelor	69.83	1.9688	1.8758	1.2481	48.5	3.83	0.58	2.12
	Battle Park	55.83	3.7166	3.3477	1	141.34	4.68	0.74	3.24
	Boddie Noell	35.5	2.1992	3.9169	2.235	144.6	4.44	0.66	2.21
	Cox	43.67	2.5345	1.88	1.2906	87.13	4.56	0.25	0.67
	East Fayetteville North	70.5	2.2652	2.2205	1.0993	59.05	4.48	0.74	1.18
	East Fayetteville South	57	1.5135	1.9417	1.406	140.49	4.22	0.5	1.37
	Hog Farm Lower	37.67	2.6053	2.263	1.6622	86.56	4.47	0.76	2.61
	Hog Farm Upper	42.67	2.669	2.7204	1.1758	219.51	5.15	0.47	3.95
	Nahunta	47.67	2.9807	2.9719	2.4159	120.13	4.99	0.68	3.49
	PCS	57.17	1.3717	1.5985	1.204	97.06	3.84	0.5	2.68
	Rough Rider	64	2.0479	2.3439	1.4005	55.64	4.73	0.1	0.85
Piedmont	Black Ankle Non-Powerline	64.17	2.3289	2.0975	1.1198	99.46	4.46	0.92	1.19
	Black Ankle Powerline	58.33	1.5503	2.1324	1.0273	140.76	4.52	0.67	1.44
	Duke Forest	53.5	1.151	1.2591	1.0748	83.88	6.16	2.02	1.2
	East of Mason	60.33	1.2907	1.9306	1	161.91	4.48	0.45	3.39
	Fire Tower	45.5	3.2091	2.3031	2.6598	99.58	4.72	1.26	4.66
	Kelly Rd	48.33	2.0395	1.8302	1.5308	70.04	4.54	0.83	5.57
	Moonshine	42	3.1222	3.9891	1.0081	75.42	4.65	0.53	1.4
	Pete Harris	59.67	1.7574	1.7466	1.1227	174.86	4.91	0.84	1.11
	Spring Garden	74.33	1.1687	1.6471	1.0796	65.31	4.98	0.49	1.68
	Troxler	20.5	5.3097	4.8182	3.9466	79.75	5.24	2.8	14.18
	Umstead	70	1.07	1.1625	1	104.17	4.9	0.43	1.27
	Walmart	38.17	5.9549	5.791	5.1612	44.86	4.95	1.09	7.51

*Water Quality Pollutant Disturbance Scale = Sum of Relative Average Values by Region for Nutrients+Metals+Fecal Coliform+TSS+Specific Conductivity (surface water only).

See Appendix XX for other Water Quality Disturbance Scales

Section 4 - Water Quality Monitoring Section

Section 4.1 Water Quality Introduction and Background

Headwater wetlands are believed to play a critical role in terms of water quality, hydrology, and habitat in North Carolina watersheds. Water quality in North Carolina has been affected by watershed development: urbanization, agriculture, and silviculture have decreased the quality of storm- water runoff that flows into wetlands and streams. This can result in the increase of pollutants such as nutrients, pesticides, metals, oil, grease, bacteria, and sediments that enter wetlands and streams. Headwater wetlands and streams (1st and 2nd order) drain 55-85% of watersheds in North Carolina (USFWS 2000). Since headwater systems are small and numerous in the landscape, historically their importance has been underestimated and therefore managed poorly in comparison with rivers and lakes (Peterson *et al*. 2001). A better understanding of the role these headwater systems have on improving water quality and how the surrounding landscape affects that water quality is necessary to better protect and manage these highly important aquatic systems.

Pollutants enter bodies of water, including wetlands and small streams, through “point source” and “nonpoint source” means. “Point source” refers to pollutants that originate from a single source. Examples are discharges from sewage treatment plants or any industry that utilizes water: textile mills, pharmaceutical plants, and pulp and paper mills. “Nonpoint source” pollution refers to pollutants that do not enter from a single point. Examples are all other sources of inflow: stormwater runoff, base flow, surface flow, rain, and tides. Water can carry pollutants in particulate and dissolved forms that can be organic or inorganic in nature (Vigil 2003).

Stormwater runoff from urban roadways, parking lots, and new development areas contains metals (copper, zinc, lead, magnesium, and calcium), sediments, and oil and grease. Sediments can be abrasive or clog the gills of fish, amphibians, mollusks, and smother other macroinvertebrates. Toxic metals accumulate in fish and amphibians, causing malformations and posing a danger to wildlife higher on the food chain (Ohio EPA, Mitch and Gosselink 2003). Sediment and silt can cause turbidity in the water, affecting visibility and the ability of light to penetrate and reach aquatic plants. Excessive oil or grease can also be toxic to aquatic life. High sediment loads can scour and remove plant life during storm surges (Reinelt and Horner 1995, Ohio EPA). Sediments, metals, oil, and grease can also originate from point source industrial discharges and agricultural areas.

Agricultural lands, golf courses, and even neighborhood lawns are often a source of fertilizer-driven nutrient loads of phosphorous and nitrogen. Additionally, nitrogen-fixing crops and animal waste can add to the nitrogen levels in agricultural areas (Peterson *et al*. 2001, Vigil 2003). Other sources of nitrogen include sewage treatment plants and septic tanks (Vigil 2003). Hog farming in North Carolina can be a major source of phosphorous and nitrogen in rural areas of the Coastal Plain (Environmental Defense 2000). High levels of nutrients can cause eutrophication and algal blooms, producing decaying plant material that decreases oxygen in downstream waters (WI DNR 2006). Initially, increases in levels of nitrogen causes plant species to increase in diversity, but excessive levels will cause a decrease in diversity (U.S. EPA 1998).

Nitrogen in the form of ammonia can be toxic to freshwater organisms in higher concentrations (Scorecard).

Stormwater runoff from agricultural areas, road rights-of-way, golf courses and lawns can also contain toxic pesticides bound to the inflowing sediments. Certain types of pesticides act by inhibiting important enzymes in the nervous system. Pesticides have been known to cause large species kills of fish, frogs, turtles, mussels, water birds, and even rare and endangered species like peregrine falcons, bald eagles, and osprey (University of California 2006, Virginia Cooperative Extension 1996, USFWS Peregrine Falcon).

Fecal coliform are micro-organisms that live in the intestines of humans and other warm-blooded animals. Fecal coliform bacteria are generally harmless, although *Escherichia coli* (E-coli) and viruses that attach to certain bacteria can be highly harmful (Vigil 2003). Fecal coliform originates from livestock operations, sewage treatment plants and septic tanks (Vigil 2003).

Wetlands act as a natural filter for these pollutants by removing, reducing, or transforming pollutants through the processes of sedimentation, biodegradation, filtration, and sorption (Ohio EPA, Azous and Horner 2001, Mitsch and Gosselink 2000, Vigil 2003). Sedimentation is the process by which particulate matter falls or settles out of the water column. Water flowing through wetlands moves much slower than in rivers or streams, resulting in sediment deposition. Nutrients such as phosphorous, nitrogen, and sediments can be removed through the process of sedimentation. Filtration occurs in wetlands when water carrying solids passes through vegetation or percolates through the soil. Sediment, metals in particulate forms, and phosphate can be removed through the process of filtration. Biodegradation is the process by which complex organic materials are broken down into simpler substances by micro-organisms, particularly bacteria. Oils and pesticides are removed from wetlands through the process of biodegradation. Sorption is the combined process of absorption and adsorption. Absorption occurs when pollutants come in contact with absorbent materials that have an affinity for the pollutant, while adsorption occurs when pollutants adhere to the surfaces of materials they are attracted to. Nutrients, metals, pesticides, and fecal coliform are removed through the process of sorption (Vigil 2003, Mitch and Gosselink 2000, Reinelt and Horner 1993).

Small first or second order headwater streams also have been documented to remove nitrogen from the water by biological assimilation and denitrification. Ammonia can be removed within 200-300m while nitrates need five times the distance. Headwater streams have also been documented to remove more than half of all nitrogen imports (Peterson *et al*. 2001).

Many different factors can directly affect a wetland's ability to remove pollutants and work as a natural filtering system within the larger surrounding watershed. A wetland's location within the landscape is of particular importance. Wetlands that are isolated often have intermittent surface or groundwater connections to streams and rivers, therefore their proximity to downstream waters can still effect water quality even though there may not be a surface hydrological connection (Whigham and Jordan 2003). Headwater wetlands and wetlands that have inflow and out flow, and wetlands associated with rivers like riverine swamps and bottomland hardwoods have the potential to directly affect the quality of downstream waters (Mitsch and Gosselink

2000). Headwater wetlands are of particular importance due to their location in upper reaches of the watershed where they can filter pollutants from their upstream watershed.

The surrounding land use and the size of the watershed relative to wetland size can also have an effect on the wetlands ability to remove pollutants (Brown and Vivas 2003, Azous and Horner 2001, Reinelt and Horner 1993). A study in Washington State showed that a rural wetland removed 56% total suspended solids and 82% total phosphate in comparison to the 14% and 8% removal, respectively, of a wetland located in an urban area (Reinelt and Horner 1993). Another Washington State study showed that urban wetlands have higher pH, conductivity, ammonia, nitrite + nitrate (NO_2+NO_3), and total phosphate in comparison with rural wetlands; however, the same study showed that dissolved oxygen levels were due to wetland morphology rather than urbanization. Wetland morphology includes the wetland's shape, perimeter, length, internal dimensions, inlet and outlet structure, and topography (Azous and Horner 2001). Wetland morphology also affects water flow patterns and pooling patterns. The amount of recent precipitation and surrounding impervious surfaces, in addition to wetland morphology, also affect flow rate (Azous and Horner 2001, Reinelt and Horner 1993, Ohio EPA). Faster flowing water has a lower residence time, therefore less sedimentation or filtration will occur in the wetland. Sedimentation is often the principal mechanism in which pollutants are retained by wetlands. Wetlands with a higher flow velocity have lower temperatures, higher dissolved oxygen levels and higher pollutant concentrations, especially NO_2+NO_3 (Azous and Horner 2001).

Seasonality can also be a highly important factor in a wetland's ability to remove, reduce, or transform pollutants. Seasonal plant growth is related to temperature and precipitation because plants absorb metals, phosphates and other pollutants during the growing season. Seasonal rains affect surface and base flow rates and therefore sediment, nutrient, and other pollution loads. Azous and Horner (2001) showed the following seasonal trends: (1) dissolved oxygen tends to increase from November to May due to flow and colder temperatures; (2) conductivity sometimes increased from May to November; (3) total suspended solids increased from November to March due to runoff and flow rates; (4) ammonia and phosphorous decreased from November to May probably due to the lack of fertilizer applications during the colder months; and (5) fecal coliform, although variable, tended to increase in late August to September and decrease from mid-November to February. Wetlands can be a sink or a source for nutrients depending on the season (Mitsch and Gosselink 2000). During the growing season, higher temperatures accelerate microbial activity plus plant growth and uptake. This reduces nutrient levels and causes wetlands to be a nutrient sink (import > export) whereas during the fall and winter wetlands can become a nutrient source (export > import).

If wetland water quality standards exist, these can be compared to wetland water quality results to assist in determining the quality of a wetland. In North Carolina (as in many other states), a set of numeric wetland water quality standards does not exist for wetlands nor has a large comprehensive study of wetland water quality been done prior to this research. However, North Carolina does have numeric standards for North Carolina streams, rivers and lakes (www.h2o.enr.state.nc.us/csu/ 2007). In addition, the North Carolina DWQ Ambient Monitoring System (AMS) maintains a large water quality data set obtained from rivers, streams (mostly), and lakes in the Coastal Plain, Sand Hill, Piedmont and Mountain regions of North Carolina. The

AMS is a network of stations established to provide site-specific and long-term water quality information on significant rivers, streams, and estuaries throughout the state. It should be noted that a number of the DWQ AMS stations were chosen because it was suspected there was a water quality discharge problem. Additionally, there are dissimilarities between streams and wetlands due to the the flow and morphological differences of these two systems. Therefore, this data set cannot be considered a reference data set. However, this is a large existing NC data set and some general comparisons can still be made while taking into account the differences between wetlands and streams which are discussed further below. Table 4.1.1 contains results from the North Carolina DWQ AMS, the EPA, and the U.S. Geological Survey. The EPA results are from the “Ambient Water Quality Criteria Recommendations for Rivers and Streams in Nutrient Ecoregion IX and XIV” (US EPA 2000). The US Geological Survey results are from the “Water Quality in the Appalachian Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces, Eastern United States” (USGS 1997). The results in Table 4.1.1 were compared to the wetlands researched by DWQ in this study and will be discussed further in the Results and Conclusion Section In this study, headwater wetlands of the Piedmont tended to be bowl-shaped wetlands that graded into streams. While some of the Coastal Plain sites were similar, others were flatter and larger systems that exhibited a slower moving, sheet flow hydrology. Additionally, some of the sites had intermittent surface water connections to downstream waters. Wetlands that were bowl-shaped with a steeper gradient may be more comparable to stream results than some of the Coastal Plain wetlands or other slow moving, open water wetland systems. The Azous and Horner study, in Washington State, compared 346 wetlands located in non-urban, medium urban, and high urban areas to streams and found the following results which outlines some of the differences between streams and wetlands:

1. Flowing streams had higher dissolved oxygen levels with the median value of streams twice that of wetlands.
2. Wetlands located in moderate to highly developed urban areas had similar conductivity as streams, but rural wetlands had a median value lower than that of streams.
3. Total suspended solid levels were similar between wetlands and streams.
4. Ammonia levels were higher in wetlands than streams probably due to the presence of decomposed organic matter in wetlands.
5. Streams had higher levels of NO_2 + NO_3 possibly due to the slower rate of nitrification in the oxygen depleted wetland environment.
6. Median stream phosphate levels were higher in wetlands located in rural areas, but lower in wetlands located in moderate to highly urbanized areas.
7. Median fecal coliform levels of streams were lower than wetlands; however stream data did not contain larger data outliers as in wetlands.

The location of headwater wetlands in the landscape is highly significant for water quality. Downstream waters from headwater wetlands flow into small streams, rivers, lakes, other wetlands, and estuaries and oceans. The water quality results, obtained from monitoring 12 Piedmont and 11 Coastal Plain headwater wetland sites (see Figure 2.1), were used to develop Indices of Biotic Integrity (see Section 3.1). Water chemistry and physical parameters were obtained at two to three sample stations (upstream, downstream, and further downstream) within each site over the course of 18 months. These results were also used to answer the following questions:

- How does the water quality of headwater wetlands within more developed watersheds compared with the water quality of headwater wetlands within less developed watersheds?
- Are headwater wetlands able to filter pollutants by comparisons of upstream station results to downstream station results?, and
- Do headwater wetlands located in a more natural watershed have a better filtering capacity for removing pollutants than wetlands located in a more developed watershed?

Table 4.1.1 Stream Water Quality for Streams in the Coastal Plain, Piedmont, and Sand Hills of North Carolina and the U.S.

Source and Region for stream parameter results	North Carolina Coastal Plain[1]			North Carolina Piedmont[1]			North Carolina Sand Hills[1]			EPA Coastal Plain[2]			EPA Piedmont[2]			USGS Piedmont[3]
Parameters	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	25th Percent	Minimum	Maximum	25th Percent	Median
Ammonia (mg/L)	0.01	3.80	0.04	0.01	18	0.04	0.01	1.20	0.03	-	-	-	-	-	-	0.05
Calcium (mg/L)	1.6	6.1	4.2	3.7	19	16	-	-	-	-	-	-	-	-	-	25
Copper (ug/L)	2	180	2	1.9	350	3.4	2	42	2	-	-	-	-	-	-	-
Dissolved Oxygen (mg/L)	0	19.5	7.7	0	20	8.7	0.3	16.6	8.1	-	-	-	-	-	-	4.1
Fecal Coliform cfu/100mL	1	9600	18	1	61000	91	1	7400	46	-	-	-	-	-	-	-
Lead (ug/L)	10	680	10	10	8900	10	10	25	10	-	-	-	-	-	-	-
Magnesium (mg/L)	1.40	2.30	1.50	0.79	6.9	1.4	-	-	-	-	-	-	-	-	-	6.6
NO_2+NO_3 (mg/L)	0.01	490	0.32	0.01	31	0.49	0.01	1.4	0.21	0.10	4.12	0.31	0	9.78	0.125	0.99
Total Phosphorus (mg/L)	0.01	7.4	0.10	0.01	20	0.10	0.01	0.68	0.04	0	0.09	0.0024	0.24	0.0036	0	0.05
Specific Conductivity (us/cm)	11	58760	5760	6	3746	102	6	423	44	-	-	-	-	-	-	280
Total Kjeldahl (TKN) (mg/L)	0.1	70	0.45	0.01	61	0.4	0.1	1.8	0.3	0.05	1.45	0.30	0.05	1.45	0.30	-
Total Organic Carbon (mg/L)	4.5	85	9.0	2.8	37	5	5	10	6	-	-	-	-	-	-	-
Total Suspended Solids (mg/L)	0	700	6	0	2000	7	1	62	3	-	-	-	-	-	-	159
Turbidity (NTU)	-	-	-	-	-	-	-	-	-	0.84	2.58	1.68	0.175	162.5	7.02	-
Water, Temperature (C°)	0	36	18.5	0	36.8	17	1	31	15.4	-	-	-	-	-	-	14
Zinc (mg/L)	3	2300	13	9	4000	14.5	10	180	11	-	-	-	-	-	-	-
PH (S.U).	2	13.3	7.3	2.7	10	7.10	3.10	8.2	6.2	-	-	-	-	-	-	6.7

References: [1]NCDWQ Ambient Monitoring System 2007, [2]EPA 2000, [3]USGS 1997

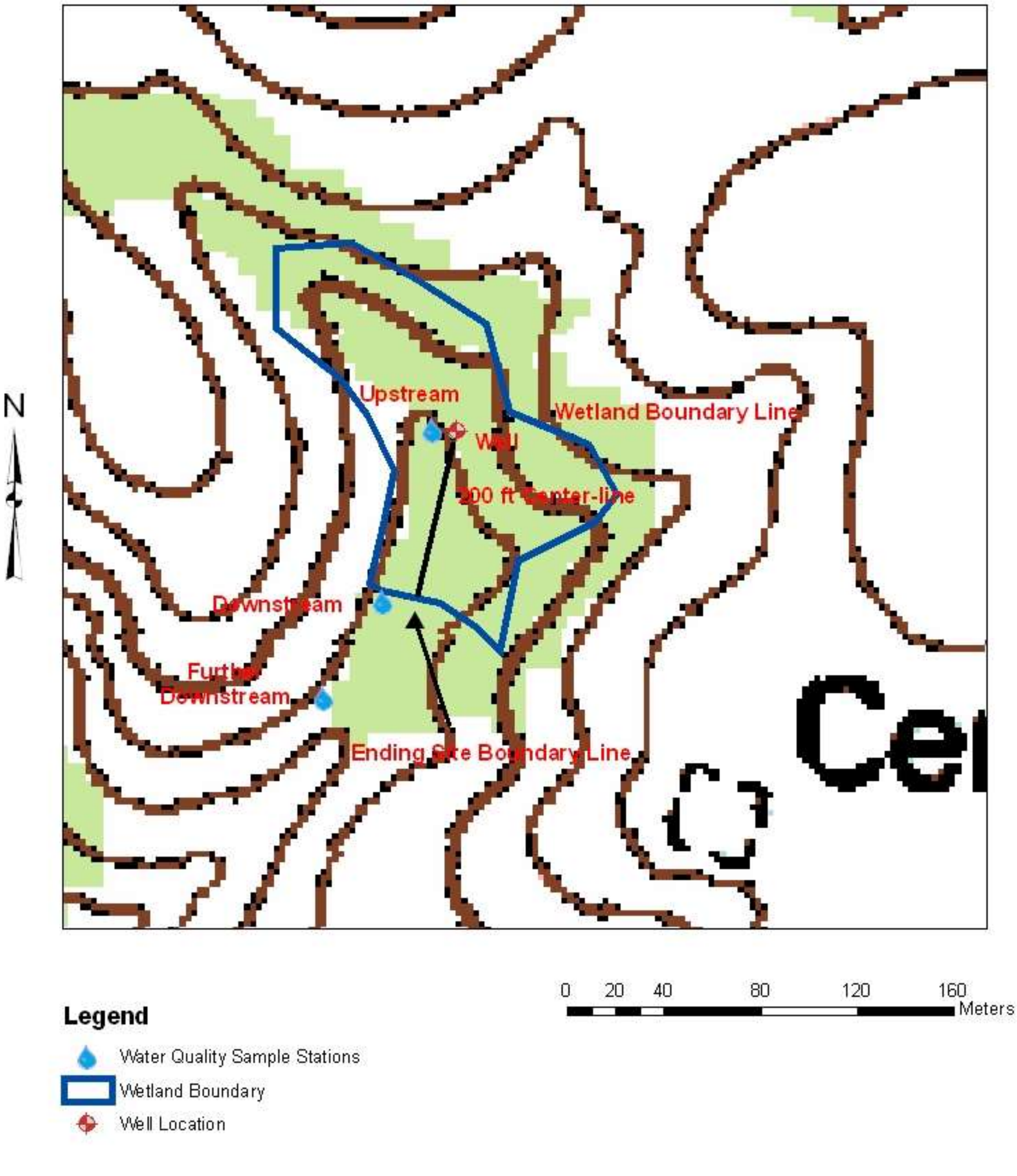
Section 4.2.1 Water Quality Field Methods and Lab Analysis

Water quality parameters were sampled on a quarterly basis during six time periods; April 2005, July 2005, October 2005, January 2006, April 2006, and July 2006. Sampling during these times allowed DWQ to obtain information on water quality during the dry season, wet season, and transition periods. Physical parameters (pH, DO, specific conductivity, and temperature) were taken in the field with a YSI pH 100 meter and YSI model 85 meter and recorded on field sheets (see Appendix B). All water samples were collected, preserved, and transported in accordance with Division of Water Quality Laboratory Standard Operating Procedures (NCDWQ 2003) and DWQ Laboratory Sample Submission guidelines (NCDWQ 2005). Water samples were always analyzed for nutrients (P, NO_2+NO_3 as N, total Kjeldahl nitrogen [TKN], NH_3-N), heavy metals (Mg, Ca, Cu, Pb, and Zn), dissolved organic carbon (DOC), total organic carbon (TOC), total suspended solids (TSS), and fecal coliform. Turbidity was only analyzed in the first sample period and was then deemed to be an unnecessary parameter for headwater systems. Additionally, due to drought conditions, DOC was not analyzed in the second and third (July 2005 and Oct 2005) sample periods, while magnesium and calcium were not analyzed in the first sample period. Chlorine was tested in the field using chlorine strips during the first and second sample periods. All results were negative and no samples were further analyzed at the lab. A total of up to 20 sample parameters were collected during each sample session at each sample station; however, numerical values were not collected for chlorine so only up to 19 parameter results were collected. Water sample lab analysis and water meters were funded by a 319 state grant for the first 4 quarters of water sampling.

Water samples were taken near the well at the head of the wetland and 200 feet downstream in order to obtain a measure of the wetland's capacity to affect pollutant levels (See Figure 4.2.1 for an example). Sample station locations were recorded with GPS and marked in the field with flagging. Additionally, station locations were photographed with a digital camera each time the station was sampled in order to make a visual record of the station's hydrology. The best sampling methodology was chosen according to the hydrological conditions on the sampling day. Samples were taken by 4 methods: 1) direct grab, 2) bail, 3) dig (with plastic/metal shovel), and 4) bailed. DOC, turbidity, and TSS were not taken at recently dug sample sites since water was turbid. Digging with a shovel could affect the results as a metal shovel (in particular) may affect the metal results for copper, lead, or zinc. For the data analyses, as described in the next section, a set of analyses was completed using "all" the data (samples collected with direct grab, bail, and dug with plastic or metal shovel methods) and "dig" only data (samples collected by digging first). A few of the metal results from digging were extreme outliers that were not used in the analysis. Field data sheets were completed for each station as well as DWQ lab sheets and labels for sample bottles (see Appendix B). A unique station number that reflected the site name, sample location (upstream, downstream), and sample time (month and year) was assigned for each sample event. Field data sheets included information on physical parameters, sample location, station number, 48-hour precipitation history from the nearest weather station, wetland site name, date, sampler's initials, air temperature, sample method, chlorine strip results, picture number, sample method, comments on hydrology, water quality, and details on the microhabitat of station location, sample time, preservation time, and which lab tests were to be performed. All samples were analyzed at the Division of Water Quality Laboratory Section in Raleigh, North Carolina. Lab sheets and bottle labels are used by the DWQ Lab to identify the proper lab test to perform on each water sample.

Meters were calibrated at the beginning and end of each day and during the day if deemed necessary. Probes were rinsed with deionized water before and after each use. To avoid contamination of samples, gloves were worn for sampling, filtering, and preservation. Bail bottles were triple rinsed before usage. For DOC samples, 200 ml of water collected in the field was suction-filtered through 0.45-micron filters within half an hour of collection. DOC filtering equipment was triple-rinsed with deionized water before and after each sample was filtered and filters were changed between samples. Filtering blanks were prepared at the beginning and end of each sample day to test for DOC contamination. Additionally, one set of unlabeled duplicates was sent to the lab during each sample period to check for accuracy. DWQ Standard Operating Procedure and Laboratory Sample Submission Guidelines were followed to ensure that sample preservation, storage, labeling, and hold times are met. The DWQ Lab was responsible for selection and preparation of sample containers, sample volumes needed for each chemical analysis, and decontamination of any lab equipment. Details of these processes are explained in "The Quality Assurance Manual for the North Carolina DWQ Laboratory section" (NCDWQ 2003b).

Figure 4.2.1 Hog Farm Upper Water Quality Sample Stations



Section 4.2.2 Water Quality Data Analysis Methods

Section 4.2.2.1 General Water Quality Analysis Methods

Water quality results were organized and entered into an Excel spreadsheet. All duplicate results were averaged and physical parameter outliers deleted on days when the meters did not calibrate correctly. Microsoft Access was further used to organize data according to sample method. JMP (Version 6, SAS Institute Inc., 2006) statistical software was used for all statistical analyses on the data. Generally, two sets of results were calculated for each statistical analysis. One set of results was calculated with "all" water quality data and the other set was calculated with just the "no dig" data. The "no dig" data were from samples obtained by bail and direct grab methods, rather than digging with a plastic or metal shovel. These two sets of analyses were in order account for the effects that digging to obtain a sample might have on the sample. This is why a separate analysis for surface water was completed.

REGIONAL DATA ANALYSIS

For each region, the overall mean and median were calculated for each water quality parameter using all the data results and using just the no dig results. An analysis of variance (ANOVA) was run to determine if there was a significant difference between regions (Coastal Plain versus Piedmont) for all the data and for the no dig data results. ANOVAs were run on both raw and log-transformed results for both sets of data. The residual errors of the ANOVA analyses (All, All-transformed, No Dig, No Dig transformed) were tested for normality using the Shapiro-Wilk W Goodness of Fit test. The ANOVA results that had normally distributed raw data residuals were shown in the results table. Otherwise ANOVA results of log-transformed data that had normally distributed were shown in the results table when raw data residuals were not normally distributed. ANOVA analyses that did not have normally distributed residual errors, either raw data or log-transformed, and therefore did not meet the assumptions of the ANOVA test, were not shown in the results table. The non-parametric and less powerful ranks sum Wilcoxon test was also performed to see if there were any significant differences between regions for all the raw data and for the raw no dig data sets. A p-value ≤ 0.10 was considered significant for the regional comparison of water quality data.

REGIONAL DATA ANALYSIS BY STATION

The overall mean and median for the station locations (upstream, downstream, and further downstream) were determined for each parameter within each region using all the data and the no dig data sets. The upstream (UP), downstream (DN), and further downstream (FD) results were compared to determine if there was an average overall improvement of water quality downstream. Station comparisons, upstream to downstream (UP-DN), upstream to further downstream (UP-FD), and downstream to further downstream (DN-FD) were deemed to have either "improvement" or "no improvement" for each of the 19 parameters. A reduced result value for all parameters at the downstream station (DN or FD) indicated improvement, except for dissolved oxygen (percent and mg) and pH, where an increased result indicated improvement. Samples were collected for the first year (four sample sessions) at just the upstream and downstream results; however, preliminary results suggested there was not much improvement in water quality from the upstream to downstream stations in the Coastal Plain so a further downstream station was added at five of the Coastal Plain Sites (Cox, East Fayetteville North, East Fayetteville South, Hog Farm Upper, and PCS). It was not possible to locate further downstream stations at the other Coastal Plain sites. The "further downstream" station was located 200ft-300ft downstream from the "downstream" station.

For the regional station comparison, a chi-square test was performed on the categorical nature of the water quality (improved or not improved). The chi-square test was performed to determine if the number of site comparisons that improved was significantly different for the number of site comparisons that did not improve. The chi-square test was performed on both sets of data (all and no dig).

The upstream to downstream to further downstream data sets were compared (UP-DN, UP-FD, DN-FD) to see if there was a significant improvement in downstream water quality. An ANOVA test was performed to see if there was a significant difference between station locations (UP, DN, and FD) within regions for all the water quality data and the no dig data separately. Similar to the regional comparison of the results, ANOVAs were also run on raw and log-transformed results for both sets of data. Residual errors for the ANOVA analyses ([Coastal Plain – all, no dig, all transformed, no dig transformed] and [Piedmont – all, no dig, all transformed, no dig transformed]) were tested for normality with the Shapiro-Wilk W Goodness of Fit test. ANOVA results that had normally distributed raw data residuals were shown in the results table. Otherwise, ANOVA results of log-transformed data that had normally distributed residuals were shown in the results table when raw data residuals were not normally distributed. ANOVA tests that did not have normally distributed residual errors, either raw data or log-transformed, and therefore did not meet the assumptions of the ANOVA test, were not shown in the results table. The non-parametric ranks sum Wilcoxon test, for the comparison of two sets of data in the Piedmont, and Kruskal-Wallis test for the comparison of three sets of data in the Coastal Plain, were also used on all site station comparisons (UP-DN, UP-FD, or DN-FD) to determine if there was a significant difference between stations for all the data and the no dig data. For the Coastal Plain, follow-up multiple comparison tests (Tukey Kramer, HSU's MCB and Student's T-test) were used to determine which station comparison (UP-DN, UP-FD, or DN-FD) was significantly different in situations where the ANOVA and / or Kruskal Wallis Test(s) had a significant result (p-value < 0.10). Results of the comparison of the station means, as previously described, were used to determine if there was significant improvement or no improvement at downstream stations.

SITE PAIRED STATION COMPARISON DATA ANALYSIS FOR REGION

Station comparison (UP-DN, UP-FD, and DN-FD) statistical analyses (ANOVA and ranks sums tests) were also performed for each parameter within each region using sample period results in which a water quality sample was obtained from at least two sample stations; upstream and downstream, upstream and further downstream, or downstream and further downstream. This statistical analysis will be referred to as "site-paired" station comparisons. Sample period data in which water quality samples were collected at only one station were not used in this analysis. ANOVAs were run on raw and log-transformed results for all the "site-paired" data and for the no dig "site-paired" data. Residual errors for the ANOVA analyses ([Coastal Plain – all, no dig, all transformed, no dig transformed] and [Piedmont - all, no dig, all transformed, no dig transformed]) were tested for normality with the Shapiro-Wilk W Goodness of Fit test. ANOVA results that had normally distributed raw data residuals were reported. ANOVA results of log-transformed data that had normally distributed residuals were reported when raw data residuals were not normally distributed. ANOVA tests that did not have normally distributed residual errors, either raw data or log-transformed, and therefore did not meet the assumptions of the ANOVA test, were reported only if both the ranks sum test and ANOVA test on the raw data were significant. The non-parametric ranks sum Wilcoxon test was used for the comparison of two sets of data (UP-DN) and Kruskal-Wallis test was used for the comparison of three sets of data for the five Coastal Plain sites that had further downstream stations (UP-DN, UP-FD, and DN-FD). The ranks sums tests were used to determine if there was a significant difference between stations for all the raw data and the no dig raw data. For the Coastal Plain, follow-up multiple comparison tests (Tukey Kramer, HSU's MCB and Student's T-test) were used to determine which station comparison (UP-DN, UP-FD, or DN-FD) was significantly different in situations where the ANOVA and / or Kruskal Wallis Test(s) had a significant result (p-value < 0.10). Station means were compared to see if there was significant "improvement" or "no improvement" at the downstream station.

SITE STATION DATA ANALYSIS

The mean for the water quality results of each parameter at each station location (UP, DN, and FD) was also calculated within each site using all the data results and using just the "no dig" results. Station comparisons, upstream to downstream (UP-DN), upstream to further downstream (UP-FD), and downstream to further downstream (DN-FD), were deemed to have had either "improvement" or "no improvement" for each of the 19 parameters at each site. A reduced result value for all parameters at the downstream station (DN or FD) indicated improvement, except for dissolved oxygen (percent and mg) and pH, in which an increased result value indicated improvement. A tally of the "improvements" or "no improvements" was determined for the station comparisons (UP-DN, UP-FD, and DN-FD) at each site. The total number of improvements for each station comparison within region was also tallied for all the data and the no dig data separately. An additional chi-square analysis was performed on the categorical data ("improved" or "not improved") results for each station comparison within region for all data and no dig data sets. Both the regional and site comparison analyses of station location means and medians were completed to determine if headwater wetlands filter out pollutants.

The non-parametric ranks sums tests (Wilcoxon or Kruskal-Wallis) were also performed for each parameter station comparison at each site, to determine the number of sites that independently showed significant improvement (or no improvement) for each parameter. The ranks sums tests were performed on the parameter data at each site for all the data and for all the site-paired data. A ranks sums test was used, rather than an ANOVA test, to detect significant differences between stations due to the non-parametric nature and small size of the data sets (up to 6). A p-value of 0.10 was considered to be significant. This analysis was not performed on no-dig data since the data set was even smaller. The comparison of station means (UP-DN, UP-FD, and DN-FD), as described previously, were used to determine which site station comparisons had significant "improvement" or "no improvement". In situations where there were three station comparisons (UP-DN, UP-FD, and DN-FD) the station comparison that had the greatest absolute value was considered to be the significant result of the ANOVA or Kruskal-Wallis statistical test.

Section 4.2.2.2 Exploratory Analysis of Seasonal Trends, Comparisons to known Stream Parameters and Cluster and Partition Analysis

Additional general summary water quality analyses were completed, including the analysis of seasonal trends, comparison of headwater wetland parameters to stream parameters, and cluster and partition analysis. For the time series analysis, the overall median for each sample time series (April 2005, July 2005, October 2005, January 2006, April 2006, and July 2006) by region was determined to see if there were any notable seasonal trends. The median parameter values of each site were compared to the parameter values for streams in the Piedmont and Coastal Plain shown in Table 4.1.1 in order to see how water quality of Coastal Plain and Piedmont headwater wetlands compared to North Carolina Coastal Plain and Piedmont streams.

A cluster and a partition analysis using the 19 water quality parameter means and medians for each site was performed to see how similar the sites were based on water quality results alone. The cluster analysis was performed on the water quality parameters to attempt to determine clustering patterns of the sites in terms of how they related to each other and to the water quality data results. A mean and median cluster analysis was performed using all the water quality data results and just the sample directly water quality data results resulting in four cluster analyses. The cluster analysis used Wade's hierarchical cluster method in which the sites that are closest together were joined together in groups. The objective of the cluster analysis was to minimize with-cluster variation and maximize between-cluster variation.

A partition analysis was performed on the site's water quality parameter mean and median results for all the data and the sample directly data. This is a useful method for exploring relationships without having a good prior model. When the results are continuous, (as was in this analysis), the Partition method fits means between the sites and creates splits that significantly separate the means based on the sums of squares. This method looks at how the sites predict the results, whereas the Cluster analysis looks at how similar the sites are based on the results.

Section 4.2.2.3 Correlation Analysis with ORAM and LDI Watershed Values

Correlation analyses were run using Spearman's Rho non-parametric correlation analysis with the results of the water quality analysis for each parameter against two different general disturbance measurements, ORAM and LDI watershed scores calculated for each site (See Section 3.3 and 3.2). Spearman's Rho correlation analysis was used since this test can be used on data sets that are not normally distributed as was the case with the LDI data and some of the water quality parameter data sets. Two sets of Spearman's Rho non-parametric correlation analyses were run for each water quality parameter against each site's ORAM score and each site's LDI score. One set contained all the water quality results data and the other set contained only the no dig data. The correlation of ORAM and the water quality parameters shows how the water quality parameters measured at each site compares with the rapid wetland assessment results of each site. North Carolina has also recently developed rapid assessment methods, North Carolina Wetland Assessment Method (NCWAM) (NC WAM 2007) that is currently being finalized. NCWAM forms were completed on the headwater wetland sites and will be used in future wetland monitoring work but are not reported in this EPA final report. The correlation of the watershed LDI and the water quality parameters shows how the water quality parameters measured at each site compares with the quality of the land use of each site's watershed.

A final set of Spearman's Rho correlation analyses were run to determine if headwater wetlands that are more disturbed, or located in a more developed watershed, have a lower capacity to filter out pollutants than more pristine headwater wetlands located in more natural watersheds. The percent improvement capacity of each wetland site was determined with the following equation by using the station water quality parameter mean comparisons that were calculated in the site station data analyses.

$$\text{Percent Improvement Capacity} = \frac{[(UP - DN) + (UP - FD) + (DN - FD)]_{improvement}}{[(UP - DN) + (UP - FD) + (DN - FD)]_{improvement\ +\ noimprovement}} - \text{A}$$

Spearman's Rho correlation analysis was run with the wetland site improvement capacity against the wetland site ORAM score. Another correlation analysis was run with the wetland site improvement capacity against the wetland site watershed LDI score. Both correlation analyses were run using wetland improvement capacities calculated from all the water quality results and from the no dig results only.

Section 4.3 Water Quality Results and Conclusions

4.3.1 General Summary Data Results

REGIONAL DATA ANALYSIS RESULTS

Table 4.3.1A and 4.3.1B shows the summary results for the regional comparison between the Coastal Plain and Piedmont. Table 4.3.1A shows all the water quality data results and Table 4.3.1B shows only the no dig results (samples collected when surface water was present and no digging was required to obtain the sample - see methods section). Overall means and medians are also shown on these tables. The ANOVA assumptions were met (normal distribution of residual errors) for the log-transformed data for calcium, DOC, fecal coliform, TSS, turbidity for all the data and for calcium, dissolved organic carbon (DOC), total organic carbon (TOC), total suspended solids (TSS), and turbidity for the no dig data. The ANOVA assumptions were also met for pH (not log-transformed) for all the data and for the no dig data. The ANOVA analysis showed there was a significant difference for calcium, DOC, and pH for the regional comparison of all the data (see Table 4.3.1.A). The Ranks Sum's Wilcoxon test showed there was a significant difference between 12 of the 19 parameters, including the same significant parameters as shown by the more powerful ANOVA test. Those parameters are: ammonia, calcium, DOC, dissolved oxygen (percent and mg/L), magnesium, NO_2+NO_3, phosphorous, specific conductivity, TKN, TOC, and pH (see Table 4.3.1A). It should also be noted that the ANOVA analysis of all the raw data on parameters that were significant (although not meeting the assumptions of the ANOVA test for raw or transformed residuals) and also significant for the Ranks sum test included dissolved oxygen (percent and mg/L at p-value < 0.0001), NO_2+NO_3 (p-value = 0.0009), phosphorous (p-value = 0.0628), specific conductivity (p-value < 0.0001), and TOC (p-value = 0.095). Since these ANOVA results did not meet the test assumptions, they were not shown in the results table.

For the analysis of the no dig data, the ANOVA test showed there was a significant difference for calcium, DOC, TOC, and pH between the Coastal Plain and Piedmont regions. Similar to the analysis of all the data, the Wilcoxon test showed there was a significant difference between regions of the same parameters as the ANOVA test. There was a total of 14 significant differences for parameters between regions, including ammonia, calcium, copper, DOC, dissolved oxygen (% and mg/L), fecal coliform, magnesium, NO_2+NO_3, phosphorous, specific conductivity, TKN, TOC, and pH (see Table 4.3.B). It should also be noted that the ANOVA analysis of the no dig raw data on parameters that were significant (although not meeting the assumptions of the ANOVA test for raw or transformed residuals) and also significant for the Ranks sum test included dissolved oxygen (p-value = 0.0001 and 0.0006), magnesium (p-value = 0.0003), NO_2+NO_3 (p-value = 0.0021), phosphorous (p-value = 0.0196), specific conductivity (p-value < 0.0001), and TOC (p-value = 0.0078). Since these ANOVA results did not meet the test assumptions they were not shown in the results table.

These differences can potentially be attributed to the regions' physiography, soil and plant cover, and surrounding land uses. Dissolved oxygen levels in the Piedmont were higher likely because there was usually a greater slope and water flow rate at these sites in comparison with the Coastal Plain. The difference in pH is likely a factor of soil type since more sites in the Coastal Plain had organic soils, making the water more acidic. The higher levels of calcium and magnesium in the Coastal Plain may be because the Coastal Plain tends to have harder water. The higher rates of nutrients and specific conductivity in the Coastal Plain are probably due to land use activities, i.e. atmospheric deposition from hog farming and phosphate mining in some sites. The differences in DOC and TOC are probably related to the dense plant cover and slow moving water in the flatter Coastal Plain sites, allowing organic matter to build up.

Table 4.3.1a Regional Comparison of Summary Results (All Water Quality Results)

	Coastal Plain		**Piedmont**					
Parameter	**Mean**	**Median**	**Mean**	**Median**	**ANOVA P-value**	**Significance by ANOVA***	**Wilcoxon P-value**	**Significance by Wilcoxon**
Ammonia mg/L	0.11	0.05	0.09	0.03		N/A	0.0697	Significant
Calcium mg/L	8.14	5.3	5.71	3.25	0.0152	Significant	0.0151	Significant
Copper ug/L	14.87	2	20.64	3.05		N/A	0.1129	Not
DOC mg/L	14.51	13	7.71	5.6	<0.0001	Significant	<0.0001	Significant
Dissolved Oxygen (%)	24.8	16.95	37.63	36.9		N/A	<0.0001	Significant
Dissolved Oxygen (mg/L)	2.46	1.51	3.66	3.58		N/A	<0.0001	Significant
Fecal Coliform cfu/100 ml	2403.42	170	1525.23	90	0.2259	Not	0.2034	Not
Lead ug/L	47.35	10	48.67	10		N/A	0.5154	Not
Magnesium mg/L	3.97	2.25	2.73	1.48		N/A	0.0551	Significant
NO_2+NO_3 mg/L	2.61	0.02	0.04	0.02		N/A	0.0003	Significant

Table 4.3.1a Regional Comparison of Summary Results (All Water Quality Results)

Parameter	Coastal Plain		Piedmont		ANOVA P-value	Significance by ANOVA*	Wilcoxon P-value	Significance by Wilcoxon
	Mean	Median	Mean	Median				
Phosphorus mg/L	0.56	0.23	0.35	0.1		N/A	0.0075	Significant
Specific Conductivity	118.5	84	53.59	47.4		N/A	<0.0001	Significant
Total Kjeldahl (TKN) mg/L	6.88	1.2	2.54	0.82		N/A	0.0001	Significant
TOC mg/L	138.64	26	38.87	13		N/A	<0.0001	Significant
TSS mg/L	184.79	52	269.43	57.5	0.8243	Not	0.9842	Not
Turbidity NTU	43.85	25	90.31	27	0.5657	Not	0.8101	Not
Water, Temperature C°	17.06	16.5	17.32	17.55		N/A	0.6576	Not
Zinc mg/L	51.77	19	75.44	16.5		N/A	0.7478	Not
pH S.U.	4.78	4.73	5.43	5.4	<0.0001	Significant	<0.0001	Significant

Table 4.3.1b Regional Comparison of Summary Results (No Dig Water Quality Results)

Parameter	Coastal Plain		Piedmont		ANOVA P-value	Significance by ANOVA*	Wilcoxon P-value	Significance by Wilcoxon
	Mean	Median	Mean	Median				
Ammonia mg/L	0.06	0.04	0.06	0.02		N/A	0.0488	Significant
Calcium mg/L	6.72	4.9	3.51	3.05	0.0003	Significant	0.001	Significant
Copper ug/L	4.52	2	4.38	2.4		N/A	0.0749	Significant
DOC mg/L	14.33	13	7.7	5.5	<0.0001	Significant	<0.0001	Significant
Dissolved Oxygen (%)	28.07	20.7	41.14	41		N/A	<0.0001	Significant
Dissolved Oxygen (mg/L)	2.79	1.82	3.97	3.9		N/A	0.0001	Significant
Fecal Coliform cfu/100 ml	929.66	140	573.18	72.67		N/A	0.0747	Significant
Lead ug/L	15.97	10	17.17	10		N/A	0.2436	Not
Magnesium mg/L	3.8	1.8	1.48	1.2		N/A	0.0149	Significant
NO_2+NO_3 mg/L	3.16	0.02	0.04	0.02		N/A	<0.0001	Significant
Phosphorus mg/L	0.31	0.17	0.16	0.08		N/A	0.0003	Significant
Specific Conductivity	122.47	84	55.49	47.8		N/A	<0.0001	Significant
Total Kjeldahl (TKN) mg/L	2.15	1.1	0.89	0.63		N/A	<0.0001	Significant
TOC mg/L	33.36	20.5	17.07	11	<0.0001	Significant	<0.0001	Significant
TSS mg/L	132.91	48	164.04	54	0.6331	Not	0.7436	Not
Turbidity NTU	43.85	25	89.96	29.5	0.5456	Not	0.7358	Not
Water, Temperature C°	16.39	16.3	17.16	17.4		N/A	0.3488	Not
Zinc mg/L	25.03	14	21.59	14		N/A	0.4651	Not
PH S.U.	4.87	4.81	5.39	5.4	<0.0001	Significant	0.0001	Significant

* N/A ANOVA results mean the residuals were not normally distributed, therefore the assumptions of the ANOVA test were not met.

REGIONAL ANALYSIS BY STATION RESULTS

The results of the comparison of the means of the regional station water quality parameters are shown in Tables 4.3.2A, 4.3.2B, and 4.3.2.C. Table 4.3.2A shows the results for the analysis of all Coastal Plain water quality data. Table 4.3.2B shows the results for the analysis of the no dig data (no digging was done to obtain water quality samples). Table 4.3.2C shows results for the Piedmont with the total data analysis on the left side of the table and the no dig data analysis on the right side of the table. The regional mean of the upstream (UP), downstream (DN), and further downstream (FD) water quality results are shown for each parameter on the tables. Stations were sampled up to six times at the upstream and downstream stations in the Coastal Plain and Piedmont (sampling depends on whether water was present within 8 inches of the surface, see section Field Methods 4.2.1) and twice at the further downstream location at five of the Coastal Plain sites. These further downstream stations were established from 200ft to 300ft further downstream from the downstream station. It was possible to sample at further downstream locations at only five of the Coastal Plain sites (Cox, East Fayetteville North, East Fayetteville South, Hog Farm Upper and PCS). In the Coastal Plain, three sample station comparisons were made in order to determine if water quality improved as it flowed downstream in the headwater wetland. Comparisons of the sample station mean parameters were made upstream to downstream (UP-DN), upstream to further downstream (UP-FD), and downstream to further downstream (DN-FD) (Tables 4.3.2A-4.3.2C). In the Piedmont, there was just one sample station comparison (upstream to downstream [UP-DN]). The numerical difference (UP-DN, UP-FD, and DN-FD) between the sample station location water quality parameter means and whether an actual "improvement" or "no improvement" occurred is shown on all three tables. UP-DN, UP-FD, and DN-FD values that were greater than zero indicated an improvement for all parameters except pH and dissolved oxygen (% and mg/L), which improved if UP-DN, UP-FD, and DN-FD values were less than zero. A summary table that is appended to each of the 4.3.2A-4.3.2C tables shows the number of water quality parameters that showed improvement or no improvement for each of the UP-DN, UP-FD, and DN-FD station comparisons. This summary table shows the number of parameter improvements by station comparison for both the means (also shown in the main table) and the medians. There were generally more improvements when comparing the means of stations than when comparing the medians of stations. This may be due to the effects of outliers and that samples were taken six times (April 2005, July 2005, October 2005, January 2006, April 2006, and July 2006) with a possible seasonal weighting of the results.

In the Coastal Plain, the number of parameters that improved or did not improve for the UP-DN station comparisons were fairly similar when analyzing all the data (10 of 19 and 8 of 19 improved for the mean and median, respectively), but less similar when analyzing just the no dig data (4 of 19 and 3 of 19 improved for the mean and median, respectively). The further downstream water quality samples had generally better results for most parameters. For the analysis of all water quality results, the UP-FD station comparison resulted in 16 and 13 parameters improving for the mean and median, respectively. The results of the UP-FD station comparison were the same for the no dig data. The DN-FD results were also comparable for the analysis of all the data and the no dig data with 16 and 13 (mean and median) improving for all the data and 15 and 11 improving for the no dig data (see Tables 4.3.2A and 4.3.2B).

For the Coastal Plain analysis, ANOVAs were performed on 12 and 9 of the 19-parameter station comparisons for the analysis of all the data and the no dig data, respectively (other parameter results by station did not meet ANOVA assumption for normality of residual errors) (see Tables 4.3.2.A and 4.3.2.B). Fecal coliform was the only parameter that had significant results although not as expected for the Coastal Plain analysis of all the data. Fecal coliform showed significant "no improvement" for the UP- FD station comparison for both the ANOVA (p-value = 0.0380) and Ranks Sums (p-value = 0.0606) tests (see Table 4.3.2A). Fecal coliform also showed significant no improvement for the analysis of the no dig data only for the UP-FD station comparison for both the ANOVA (p-value = 0.0624) and Ranks Sums (p-value = 0.0628) tests (see Table 4.3.2.B). The fecal coliform result may be attributed to fecal coliform data being extremely variable, and it is probable that one or two outliers weighted the results. For instance, one sample taken further downstream at the East Fayetteville South site had 110,000 cfu/100ml, a result that was more than twice any other fecal coliform sample analyzed in this study. For the no dig data, there was also a significant improvement for copper from the DN to FD station for the Ranks Sums test (p-value = 0.0802) (see Table 4.3.2.B). All ANOVA and Rank Sums Tests performed on water quality data utilized the raw data of "all" data and "no-dig" data sets, not the means of the data sets.

Other Coastal Plain parameters were approaching significant improvement (p-value < 0.15) for the Ranks Sums analysis of all the data including ammonia (UP-DN, UP-FD), copper (DN-FD), percent dissolved oxygen (UP-FD), specific conductivity (DN-FD), TKN (UP-FD), TSS (UP-FD, DN-FD), and zinc (DN-FD). For the analysis of the no dig data with the Ranks Sums test, ammonia (UP-DN, UP-FD), TKN, (DN-FD), TSS (DN-FD), and zinc (DN-FD) were also approaching significant improvement. The ANOVA test was also approaching significant improvement for percent dissolved oxygen (UP-FD) for the analysis of all the data, and TSS (DN-FD) for the analysis of the no dig data. It should be noted that there were only 10 samples (with 2 sample periods) taken for each parameter during April 2006 and July 2006 at the further downstream station, while other parameters were sampled at 11 sites up to six times (with 6 sample periods) at the upstream and downstream stations. Therefore, the UP-DN station comparison is a more powerful comparison than the UP-FD and DN-FD station comparisons due to the larger sample size. It is possible that the flat topography and lack of flow at a number of the Coastal Plain sites resulted in fewer improvements from the upstream to downstream stations than from the upstream and further downstream and downstream to further downstream stations.

Overall, the Piedmont results were more consistent in terms of downstream water quality improvement than in the Coastal Plain (see Table 4.3.2.C). Water quality improved downstream for 14 of the 19 parameters for the mean and 13 of the 19 parameters for the median when analyzing all the data results, but only 9 of 19 for the mean and 9 of 19 for the median when analyzing the no dig data only. The ANOVA test met the assumption of normally distributed residuals for 10 Coastal Plain and 10 Piedmont parameters for the analysis of all the data, and nine Coastal Plain and 11 Piedmont parameters for the analysis of the no dig data (see Table 4.3.2.C). For the ANOVA analysis of all the water quality data, there was significant improvement for dissolved oxygen (percent - p-value = 0.0544, mg/L p-value = 0.0225) and TSS (p-value = 0.0962). For the Ranks Sum's Wilcoxon analysis of all the water quality there was significant improvement for copper (p-value = 0.0043), dissolved oxygen (percent p-value = 0.0270, mg/L p-value = 0.0232), phosphorous (p-value = 0.0055), TKN (p-value = 0.0010), TOC (p-value = 0.0188), turbidity (p-value = 0.0962) and zinc (p-value = 0.0195). There was also significant no improvement for the Wilcoxon test for lead (p-value = 0.0242) (see Table 4.3.2C). The analysis of the Piedmont no dig data had fewer significant results than the analysis of all the water quality for the Piedmont. The ANOVA test showed there was significant improvement downstream for dissolved oxygen (mg/L p-value = 0.0715) and TKN (p-value = 0.0824). The Wilcoxon analysis of the no dig data showed there was significant improvement downstream for just dissolved oxygen (mg/L p-value = 0.0851), TKN (p-value = 0.0361), and turbidity (p-value = 0.0870) (see Table 4.3.2C).

Table 4.3.2D shows an additional analysis of the comparison of the regional station location result means using the chi-square test. The ANOVAs were a quantitative analysis of the water quality data using the actual measurements; however, the results show that most parameters showed improvement, but not enough to gain statistical significance using the ANOVA. Therefore, the chi-square analysis used the categorical approach to determine whether the majority of the parameters that improved downstream and further downstream (in the Coastal Plain) were significant. For the analysis of all the water quality there was a chi-square significant result for the Piedmont UP-DN (p-value = 0.039), Coastal Plain UP-FD (p-value = 0.001), and Coastal Plain DN-FD (p-value = 0.001). Coastal Plain UP-DN was not significant for the analysis of all the water quality. For the analysis of the no dig water quality there was a chi-square significant result for Coastal Plain UP-DN (p-value = 0.012), UP-FD (p-value = 0.001) and DN-FD (p-value = 0.005). Piedmont UP-DN was not significant for the analysis of the no dig water quality.

Table 4.3.2a Coastal Plain Station Summary Results - All Water Quality Results

Parameter	Coastal Plain Parameter Means			Coastal Plain Parameter Improvement						
	Upstream (UP)	Downstream (DN)	Further Downstream (FD)	Upstream to Downstream Difference	**Upstream to Downstream Improvement**	Upstream to Further Downstream Difference	**Upstream to Further Downstream Improvement**	Downstream to Further Downstream Difference	**Downstream to Further Downstream Improvement**	**ANOVA / Kruskal Wallis Tests and p-values**
Ammonia mg/L	0.12	0.12	0.04	0.01	No improvement	0.09	improvement	0.08	improvement	RS - Not
Calcium mg/L	9.65	7.54	4.3	2.11	improvement	5.35	improvement	3.24	improvement	ANOVA & RS Not
Copper ug/L	15.57	16.25	3.22	-0.68	no improvement	12.35	improvement	13.02	improvement	RS Not
Dissolved Oxygen (%)	21.74	25.76	36.3	-4.03	improvement	-14.56	improvement	-10.54	improvement	ANOVA & RS Not
Dissolved Oxygen (mg/L)	2.11	2.68	3.13	-0.57	improvement	-1.02	improvement	-0.44	improvement	ANOVA & RS Not
DOC mg/L	16.71	13.42	11	3.29	improvement	5.71	improvement	2.42	improvement	ANOVA & RS Not
Fecal Coliform cfu/100 ml	1721.41	989.33	15071.5	732.09	improvement	-13350.1	no improvement	-14082.2	no improvement	UP-FD ANOVA Sig No Imp P=0.0380 , RS Sig No Imp P=0.0606
Lead ug/L	44.93	55.29	15.78	-10.36	no improvement	29.15	improvement	39.52	improvement	RS - Not
Magnesium mg/L	4.53	3.75	2.53	0.78	improvement	2	improvement	1.22	improvement	ANOVA & RS Not
NO_2+NO_3 mg/L	2.5	2.79	2.24	-0.29	no improvement	0.26	improvement	0.55	improvement	RS - Not
Phosphorus mg/L	0.54	0.65	0.24	-0.11	no improvement	0.3	improvement	0.41	improvement	ANOVA & RS Not
Specific Conductivity	119.25	121.97	94.74	-2.72	no improvement	24.5	improvement	27.22	improvement	RS - Not
Total Kjeldahl (TKN) mg/L	10.19	4.63	1	5.55	improvement	9.19	improvement	3.63	improvement	RS - Not
TOC mg/L	171.15	126.29	26.64	44.87	improvement	144.51	improvement	99.64	improvement	RS Not
TSS mg/L	200.02	202.93	44.93	-2.92	no improvement	155.09	improvement	158.01	improvement	ANOVA & RS Not
Turbidity NTU	41.91	46.01	.	-4.1	no improvement	.		.		ANOVA & RS Not
Water, Temperature C^o	17.16	16.53	19.44	0.64	improvement	-2.28	no improvement	-2.92	no improvement	ANOVA & RS Not
Zinc mg/L	49.87	60.12	15	-10.25	no improvement	34.87	improvement	45.12	improvement	RS - Not
pH S.U.	4.68	4.84	4.95	-0.16	improvement	-0.26	improvement	-0.11	improvement	ANOVA & RS Not

RS=Ranks sums Kruskal-Wallis or Wilcoxon

Water Quality All Data Results Coastal Plain	**UP - DN Mean**	**UP-DN Median**	**UP-FD Mean**	**UP-FD Median**	**DN-FD Mean**	**DN-FD Median**
Improvement	10	8	16	13	16	13
No Improvement	9	11	2	5	2	5

Table 4.3.2b Coastal Plain Station Summary Results - No Dig

Parameter	Coastal Plain Parameter Means			Coastal Plain Parameter Improvement						
	Upstream (UP)	Downstream (DN)	Further Downstream (FD)	Upstream to Downstream Difference	**Upstream to Downstream Improvement**	Upstream to Further Downstream Difference	**Upstream to Further Downstream Improvement**	Downstream to Further Downstream Difference	**Downstream to Further Downstream Improvement**	**ANOVA / Kruskal Wallis Tests and p-values**
Ammonia mg/L	0.07	0.07	0.03	0	no improvement	0.04	improvement	0.04	improvement	RS – Not
Calcium mg/L	6.61	7.45	4.18	-0.84	no improvement	2.44	improvement	3.28	improvement	RS – Not
Copper ug/L	3.97	5.48	2	-1.51	no improvement	1.97	improvement	3.48	improvement	DN-FD, RS Sig Imp P= 0.0802
Dissolved Oxygen (%)	25.15	28.74	38.41	-3.59	improvement	-13.27	improvement	-9.68	improvement	RS – Not
Dissolved Oxygen (mg/L)	2.45	3.01	3.31	-0.57	improvement	-0.87	improvement	-0.3	improvement	ANOVA & RS Not
DOC mg/L	17.06	12.74	11	4.32	improvement	6. 06	improvement	1.74	improvement	ANOVA & RS Not
Fecal Coliform cfu/100 ml	722.1	1010.81	1510.29	-288.71	no improvement	-788.19	no improvement	-499.48	no improvement	UP-FD ANOVA Sig No Imp P=0.0624 , RS Sig No Imp P=0.0628
Lead ug/L	12.73	19.95	10	-7.22	no improvement	2.73	improvement	9.95	improvement	RS – Not
Magnesium mg/L	3.92	3.97	2.7	-0.05	no improvement	1.22	improvement	1.28	improvement	RS – Not
NO_2+NO_3 mg/L	3.05	3.39	2.52	-0.35	no improvement	0.53	improvement	0.88	improvement	RS – Not
Phosphorus mg/L	0.23	0.41	0.16	-0.18	no improvement	0.07	improvement	0.25	improvement	ANOVA & RS Not
Specific Conductivity	120.02	128.69	100.71	-8.67	no improvement	19.31	improvement	27.98	improvement	RS – Not
Total Kjeldahl (TKN) mg/L	1.52	2.96	0.93	-1.44	no improvement	0.59	improvement	2.03	improvement	RS – Not
TOC mg/L	26.21	42.81	17.98	-16.61	no improvement	8.23	improvement	24.84	improvement	ANOVA & RS Not
TSS mg/L	114.6	170.4	37.34	-55.79	no improvement	77.26	improvement	133.05	improvement	ANOVA & RS Not
Turbidity NTU	41.91	46.01	.	-4.1	no improvement	.		.		ANOVA & RS Not
Water, Temperature C°	16.23	16.08	18.88	0.15	no improvement	-2.64	no improvement	-2.8	no improvement	ANOVA & RS Not
Zinc mg/L	23.01	29.17	12.63	-6.15	no improvement	10.39	improvement	16.54	improvement	RS – Not
pH S.U.	4.73	4.99	4.91	-0.25	improvement	-0.17	improvement	0.08	no improvement	ANOVA & RS Not

RS = Ranks Sum Kruskal Wallis or Wilcoxon

Water Quality All Data Results Coastal Plain	UP - DN Mean	UP-DN Median	UP-FD Mean	UP-FD Median	DN-FD Mean	DN-FD Median
Improvement	4	3	16	13	15	11
No Improvement	15	16	2	5	3	7

Table 4.3.2c Piedmont Summary Results All data and no dig data										
	All Data					No Dig Data				
	Piedmont Means		Piedmont Improvement			Piedmont Means		Piedmont Improvement		
Parameter	Upstream (UP)	Downstream (DN)	Upstream to Downstream Difference	**Upstream to Downstream Improvement**	**ANOVA / Wilcoxon**	Upstream (UP)	Downstream (DN)	Upstream to Downstream Difference	**Upstream to Downstream Improvement**	**ANOVA / Wilcoxon**
Ammonia mg/L	0.1	0.08	0.01	improvement	WC - Not	0.06	0.07	-0.01	no improvement	WC - Not
Calcium mg/L	5.16	6.17	-1.01	no improvement	ANOVA & WC - Not	3.12	3.73	-0.61	improvement	ANOVA & WC -Not
Copper ug/L	22.11	19.34	2.77	improvement	WC – Sig Imp P = 0.0043	4.43	4.35	0.08	no improvement	WC - Not
Dissolved Oxygen (%)	33.39	41.51	-8.13	improvement	ANOVA Sig Imp P = 0.0544, WC Sig Imp P = 0.0270	37.59	43.88	-6.29	improvement	WC - Not
Dissolved Oxygen (mg/L)	3.18	4.09	-0.91	improvement	ANOVA Sig Imp P = 0.0225, WC Sig Imp P=0.0232	3.52	4.32	-0.8	improvement	ANOVA Sig Imp P= 0.0715, WC Sig Imp P=0.0851
DOC mg/L	7.99	7.5	0.49	improvement	ANOVA & WC -Not	7.85	7.59	0.25	no improvement	ANOVA & WC -Not
Fecal Coliform cfu/100 ml	1705.33	1367.18	338.16	improvement	ANOVA & WC -Not	1028.74	277.07	751.68	improvement	WC - Not
Lead ug/L	34.67	60.95	-26.27	no improvement	WC Sig No Imp P=0.0242	17.04	17.25	-0.21	no improvement	WC - Not
Magnesium mg/L	2.66	2.79	-0.13	no improvement	WC - Not	1.29	1.59	-0.3	no improvement	ANOVA & WC -Not
NO_2+NO_3 mg/L	0.04	0.04	0	no improvement	WC - Not	0.04	0.04	0	no improvement	WC - Not
Phosphorus mg/L	0.41	0.29	0.11	improvement	WC Sig Imp P = 0.0055	0.15	0.17	-0.01	no improvement	WC - Not
Specific Conductivity	49.98	56.89	-6.9	no improvement	ANOVA & WC -Not	52.64	57.55	-4.91	no improvement	ANOVA & WC -Not
Total Kjeldahl (TKN) mg/L	3.1	2.03	1.07	improvement	WC Sig Imp P = 0.0010	1.12	0.75	0.38	improvement	ANOVA Sig Imp P= 0.0824, WC Sig Imp P=0.0361
TOC mg/L	40.77	37.16	3.61	improvement	WC Sig Imp P = 0.0188	18.36	16.2	2.16	improvement	ANOVA & WC -Not
TSS mg/L	396.3	168.58	227.72	improvement	ANOVA Sig Imp P=0.0918	155.25	170.31	-15.06	no improvement	ANOVA & WC -Not
Turbidity NTU	114.82	67.85	46.97	improvement	ANOVA – Not, WC Sig Imp P = 0.0962	110.89	72.84	38.05	improvement	ANOVA & WC Sig Imp P=0.0870
Water, Temperature C°	17.58	17.08	0.5	improvement	ANOVA & WC -Not	17.64	16.8	0.84	improvement	ANOVA & WC -Not
Zinc mg/L	91.39	61.44	29.95	improvement	WC - Sig Imp P = 0.0195	20.72	22.15	-1.43	no improvement	WC – Not
PH S.U.	5.38	5.48	-0.1	improvement	ANOVA & WC -Not	5.34	5.44	-0.1	improvement	ANOVA & WC -Not

WC=Wilcoxon

Water Quality All Data Results Piedmont	UP - DN Mean	UP-DN Median		**Water Quality No Dig Data Results Piedmont**	UP – DN Mean	UP-DN Median
Improvement	14	13		**Improvement**	9	9
No Improvement	5	6		**No Improvement**	10	10

Table 4.3.2D Further Analysis Regional Station Location Comparison of Water Quality Parameter Means

All Water Quality Data									
	UP-DN Station Comparison Count			UP-FD Station Comparison Count			DN-FD Station Comparison Count		
Region	Improvement	No Improvement	Chi-Square Significance	Improvement	No Improvement	Chi-Square Significance	Improvement	No Improvement	Chi-Square Significance
Piedmont	14	5	p-value = 0.039	N/A	N/A	N/A	N/A	N/A	N/A
Coastal Plain	10	9	Not Significant	16	2	P =0.001	16	2	P = 0.001

No Dig Water Quality Results Only									
	UP-DN Station Comparison Count			UP-FD Station Comparison Count			DN-FD Station Comparison Count		
Region	Improvement	No Improvement	Chi-Square Significance	Improvement	No Improvement	Chi-Square Significance	Improvement	No Improvement	Chi-Square Significance
Piedmont	9	10	Not Significant	N/A	N/A	N/A	N/A	N/A	N/A
Coastal Plain	4	15	p-value = 0.012 *	16	2	P = 0.001	15	3	P = 0.005

UP-DN = Upstream to Downstream Station Comparison of Regional Parameter Means

UP-FD = Upstream to Further Downstream Station Comparison of Regional Parameter Means

DN-FD = Downstream to Further Downstream Station Comparison of Regional Parameter Means
Improvement = Water Quality Parameter Improvement from upstream station location to downstream station location

No improvement = No Water Quality Parameter Improvement from upstream station location to downstream station location

Significant = p-Value<.05, Approaching Significant = p-Value =0.05<0.15
* p-value for no-dig Coastal Plain indicated there were significantly few improvements than improvements

SITE-PAIRED STATION COMPARISON DATA ANALYSIS FOR REGION RESULTS

The ANOVA and ranks sum (Wilcoxon for two station comparisons and Kruskal-Wallis for three station comparisons) statistical analysis results for the site-paired station comparisons were very comparable to the Regional Analysis by Station Results as reported in the previous section and shown in Tables 4.3.2A-4.3.2.C. The Coastal Plain analysis of the fecal coliform data showed significant no improvement for the UP-FD station comparison for both the ANOVA (p-value = 0.0226) and Kruskal-Wallis (p-value = 0.0390) statistical tests for the analysis of all the data. Similarly, there was significant no improvement for UP-FD for both the ANOVA (p-value = 0.0265) and Kruskal-Wallis (p-value = 0.0303) statistical analysis of the no dig fecal coliform data. It should be noted that fecal coliform had a 60% relative percent difference (RPD) of the duplicates (the RPD for the no dig duplicates was 42%) which was higher than all of the other parameter RPD values. This high RPD value indicates that the lab analysis of the fecal coliform parameter was highly variable. Fecal coliform samples have a hold time of 6 hours for NPDES (National Pollution Discharge Ellimination System) standards however due to logistics it was not possible to submit the majority of our samples in that time frame to the DWQ Lab, all were submitted in 24 hours. Additionally, there was an outlier in the fecal coliform results at the Fayetteville South Further Down site of 110000 CFU/100ml which was more than two times as high as the next highest reading of fecal coliform at all the wetland sample stations of all sites. It is also possible there was a point source issue at that further down station, but nothing was observed that would suggest this. There were no other significant results for the Coastal Plain site-paired data. Comparing the upstream, downstream, and further downstream means of the data sets (all and no dig) for the site-paired data does show there was a number of improvements, though none of them were significant. Again, this is potentially due to the flat topography and lack of flow at the Coastal Plain sites.

The statistical analysis of the Piedmont site-paired data showed there were a notable number of improvements for the analysis of all the data. The Wilcoxon test had significant improvement results for copper (p-value = 0.0002), percent and mg/L dissolved oxygen (p-value = 0.0079 and 0.0068), phosphorous (p-value = 0.0006), TKN (p-value = 0.0003), TOC (p-value = 0.0016), and zinc (p-value = 0.0039); however, there was significant no improvement for lead (p-value = 0.0018). ANOVA results of the analysis of all the data that met the assumptions of the ANOVA test (normally distributed raw or log-transformed residuals, see Section 4.2.2.1) and showed significant improvement for the site-paired analysis of all the data were percent and mg/L dissolved oxygen (p-value = 0.0194 and 0.0064), TOC (p-value = 0.0010), and TSS (p-value = 0.0821). ANOVA results of all the raw site-paired data that did not meet the assumptions of the ANOVA test (raw and log-transformed residuals were not normally distributed) and had comparable significant results to the Wilcoxon test were phosphorous (p-value = 0.0113) and TKN (p-value = 0.0061), which significantly improved, and lead (p-value = 0.0067), which did not improve significantly. The ANOVA and Wilcoxon analysis tests on the site-paired no dig data in the Piedmont had no significant results.

SITE STATION DATA ANALYSIS RESULTS

The results of the comparison of the site station means for UP-DN, UP-FD, and DN-FD are shown in Tables 4.3.3A-4.3.3C. Table 4.3.3A and 4.3.3B show the number station comparisons for UP-DN, UP-FD, and DN-FD that had “improvement” and “no improvement” for the 19 parameters for the analysis of all the water quality (Table 4.3.3A) and the analysis of just the no dig water quality (Table 4.3.3.B). “Improvement” or “no improvement” was calculated by comparing the means of the upstream, downstream, and further downstream station locations. Table 4.3.3C shows the total number of stations analyzed for UP-DN, UP-FD, and DN-FD in the Coastal Plain and Piedmont for all the water quality results and the no dig results only.

For the Coastal Plain analysis of all the data, the East Fayetteville South site had the best rate of improvement, with 43 of the 54 for station comparison parameters improving (15+16+12=43 improved and 3+2+6=11 no improvement- see Table 4.3.3A), while the Cox and Hog Farm Upper sites had the second best rate of improvement with 41 of 55 station comparison parameters improving. The Hog Farm Lower site showed the least improvement with only 5 of 19 station comparison parameters improving, with the Bachelor site being second with 7 of 12 parameters improving. If the UP-FD and DN-FD station parameter comparisons are not included, then the PCS site would have only slightly better results than the Hog Farm Lower site with 5 of 18 parameters improving. The Hog Farm Lower site receives direct stormwater discharges from a nearby hog farm operation and it is likely the PCS site is influenced by nearby phosphate mining operations through atmospheric deposition. The analysis of the no dig data was somewhat different; the Bachelor site had the best results with 15 out of 19 parameters improving, and the Hog Farm Upper site had the second best results with 40 out of 55 station parameter comparisons improving. The Nahunta site had the least improvement downstream, with only 5 of 19 downstream station means improving. The Hog Farm Lower site had the second least improvement with 7 of 19 stations improving downstream (see Table 4.3.3A and 4.3.3B).

In the Piedmont region, the Black Ankle Powerline and Troxler sites were tied for the best rate of improvement with 17 of the 19 parameters improving downstream for the all water quality analysis of station comparison of means. The least improvement was at the Black Ankle Non-Powerline site in which only 4 of 19 parameters showed improvement. For the no dig only results, the Black Ankle Powerline and Fire Tower sites had the best results with 15 out of 19 and 14 out of 19 parameters improving, respectively, and the Black Ankle Non-Powerline and Moonshine sites had the least improvement with 5 of 19 parameters and 6 of 17 parameters improving, respectively.

The summary Table 4.3.3C, Regional Sample Station Location Comparisons by site of Water Quality Parameter Means, shows there are 385 “improvements” and 224 “no improvements” for total station comparisons, or a 63% rate of improvement (385/609) for the analysis of all the water quality data. The improvement rate of 56% for the no dig data was not quite as high with results being 326 “improvement” and 254 “no improvement”. The total results of each station location comparison for the Coastal Plain and Piedmont show there was a 66% rate of improvement ([117+73+66]/[205+90+90]) for the Coastal Plain and 58% rate of improvement (130/224) for the Piedmont for the all water quality data analysis of the station means. For the no dig results there was a 58% rate of ([104+55+63]/[205+90+90]) improvement for the Coastal Plain and 53% (104/195) rate of improvement for the Piedmont.

As with the regional station site results, a chi-square analysis was used to see if the number of "improvements", as compared with the number of "no improvements", were significantly different. For the Coastal Plain site's all data analysis, the number of improvements for UP-DN were significant ($p = 0.04$), as was the number of improvements for UP-FD and DN-FD (both at $p < 0.0001$); however, for the no dig data the number of improvements for UP-DN was not significant. The number of improvements was significant for UP-FD ($p = 0.035$) and for DN to FD ($p < 0.0001$). In the Piedmont, there were significantly more improvements for UP-DN station comparisons ($p = 0.016$ for the all data summary analysis), but not for the no dig summary analysis ($p = 0.35$).

These results, along with the results by ecoregion, show that the number of water quality parameters that improve downstream is significantly larger than the number of parameters that do not improve. Furthermore, for the Coastal Plain, sampling further downstream did show more improvement. This indicates that sampling closer to or outside of the outflow location, as was generally done in the Piedmont, appears to demonstrate better water quality improvements.

There are some differences between the analysis of all the water quality results and the no dig results, though both sets of results showed improvement of water quality. The lower improvement results for the regional and site comparison of stations (UP-DN, UP-FD, DN-FD) for the no dig data may be seasonally related. Much of the digging to obtain samples occurred during the drier season when flow rates were down and seasonal plant growth and microbial activity were up. The wetlands may have had a better capacity to remove pollutants during the warmer season when water has a longer residence time and plant uptake of nutrients and microbial activity aids in pollution reduction. The dig samples were rarely obtained during the colder sampling periods when wetlands may have been less efficient at removing pollutants as during the warmer months.

Tables 4.3.4A and 4.3.4B show the results of the ranks sums test on parameter station comparisons at each site for all the data and the site-paired data sets. The site-paired results (see Table 4.3.4B) were very similar to the non-site-paired results (see Table 4.3.4A). The non-site-paired results of the analysis of all the data had 65 station comparisons that were significantly different, and the site-paired results of the analysis of all the data had 52 station comparisons that were significantly different. The larger non-site-paired data set was probably the cause of more significant results than the site-paired data set. For the non-site-paired analysis, 54 of the 65 station comparisons showed significant improvement downstream. For the site-paired analysis, 46 of the 52 station comparisons showed significant improvement downstream (p-value < 0.10). The non-site-paired data set had significant results for all 19 parameters except turbidity and NO_2+$NO_{3,}$ and the site-paired data set had significant results for all 19 parameters except TSS, turbidity, and NO_2+NO_3. Turbidity was only tested during the first sample period, therefore, the data set was too small to obtain a significant result for any of the sites for other site-paired or non-site paired data sets.

The parameters that showed the most improvements were: dissolved oxygen (percent and mg/L) at five sites for non-site-paired and four sites for site-paired; TKN at six sites for non-site-paired and four sites for site-paired; copper at four sites for non-site-paired and five sites for site-paired; zinc at five sites for non-site-paired and four sites for site-paired; and TOC at four sites for non-site-paired and site-paired (See Tables 4.3.4A and 4.3.4B). More moderate improvements were shown for the following: lead at four sites for non-site-paired and three sites for site-paired; magnesium at four sites for non-site-paired and three sites for site-paired; specific conductivity at four sites for non-site-paired and three sites for site-paired; ammonia at three sites for non-site-paired and two sites for site-paired; phosphorous at three sites for non-site-paired and site-paired; pH at three sites for non-site-paired and site-paired; and calcium at two sites for non-site-paired and site-paired. There was significant no improvement for DOC at two sites for non-site-paired and one site for site-paired; and for one site for fecal coliform for both site-paired and non-site-paired. The site-paired data set also had one site that showed significant improvement for fecal coliform (see tables 4.3.4A and 4.3.4B). The significant improvements downstream for dissolved oxygen may be attributed to streams having higher levels of oxygen than wetlands due to flowing water. Wetlands also tend to have higher levels of carbon than streams, which would explain the number of sites that had significantly reduced total organic carbon (TOC), though this would not explain why there was only significant no improvement for DOC at downstream stations. The more acidic pH found within wetland sites as compared to downstream sites was not unusual, as wetlands with standing water are generally more acidic than flowing streams. The other parameters that showed significant improvement downstream (TKN, copper, zinc, magnesium, lead, specific conductivity, ammonia, phosphorus, and calcium) indicate headwater wetland sites are in fact filtering out pollutants.

The sites that had the highest number of parameters with significant downstream improvement were Walmart and Fire Tower, both at 12 parameters for the analysis of the site-paired data and 12 and 11, respectively, for the non-site-paired data. PCS and Hog Farm Upper had significant downstream improvements for six parameters for the site-paired data and six for the non-site-paired data. Boddie Noell had significant improvement for four parameters downstream for the non-site-paired data, but no significant results for the site-paired data. All other sites had between zero and three parameters that significantly improved downstream for both sets of data.

For the non-site-paired data and site-paired data, Spring Garden and East of Mason had no significant improvements and one significant no improvement (DOC for Spring Garden and fecal coliform for East of Mason). For the non-site-paired and site-paired data sets there were no significant results for Black Ankle Non-Powerline, Rough Rider, Troxler, Kelly Road and Moonshine. In addition, there were no significant results for the site-paired data for Pete Harris, Boddie Noell, Battle Park, Cox, and Duke Forest. The sites with the highest number of improvements, Walmart, Fire Tower, Hog Farm Upper, and PCS all had downstream or further downstream stations that were located in unquestionably perennial waterways. The PCS sample was taken in a perennial ditch and the other three samples were taken in perennial streams. The significant improvements occurred at the further downstream stations in all cases for PCS and all cases for the site-paired data set, and five out of six times for the non-site-paired data set for Hog Farm Upper. It should be noted that the downstream seepage at Hog Farm Upper curves from southeast to directly south. Potential pollutants most likely are received between the upstream and downstream water quality stations at Hog Farm Upper due to the fact that field runoff comes from the northeast, the curvature of the headwater seepage, and location of the water quality stations. This is probably why there are higher pollutants at the downstream station than the upstream and further downstream stations, even though the downstream and further downstream stations occur in a perennial stream.

Walmart and Fire Tower had 11 or 12 parameters that significantly improved and Hog Farm Upper and PCS had six parameters that significantly improved may be that these sites received higher rates of pollutants in the headwater areas, thereby allowing for greater difference between headwater and downstream stations. Walmart is an urban site, while Hog Farm Upper receives input from neighboring hog farm operations, Fire Tower is downstream of a mobile home park and adjacent to a car junkyard, and PCS, although located in a natural setting, is situated near a phosphate mine.

Table 4.3.3.a Wetland Study Sites Station Location Comparison Water Quality Parameters Means – All

Region	Site Name	UP-DN		UP-FD		DN-FD	
		improvement	no improvement	improvement	no improvement	improvement	no improvement
Coastal Plain	Bachelor	7	12	.	.	.	.
	Battle Park	12	7	.	.	.	.
	Boddie Noell	12	5	.	.	.	.
	Cox	13	6	14	4	14	4
	East Fayetteville North	12	7	11	7	10	8
	East Fayetteville South	15	3	16	2	12	6
	Hog Farm Lower	5	14	.	.	.	.
	Hog Farm Upper	13	6	15	3	13	5
	Nahunta	13	6	.	.	.	.
	PCS	5	13	17	1	16	2
	Rough Rider	10	9	.	.	.	.
Piedmont	Black Ankle Non-Powerline	4	15	.	.	.	.
	Black Ankle Powerline	17	2	.	.	.	.
	Duke Forest	12	7	.	.	.	.
	East of Mason	8	11	.	.	.	.
	Fire Tower	16	3	.	.	.	.
	Kelly Rd	6	13	.	.	.	.
	Moonshine	6	11	.	.	.	.
	Pete Harris	8	11	.	.	.	.
	Spring Garden	10	9	.	.	.	.
	Troxler	17	2	.	.	.	.
	Umstead	11	8	.	.	.	.
	Walmart	15	2	.	.	.	.

UP-DN = Upstream to Downstream Station Comparison of Site Parameter Means

UP-FD = Upstream to Further Downstream Station Comparison of Site Parameter Means

DN-FD = Downstream to Further Downstream Station Comparison of Site Parameter Means

Improvement = Water Quality Parameter Improvement from upstream station location to downstream station location

Table 4.3.3.b Wetland Study Sites Station Location Comparison Water Quality Parameters Means - No Dig

Region	Site Name	UP-DN		UP-FD		DN-FD	
		improvement	no improvement	improvement	no improvement	improvement	no improvement
Coastal Plain	Bachelor	15	4	.	.	.	.
	Battle Park	12	7	.	.	.	.
	Boddie Noell	12	5	.	.	.	.
	Cox	5	14	9	9	14	4
	East Fayetteville North	13	6	5	13	5	13
	East Fayetteville South	7	11	12	6	15	3
	Hog Farm Lower	7	12	.	.	.	.
	Hog Farm Upper	12	7	15	3	13	5
	Nahunta	5	14	.	.	.	.
	PCS	6	12	14	4	16	2
	Rough Rider	10	9	.	.	.	.
Piedmont	Black Ankle Non-Powerline	5	14	.	.	.	.
	Black Ankle Powerline	15	4	.	.	.	.
	Duke Forest	10	7	.	.	.	.
	East of Mason	8	11	.	.	.	.
	Fire Tower	14	5	.	.	.	.
	Kelly Rd	9	10	.	.	.	.
	Moonshine	6	11	.	.	.	.
	Pete Harris	12	7	.	.	.	.
	Spring Garden	8	10	.	.	.	.
	Troxler	2	3	.	.	.	.
	Umstead	11	8	.	.	.	.
	Walmart	4	1	.	.	.	.

UP-DN = Upstream to Downstream Station Comparison of Site Parameter Means

UP-FD = Upstream to Further Downstream Station Comparison of Site Parameter Means

DN-FD = Downstream to Further Downstream Station Comparison of Site Parameter Means

Improvement = Water Quality Parameter Improvement from upstream station location to downstream station location

Table 4.3.3c Regional Sample Station Location Comparison by Site of Water Quality Parameter Means

All Water Quality Results

Upstream to Downstream Station Comparisons	Piedmont	Coastal Plain			Total Site Stations
	UP-DN	UP-DN	UP-FD	DN-FD	
Improvement	130[1]	117[2]	73[3]	66[4]	**385**
No Improvement	94[1]	88[2]	17[3]	24[4]	**224**
Total Site Stations	224	205	90	90	609
Chi-square Results	1=P=0.016 Approaching	2=P=0.043 Significant	3=P<0.0001 Significant	4=P<0.0001 Significant	

No Dig Water Quality Results Only

Upstream to Downstream Station Comparisons	Piedmont	Coastal Plain			Total Site Stations
	UP-DN	UP-DN	UP-FD	DN-FD	
Improvement	104[1]	104[2]	55[3]	63[4]	**326**
No Improvement	91[1]	101[2]	35[3]	27[4]	**254**
Total Site Stations	195	205	90	90	580
Chi-square Results	1=P=0.35 Not	2=P=0.83 Not	3=P=0.035 Significant	4=P<0.0001 Significant	

UP-DN = Upstream to Downstream Station Comparison of Site Parameter Means

UP-FD = Upstream to Further Downstream Station Comparison of Site Parameter Means

DN-FD = Downstream to Further Downstream Station Comparison of Regional Parameter Means

Improvement = Water Quality Parameter Improvement from upstream station location to downstream station location

No improvement = No Water Quality Parameter Improvement from upstream station location to downstream station location

Table 4.3.4a Parameter Station Comparisons for Individual Sites

Site Name	**Parameter**	**Wilcoxon / Kruskal-Wallis P-Value**	**Significant Station Comparison**
Bachelor	Specific Conductivity	0.009	**UP-DN**
Battle Park	Ammonia	0.0833	**UP-DN**
Battle Park	Dissolved Oxygen (%)	0.0833	**UP-DN**
Battle Park	Dissolved Oxygen (mg/L)	0.0833	**UP-DN**
Black Ankle Powerline	Dissolved Oxygen (%)	0.0495	**UP-DN**
Black Ankle Powerline	Dissolved Oxygen (mg/L)	0.0495	**UP-DN**
Boddie Noell	Dissolved Oxygen (%)	0.0641	**UP-DN**
Boddie Noell	Dissolved Oxygen (mg/L)	0.0641	**UP-DN**
Boddie Noell	Lead	0.0491	**UP-DN**
Boddie Noell	Zinc	0.0603	**UP-DN**
Cox	TKN	0.0642	UP-DN & **DN-FD**
Duke Forest	TKN	0.0833	**UP-DN**
East Fayetteville North	Copper	0.0979	UP-DN & **DN-FD**
East Fayetteville North	pH	0.0995	**UP-DN**

Table 4.3.4a Parameter Station Comparisons for Individual Sites

Site Name	Parameter	Wilcoxon / Kruskal-Wallis P-Value	Significant Station Comparison
East Fayetteville North	Specific Conductivity	0.0244	**DN-FD**
East Fayetteville South	Magnesium	0.0635	**UP-DN**
East Fayetteville South	pH	0.0861	**UP-DN**
East of Mason	Fecal Coliform	0.0339	UP-DN
Fire Tower	Calcium	0.0731	**UP-DN**
Fire Tower	Copper	0.0021	**UP-DN**
Fire Tower	Dissolved Oxygen (%)	0.0027	**UP-DN**
Fire Tower	Dissolved Oxygen (mg/L)	0.0027	**UP-DN**
Fire Tower	Lead	0.0074	**UP-DN**
Fire Tower	Magnesium	0.0758	**UP-DN**
Fire Tower	pH	0.0026	**UP-DN**
Fire Tower	Phosphorus	0.0037	**UP-DN**
Fire Tower	TKN	0.0065	**UP-DN**
Fire Tower	TOC	0.0039	**UP-DN**
Fire Tower	Total Suspended Residue	0.0603	**UP-DN**
Fire Tower	Zinc	0.0401	**UP-DN**
Hog Farm Lower	DOC	0.0641	UP-DN
Hog Farm Lower	Phosphorus	0.0679	UP-DN
Hog Farm Lower	Specific Conductivity	0.0176	UP-DN
Hog Farm Lower	TKN	0.0174	UP-DN
Hog Farm Lower	TOC	0.0176	UP-DN
Hog Farm Upper	Dissolved Oxygen (%)	0.0041	**UP-FD**
Hog Farm Upper	Dissolved Oxygen (mg/L)	0.0099	**UP-FD**
Hog Farm Upper	Magnesium	0.0802	**UP-FD**
Hog Farm Upper	Phosphorus	0.0266	**UP-FD**
Hog Farm Upper	TKN	0.0873	**UP-DN**
Hog Farm Upper	TOC	0.0069	**UP-FD**
Nahunta	Zinc	0.0459	**UP-DN**
PCS	Ammonia	0.0289	**DN-FD**
PCS	Copper	0.0871	**DN-FD**
PCS	Lead	0.0477	**DN-FD**
PCS	TKN	0.0414	**DN-FD**
PCS	TOC	0.049	**DN-FD**
PCS	Zinc	0.0287	**DN-FD**
Pete Harris	Calcium	0.0833	UP-DN
Pete Harris	Magnesium	0.0833	UP-DN
Spring Garden	DOC	0.0833	UP-DN
Umstead	Water, Temperature	0.0209	**UP-DN**
Walmart	Ammonia	0.0086	**UP-DN**
Walmart	Calcium	0.0143	**UP-DN**
Walmart	Copper	0.0027	**UP-DN**
Walmart	Dissolved Oxygen (%)	0.05	**UP-DN**
Walmart	Lead	0.0028	**UP-DN**

Table 4.3.4a Parameter Station Comparisons for Individual Sites

Site Name	Parameter	Wilcoxon / Kruskal-Wallis P-Value	Significant Station Comparison
Walmart	Magnesium	0.0143	**UP-DN**
Walmart	Phosphorus	0.0082	**UP-DN**
Walmart	Specific Conductivity	0.0176	**UP-DN**
Walmart	TKN	0.0088	**UP-DN**
Walmart	TOC	0.0061	**UP-DN**
Walmart	Zinc	0.0041	**UP-DN**

Bold Blue = Improvement and Red = No Improvement

Table 4.3.4b Parameter Site-Paired Station Comparisons for Individual Sites

Site Name	Parameter	Wilcoxon / Kruskal-Wallis P-Value	Significant Station Comparison
Bachelor	Specific Conductivity	0.009	**UP-DN**
Black Ankle Powerline	Dissolved Oxygen (%)	0.0495	**UP-DN**
Black Ankle Powerline	Dissolved Oxygen (mg/L)	0.0495	**UP-DN**
East Fayetteville North	Copper	0.0979	UP-DN & **DN-FD**
East Fayetteville North	pH	0.0995	**UP-FD**
East Fayetteville North	Specific Conductivity	0.0244	**DN-FD**
East Fayetteville South	pH	0.0941	**UP-FD**
East of Mason	Fecal Coliform	0.0495	UP-DN
Fire Tower	Calcium	0.0731	**UP-DN**
Fire Tower	Copper	0.0021	**UP-DN**
Fire Tower	Dissolved Oxygen (%)	0.0039	**UP-DN**
Fire Tower	Dissolved Oxygen (mg/L)	0.0039	**UP-DN**
Fire Tower	Fecal Coliform	0.0758	**UP-DN**
Fire Tower	Lead	0.0074	**UP-DN**
Fire Tower	Magnesium	0.0758	**UP-DN**
Fire Tower	pH	0.0037	**UP-DN**
Fire Tower	Phosphorus	0.0037	**UP-DN**
Fire Tower	TKN	0.0065	**UP-DN**
Fire Tower	TOC	0.0039	**UP-DN**
Fire Tower	Zinc	0.0401	**UP-DN**
Hog Farm Lower	Phosphorus	0.0758	UP-DN
Hog Farm Lower	Specific Conductivity	0.0283	UP-DN
Hog Farm Lower	TKN	0.016	UP-DN
Hog Farm Lower	TOC	0.0283	UP-DN
Hog Farm Upper	Dissolved Oxygen (%)	0.0041	**UP-FD**
Hog Farm Upper	Dissolved Oxygen (mg/L)	0.0099	**UP-FD**
Hog Farm Upper	Magnesium	0.0802	**UP-FD**
Hog Farm Upper	Phosphorus	0.0266	**UP-FD**

Table 4.3.4b Parameter Site-Paired Station Comparisons for Individual Sites

Site Name	Parameter	Wilcoxon / Kruskal-Wallis P-Value	Significant Station Comparison
Hog Farm bpper	TKN	0.0873	**UP-DN**
Hog Farm Upper	TOC	0.0069	**UP-FD**
Nahunta	Zinc	0.0459	**UP-DN**
PCS	Ammonia	0.0289	**DN-FD**
PCS	Copper	0.0871	**DN-FD**
PCS	Lead	0.0477	**DN-FD**
PCS	TKN	0.0414	**DN-FD**
PCS	TOC	0.049	**DN-FD**
PCS	Zinc	0.0287	**DN-FD**
Spring Garden	DOC	0.0833	UP-DN
Umstead	Copper	0.0495	**UP-DN**
Umstead	Water, Temperature	0.0495	**UP-DN**
Walmart	Ammonia	0.0202	**UP-DN**
Walmart	Calcium	0.0209	**UP-DN**
Walmart	Copper	0.0052	**UP-DN**
Walmart	Dissolved Oxygen (%)	0.0209	**UP-DN**
Walmart	Dissolved Oxygen (mg/L)	0.0433	**UP-DN**
Walmart	Lead	0.0053	**UP-DN**
Walmart	Magnesium	0.0209	**UP-DN**
Walmart	Phosphorus	0.018	**UP-DN**
Walmart	Specific Conductivity	0.009	**UP-DN**
Walmart	TKN	0.0202	**UP-DN**
Walmart	TOC	0.009	**UP-DN**
Walmart	Zinc	0.0071	**UP-DN**

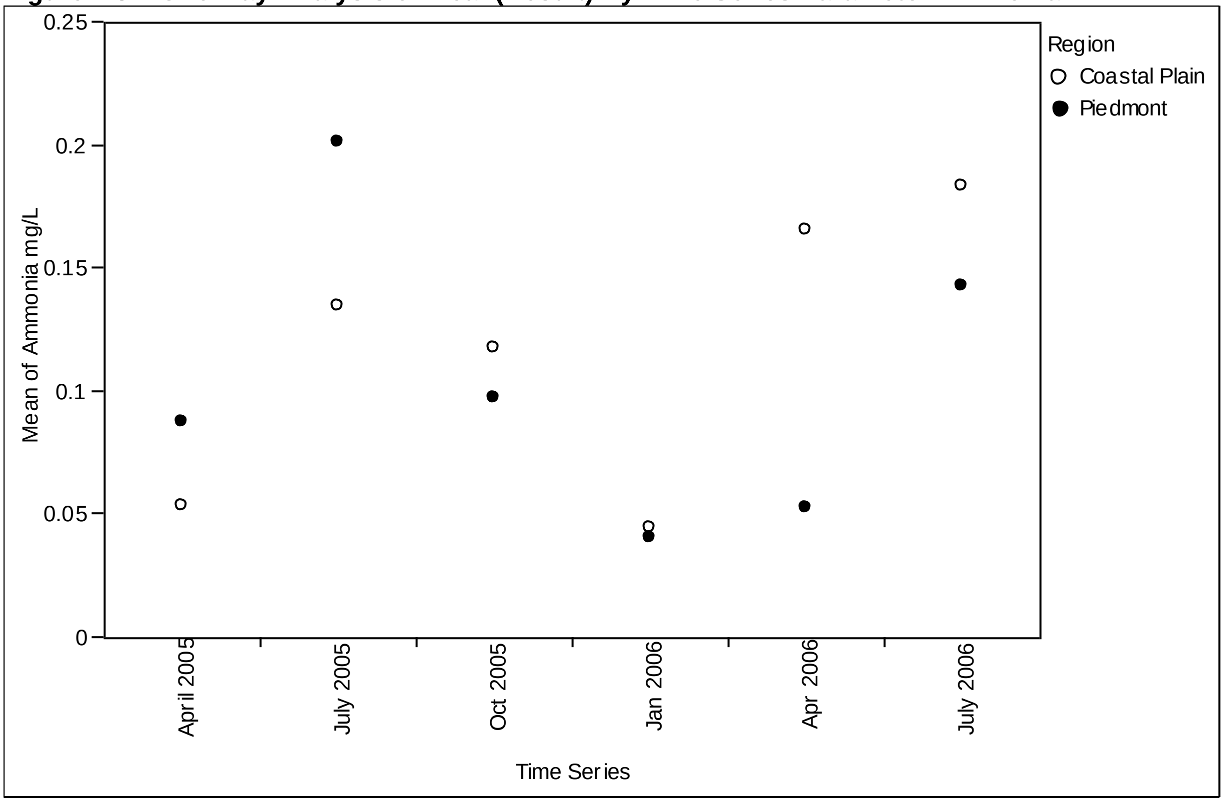
Bold Blue = Improvement and Red = No Improvement

Section 4.3.2 Exploratory analysis of seasonal trends – comparisons to known stream parameter values, and results of cluster and partition analysis.

SEASONAL TRENDS ANALYSIS OF WATER QUALITY RESULTS

Seasonal trends of water quality parameter means and medians for all the data in the Coastal Plain and Piedmont were similar to the Azous and Horner (2001) study. Seasonal trends were fairly similar between regions. The nutrients (phosphorous, ammonia, TKN, and NO_2+NO_3) all tended to have higher levels in the warmer months. Ammonia and NO_2+NO_3 had higher levels in the April and July sampling, phosphorous had higher levels in the April, July and October sampling, and TKN had higher levels in the July and October sampling. Figure 4.3.1 shows the ammonia seasonal trend. Temperature was lower in January, which enabled DO levels to be highest at this time of year. Fecal coliform was higher in July and October than April and January. TOC was higher in April and July (DOC was not sampled year-round). Specific conductivity was highest in April, July, and October, but low in January. pH did not exhibit much in the way of seasonal trends. None of the metals except magnesium exhibited seasonal trends either. Magnesium appeared to be higher in July.

Figure 4.3.1 One-way Analysis of Mean(Result) By Time Series Parameter-Ammonia



COMPARISON OF HEADWATER WETLAND AND STREAM WATER QUALITY IN NORTH CAROLINA

The median results of each parameter for each site were compared to the appropriate stream region parameter results to data from the DWQ Ambient Monitoring System (AMS), EPA, and USGS (see Table 4.1.1). The comparison of Coastal Plain and Piedmont stream water quality to Coastal Plain and Piedmont wetland water quality in this study yielded results similar to the Azous and Horner (2001) study (see Section 4.1). As was expected there were differences between certain wetland and stream water quality parameters, even within the same region. For ammonia, most wetland sites were comparable to the stream median results; however, five sites had values greater than twice the median stream values. NO_2+NO_3 median levels were lower at most wetland sites, except the Hog Farm Upper site at 16 mg/L, which was considerably higher than stream median levels. For the other nutrients, phosphorous and TKN had higher median levels in wetlands than streams. Calcium levels were generally lower in wetlands than streams, except for the Duke Forest site, where the wetland value was nearly twice as high as the stream value. Magnesium was generally similar between wetland sites and streams, though the Hog Farm Upper, PCS and Duke Forest sites had median values above maximum stream levels. Copper and lead median levels were similar between wetlands and streams for approximately 75% of the sites, while the other 25% had higher copper and lead levels, considerably higher for lead even with the no dig data evaluation. As expected, dissolved oxygen (% and mg/L) was lower in wetland sites than stream sites. Temperature was comparable but specific conductivity and pH was lower in wetlands. Total suspended solid levels were considerably higher in wetlands with both data sets (all and no dig). The DWQ AMS program did not assess DOC, but TOC was higher in wetlands. Fecal coliform median levels were higher in wetlands at about a third of the sites, and due to outliers, extremely higher at five of the wetland sites.

CLUSTER ANALYSIS RESULTS

Four cluster analyses were done: the means and medians of the water quality parameters for all the data and for sampled directly data only. Table 4.3.5 shows the sites in the groups for the four cluster analyses. The relationships between the groups are difficult to identify, but some consistent patterns can be found. The rule of thumb was to find consistent groupings or pairings of sites in three of the four cluster analysis runs.

First, Hog Farm Upper and Pete Harris sites came out grouping by themselves in three of the four cluster analyses, so these two sites appear to be unique and therefore not similar to any of the other sites. Moonshine and Umstead paired in all four analyses. The similarity between these two sites may be due to their proximity to each other in Wake County. Both sites are on sloping ground with a less defined, bowl-shaped topography. The surrounding vegetation for both sites is woodland. In terms of the water quality parameters the two sites had similar pH levels, ammonia levels, TOC levels, TKN levels, phosphorus levels, NO_2+NO_3 levels, lead levels, fecal coliform levels, DOC levels, and copper levels. Given the number of parameters where they were similar, this shows why they were paired so strongly.

PCS and East Fayetteville South paired three times, and in the fourth analysis, they were in adjacent groups. The pairing of these two sites is strong but difficult to understand because they are very different in terms of vegetation (PCS is pocosin-like and East Fayetteville South is mixed) and topography (PCS is Flat and East Fayetteville South is bowl-shaped), and are separated spatially with PCS being in the outer Coastal Plain and East Fayetteville South being in the inner Coastal Plain, which borders the Piedmont. For the water quality parameters, the two sites were similar on dissolved oxygen levels, ammonia levels, and NO_2+NO_3 levels.

Also being paired three times were Boddie Noell and Battle Park. Both of these sites are within two miles of each other and both are urban sites. Topographically, Boddie Noell is slightly sloping and Battle Park has an elongated bowl. There is woodland vegetation in both sites, but Battle Park has several bald cypress trees (*Taxodium distichum*). The two sites were similar on several water quality parameters: ammonia levels, calcium levels, dissolved oxygen levels, magnesium levels, phosphorus levels, specific conductivity levels, and TKN levels.

Another grouping was the pairing of Kelly Road and Spring Garden three times, Kelly Road and Black Ankle Non-Powerline three times, with all three sites paired twice. All three sites are typical Piedmont headwater wetlands with a bowl-shaped topography and well-defined streams. The vegetation for all three sites is typical Piedmont woodland, and all three sites are in different counties. In terms of the water quality parameters, all three sites were similar on DOC levels, NO_2+NO_3 levels, TKN levels, and pH levels. Kelly Road and Spring Garden were also similar in levels of ammonia, calcium, copper, dissolved oxygen, lead, magnesium, TOC, and TSS. Kelly Road and Black Ankle Non-Powerline were also similar in levels of phosphorus levels and zinc.

Bachelor and East Fayetteville North were paired three times, and East Fayetteville North and Rough Rider were paired in three of the four cluster analyses. The three sites were then grouped together twice. Bachelor is in the inner Coastal Plain and has vegetation similar to a pocosin with wide and flat topography. Rough Rider too is also in the inner Coastal Plain and is also very flat, but the vegetation is more woodland, resembling a bottomland hardwood forest. East Fayetteville North is in the outer Coastal Plain and its topography is bowl-shaped and its vegetation is woodland. All three sites were similar in terms of the water quality parameters on levels of fecal coliform, lead, magnesium, NO_2+NO_3, phosphorus, and specific conductivity. Bachelor and East Fayetteville North were additionally similar on ammonia levels and TKN levels, and East Fayetteville North and Rough Rider were similar on levels of calcium, dissolved oxygen, TOC, and zinc.

For the two sampled directly cluster analyses (mean and median), one larger group occurred in both results and is worth noting since there was no other large grouping that consistently resulted. The sites were Spring Garden, Kelly Road, Black Ankle Non-Powerline, Fire Tower, and Walmart. All of these sites have a bowl-shaped topography and are in the Piedmont. Vegetation at these sites is forested with mature trees, but there are some differences. Walmart and Fire Tower are similar to each other but different from the other three. Walmart is a heavily urban site. There were six water quality parameters that were similar in the five sites: calcium levels, DOC levels, lead levels, magnesium levels, NO_2+NO_3 levels, and specific conductivity levels.

The Partition Analysis (see Table 4.3.5) resulted in exactly the same six groups for all the data and for the no dig data. The only relationship to the cluster analyses is that Umstead and Moonshine are again paired, and Boddie Noell and Battle Park, while not paired, are in adjacent groups.

The first group (Nahunta, Black Ankle Non-Powerline, and East Fayetteville North) in Table 4.3.5, had similar ammonia, phosphorus, and pH water quality parameters. For the second group there were ammonia, calcium, fecal coliform, lead, magnesium, phosphorus, TKN, and pH water quality parameters. For the third group at least three of the four members were similar on calcium, DOC, NO_2+NO_3, phosphorus, and TKN. The four group members were not similar as a total group on any one water quality parameter.

The fourth group (Boddie Noell, Hog Farm Lower, and Spring Garden) had similar results on the calcium, copper, and fecal coliform water quality parameters. The largest group was the fifth group (see Table 4.3.5). This group was similar on the fecal coliform, magnesium, NO_2+NO_3, and TKN levels. The last group had similar water quality results for levels of calcium, copper, fecal coliform, lead, NO_2+NO_3, TKN, and pH .

The results of the Cluster Analysis and the Partition Analysis await further analysis. Similarities in the water quality parameters give the basis for the clusterings or groupings, but additional variables, such as Land Development Index (LDI), Ohio Rapid Assessment Method (ORAM), region, soil type, etc., need to be included to better understand what is causing these groupings or whether they are even the correct groupings. This should give a better understanding of the sites relationship to each other, on what parameters they relate, and how they relate to land use, disturbance, etc.

Table 4.3.5 Partition and Cluster Analyses

Partition Analysis

Group1	Group2	Group3	Group4	Group5	Group 6
Nahunta	Troxler	Hog Farm Upper	Boddie Noell	Bachelor	Kelly Rd.
Black Ankle NonP	Cox	E Fayetteville North	Hog Farm Lower	Black Ankle Pow	Rough Rider
E Fayetteville South	Fire Tower	PCS	Spring Garden	Walmart	Umstead
	Pete Harris	Duke Forest		East of Mason	Moonshine
				Battle Park	

Cluster Analysis for No Dig Median Analysis

Group1	Group2	Group3	Group4	Group5	Group 6	Group 7
Hog Farm Upper	Battle Park	Moonshine	Spring Garden	Pete Harris	Nahunta	Rough Rider
	Boddie Noell	Umstead	Kelly Rd		Hog Farm Lower	E Fayetteville South
		Duke Forrest	Walmart		East of Mason	E Fayetteville North
		Black Ankle Pow	Fire Tower			Cox
			Black Ankle Non-Powerline			PCS
						Bachelor

Cluster Analysis for No Dig Water Quality Mean Analysis

Group1	Group2	Group3	Group4	Group5	Group 6	Group 7
Pete Harris	East of Mason	Hog Farm Upper	Moonshine	Spring Garden	Nahunta	Rough Rider
E Fayetteville South	Black Ankle Pow		Umstead	Duke Forest		Hog Farm Lower
PCS	Boddie Noell			Walmart		E Fayetteville North
Cox	Battle Park			Kelly Rd		Bachelor
				Fire Tower		
				Black Ankle Non-Powerline		

Table 4.3.5 Partition and Cluster Analyses

Cluster Analysis for All Water Quality Mean Data

Group1	Group2	Group3	Group4	Group5	Group 6	Group 7	Group8
PCS	Hog Farm Upper	Pete Harris	Troxler	Spring Garden	Rough Rider	Walmart	Umstead
Nahunta	Duke Forest			Kelly Rd	Boddie Noell	Hog Farm Lower	Moonshine
E Fayetteville South				East of Mason	Battle Park		Fire Tower
Black Ankle Non-Powerline				Black Ankle Powerline			E Fayetteville North
							Cox
							Bachelor

Cluster Analysis for All Water Quality Median Data

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Hog Farm upper	Troxler	PCS	Boddie Noell	Walmart	Cox	Pete Harris	Rough Rider	East of Mason	Bachelor
	Spring Garden		E Fayetteville South	Nahunta			Hog Farm Lower	Kelly Rd	
	Umstead		Black Ankle Pow	Battle Park			Fire Tower	Black Ankle NonP	
	Moonshine						E Fayetteville North		
	Duke Forest								

Section 4.3.3 Correlation Analysis with ORAM and LDI Watershed Values Results

Table 3.2 in Section 3 shows the Land Development Index scores (LDI) for each site's watershed and Ohio Rapid Assessment Method (ORAM) site scores (LDI and ORAM are explained further in Sections 3.2 and 3.3) . LDI scores rate the land use of a given area according to development of each parcel of land in that given area. Watershed LDI scores ranged from 137.17 to 317.66 and 107.00 to 595.49 in the Coastal Plain and Piedmont, respectively. The LDI scores average 235.2 in the Coastal Plain and 249.6 in the Piedmont. ORAM scores range from 0 to 90, with higher scores indicating a higher quality wetland site. ORAM scores ranged from 35.50 to 70.50 in the Coastal Plain and 20.5 to 74.33 in the Piedmont.

The Correlation Analysis results are shown in Tables 4.3.6A and 4.3.6B. The results for the analysis of all the water quality results are shown on the left side of the tables and the results for the analysis of the no dig results (surface water sample only) are shown on the right side of the tables. Generally, these two sets of results were comparable. The sign of the correlation value (Spearman's ρ) indicates whether there was a positive correlation or negative correlation between the water quality parameter results and the LDI or ORAM scores. Therefore, a positive Spearman's ρ for the LDI scores means that the water quality parameter increases as the LDI score increases or the land cover type becomes more developed. Higher water quality results indicate degraded water quality for all parameters except dissolved oxygen and pH, as lower dissolved oxygen higher acidic pH indicates a lower water quality level. A p-value< 0.10 indicates there was a significant correlation between the water quality parameter and the LDI or ORAM score.

Table 4.3.6A shows the correlation analysis for the site watershed LDI scores against the water quality parameter results. There is a significantly positive correlation between the LDI scores and fecal coliform, magnesium, and NO_2+NO_3 for all the water quality results and no dig results. This indicates that as land use intensifies in the watersheds of headwater wetlands, fecal coliform, magnesium, and NO_2+NO_3 levels increase, causing a decrease in water quality. A transformation of the fecal coliform data set was done for a second correlation, using Pearson's correlation coefficient and pairwise comparisons, in order to reduce the effects of outliers. The transformed fecal coliform data showed there was a significant positive relationship for all the data and watershed LDI scores and no significant relationship for the no dig data and watershed LDI scores. The significant correlation between the LDI and fecal coliform and LDI and NO_2+NO_3 is likely because of hog farming operations in the Coastal Plain. Other agricultural practices would also affect the NO_2+NO_3 levels within the Coastal Plain watersheds. The Hog Farm Upper site in Sampson County had particularly high levels of NO_2+NO_3 (19.21 mg/L average).

Table 4.3.6B shows the Spearman's Rho correlation analysis for the site ORAM scores against the water quality parameter results. The ORAM metrics completed for this analysis did include information on upland buffers and surrounding land use, as well as wetland size, hydrology, habitat alteration and development, plant communities, interspersion, and microtopography (see Appendix B). There was a significant negative correlation for calcium, magnesium, NO_2+NO_3, specific conductivity, and zinc for both sets of results (all water quality data and no digs data only). There was also a significant negative correlation for ammonia and fecal coliform for the no dig correlation analysis. Therefore, calcium, magnesium, NO_2+NO_3, specific conductivity, and zinc increased as the quality of the wetland and surrounding buffer decreased as indicated by the ORAM score. Ammonia and fecal coliform also increased as the ORAM score decreased (lower quality wetland) for the no dig data sample correlation analysis. Similar to the LDI analysis, a Pearson's correlation coefficient and pairwise comparison analysis was also run with transformed fecal coliform results for both data sets against the ORAM scores. There was no significant correlation of the transformed fecal coliform data and ORAM scores for the analysis of all the data or for the analysis of the no dig data only.

In summary, it can be concluded from the results of the Watershed LDI and ORAM correlation analyses that headwater wetlands located in the more urban and highly agricultural watersheds have lower water quality than wetlands in more natural areas with regard to magnesium, NO_2+NO_3, and fecal coliform. Wetland quality as assessed by ORAM is also directly related to ammonia, calcium, magnesium, fecal coliform, NO_2+NO_3, specific conductivity, and zinc levels.

Table 4.3.6a Correlation Analysis - Site Watershed Land Development Index by Water Quality Results

	All Sample Data				**Sample Directly Data Only**			
Water Quality Parameter	**Correlation Value (Spearman ρ)**	**Significant Probability of Correlation - All Data**	**Significance**	**Correct Correlation**	**Correlation Value (Spearman ρ)**	**Significant Probability of Correlation -no dig**	**Significance**	**Correct Correlation**
Ammonia mg/L	0.0737	0.3022	Not		0.1073	0.1926	Not	
Calcium mg/L	0.0438	0.587	Not		0.1477	0.1184	Not	
Copper ug/L	-0.113	0.1094	Not		-0.2565	0.0014	Significant	No
DOC mg/L	-0.1525	0.0773	Significant	No	-0.19	0.0346	Significant	No
Dissolved Oxygen (%)	-0.0124	0.8609	Not		0.0051	0.949	Not	
Dissolved Oxygen (mg/L)	0.0026	0.9701	Not		0.0286	0.719	Not	
Fecal Coliform cfu/100 ml	0.1304	0.0685	Significant	Yes	0.1439	0.0779	Significant	Yes
Lead ug/L	-0.0935	0.1855	Not		-0.2106	0.009	Significant	No
Magnesium mg/L	0.1346	0.0939	Significant	Yes	0.219	0.0198	Significant	Yes
NO_2+NO_3 mg/L	0.3235	<0.0001	Significant	Yes	0.424	<0.0001	Significant	Yes
Phosphorus mg/L	-0.0123	0.8638	Not		-0.0507	0.5394	Not	
Specific Conductivity	0.0188	0.7925	Not		0.0515	0.5209	Not	
Total Kjeldahl (TKN) mg/L	-0.0047	0.9481	Not		-0.0762	0.3559	Not	
TOC mg/L	-0.1215	0.0864	Significant	No	-0.2291	0.0047	Significant	No
TSS mg/L	-0.2054	0.0132	Significant	No	-0.2334	0.008	Significant	No
Turbidity NTU	-0.2185	0.1644	Not		-0.3433	0.0324	Significant	No
Water, Temperature C°	0.0448	0.5212	Not		0.0451	0.5661	Not	
Zinc mg/L	-0.0287	0.685	Not		-0.1335	0.0999	Significant	No
pH S.U.	0.0402	0.5737	Not		0.1085	0.1789	Not	

Table 4.3.6b Correlation Analysis - Site ORAM Scores by Water Quality Results

Water Quality Parameter	All Sample Data				Sample Directly Data Only			
	Correlation Value (Spearman ρ)	Significant Probability of Correlation - All Data	Significance	Correct Correlation	Correlation Value (Spearman ρ)	Significant Probability of Correlation -no dig	Significance	Correct Correlation
Ammonia mg/L	-0.0973	0.1726	Not		-0.1556	0.058	Significant	Yes
Calcium mg/L	-0.2781	0.0004	Significant	Yes	-0.384	< 0.0001	Significant	Yes
Copper ug/L	-0.0689	0.3296	Not		0.0466	0.5673	Not	
DOC mg/L	-0.0124	0.8866	Not		0.0232	0.7986	Not	
Dissolved Oxygen (%)	-0.051	0.4712	Not		-0.0441	0.5796	Not	
Dissolved Oxygen (mg/L)	-0.0651	0.3559	Not		-0.0642	0.4183	Not	
Fecal Coliform cfu/100 ml	-0.1096	0.1262	Not		-0.1561	0.0557	Significant	Yes
Lead ug/L	0.0082	0.9083	Not		0.1179	0.1465	Not	
Magnesium mg/L	-0.3911	< 0.0001	Significant	Yes	-0.4689	< 0.0001	Significant	Yes
NO_2+NO_3 mg/L	-0.367	< 0.0001	Significant	Yes	-0.4713	< 0.0001	Significant	Yes
Phosphorus mg/L	-0.0867	0.2243	Not		-0.0889	0.2811	Not	
Specific Conductivity	-0.2194	0.0018	Significant	Yes	-0.2665	0.0007	Significant	Yes
Total Kjeldahl (TKN) mg/L	-0.0896	0.2093	Not		-0.045	0.5859	Not	
TOC mg/L	0.0428	0.5473	Not		0.1463	0.0731	Significant	No
TSS mg/L	0.1058	0.2052	Not		0.1387	0.1184	Not	
Turbidity NTU	0.0614	0.6991	Not		0.1855	0.2582	Not	
Water, Temperature C^o	0.0024	0.9722	Not		-0.0326	0.679	Not	
Zinc mg/L	-0.1919	0.0062	Significant	Yes	-0.1393	0.0859	Significant	Yes
pH S.U.	-0.0251	0.7257	Not		-0.0432	0.5936	Not	

Table 4.3.7A and 4.3.7B summarizes the results of the Spearman's Rho Correlation analysis for site percent improvement capacity against site ORAM and Watershed LDI scores separately. Table 4.3.6A shows the results for the analysis of all the data and Table 4.3.6.B shows the results for the analysis of the no dig data. The percent improvement capacity is the number of site station comparisons (UP-DN + UP-FD + DN-FD *improvement*) that showed improvement divided by the total number of station comparisons (UP-DN + UP-FD + DN-FD *total*) for that site (see Section 4.2.2.3). There was a significant correlation of a Prob>|ρ| = 0.07 with a correlation coefficient (Spearman's ρ) of –0.38 for the analysis of ORAM against the percent improvement capacity of all the data (see Table 4.3.7.A). The negative Spearman's ρ correlation coefficient for the ORAM correlation with percent improvement capacity indicated that the ORAM score increases (or the quality of the wetland improves) as the percent improvement capacity decreases. There were no significant results for the analysis of percent improvement

capacity for all the data against watershed LDI or for any of the no dig data analysis (see Table 4.3.7.B). The results of the correlation analysis of all the water quality indicate that headwater wetlands still maintain the ability to filter pollutants even when not of the highest quality. This reinforces the importance of maintaining these headwater wetland systems even when they do not appear to be of the highest quality.

Table 4.3.7a Correlation Analysis of Wetland Site Improvement Capacity by ORAM and Land Development Index - All Data

Coastal Plain Sites	Percent Improvement Capacity	**Piedmont Sites**	Percent Improvement Capacity
Bachelor	0.37	Black Ankle Non-Powerline	0.21
Battle Park	0.63	Black Ankle Powerline	0.89
Boddie Noell	0.71	Duke Forest	0.63
Cox	0.75	East of Mason	0.42
East Fayetteville North	0.60	Fire Tower	0.84
East Fayetteville South	0.80	Kelly Rd	0.32
Hog Farm Lower	0.26	Moonshine	0.35
Hog Farm Upper	0.75	Pete Harris	0.42
Nahunta	0.68	Spring Garden	0.53
PCS	0.70	Troxler	0.89
Rough Rider	0.53	Umstead	0.58
		Walmart	0.88
ORAM	Spearman's ρ	-0.384	Significant
	Prob>|ρ|	0.071	
Watershed LDI	Spearman's ρ	0.248	Not Significant
	Prob>|ρ|	0.253	

Table 4.3.7b Correlation Analysis of Wetland Site Improvement Capacity by ORAM and Land Development Index - No Dig Data

Coastal Plain Sites	Percent Improvement Capacity	**Piedmont Sites**	Percent Improvement Capacity
Bachelor	0.79	Black Ankle Non-Powerline	0.26
Battle Park	0.63	Black Ankle Powerline	0.79
Boddie Noell	0.71	Duke Forest	0.59
Cox	0.51	East of Mason	0.42
East Fayetteville North	0.42	Fire Tower	0.74
East Fayetteville South	0.63	Kelly Rd	0.47
Hog Farm Lower	0.37	Moonshine	0.35
Hog Farm Upper	0.73	Pete Harris	0.63
Nahunta	0.26	Spring Garden	0.44
PCS	0.67	Troxler	0.40
Rough Rider	0.53	Umstead	0.58
		Walmart	0.80

Table 4.3.7b Correlation Analysis of Wetland Site Improvement Capacity by ORAM and Land Development Index - No Dig Data

Coastal Plain Sites	Percent Improvement Capacity	**Piedmont Sites**	Percent Improvement Capacity
ORAM	r-Value	-0.041	Not Significant
	P-Value	0.853	
Watershed LDI	r-Value	-0.073	Not Significant
	P-Value	0.742	

Section 5 – Hydrology Monitoring Section

Section 5.1 Hydrology Introduction and Background

Most wetlands experts would agree that hydrology is the single most important variable in the formation and maintenance of wetland systems. When the hydrology of a wetland is altered, significant changes to the functioning of the wetland often occur. Some alterations to hydrology occur naturally, such as storms, hurricanes and beavers; however, most are human-induced, such as harmful agricultural and silvicultural practices, ditching and channelization of streams, invasive plant species introductions, and road construction.

Hydrologists investigate the relationship of the water table relative to the ground surface. Hydrology is concerned with the transport of water through the air, over the ground surface, and through the strata of the earth (Ward and Elliot 1995 and Davie 2003). While definitions of wetlands may differ among scientists, individual states, and government agencies (Tiner 1997), the important role of hydrology in wetlands is not in dispute. Mitsch and Gosselink (1993) state that "hydrology is probably the single most important determinant of the establishment and maintenance of specific types of wetlands and wetland processes". Wetlands are more sensitive to changes that affect their hydrology than to changes to either soil or vegetation. If the plants were to be eliminated but the hydrology remained, wetland plants will soon re-inhabit the wetland. Hydric soils will eventually develop as organic matter accumulates and chemical elements change from under saturated conditions; however, if the hydrology is altered in any significant way, the hydric soils and wetland plants will be lost over time (Ward and Elliot 1995 and Richardson and Verpraskas 2001).

The study of wetland hydrology focuses on the flow of water in and out of the wetland and the degree of soil saturation or inundation. Water flows into wetlands by precipitation, groundwater, and surface flow (Tiner 1999). Precipitation, in terms of rain, sleet, fog, and snow, deposits water into wetlands with rainfall providing the greatest volume. North Carolina has an annual average precipitation of approximately 40-55 inches (Robinson 2005). Rainfall is greatest in the summer with July being the wettest month, while autumn is the driest season with November being the driest month.

Groundwater is water that collects between soil particles, in soil layers above impervious layers and in layers of rock called aquifers. Groundwater is discharged where the water table intercepts the surface of the ground, generally on slopes on hillsides (Tiner 1999 and Ward and Elliot 1995), as is typical of headwater wetlands in the Piedmont. Some wetlands have surface water or shallow groundwater that seeps into deeper groundwater aquifers. Other wetlands have surface and shallow groundwater that is isolated from the underlying water table by impervious layers of soil or rock. These shallow lenses of groundwater that are isolated from the groundwater reservoirs are referred to as perched water tables (Tiner 1999).

Surface water in terms of runoff, streamflow and overbank flooding provide water to wetlands. Runoff is sheets of water not contained in channels, whereas streamflow occurs in channels. Overbank flooding occurs when streams fill their channels and spill over into the relatively flat area parallel to the stream, often referred to as the floodplain. The amount of surface water flowing into a wetland depends on watershed characteristics such as the amount of impervious cover, soil types, slope, and the height of the stream bank. The landscape position of the wetland also determines the amount of surface water flow; for example, estuarine wetlands receive surface water from overland flow and inland flow in tidal creeks, streams, and rivers. Headwater wetlands receive most of their water from rainfall and from groundwater with a shallow water table as in the coastal plain or seeps from hillside slopes in the piedmont. Some headwater wetlands will also receive some water from runoff.

Water leaves wetlands by evapotranspiration, runoff, and streamflow (Tiner 1999). Evapotranspiration is the evaporation of water from the surfaces of water, soil, and plants, and transpiration of water vapor from plant leaves and stems. Most of the water loss in wetlands is through evapotranspiration; however, some wetlands can also lose water when the surface layers of soils drains water into the deeper layers or into aquifers.

Water accumulation in wetlands first occurs in the pore spaces between soil particles (Tiner 1999 and Richardson and Vepraskas 1995). When most of the pore spaces are filled and water flows through the soil from the force of gravity, the soil is said to be saturated. If the water pools above the surface of the ground, the wetland is said to be inundated. When overbank flooding occurs and submerges the surrounding wetland, flooding is the result. Most wetlands show seasonal fluctuations of saturation or inundation. During the winter to late spring, water is typically at or above the surface of the ground. From summer to early fall, water levels in wetlands drop as the day lengthens and air temperatures rise and evapotranspiration increases. Finally, from mid-fall to mid-winter water accumulates as temperatures and evapotranspiration decrease. Wetlands created by groundwater discharges are less susceptible to seasonal changes in their saturation or inundation since the groundwater flow is more constant. This is true with many headwater wetlands.

Wetlands themselves have a significant impact on the hydrological cycle. Wetlands can both increase and decrease floods, either facilitate or reduce groundwater recharge, or either augment or reduce low flows (Bullock and Acreman 2003). Contributions from groundwater are often the biggest factors in determining the amount and duration of streamflow from its headwater to downstream reaches (Varney 2006). The source of a stream's groundwater also has importance on its hydrology. Those streams whose groundwater emanates from impermeable rocks or sediments (rocks and sediments with a low ability to transmit water) have an ever-changing point of origin that migrates up and down the channel on a seasonal basis, have small incipient discharges, and consequently, commonly dry up. But streams beginning in large aquifers have a point of origin that is stable and have larger volumes of discharge so that they dry up less frequently. Sustained hydrology is also vital if a stream is going to provide reliable and healthy habitat for hydrophytic vegetation and aquatic organisms such as macroinvertebrates, fish, and amphibians. Natural and anthropogenic activities are other determinants of stream flows from their headwater to downstream reaches. In humid regions of the United States like the southeast, stream water is lost to groundwater when and where their head is perched above the water table. Besides groundwater, other sources of hydrology in headwaters and streams are runoff from precipitation like rain and snow and shallow subsurface flow through the unsaturated zone (Winter 2007). Hydrological outflows from a headwater wetland or stream come from evaporation of standing water or saturated soils, transpiration from plants, and surface water or groundwater outflow.

Wetland hydrology is varied and vital to local and regional aquifers (Ward and Elliot 1995). Groundwater recharge is the replenishment of an aquifer with water from the land surface (Alley *et al*. 2002). Recharge happens when precipitation or irrigation waters runoff from a surface where it briefly ponds until being absorbed into the groundwater system. The floodplains of rivers and streams are important in slowing the flow of some of this stormwater runoff. If these floodwaters are not allowed to enter floodplains and then slowly reenter rivers, rivers will flow deeper and faster and increase the likelihood of flash floods (Ward and Elliot 1995).

Seasonal hydrology plays an important role in nutrient export rates. In Chescheir *et al*. (2003), studies in the North Carolina coastal plain showed that most of a watershed's annual total nitrogen export, and to a lesser degree its total phosphorus export, happened in the winter months when outflow levels were highest. The season with the lowest nutrient exports was spring. Another hydrologic factor affecting the seasonal distribution of nutrient exports are tropical storms and the abundant rainfall that comes with them. Nutrient exports associated with these high precipitation events were highest in the summer and/or fall, the time of year these storms most often occur. This was particularly true for the removal of total nitrogen and nitrate+nitrites. Elevated losses of total phosphorus were also reported during the summer and fall seasons at some sites. Spring was usually the season with the lowest nutrient export. Because of the effect of hydrology on seasonal nutrient exports, results from short-term studies conducted over two to three years need to be interpreted in the context of the seasonal rainfall distribution during the study, particularly in years affected by large, infrequent storms such as hurricanes (Chescheir *et al*. 2003).

Activities such as agriculture or flood control change the hydrology of a wetland causing a decrease in its size and altering its hydrologic regime (Mathias and Moyle 1992). When water is diverted by activities such as damming, pumping of groundwater, or irrigation projects, the alteration of the hydroperiod has great effects on the distribution of wetland plant species (Cronk and Fennessey 2001).

Headwater wetlands are also very important to discharge areas. As water levels in streams and rivers begin to drop during the summer months, water stored in adjacent headwater wetlands is released slowly into the stream and river system, maintaining healthy flow levels (Varney 2006).

Roads generally have negative impacts on terrestrial and aquatic ecosystems. Impervious road surfaces are defined as any surface through which water cannot penetrate, i.e., paved roads, sidewalks, parking lots, buildings, rooftops, as well as many other land cover types (Sleavin *et al*. 2000). These surfaces alter natural water flows and decrease the amount of water that infiltrates the soil resulting in an increase in the velocity and volume of surface runoff. This in turn increases the occurrence and strength of flooding in our urban and suburban streams and wetlands and increases the peak flow of streams (N.C. WSWA, Forman and Alexander 1998). While runoff from impervious surfaces presents certain problems, the destructive forces that follow the rapid conversion of slow-moving groundwater to fast-moving surface water at cutbanks by roads are even more problematic. This destructive and fast-moving surface water is carried by roadside ditches which often drain straight to streams or culverts with gullies cut-out below their outlets (Wemple *et al*. 1996). Increased runoff from roads may increase the rates and scope of erosion, reduce percolation and aquifer recharge rates, alter channel morphology, and increase stream discharge rates (Beschta 1978, Bilby *et al*. 1989). These increased peak discharges or floods then restructure riparian areas by rearranging channels, logs, branches, boulders, fine-sediment deposits, and pools (Forman and Alexander 1998). The sheer energy generated from the forces of gravity and resistance from this runoff cause streams to carve channels, transport materials and chemicals, and change the landscape (Leopold *et al*. 1964).

Roads also affect the movement of water and sediment through landscapes (Luce and Wemple 2001). Water runoff and sediment yields are what most affect streams and other aquatic systems from road impacts. This combination of effects can be detrimental to native terrestrial and aquatic organisms, and negative correlations between road density and fish stocks have been noted (Lee *et al.* 1997 and Thompson and Lee 2000).

Worldwide, agriculture is the single largest user of freshwater resources and has a major effect on wetland hydrology. Globally, an average of 70% of all surface waters are used for farming, and except for water lost through evapotranspiration, this agricultural water is returned to the Earth's surface or groundwaters, and often that returned water is polluted (FAO). Waters returned to our surface and groundwaters often carries salts, excess nutrients, and pollutants such as herbicides and pesticides. (IJC 2004).

In North Carolina farmers grow crops on over 2 million acres of poorly drained soils representing almost 40% of the state's total cropland (Evans *et al*. 1996). Cropland irrigation can alter the local hydrograph and thus has an effect on the organisms that depend on these waters for life. Irrigation also depletes local aquifers, and can affect municipalities use for drinking water. But converting forests, wetlands, and marshes to cropland also contributes runoff from these agricultural operations in the form of pollution from herbicides, pesticides, and nutrients. These pollutants and nutrients often drain to these waters and accumulate in waters and sediments adversely effecting water quality (Kirby-Smith and Barber 1979, NDCR 1982, NRCD 1987, Pate and Jones 1981). In a three-year study on the effects of agricultural drainage in the North Carolina tidewater region, Skaggs *et al*. (1981) found that agricultural development caused a decrease in evapotranspiration with a consequent small increase in annual outflow even during years when droughts occurred.

Careless forestry practices, silvicultural operations, and the placement of logging roads can have negative effects on hydrology. Foresting operations and logging roads can increase peak discharges of runoff thus increasing downstream flooding (Jones and Grant 1996 and Wemple *et al*. 1996). The cutting of forests causes lower levels of evapotranspiration, reduces the amount of precipitation intercepted by the tree canopy, and lowers water-storage capabilities. Forests also slow down the flow of water over the soil surface letting it infiltrate into the porous surface soils (Moore 1999 and Jones and Grant 1996). Also, flood frequency apparently correlates with the percentage of road cover in a basin (Harr *et al*. 1975, Sauer *et al*. 1982, Jones and Grant 1996, Forman and Alexander 1998).

One last major impact that logging operations can have on hydrology in wetlands is the indirect effect of soil compaction from the use of heavy machinery to harvest trees and prepare sites for harvesting. Soil compaction reduces openings in the soil that hold air and water. This increases the rate of runoff, decreases infiltration and the storage capacity of soil, and lowers the underground transference of water. The excess water that is not allowed to infiltrate puddles or runs off. This effect increases the volume, duration and intensity of runoff and is a major contributor to downstream flooding events, while puddling can prevent vegetation from reestablishing itself after forests are cut. Vegetation dissipates the excessive energy caused by fast-flowing water over the surface and slows it down to be infiltrated into the soil (Moore 1999, van Dijck and van Asch 2002, Despres and Whittecar 2004).

There are a few non-human impacts that have an effect on a regions' hydrology, notably hydrological impacts from beavers and large storm events such as hurricanes. North Carolina experiences, on average, five hurricanes per decade (Robinson 2005). The most obvious impact that hurricanes have on a regions' hydrology comes from the large amounts of rain that accompany such storms.

A study of the effects of a quick succession of hurricanes in the Pamlico Sound region of coastal North Carolina in the late-1990's showed major effects on the regions' hydrology (Paerl *et al*. 2001, Paerl *et al*. 2006). As a result of the large amounts of rain dumped by these storms, large volumes of runoff were created and subsequently discharged through the regions' streams, canals, and waterways.

Beavers also affect hydrology on a smaller, watershed scale (Mitsch and Gosselink 1993). Beaver are also an important hydrogeomorphic factor of swamp and marsh development. Beaver dams clog streams and rivers and impound surface water which creates open water areas. When a beaver dam is first built, flooding of the stream or river occurs behind it, killing large swaths of former forest and shrubland. These forests and shrubs are replaced by emergent and submergent herbaceous vegetation. These new vegetation communities are often classified as marshes or wet meadows depending on the intensity and duration of flooding (NatureServe 2005). As beaver food supplies dwindle, the beaver move further downstream or upstream looking for food and potential dam sites, creating additional impoundments, marshes, and wet meadows (Baker 1987).

In a study of the expansion of beaver populations from 1944-1997 in Maine's Acadia National Park, analysis of aerial photographs showed an increase of 89% in ponded wetlands. In general, beavers convert forested and riparian areas to open water that increases the ratio of open water to forests and forested wetlands (Cunningham *et al*. 2006). In a survey of Vermont's hardwood swamps, Sorenson *et al*. (2004) discovered that 21% of the swamps had some beaver activity that led to flooding. It is becoming clear that active beaver colonies are important to a watershed's hydrology, especially in their potential for alterations. In a study of beaver impacts in Canada, Naiman *et al*. (1986) claim that if beaver populations are not actively managed or harvested, they may exert an impact on 20-40% of the total length of second to fifth order streams.

Another vital role hydrology plays in a wetland ecosystem is to determine the species richness and abundance of amphibian communities with a great effect on primary productivity, on types of vegetation, and in nutrient cycling. In summary, hydrology is a crucial component of wetlands. Wetlands have an important role to play in a region's hydrologic cycle. Wetlands can both increase and decrease floods, facilitate or reduce groundwater recharge, and either augment or reduce low flow. Hydrological alterations can greatly interfere with the functioning of a wetland, particularly headwater wetlands (partly because of their small size) and the headwater streams that result which in turn can alter the benefits such as improvement in water quality. Headwater wetlands used in this study exhibited a number of human induced alterations including agricultural ditches, soil compaction by cattle, impermeable surfaces and road crossings.

The following methods and results sections will investigate the differences between the hydrology of sites located in natural, agricultural and urban watersheds and sites that have varying degrees of human induced hydrology alterations (eg., ditching, road crossings, etc.). The methods and results sections will also discuss the topography associated with each headwater wetland site. Slope also has the potential to affect the specific hydrology of a wetland. Headwater wetland sites tend to be more bowl-shaped in the Piedmont and flatter with sheet-flow in the Coastal Plain.

Section 5.2.1 Hydrology Field Methods

Well and Transducer Installation and Setup

Monitoring wells were installed in the approximate center of the wetland study site where hydrological variations could be observed and recorded. Some monitoring wells were installed during the dry season and thus were placed in deeper areas of the wetland where standing water existed during the wet season while other wells were placed in areas that were not as deep and did not have standing surface water during the wet season. Therefore, exact depth comparisons between the sites are not feasible; however the relative patterns were comparable. The Army Corps of Engineers document entitled, "Wetlands Regulatory Assistance Program (WRAP) for Installing Monitoring Wells/piezometerin Wetlands" (http://el.erdc.usace.army.mil/elpubs/pdf/tnwrap00-2.pdf) was used to install monitoring wells. The wells had 0.01 inch slats along the lower 18 inches for water flow and vented caps to prevent a vacuum from forming and allow the water to flow freely. Wells were installed two feet below the ground surface. Sand was used in the bottom of the installation hole and around the circumference of the well up to four to six inches from the ground surface where bentonite was used for a seal. Bentonite was piled around the well four to six inches above the ground surface and covered with wet soil. Wells were installed for at least 24 hours before the first water level readings were taken. The well location was recorded with GPS and later imported into a GIS project/database.

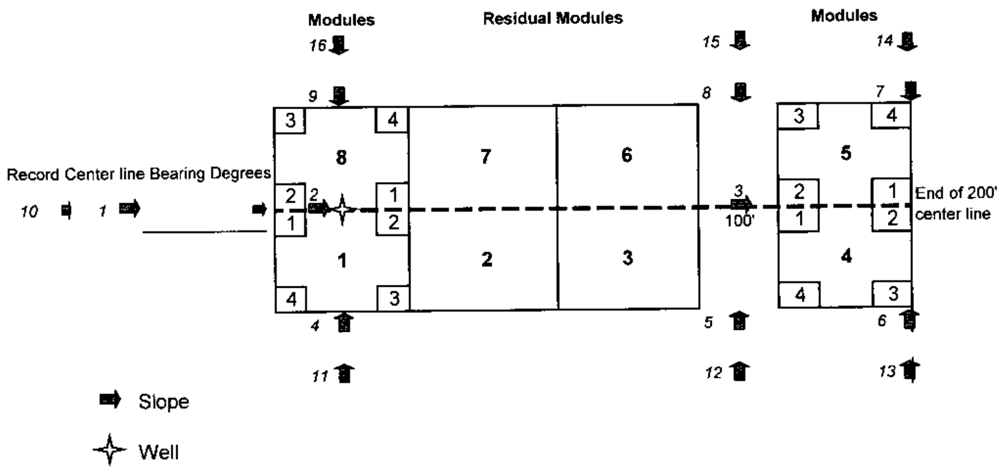
Before the transducers were installed in the field, they were checked for accuracy in a controlled indoor environment prior to installation. In-situ vented Level-Troll 500 transducers were installed in March 2006 at 12 of the well locations (six in the Piedmont and six in the Coastal Plain) to record information on duration, frequency, and seasonal timing of wetland inundation. Transducers were hung with the sensors located a couple inches from the bottom of the well. Data were collected from March 2006 to April 2007. Six sites in the Piedmont and six in the Coastal Plain were located in agricultural, urban, and natural watersheds and were chosen in order to obtain comparisons of the wetland hydroperiod. In the field, transducers were set to

record every 30 minutes. Hand measured water level readings were compared to automated-water levels in order to check for accuracy every time well water level data was downloaded (at least every three months). Automated well water level data that was more than 0.05 feet different than water levels measured by hand in the field was discounted. Hand measurements were taken at least two times to ensure accuracy. Monitoring wells that did not contain transducers were measured by hand during each field visit. Appendix B contains an example of the well level recording field sheets for hand measurements and In-situ transducer automated measurements.
Data from the automated transducers were downloaded using an interface cable from the transducer to a laptop computer. The data were downloaded and immediately backed up by converting the existing data format to an excel format. The last depth recording from the transducer was used to verify accuracy compared to the hand measurements. The exact procedure for the handling of the hydrology data in the field and office was written up in a detailed standard operating procedure (see Appendix D).

Slope Measurements

Slope measurements were taken in order to determine how slope affects hydrology (see Figure 5.2.1). A series of up to 16 slope measurements were taken with a clinometer and recorded on the wetland plot layout and slope field sheet (see Appendix B). Three slope readings were taken along the centerline toward the downstream direction, six slope readings were taken from the edge of the plot toward the centerline, and seven slope readings were taken from the wetland study area delineation line toward the edge of the plot. Specific directions for the location and direction of each slope are shown in Figure 5.2.1. The slope was not taken in circumstances where the vegetation was too dense for a reading or for slope numbers 10-16 in situations where the wetland study area delineation line was located within the plot or within 5 feet of the plot boundary. It should be noted that the use of a clinometer for slopes does have some inaccuracies.

Figure 5.2.1 Slope Measurement Diagram



Slope Reading Directions

Slope *1* - Read 10m from Slope *2* location (well for normal plot) along center line and shoot to slope 2 reading location.

Slope *2* - Read from well location (normal plot) or centerpoint btw modules *1* and *8* (varied plot) along center line and shoot to slope *3*.

Slope *3* - Read along center line and shoot to 200' centerline mark.

Slopes *4&9, 5&8, 6&7* - Read at edge of plot (10m from center line) at 90° to center line, shoot to slope *2, 3,* and *4* respectively.

Slope *10*-Read at head of wetland along plot center line, shoot to slope *1*.

Slopes *8-16* - Read at edge of wetland at 90° angle to center line. Shoot slope *11* to *4*, slope *12* to *5*, slope *13* to *6*, slope *14* to *7*, slope *15* to *8* and slope *16* to *9*

Section 5.2.2 Hydrology Data Analysis Methods

Hydrological data were graphed to evaluate duration, frequency, and seasonal timing of saturation and inundation from each headwater wetland. Due to differences in the way that the wells were installed, statistical comparisons between the sites are not feasible. However, relative patterns and trends were compared between sites.

The headwater wetland sites were classified into landscape classes of natural, rural, and urban. This was determined by using the 300-meter LDI scores, with a score of < 180, being classified as natural sites, between 180 – 300, being classified as rural (strong agricultural influence), and > 300 being classified as urban (subject to development pressures). The sites that were classified into each of the landscape classes are shown in Table 5.2.1.

Table 5.2.1 Landscape Class

Natural	**Rural**	**Urban**
Bachelor	Black Ankle Non-Powerline	Battle Park
Cox	Black Ankle Powerline	Boddie Noell
Duke Forest	East Fayetteville North	Moonshine
Pete Harris	East Fayetteville South	Troxler
PCS	Fire Tower	Walmart
Umstead	Kelly Rd	
Spring Garden	Nahunta	
	Hog Farm Lower	
	Hog Farm Upper	
	Rough Rider	

The slope of each wetland was determined to see how the hydrology results may be related to the topography of the headwater wetlands. Slope was measured in the field to determine if sites were bowl-shaped as was typical in the Piedmont or “flat” as was typical in the Coastal Plain. Slopes one, four, and nine (see Figure 5.2.1) were used to determine whether a wetland could be classified as “bowl-shaped” or “flat”. Wetlands that had two out of three slopes measurements less than or equal to minus two degrees were considered to be bowl-shaped. Otherwise the wetland was considered flat. The slope of the bowl-shaped wetlands and the flat wetlands were compared by using the differences in the trends and patterns in the hydrographs. The sites that were classified as bowl-shaped versus flat are shown in Table 5.2.2.

Table 5.2.2 Headwater Wetland Sites Classified by Topography

Bowl	Flat
Battle Park	Bachelor
East Fayetteville North	Boddie Noell
East Fayetteville South	Cox
Fire Tower	Duke Forest
Kelly Rd	Hog Farm Lower
Black Ankle Non-Powerline	Hog Farm Upper
Pete Harris	Moonshine
Black Ankle Powerline	Nahunta
Spring Garden	PCS
Troxler	Rough Rider
Umstead	
East of Mason	
Walmart	

Section 5.3 Hydrology Results and Conclusion

The hydrology data is clearly influenced by precipitation. The rainfall for all 12 sites was normal during the majority of the time period. According to the U. S. Drought Monitor (US Department of Agriculture, US Geological Survey and the US Environmental Protection Agency, http://www.drought.unl.edu/dm/monitor.html), the eastern two-thirds of North Carolina experienced normal rainfall with some brief periods of abnormally dry conditions during the monitoring period (March 2006 through April 2007). Therefore, the hydrology data collected ended before the serious drought conditions started in the second quarter of 2007.

The Coastal Plain sites had mean water table depth of 0.48 feet from the ground level during the growing season whereas the Piedmont had a mean depth of 0.77 feet (see Table 5.2.4). Figures 5.3.1 – 5.3.12 show the hygrographs for all 12 sites for water level depths collected from March 2006 through April 2007. The graphs show electronic depth as measured by the automated pressure transducer, such that the bottom of the graph (the x-axis, with y=0) is within a couple inches from the bottom of the well. As the depth increases, the water level approaches the ground surface. Therefore, depth was measured in tenths of feet from the sensor located at the base of the transducer to the surface of the water. There was some variability in the depth of the transducers, in addition to the variability of the monitoring well placement in the wetland (see section 5.2.1). The depth of the probe sensor ranged from 21 inches (1.75 feet) to 26 inches (2.17 feet) below the surface. The red horizontal line in Figures 5.3.1 - 5.3.12 is the ground level and the blue horizontal line is the depth at one foot. The growing season (defined as the period between the average date of the last killing frost in the spring and the average date of the first killing frost in the fall, Gregory 2005) is indicated on each hydrograph by the green vertical lines. Generally the growing season started sometime in March through sometime in November and then started again in March, hence the three green vertical lines.

Rural Site Hydrology Descriptions

Figure 5.3.1 shows the hydrograph for the Black Ankle Non-Powerline site located in the rural (sites influenced by agriculture or pature land) Piedmont. The seasonal trend is apparent in the figures with the higher levels early in the year with fluctuations probably due to rainfall. During the growing season (see Figure 5.3.1), the water levels were lower on average and with less fluctuations. In fact, the water levels were zero (meaning the water levels were at or below the depth of the transducer's sensor) during parts of August and the fluctuations are most likely due to rainfall. Figure 5.3.1 also shows the water levels increased as the growing season ended and evapotranspiration diminished and water levels remained high during the winter season. Hog Farm Upper is another rural site in the Coastal Plain and as can be seen in Figure 5.3.2; the water levels were fairly high during the spring and early summer, but dropped off during the summer months. The water depth levels picked up again in October and stayed relatively high during the winter months. Figure 5.3.2 also shows that the water levels dropped off this time in early spring, rather than late spring. Again, the fluctuations were likely due to rainfall. Also notable is that this site varied the least in its water levels from about 1.1 feet to 1.6 feet. The Hog Farm site, which was relatively large and flat, maintained nearly constant water levels. A third rural site was the Kelly Road site located in the Piedmont (see Figure 5.3.3) at a road intersection. Kelly Road showed similar seasonal trends but is a lot flashier. This can be partly attributed to it being one of the smaller sites and potentially getting a lot of runoff from two adjacent roads and a railroad crossing. Nahunta was also a rural site, but is in the Coastal Plain and its hydrograph is shown in Figure 5.3.4. Nahunta was surrounded by agricultural fields on three sides, a road on the fourth side and was also within a few hundred feet of a dirt race track. Nahunta also showed quite a bit of flashiness, again probably getting a lot of runoff from rain or regional storms. However, this site reached a fairly steady state starting about October 2007 with minor fluctuations during the non-growing season. Rough Rider was a rural site on the Coastal Plain that did not show the same flashiness since it had a larger wooded area between the site and an agricultural field and rural residences along a gravel road (see Figure 5.3.5). Therefore this site was consistently dry from about mid July to the first of September (see Figure 5.3.5). This site also reached a steady state for the non-growing season with relatively high water levels. Figures 5.3.6 showed the hydrographs for the last rural site located in the Piedmont- Fire Tower. Seasonal trends can also be seen, but this site seems to have had some tendency to be a little flashy as this site was surrounded by houses and trailers on two sides, a junkyard on the other side, and bounded by a road on the fourth side. This site reached a fairly steady state during the non-growing season, but an anomaly occurred during January 2007 that caused some wild fluctuations.

Urban Site Hydrology Descriptions

The Boddie Noell site, an urban site (sites in high development areas) in the Coastal Plain, has its hydrograph shown in Figure 5.3.7. This site showed similar seasonal trends, but was much more prone to "flashiness" as would be expected by an urban site. This site also had some dry spells (no measured water in well) during the growing season from about late July to early October. Again a steady state was reached for the non-growing season. The Walmart site (Figure 5.3.8) and Troxler (Figure 5.3.9) were also urban sites, both in the Piedmont. These two sites also showed a strong tendency to be flashy, normally during rainfall periods. Both of these sites are in heavily developed areas surrounded by large parking lots, department stores, and industry. The runoff from the surrounding area into these two wetlands was definitely significant with large spikes in the hygrographs. The Troxler monitoring well was completely dry during the growing season from about mid-July to early October as Figure 5.3.9 shows, however the Walmart site did not seem to have a similar dry trend (the site was dry at the ground level, but retained water in the well). Both sites did reach some semblance of a steady state during the non-growing season, but the flashy trends were noticeable even during the non-growing season.

Natural Site Descriptions

Three sites were classified as natural (minimal human influence) where continuous hydrological data were collected; Cox (see Figure 5.3.10), PCS (see Figure 5.3.11), and Spring Garden (see Figures 5.3.12). Cox was a site in the Coastal Plain where much of the headwater area has been logged with a logging road and a ditch adjacent to the study site boundary which intersects the headwater wetland. While the Cox site was classified as natural, there were some sharp spikes in the hydroperiod as Figures 5.3.10 shows that are similar to less natural sites. Another interesting trend that is shown for Cox in Figure 5.3.10 is the very slow and smooth change to lower water levels as the growing season approaches. This probably reflects the fact that there was little rainfall during this time period and also the site is quite flat. The ditch next to the Cox site also influenced the site by lowering the water table of the site. PCS was another natural site in the Coastal Plain. The seasonal trends are again evident as well as some spikes due to precipitation. However, like Cox, the transitions tended to be smoother, probably since the site is flatter and has a forested buffer. Both of these sites reached a steady state during the non-growing season. Finally, Spring Garden was a natural site in the Piedmont and was bowl-shaped. This site also showed seasonal trends with lower water levels during the growing season, but this site always retained well water during the dry periods. It does reach a steady state during the non-growing season, but with still a fair amount of variation. Hydrologically, Spring Garden was a very wet site, but did have quite a bit of variation.

Differences between the flatter sites versus the bowl-shaped headwater wetlands (see Table 5.2.2) were also examined. Slope was used to determine membership in this class as discussed in Section 5.2.2. Flatter sites, such as Rough Rider (see Figure 5.3.5) and PCS (see Figure 5.3.11), and Cox (see Figures 5.3.10) have hydrographs that were less flashy and the changes in water levels, even seasonally, were slower and more even. Similar trends can be seen with Nahunta (Figure 5.3.4), and Hog Farm (Figure 5.3.2) and Rough Rider (Figure 5.3.5). The more bowl-shaped sites, such as Fire Tower (see Figures 5.3.6), Spring Garden (see Figure 5.3.12), and Kelly Road (see Figure 5.3.3) have more variable hydrographs and the seasonal trends seemed to be sharper in their increases or decreases in water levels. Similar trends can be seen with Walmart (Figure 5.3.8) and Troxler (Figure 5.3.9). Therefore, bowl-shaped wetlands, due to their steeper slope and generally smaller sizes, appeared to exhibit greater fluctuations in water depth (both in frequency and in steepness or amplitude) than flatter headwater wetlands which also tend to be larger in size. The flatter headwater wetlands have hydrographs with less frequent changes and the sharpness of the changes is not a prevalent. The flatter headwater wetland systems exhibited smoother hydrographs with gradual transitions between the seasonal changes.

Figures 5.3.1 – 5.3.12 also show the depth to one foot indicated by the blue horizontal line. This area between the blue and red lines shows where the water levels were to verify wetland hydrology. As defined by the US Army Corps of Engineers (ACOE 1987), wetland hydrology is defined as 14 consecutive days with the water level being within one foot of the ground level during the growing season. The growing season in North Carolina piedmont and the vast majority of the coastal plain is between 181 – 240 days. The growing season for each county was determined from Gregory (2005). All 12 sites easily met the wetland hydrology criteria. Table 5.3.1 shows water depth data during the growing season for the 12 sites. All the sites were within the one-foot level at least 47% of the time during the growing season. The second column shows that 11 sites had a mean depth within one foot of the ground level except for Black Ankle (Non-power line) and Kelly Road which were just over a foot on average.

Table 5.3.2 describes the growing season data in two different ways. First is a comparison between the Piedmont and Coastal Plain. Coastal Plain sites were within the one-foot level for 75.53% of the growing season whereas the Piedmont value was 72.41%. The mean water level depth below the ground level shows the Coastal Plain being closer to the surface that the Piedmont sites (0.48 feet to 0.77 feet) as would be expected. The second comparison by landscape class. Natural and rural sites were within the one-foot level at least 75% of the growing season whereas the urban sites were just under 62%. What is interesting is that the mean depth from ground level was more similar for rural and urban (0.65 feet and 0.78 feet) while the natural sites were closer to ground level and a mean depth of 0.43. These results can be used to establish success criteria for headwater wetland mitigation.

The hydrology of headwater wetlands shows distinctive seasonal trends. On most sites, surface water dries up during the hotter months of the growing season, but these sites still retain shallow ground water as indicated by measurable water levels in the monitoring wells and as shown in Table 5.3.1. This would indicate that these systems do not lose their ground water connections at least during years of normal rainfall. However, the bowl-shaped headwater wetlands, primarily in the Piedmont, show sharper variations in water levels that the more flatter headwater wetlands, mostly in the Coastal Plain. Finally, urban sites on both the Coastal Plain and Piedmont showed tendencies to flashier hydrographs due to urban runoff.

Table 5.3.1 Headwater Wetland Growing Season Data

Site Name	% Time Within 1-foot	Mean Depth from ground level (ft)	Mean Depth from Sensor (ft)	lower 95% Mean	upper 95% Mean	Confidence Interval
Black Ankle	47.53	1.0703	0.6997	0.6936	0.7059	0.95
Hog Farm Upper	100.00	0.2083	1.3917	1.3905	1.3930	0.95
Kelly Road	62.10	1.0033	0.8067	0.7964	0.8169	0.95
Nahunta	90.76	0.2373	1.9327	1.9261	1.9393	0.95
Rough Rider	51.82	0.8471	0.9029	0.8894	0.9164	0.95
Fire Tower	99.53	0.5193	1.6007	1.5968	1.6045	0.95
Boddie Noell	57.96	0.6435	1.1665	1.1518	1.1812	0.95
Walmart	76.07	0.7134	1.1263	1.1206	1.1319	0.95
Troxler	50.61	0.9891	1.1009	1.0859	1.1159	0.95
Cox	58.78	0.8415	1.2485	1.2350	1.2621	0.95
PCS	93.84	0.1204	1.8196	1.8127	1.8265	0.95
Spring Garden	98.62	0.3255	1.6445	1.6401	1.6489	0.95

Table 5.3.2 Growing Season for Ecoregions and Landscape class

Ecoregion / Landscape Class	% Within One Foot	Mean Depth Below Ground Level
Coastal Plain	75.53	0.48
Piedmont	72.41	0.77
Urban	61.55	0.78
Rural	75.29	0.65
Natural	83.75	0.43

Figure 5.3.1 Black Ankle Non-Powerline Hydrograph –rural, bowl-shaped

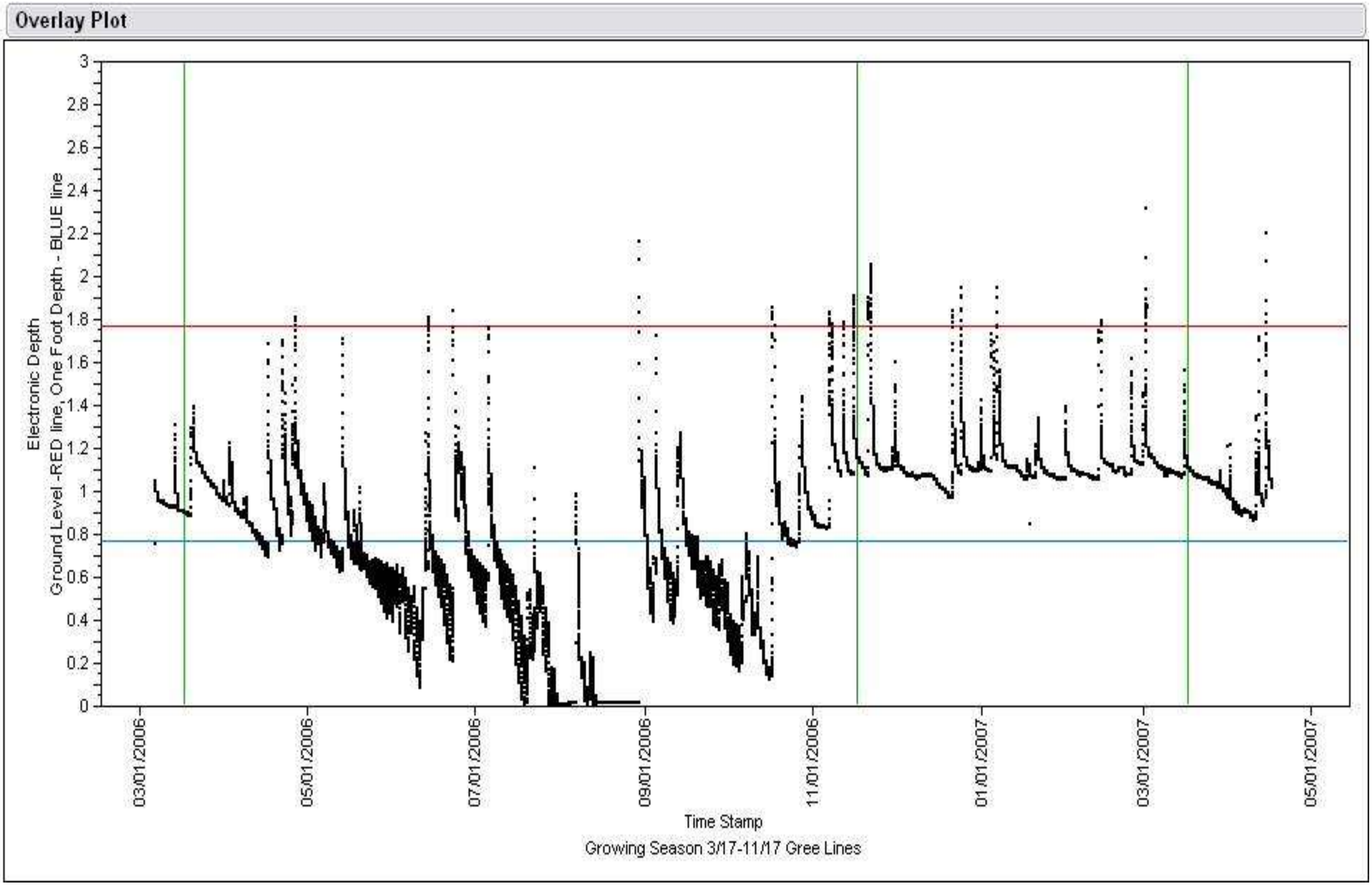


Figure 5.3.2 Hog Farm Upper Hydrograph – rural, flat

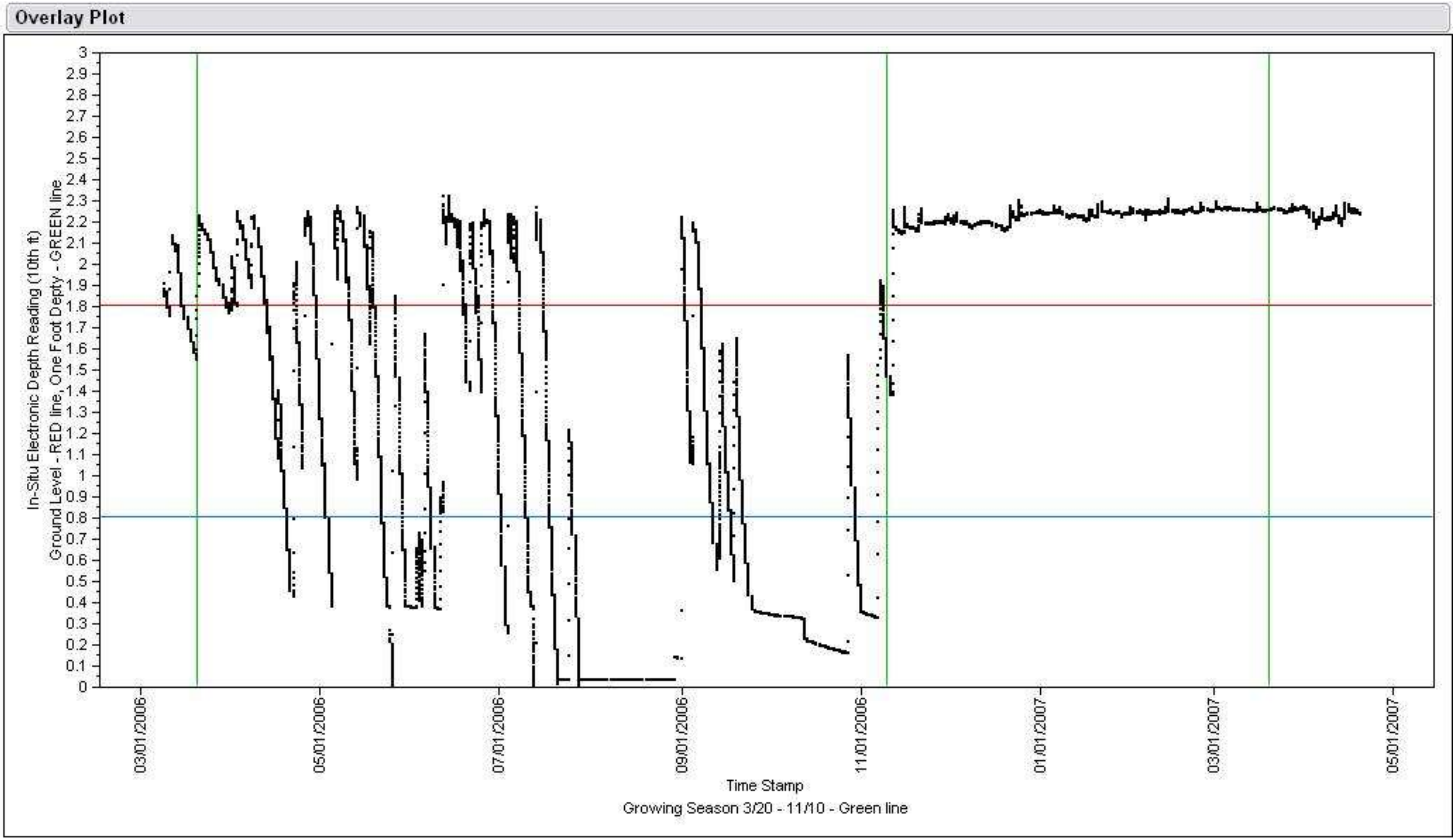


Figure 5.3.3 Kelly Road Hydrograph – rural, bowl-shaped

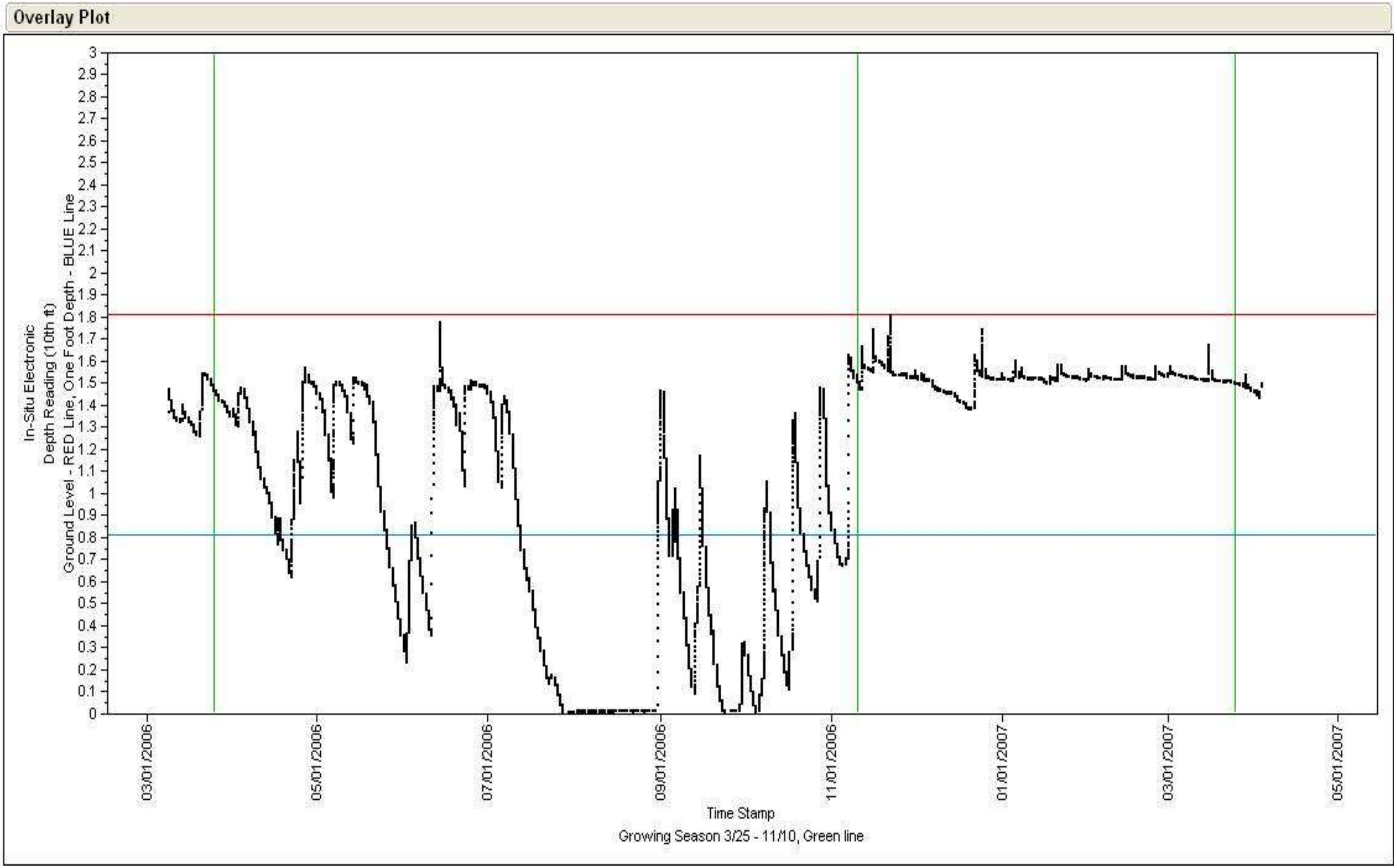


Figure 5.3.4 Nahunta Hydrograph – rural, flat

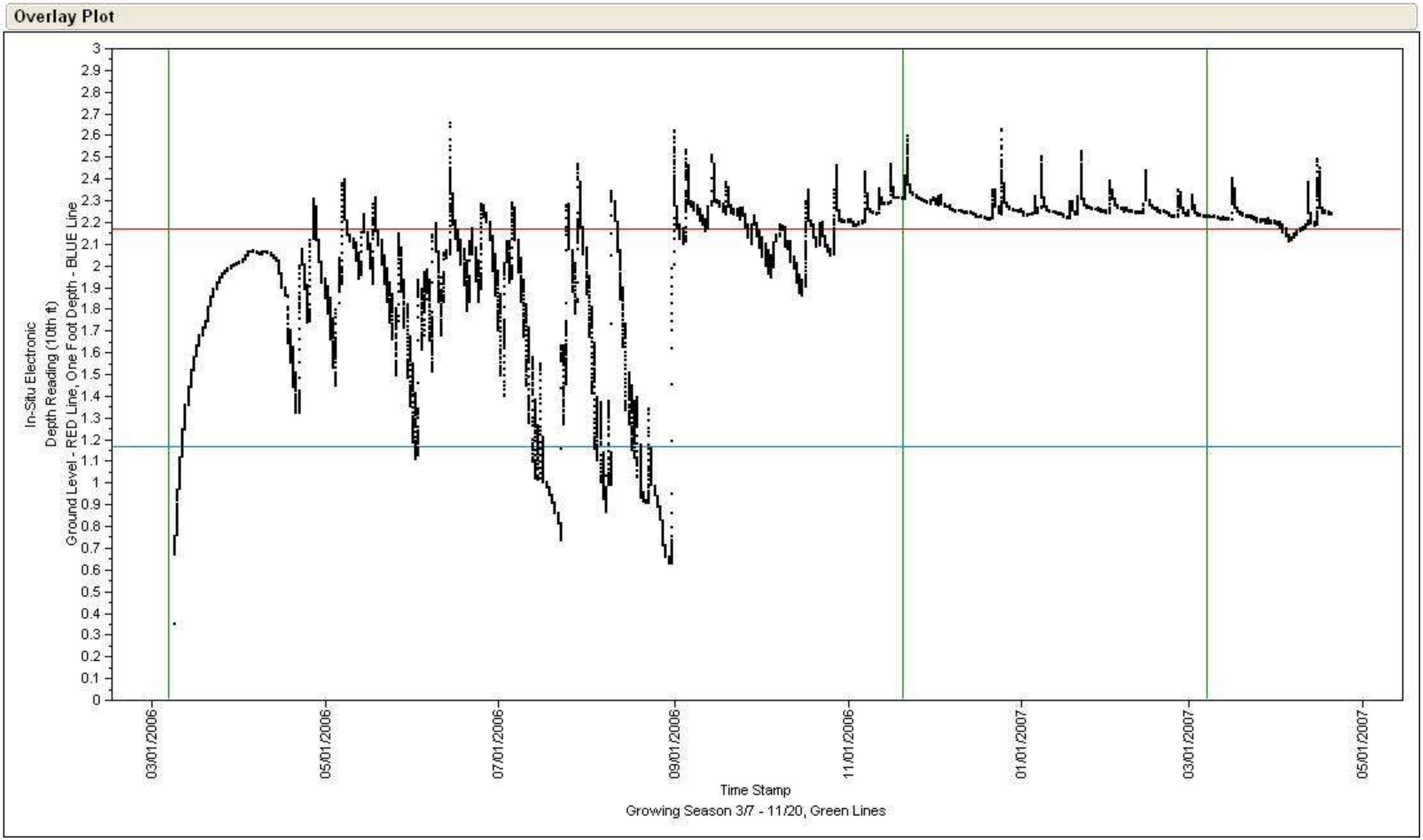


Figure 5.3.5 Rough Rider Hydrograph – rural, flat

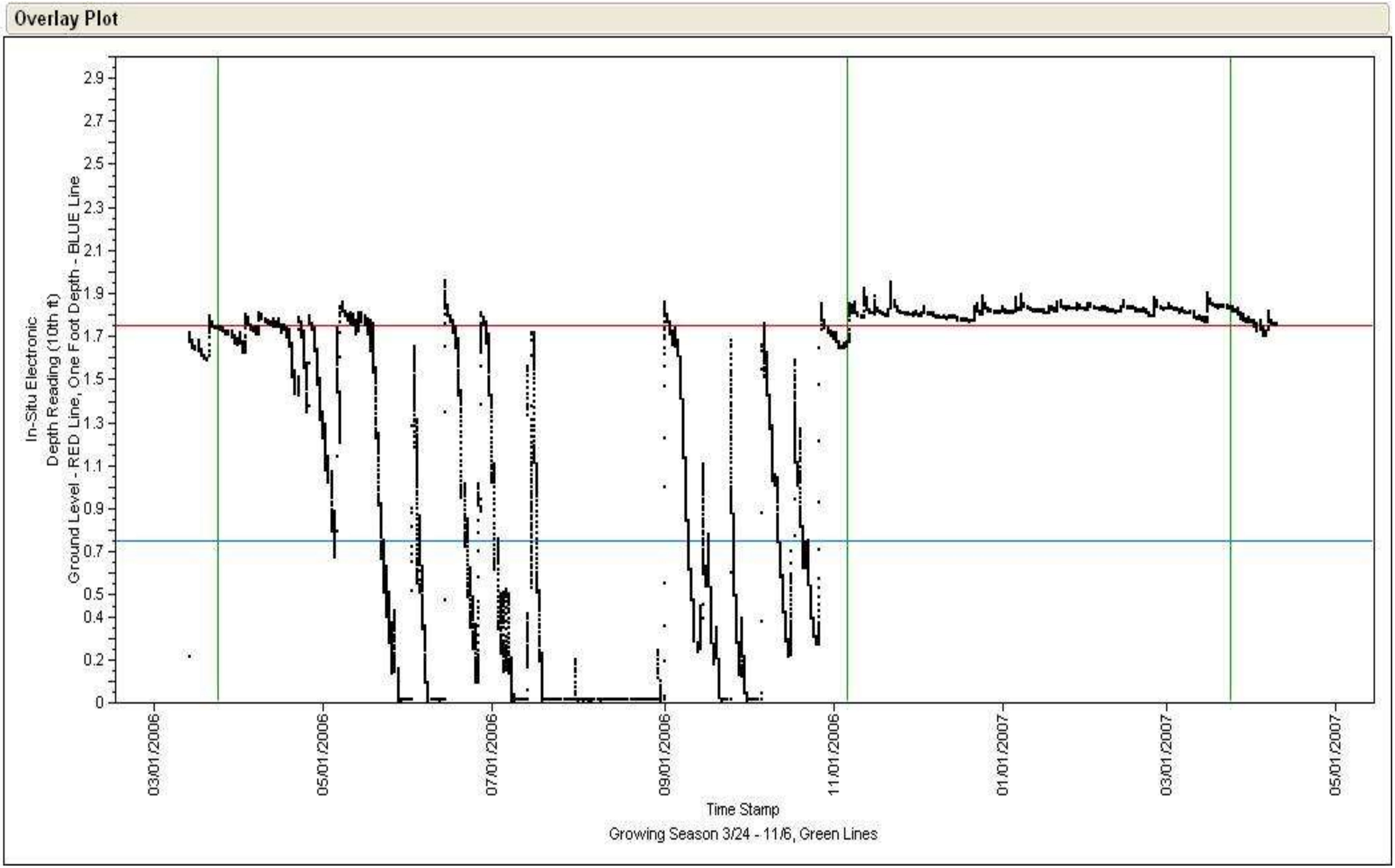


Figure 5.3.6 Fire Tower Hydrograph – rural, bowl-shaped

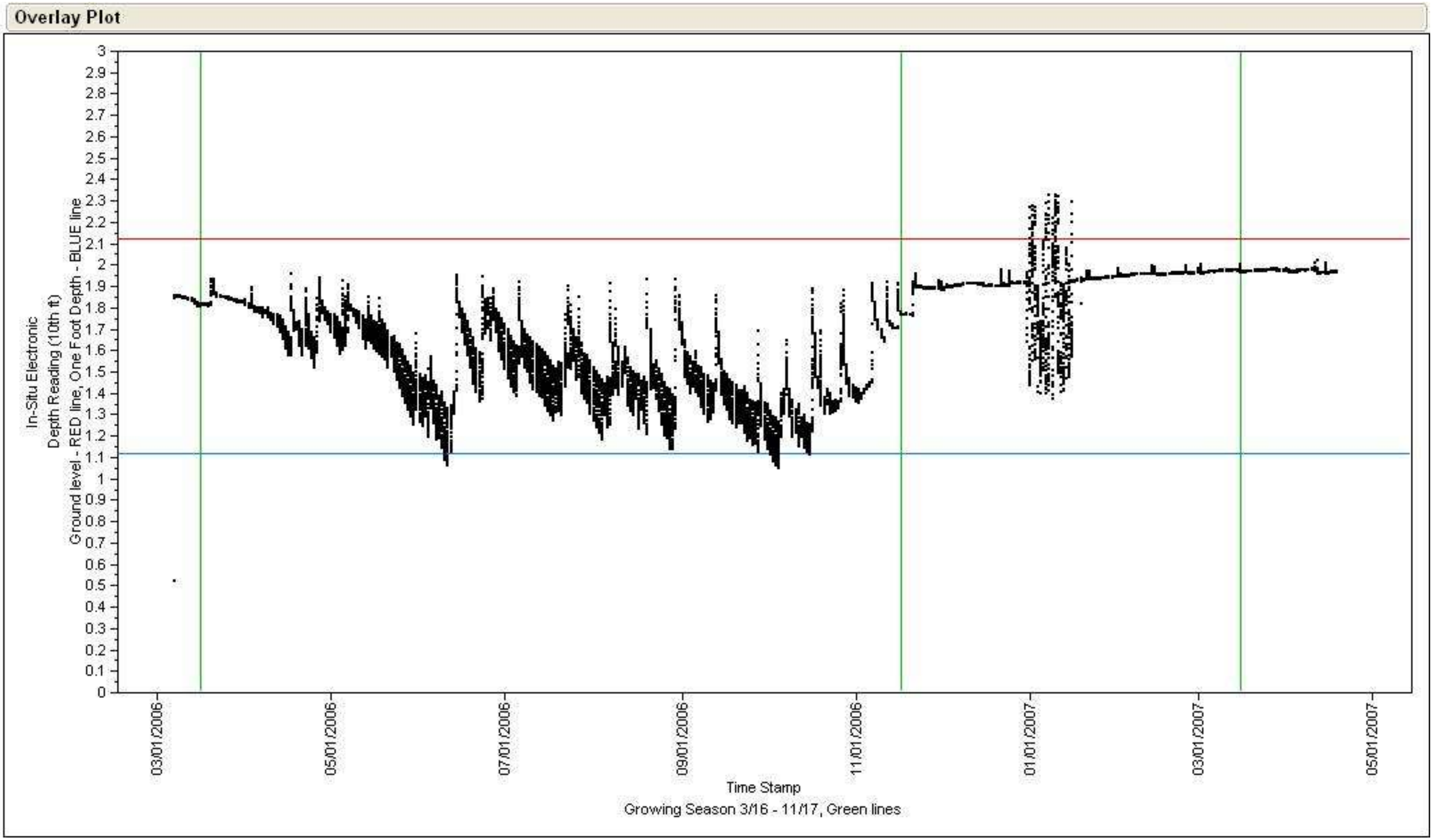


Figure 5.3.7 Boddie Noell Hydrograph – urban, flat

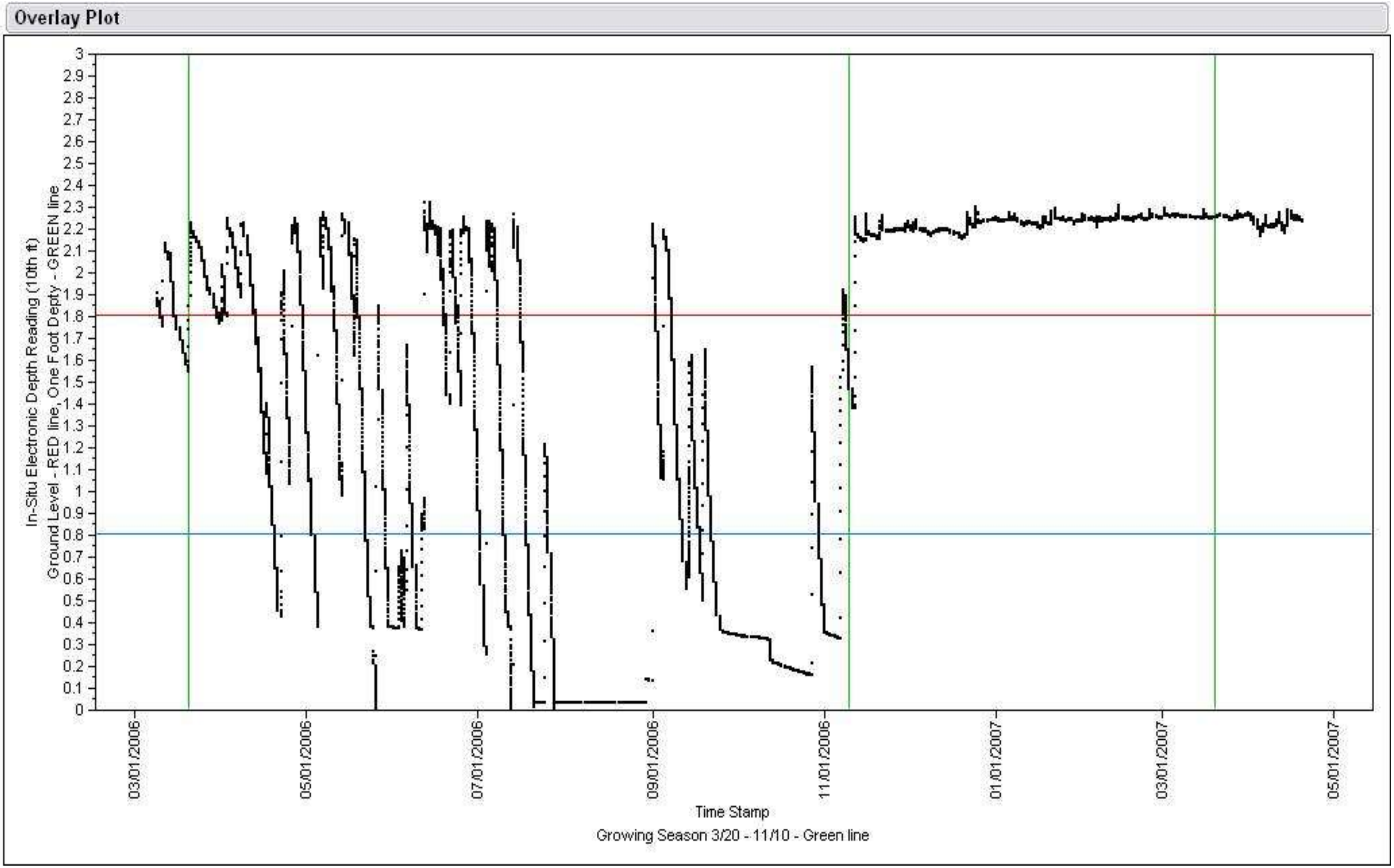


Figure 5.3.8 Walmart Hydrograph – urban, bowl-shaped

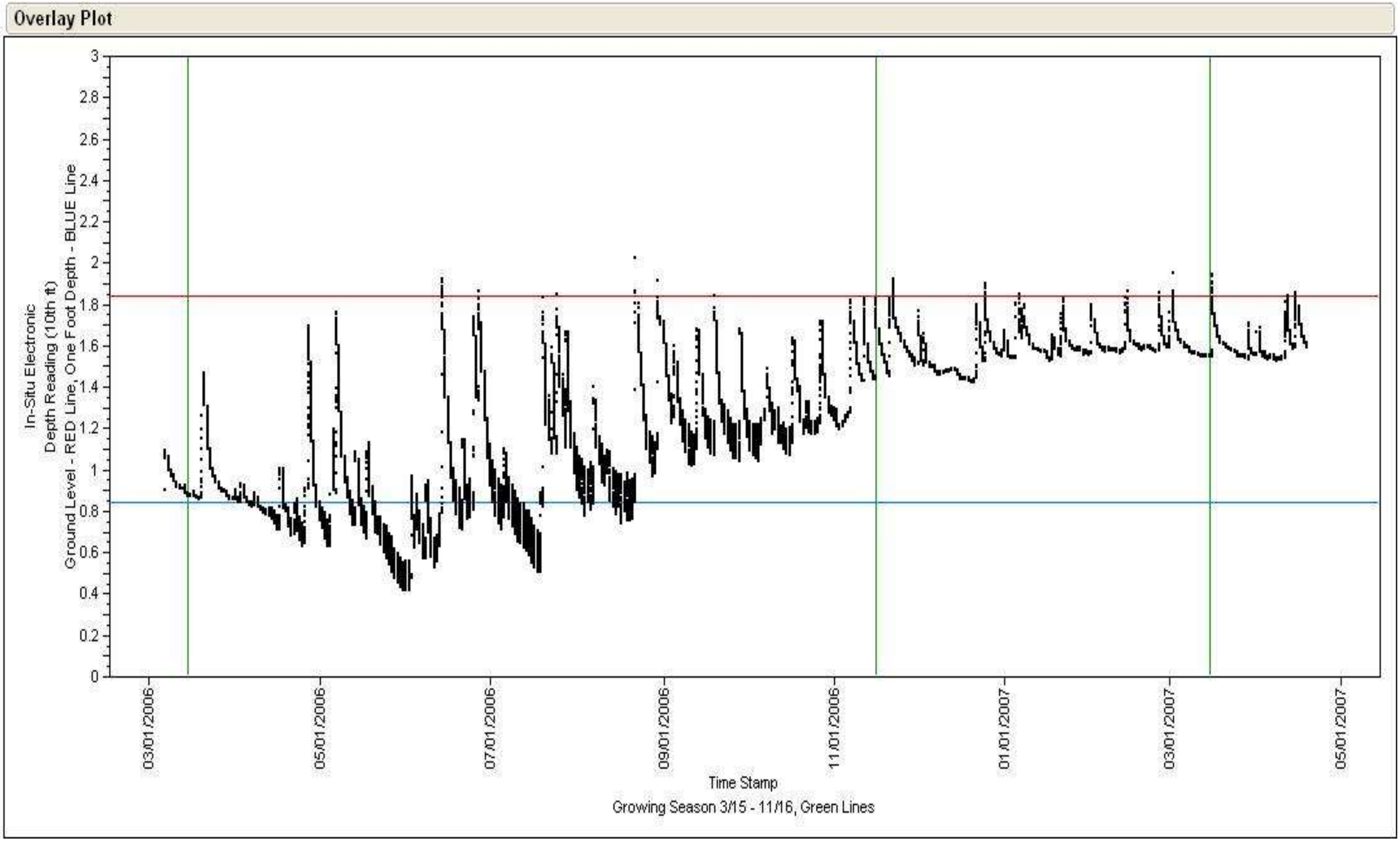


Figure 5.3.9 Troxler Hydrograph – urban, bowl-shaped

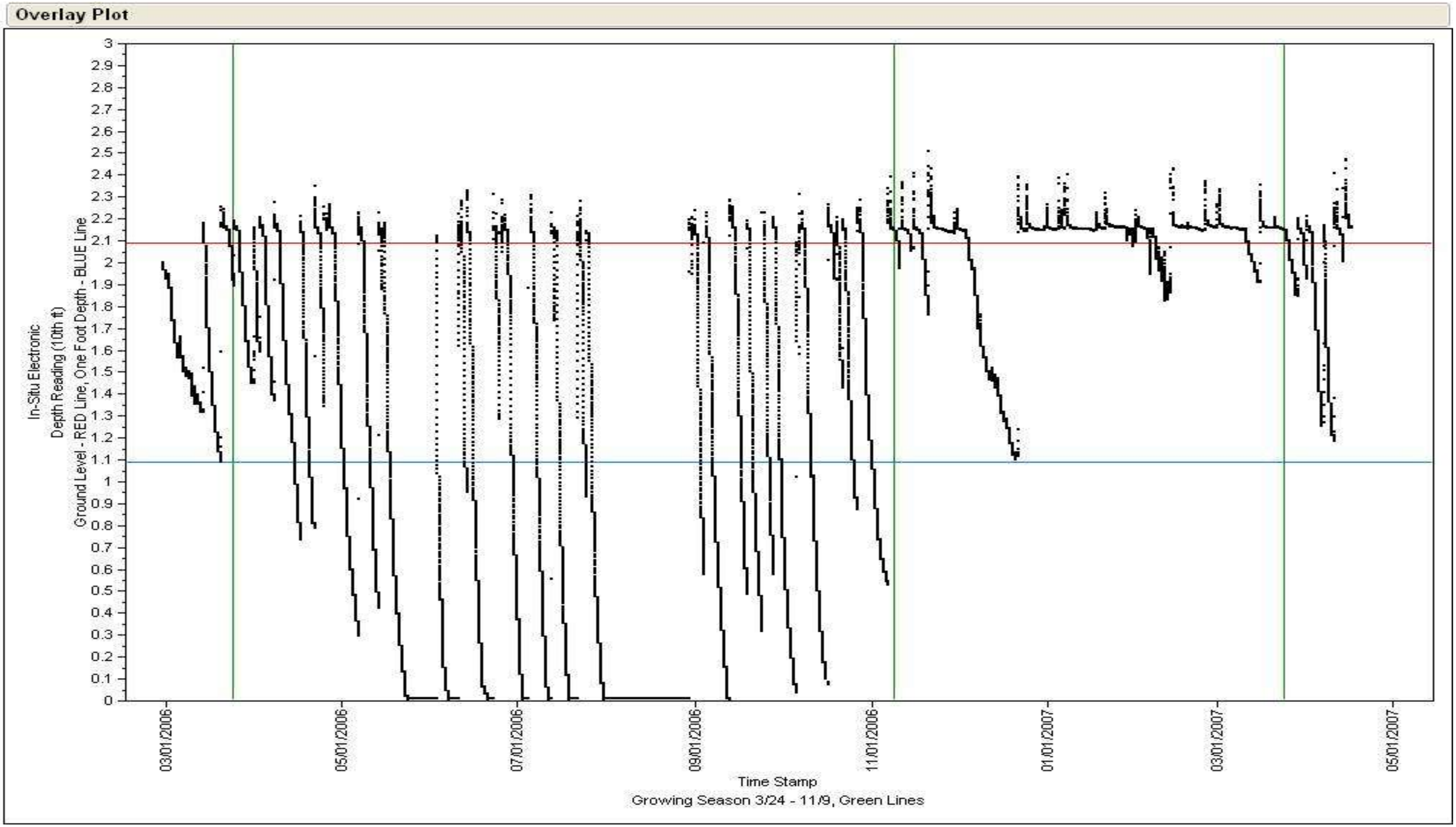


Figure 5.3.10 Cox Hydrograph – natural, flat

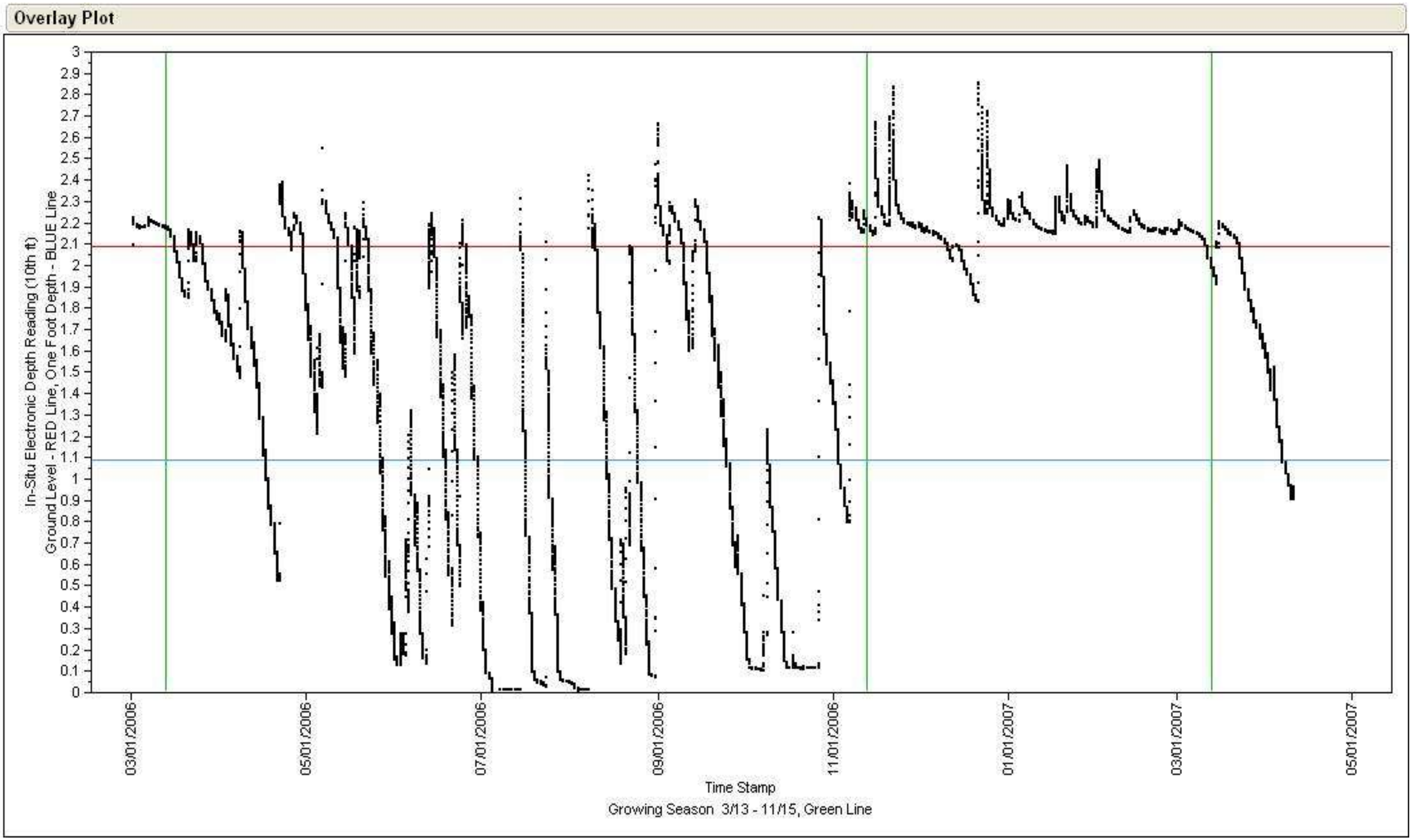


Figure 5.3.11 PCS Hydrograph – natural, flat

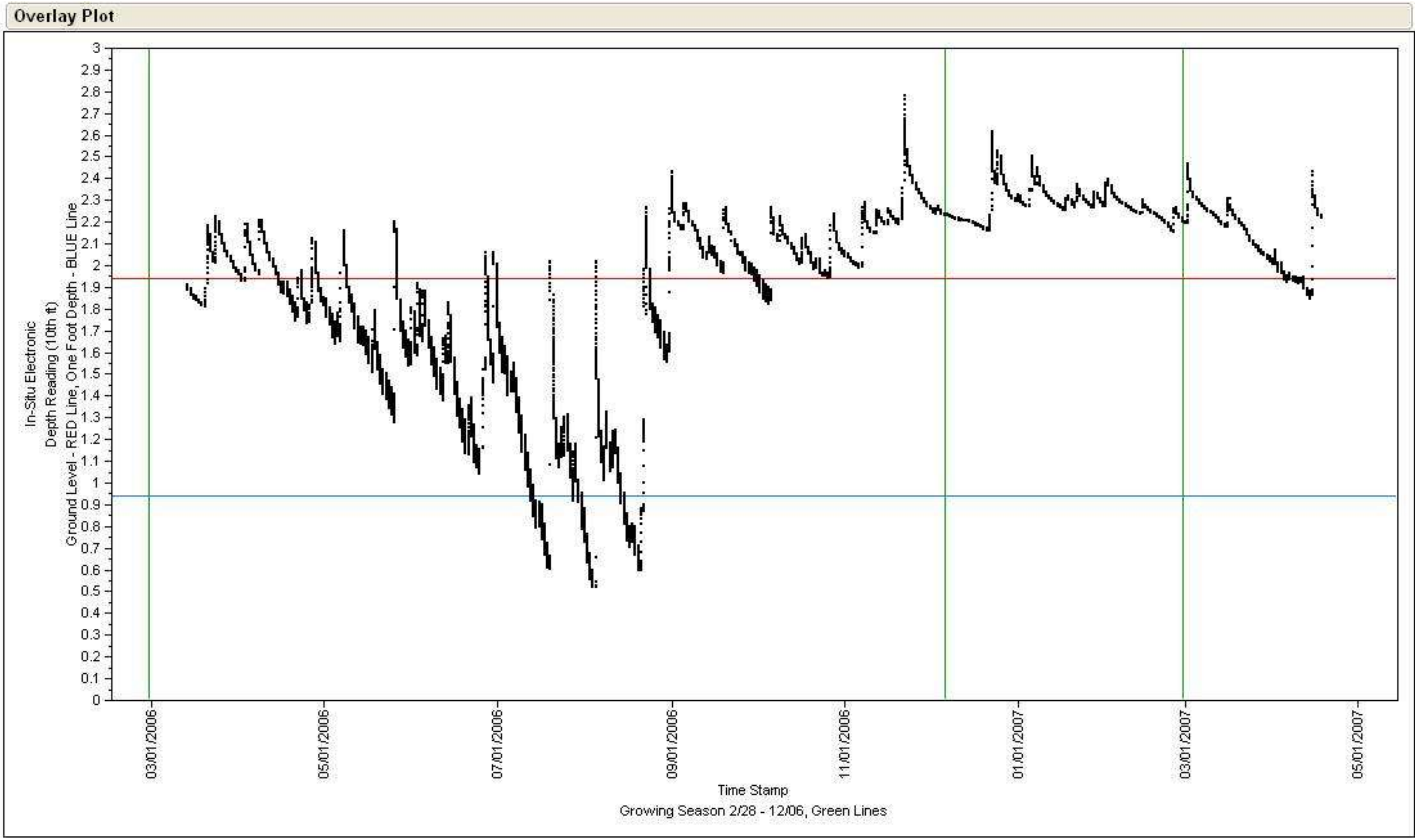
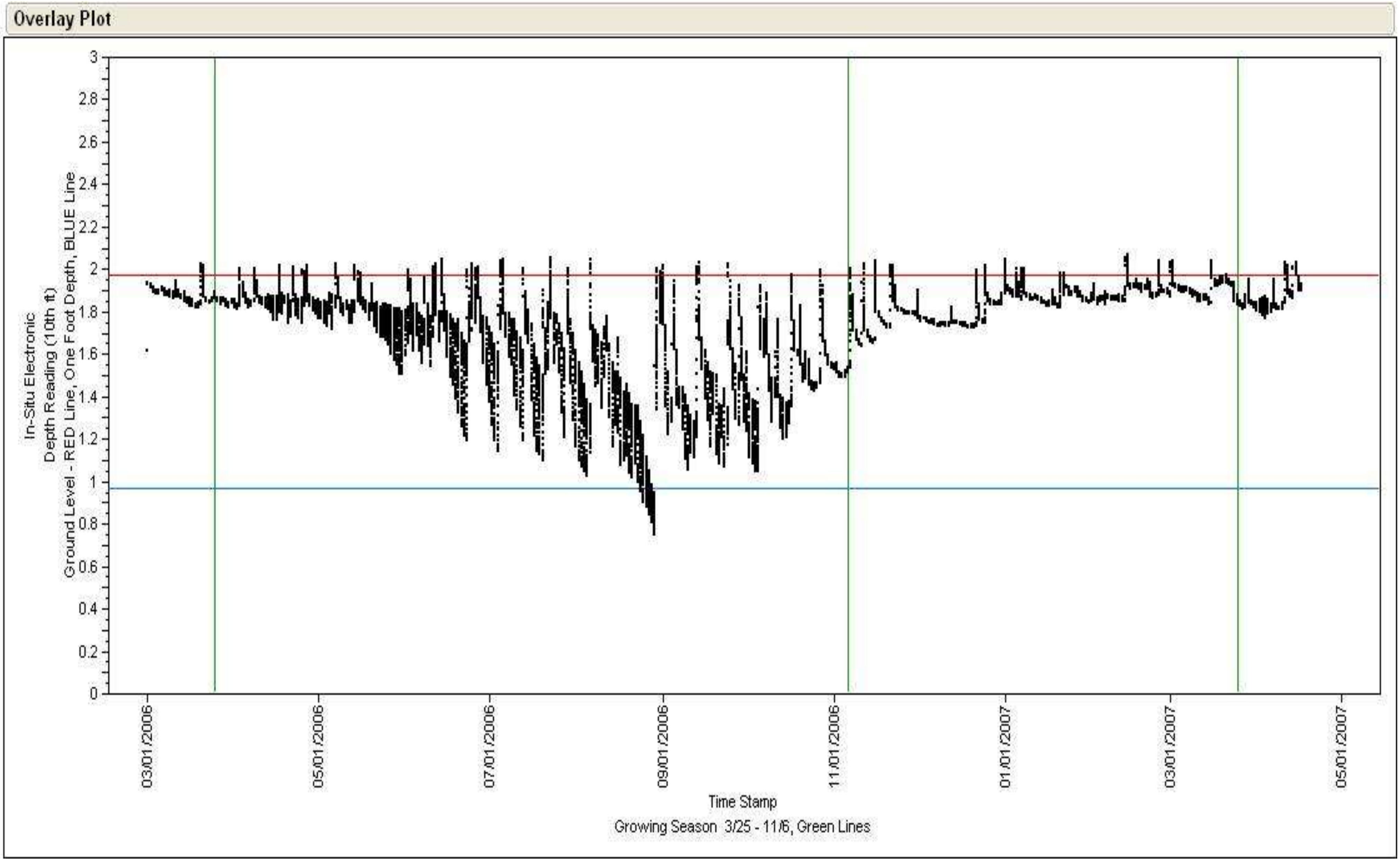


Figure 5.3.12 Spring Garden Hydrograph – natural, bowl-shaped



Section 6 – Soils Monitoring Section

Section 6.1 Soils Introduction and Background

Soils have long been recognized as a key feature in wetland function. Wetlands have soils that are unique from the surrounding terrestrial uplands. For example, undrained hydric soils are being used in combination with hydrophytic vegetation and hydrologic indicators to identify and delineate wetlands (Environmental Laboratory 1987). Hydric soils are those that have standing water for significant periods or are saturated at or near the surface for extended periods during the growing season such that anaerobic conditions may develop (NRCS 1994, Tiner 1999). Hydric soils are especially useful when verifying the presence of a wetland that does not exhibit significant hydrologic indicators or where vegetation has been removed (Tiner 1999). Interactions between hydric soils, hydrology, and vegetation directly affect the functioning and quality of a wetland. Soils have an impact on water quality function of wetlands as well as other wetland functions, including water retention and biogeochemical cycling of nutrients (MAHSC 2004).

Wetland hydrology results in periods of soil saturation or inundation. Predictable changes in soils caused by saturation can be used to infer long-term patterns of hydrology (Tiner 1999, Ward and Elliot 1995, and Richardson and Vepraskas 2001). The primary effect of long periods of saturation or inundation on soil is the development of anaerobic, or low-oxygen, conditions. Hydric soils will eventually develop as organic matter accumulates and chemical elements change from the saturated conditions. Hydric soil is defined as soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (National Technical Committee for Hydric Soils, 1985). Inundation is not enough to cause anaerobic conditions even though there are ample levels of dissolved oxygen. Anaerobic conditions occur as dissolved oxygen in soil water is used by soil organisms. With high temperatures, soil organisms use dissolved oxygen to break down organic material in the soil, therefore depleting the oxygen supply. When saturation or inundation occurs for longer periods, the oxygen is not typically replenished by diffusion because oxygen diffuses more slowly through water than through air. Hence, the result is the creation of anaerobic conditions (Richardson and Vepraskas 2001 and Tiner 1999).

Anaerobic soil conditions interfere with the biological breakdown of organic material. Soils that are largely composed of organic matter in the upper 14-16 inches are generally classified as organic soils (Richardson and Vepraskas 2001 and Tiner 1999). Organic soils generally develop under long periods of saturation or inundation. When soils are continuously saturated or inundated, they tend to develop thick layers of muck or peat. Peat can accumulate to several feet in thickness and form domes above the surrounding landscape. The highly porous peat can absorb water but transmit it poorly. Therefore, as peat builds up over the years the lower layers form an impermeable base similar to clay or rock (Richardson and Vepraskas 2001).

Soils, which contain little organic material, are mineral soils. Mineral soils also respond to anaerobic conditions by developing redoximorphic features (Richardson and Vepraskas 2001). When mineral soils are seasonally saturated, anaerobic conditions typically cause mottling or gleying. This is caused when microorganisms convert ferric iron into the reduced form, ferrous iron. Ferrous iron is easily leached from the soil, causing the color of the soil to change from bright-colored (reddish to yellowish) to neutral (grayish, greenish or bluish gray). When the soil is saturated and then aerated in a cyclic manner, the soil becomes marked with spots or blotches of contrasting color called mottling (Richardson and Vepraskas 2001). When the soil is saturated continuously, the gray or black color is continuous and is referred to as gleyed (Richardson and Vepraskas 2001). Mottling and gleying do not normally occur in sandy soils.

Under prolonged anaerobic conditions, microorganisms convert sulfur and organic material to hydrogen sulfide and methane. The rotten egg smell in some swamps is the release of hydrogen sulfide. Methane can also accumulate and may bubble out when the soil is disturbed. Manganese and iron in soils are sometimes converted into persistent hard black or dark brown balls referred to as concretions or nodules (Richardson and Vepraskas 2001).

A major function of wetlands is the storage of water. The volume of water stored depends on soil porosity and depth, as well as landscape position and microtopography of the wetland. The hydric soil of wetlands controls groundwater flow and discharge, contributing to reduction of flooding, water quality improvement, and wildlife habitat (MAHSC 2004). Water retention within wetlands is key for maintaining saturated or inundated soils that allow development of anaerobic conditions. Saturation keeps atmospheric oxygen out of the soil. Atmospheric oxygen prevents other elements in soil from being reduced to a form that is usable by plants (Richardson and Vepraskas 2001). The formation of anaerobic conditions allows for anaerobic microbes, which are necessary for reduction – oxidation (redoximorphic) reactions (Tiner 1999). Redoximorphic reactions result in the decomposition of soil organic matter and are required for cycling of elements such as nitrogen, carbon, phosphorus, sulfur, iron, and manganese (MAHSC 2004). The extent of element reduction in the soil can be monitored by measuring the redoximorphic potential. This measurement may be useful when determining the nutrient cycling level of a given wetland. In particular, cycling of nitrogen, phosphorus, and sulfur into organic and inorganic forms has a large impact on the water quality function of a wetland (Richardson and Vepraskas 2001).

Hydric soils facilitate nutrient and pollutant removal in wetlands, and in turn improve water quality. Removal of pollutants such as metals occurs as metals bind to humic materials and clay particles (MAHSC 2004). Particulate matter including nutrients and pollutants are usually removed from the water column by sedimentation. Sedimentation can allow wetlands to trap 80-90% of sediment from runoff water (Johnston 1991, Gilliam 1994, MAHSC 2004). Sedimentation increases water quality by removing turbidity sources and pollutants, as well as decreasing the biochemical oxygen demand (BOD) of the water. The BOD is the amount of oxygen required in order to decompose organic matter and oxidize inorganic compounds. High levels of organic matter often result in a high BOD level, which leads to low amounts of dissolved oxygen and negative impacts on aquatic life (MAHSC 2004). Nearly 100% of the BOD in the water column can be removed by wetlands (Hemond and Benoit 1988, MAHSC 2004).

Nutrient removal in wetlands is partially attributed to absorption by algae and plants (MAHSC 2004). The concentration of nutrients in a wetland soil is positively correlated with the aboveground biomass production of wetland macrophytes (Boyd 1970, Lopez and Fennessy 2002). In contrast, ecosystems with a large loss of nutrients tend to be stressed and have lower plant diversity (Odum 1985, Lopez and Fennessy 2002). Researchers in Ohio have conducted wetland assessments of depressional wetlands based on a plant community bioassessment tool, the floristic quality assessment index (FQAI). The index gives a measure of environmental factors that sustain and control plant communities. A higher index indicates a low likelihood of the overall plant species present being encountered at disturbed sites within the region (Lopez and Fennessy 2002). Results show that the FQAI is not correlated with differences in surface water chemistry but is correlated negatively with soil pH. However, this may be different in North Carolina wetlands such as pocosins, and basin wetlands, which are normally acidic systems (FQAI is further discussed in Section 9.0).

In addition to acidity, metal toxicity levels, salinity, and sulfides may stress vegetation (Richardson and Vepraskas 2001). Sites with greater levels of total organic carbon (TOC), phosphorus, calcium, and carbon in the soil showed relatively higher index values (Lopez and Fennessy 2002). Measuring these soil nutrient levels at a wetland site may give an indication of the extent of disturbance. Soil chemistry values may in fact be a better long-term indicator of wetland site conditions than surface water chemistry, because soil samples cumulatively measure the nutrients and minerals of a site (Lopez and Fennessy 2002).

The hydric soil of wetlands creates a chemical environment for biogeochemical cycling to occur. Biogeochemical cycling is a process where organic matter is decomposed, converting nutrients from organic to inorganic (mineral) form. This mineralization is critical to plant nutrition (MAHSC 2004). Soil chemistry can be analyzed in order to measure variables that may predict how well a wetland functions. Specifically, samples may be tested for pH, total exchange capacity, percent base saturation, percent organic matter, hydrogen ion concentration, and major and minor nutrients (Almon 1998). Ammonium (NH_4) and phosphate (PO_4) levels in water, as well as total soil phosphorus content, are indicator variables that are expected to predict accurate nutrient cycling rates (Verhoeven *et al*. 2001). Nutrient cycling rates influence the functioning capacity of wetlands, as they control the amount of minerals available to support vegetation. The main limiting factors in organic matter decomposition and net primary productivity include hydroperiod, abiotic stressors such as acidity, and nutrient availability (Richardson and Vepraskas 2001).

Many wetlands act as sinks for inorganic nutrients, such as nitrogen and phosphorus, in addition to acting as sources of organic material for nearby ecosystems (Mitsch and Gosselink 2000). The ability of wetlands to function as a sink for nitrogen is becoming increasingly important as use of wetlands for nitrogen removal in agricultural catchments grows (Davidsson and Stahl 2000). When a wetland system is disturbed, it may act as a source for nitrite instead of as a sink (Davidsson and Stahl 2000, Blackmer and Bremmer 1976). Microbial processes within the soil, such as denitrification, are essential for nitrate removal, and have been shown to remove more than wetland plants (Nelson *et al*. 1995, Tiner 1999). Denitrification, the reduction of nitrate (NO_3-) to nitrite or N_2 gases, is considered to be the most essential nitrogen removal process in wetlands, because it removes nitrogen on a long-term basis. Because soil chemistry and structure influence nitrogen turnover in varying degrees between wetlands, it is difficult to make predictions of denitrification rates based on factors such as soil organic matter and nitrogen content (Stephanauskas *et al*. 1996, Davidsson *et al*. 1997, Davidsson 2000).

Though soil organic matter content does not significantly influence denitrification rates, it does influence nitrate consumption (Davidsson 2000). Higher levels of organic matter allow for greater microbial activity. Because microbial populations are not limited by organic matter content, these conditions suggest that denitrification is limited primarily by nitrate presence. Denitrification is also dependent on redoximorphic potential and other factors such as temperature and pH that affect microbial processes (Seitzinger 1988, Groffman 1994, Richardson and Vepraskas 2001). A large increase in microbial populations may be a response to nitrate loading. Therefore, microbial denitrification activity measurements may be useful for assessing the extent of impact of nitrate additions to wetlands (White and Reddy 1999).

Soil function and chemistry composition vary across wetland types. This difference is evident between restored and natural wetlands, as well as between forested and herbaceous and tidal and non-tidal wetlands. Restored wetlands tend to have lower soil organic matter content, as well as lower total soil nitrogen and phosphorus than similar natural riverine wetlands (Verhoeven 2001). Lower levels of nitrogen and phosphorus in plants at restored wetlands suggest that nutrient cycling may have a low correlation with nutrient uptake by vegetation during early succession stages. After several years, nutrient concentrations in plants at restored sites generally reach the same level as natural wetlands (Mitsch *et al*. 1998, Verhoeven 2001). Monitoring levels of soil organic matter, nitrogen, and phosphorus may assess the progress of a restored wetland.

Natural riverine sites dominated by herbaceous vegetation have a higher nitrogen and phosphorus mineralization rate than those dominated by trees. Soil organic matter also tends to be higher in wetlands such as bogs and marshes that are dominated by herbaceous vegetation (Richardson and Vepraskas 2001). This is likely due to the combination of a long hydroperiod and high decomposition rates of herbaceous species (Richardson and Vepraskas 2001, Verhoeven 2001). Decomposition of woody plant tissues is slower, which allows for a lower bulk density of soils in forested wetlands as well as higher total N and lower total P (Odum 1984, Whigham *et al*. 1989, Verhoeven 2001). The soil nutrient content of tidal wetlands differs from non-tidal wetlands in that tidal wetlands have higher levels of soil organic matter, total N and P, and bulk density. The higher nutrient levels of tidal wetlands are in part due to regular deposition of nutrient-rich riverine sediments (Simpson *et al*. 1983, Bowden 1984, Verhoeven 2001).

Though soil composition, nutrient levels, and function vary by wetland type, the overall influence of soil on wetland quality remains strong. Soils play a significant role in the key functions of wetlands, including water storage as well as nutrient and pollution removal. Awareness of the relationships between wetland soils and hydrology and vegetation is important to understand nutrient and pollutant removal processes. While the use of wetland soils as an indicator for overall wetland health is a relatively young technique, steps can be made by understanding the factors that create a hydric soil as well as the nutrient cycling process necessary for a high functioning wetland.

Section 6.2.1 Soils Field Methods and Lab Analysis

With some exceptions, ten soil samples were taken at each site. The sample locations were based on the plant survey plot layout (see Figure 6.1). Soil samples S1-S4 were taken in the headwater wetland. Samples S5 and S6 were taken along the 200 foot (61 meters) centerline, which was generally along the stream corridor in the Piedmont and some of the Coastal Plain sites (in the Coastal Plain, the stream often formed further downstream of the study area). Sample S5 was taken 100 feet (31.5 meters) down the centerline and S6 was taken at the 200 feet (61 meters) down. Finally, soil samples S7-S10 were taken in the upland surrounding the wetland (see Figure 6.1). The four soil samples in the wetland were taken in the vegetation modules 1, 2, 7, and 8. The samples were generally taken in the center of the modules, however best professional judgment was used to make sure the sample was truly in the wetland (in some smaller sites, part of the module would extend outside of the wetland). Best professional judgment was also used in considering the terrain or vegetation changes that may need to be captured with the soil sample.

Soil sample S7 was taken in the upland about 30 degrees to the left of the vegetation plot centerline between module 1 and 8 (see Figure 6.1). Sample S8 was taken in the upland, but approximately 30 degrees to the right of the vegetation plot centerline (left and right were determined by facing upstream). Soil samples S9 and S10 were taken in the upland 100 feet (30.5 meters) downstream, with S9 to the left of the centerline and S10 to the right of the centerline (at approximately 90°, see Figure 6.1). All of the upland samples were taken when it was clear that the wetland boundary had been crossed and that upland vegetation was predominate. The intent of the upland samples was for comparative purposes.

Each sample consisted of an 18 inch core taken with a stainless steel bucket auger, 2.5 inches in diameter. Each core was then used to determine how many soil horizons existed in the core based on texture changes and color. All cores had no more than three layers. Texture was determined for each layer using the flow diagram adapted from Thien (1979). The horizon width, location (soils layer), matrix and mottle color, percent mottle abundance, and texture were recorded for each horizon. The Munsell Soil Book color charts (Munsell Soil Color Charts) were used to determine Hue, Value, and Chroma. Each sample was coded with the site abbreviation, sample number and layer (e.g., BATS2B is the Bachelor site, sample S2, second core layer). All of this information was recorded on the soil field sheet (see Appendix B). Then a sample from each layer (approximately a cup full) was collected and put into a plastic bag and labeled with the site abbreviation code. These samples were then later boxed into standard soil sample boxes (provided by the testing lab) to be sent for analysis. Lastly, North Carolina Agronomic Division, Soil Testing Section lab sheets were completed for each sample (see http://www.ncagr.com/agronomi/pdffiles/issoil.pdf).

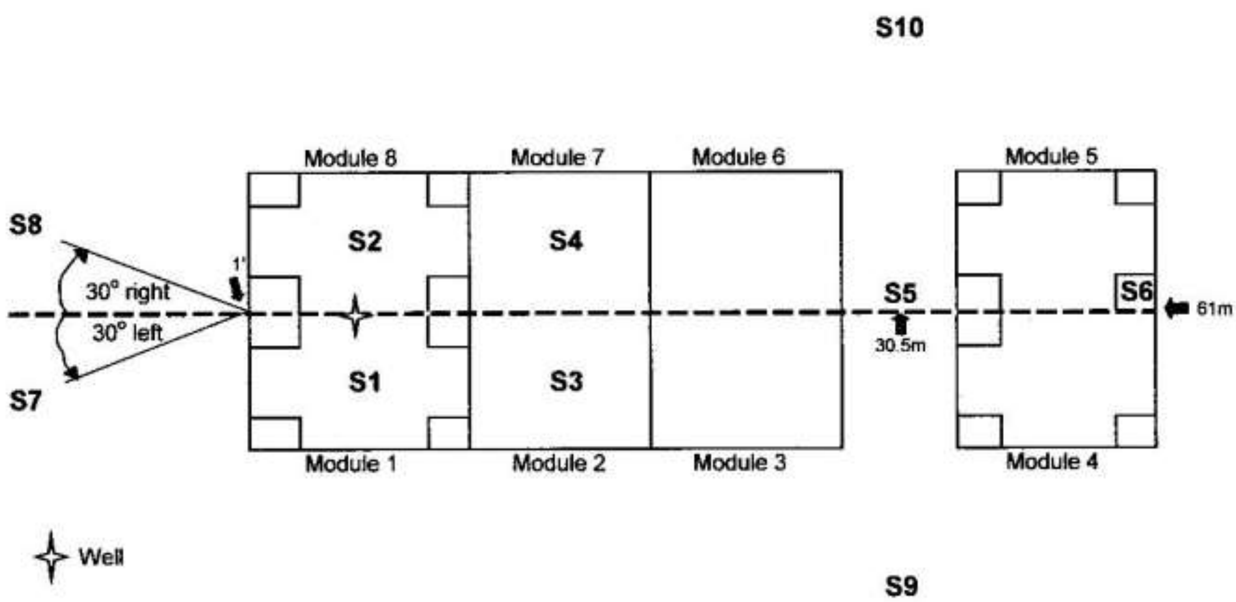
The soil samples were tested by the Soils Testing Section of the North Carolina Agronomic Division in Raleigh, North Carolina using methodologies described at http://www.ncagr.com/agronomistmethod.com. Soil samples were tested for the following:

- Levels of major plant nutrients, including phosphorus, potassium, calcium and magnesium
- Levels of plant micronutrients, including copper, manganese, sulfur and zinc
- Levels of sodium
- pH
- Exchangeable Acidity (AC, ability of soil to absorb aluminum and hydrogen ions)
- Sum Cation (sum of the charged particles in the soil, related to salinity)
- Percent base saturation (soils with low base saturation are considered to be leached and are often acid, whereas neutral and alkaline soils tend to have high base saturation)
- Percent humic matter (percent of soil organic matter)
- Cation exchange capacity (CEC, storage capacity for plant nutrients)
- Weight-to-volume ratio (used to classify soil type, normally inversely related to CEC)

Results from the field survey were entered into an Excel database. Electronic results from the lab were received and formatted and copied into an Excel database.

Slope was measured in the field to determine if sites were bowl-shaped as was typical in the Piedmont or "flat" as was typical in the Coastal Plain. Slope was taken with a clinometer around the wetland up to 16 locations (see Figure 6.2). Only slopes one, four and nine were used to determine if a site was bowl-shaped or flat which is explained in Section 6.2.2.

Figure 6.1 Soil sample locations based on the vegetation plot.



Section 6.2.2 Soils Data Analysis Methods

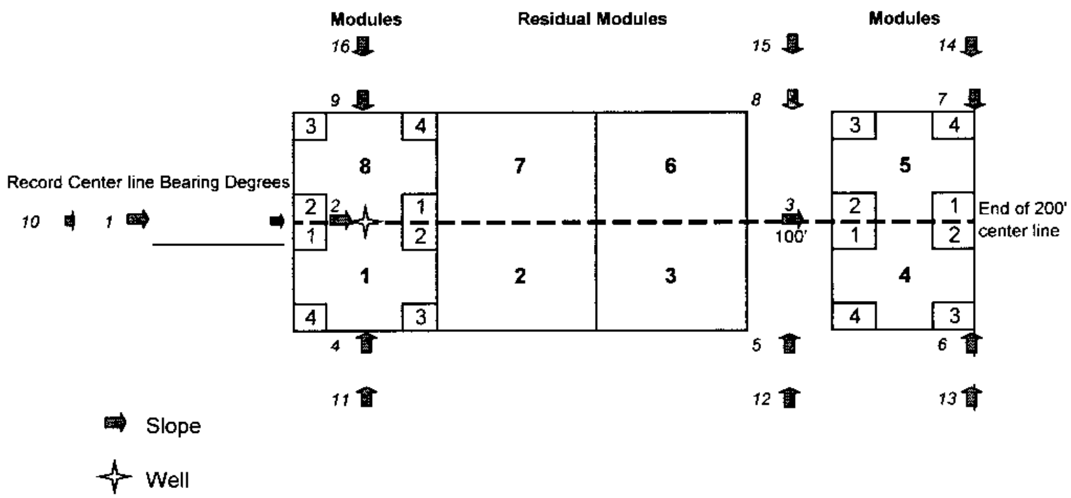
The soils data were summarized by calculating the means for each parameter. The soils data were also broken down and summarized by calculating the means for each parameter at three different sample locations; in the wetland (samples S1-S4), the plot centerline (samples S5 and S6), and in the surrounding upland (samples S7-S10, see Figure 6.1). For all of the soils data, a p-Value of ≤ 0.1 was considered significant. The soils data was analyzed using the Analysis of Variance (ANOVA) based on several independent variables. Ecoregion was one variable, in which the soils data were analyzed to determine if there were significant differences between the Coast Plain and the Piedmont. The ANOVA was also to analyze the soils data to determine if significant differences exited between soil sample locations (in the wetland, along the centerline, and in the upland). The analysis of the sample locations was performed with both ecoregions together and separately. The Turkey-Kramer multiple Comparison test was used to determine the significant differences in the landscape variable.

The slope of each wetland was determined to see how the soil results related to the topography of the headwater wetlands. Slopes 1, 4, and 9 (see Figure 6.2) were used to determine whether a wetland was classified as "bowl-shaped" or "flat". Wetland that had two out of three slope measurements that were less than or equal to -2^{o} degrees were considered to be bowl-shaped, otherwise the wetland was considered flat. The ANOVA was used to compare the bowl-shaped wetland with the flat wetlands to indentify differences in soil composition. Only the samples taken in the wetland and centerline sample locations (S1 – S6, see Figure 6.1) were used in this analysis (S1-S6, see Figure 6.1). The sites that were classified into each topographic category are shown in Table 6.4. Finally, another distinction between the sites was made for further analysis. The headwater wetland sites were classified into landscape classes of natural, rural, and urban. This was determined by using the 300-meter LDI scores, with a score of < 180, being classified as natural sites, between 180 – 300, being classified as rural (strong agricultural influence), and > 300 being classified as urban (subject to development pressures). Section 3.2 describes how LDI (Land Development Index) was calculated.

Pearson's correlations were performed between the soil parameters for wetland and centerline soil samples (S1 – S6) and the ORAM disturbance measurement to determine if there were any relationships between the soil parameters and disturbance. This analysis was performed for both ecoregions together.

A spatial GIS analysis of the headwater wetland soils was completed to determine which soil types were mapped on the Piedmont and Coastal Plain headwater wetland sites. Soils were classified according to type, description (texture), and whether the soil was hydric or not.

Figure 6.2 Slope Measurement Diagram



Slope Reading Directions

Slope *1* - Read 10m from Slope *2* location (well for normal plot) along center line and shoot to slope *2* reading location.

Slope *2* - Read from well location (normal plot) or centerpoint btw modules *1* and *8* (varied plot) along center line and shoot to slope *3*.

Slope *3* - Read along center line and shoot to 200' centerline mark.

Slopes *4&9, 5&8, 6&7* - Read at edge of plot (10m from center line) at 90° to center line, shoot to slope *2, 3,* and *4* respectively.

Slope *10*-Read at head of wetland along plot center line, shoot to slope *1*.

Slopes *8-16*- Read at edge of wetland at 90° angle to center line. Shoot slope *11* to *4*, slope *12* to *5*, slope *13* to *6*, slope *14* to *7*, slope *15* to *8* and slope *16* to *9*

Section 6.3 Soils Results and Conclusions

The means for the overall soil data (across all sample locations) are shown in Table 6.1. Tables 6.2a – 6.2f show the soil means for each site by sample location (upland, wetland, and centerline). The upland samples are noticeably different from the wetland and centerline samples as would be expected. However, there are differences between the wetland and centerline samples, which are located downstream from the wetland. These differences are reflected in the ANOVA's for the soil data.

Table 6.3 shows the p-values for the ANOVA's that yielded significant results for each soil parameter. The results that are significant are shown in bold. The first column is the comparison between the Coastal Plain and Piedmont. Phosphorus was significantly different between the two ecoregions (p=0.0001) with the Coastal Plain having significantly larger amounts of phosphorus contained in the soil. There were also statistically higher levels of potassium (p=0.0018) in the Piedmont. Calcium (p=0.0114) and magnesium (p=0.0137) were both significantly different with the Piedmont wetlands having higher levels than the Coastal Plain wetlands. There was a significant difference in pH (p=0.0001) with the Piedmont having higher soil pH levels than the Coastal Plain. This is consistent with the Coastal Plain generally having more organic and muck soils, which tend to be more acidic. The sum of the cations was also significantly different (p=0.0092), with the Piedmont wetlands again having higher levels. Base saturation was also statistically significant (p=0.0001) with the Piedmont having higher levels of saturation than the Coastal Plain wetlands. Manganese (p=0.0001), zinc (p=0.0054), and copper (p=0.0001) all had significant differences between ecoregions. When the results were split out for the soil samples only taken in the wetland and centerline, the results were very similar (see column two, Table 6.3) with only magnesium and sum cation dropping out. The Piedmont headwater wetlands had higher levels of these metals than the wetlands in the Coastal Plain. Humic matter was also significant (p=0.0001), with the Coastal Plain wetlands having higher levels, which may be attributed to the muck soils and the dense vegetation that exists in a number of the Coastal Plain sites.

The next set of ANOVAs, shown in Table 6.3, analyzed soil parameters for the two ecoregions combined by the sample location; in the headwater wetland, along the centerline (downstream, often along the stream corridor), and in the upland (see third column in Table 6.3). The p-values for the ANOVA's are presented in Table 6.3. Potassium (p=0.0202), calcium (p=0.0116), and sodium p=0.0001) were all statistically significant with the upland samples having lower levels than the wetland and centerline samples. The cation sum (p=0.0255) and Cation Exchange Capacity (CEC) buffer (p=0.0071) were also significantly different with the upland samples having lower values. Finally, base saturation (p=0.0017) and humic matter (p=0.0001) were significantly higher in the wetland and along the centerline. These data simply indicate that metals and nutrients accumulate in the wetland as the wetland filters these compounds from the water.

The next soil data analysis was by sample location for each ecoregion separately. The p-values for the ANOVA's are presented in Table 6.3. Coastal Plain sites had significantly different levels of calcium (p=0.0033), magnesium (p=0.0035), and sodium (p=0.0001) with the upland samples having lower levels of each. Soil pH (p=0.0109) was also significantly different, with pH being lower in the upland. The soil cation sum (p=0.0024) and CEC buffer (p=0.0004) were significant with the wetland and centerline samples having higher values. As would be expected, the base saturation (p=0.0103) and humic matter (p=0.0001) were also significantly different with the upland samples having lower values. For the Piedmont, phosphorus (p=0.0391) and sodium (p=0.0016) were both statistically significant with upland values having the lower values as would be expected. Base saturation (p=0.0265) was higher in the wetland and centerline samples and lower in the upland samples. For the metals, zinc (p=0.0565) and copper (p=0.0481) were significantly different with lower values occurring in the upland samples.

The results for soil sample locations consistently show that the nutrients and metals accumulate in the headwater wetland, which is consistent with the function of the wetland to remove metals and nutrients from the water and thereby improving downstream water quality. These results also show that headwater wetlands are acting as a sink for metals and nutrients. Base saturation and humic matter are higher in the soil samples in the wetland area than the upland as would be expected.

The next to last set of ANOVAs looked at wetland differences in terms of topography by comparing wetland slope. The Piedmont wetlands tend to be bowl-shaped whereas Coastal Plain wetlands tend to be flatter. There were 13 bowl-shaped wetlands (ten in the Piedmont and three in the Coastal Plain) and ten wetlands were classified as having flat topography (two in the Piedmont and eight in the Coastal Plain, see Table 6.4). The p-values are presented in Table 6.3 (see topography column). Zinc (p=0.0043) and copper (p=0.0114) were both statistically significant with the flatter wetlands having lower levels of the metals. All of the remaining results that were statistically significant resulted in the bowl-shaped wetlands having the lower values. For example, phosphorus ($p<0.0001$), calcium ($p<0.0001$), and magnesium ($p<0.0001$), all had higher levels in the flatter wetlands. CEC buffer ($p<0.0001$) and sum cation ($p<0.0001$) were also significant and had lower values in the bowl-shaped headwater wetlands. When the soil data was analyzed using the wetland and centerline samples only, the ANOVA's produced the same results and also found nitrate-nitrogen and phosphorus being statistically significant, with the bowl-shaped wetlands having less phosphorus and more nitrate-nitrogen than the flatter wetlands (see last column in Table 6.4). While these results are difficult to interpret, the majority of the results indicate that metals and nutrients have higher concentrations in the flatter wetlands, the exception being zinc and copper which are fairly soluble metals and therefore more subject to transport. One other significant difference was humic matter ($p<0.0001$), which was higher in the flatter wetlands. Flatter Coastal Plain wetlands generally have high humic matter content as is reflected in the organic material in the soils.

The final set of ANOVAs look at the variable landscape class, where the wetland sites were classified as being "urban", "rural", or "natural". These classes are shown in Table 6.5. Six sites classified as natural (four Piedmont and 3 Coastal Plain), eleven sites classified as rural (six Coastal Plain and five Piedmont), and five sites classified as urban (two Coastal Plain and 3 Piedmont). The ANOVA p-values are presented in Table 6.3 in the last column and used only the sample locations from the wetland and centerline locations for the analysis. All of the soil parameters had significant results (Table). For phosphorus, rural and urban sites had higher levels than natural sites, whereas for potassium, natural and rural sites had higher levels than urban sites. Magnesium and calcium levels were higher in natural areas than in both rural and urban. For sodium, natural areas had higher levels than rural and urban and rural had significantly higher levels than urban. Urban area had a higher weight per volume than natural and rural sites, possibly indicating soil compaction and higher clay content. The pH was higher in natural areas than in rural areas. The exchangeable acidity was higher in rural areas than both natural and urban sites. The cation sum, CEC buffer, base saturation, and manganese all had higher levels in natural areas than in urban and rural sites. Rural sites had higher CEC buffer levels than urban sites, whereas urban sites had higher base saturation and manganese levels than rural areas. Urban sites had higher level of zinc than both rural and natural and higher levels of copper than rural areas. Rural sites had higher levels of humic matter than urban and natural areas and higher levels of nitrate-nitrogen than urban areas. These results show that urban areas generally have higher levels of soil metals and greater soil compaction, whereas natural and rural areas have higher levels of nutrients (agricultural influences in the rural areas).

Correlations were performed between the soil parameters and the measures of disturbance: ORAM and LDI. The correlations are presented for all of the soil samples and then are split out based on their sample location; in the wetland, in the upland, and along the centerline. These results are presented in Table 6.6. A significant result was defined as having a p-value ≤ 0.10. For the ORAM correlations, phosphorus, zinc, and copper, all correlated significantly with the lower levels being correlated with less disturbed sites (higher ORAM scores). Sodium also correlated in the same way with lower levels in less disturbed sites, but only for the overall samples and the centerline samples. However, manganese and nitrate-nitrogen also correlated significantly; however, higher levels were correlated with less disturbed sites (for all samples and for all the sample locations, except for upland samples for nitrate-nitrogen). This shows that high quality wetlands are acting as a nitrogen sink. Humic matter had a significant correlation with ORAM, with lower values being associated with less disturbed sites (for all the correlations except for the centerline sample).

For the watershed LDI, zinc and copper were significantly correlated with lower levels found in less developed watersheds while manganese had higher levels in less developed watersheds (for all samples and for all the sample locations). Sodium was also correlated with lower levels being associated with less disturbed sites (for all samples and for wetland samples only). Lower pH values were significantly correlated with less developed watersheds (for all samples and for all the sample locations). Nitrate-nitrogen was correlated significantly, but with lower levels being associated with more developed watershed (for all samples and for all the sample locations). This is consistent with the ORAM correlations and may reflect a situation where nitrogen inputs are more likely higher in rural/agricultural areas than urban areas. The 50 and 300 meter buffer LDI also had several significant correlations. Zinc and copper were all correlated with lower values associated with less development as with the watershed LDI, showing very consistent results. Manganese and nitrate-nitrogen also had lower values associated with more developed areas (manganese was significantly correlated on seven of the eight correlations and nitrate-nitrogen on five of the eight). CEC Buffer and sodium were significantly correlated with the 300 meter LDI (for the overall samples and wetland for both, and upland also for sodium) Lower levels of sodium were associated with less development and a higher CEC Buffer being associated with more development in the landscape.

The soil results reveal that there are significant differences between the soils of the headwater wetlands in Coastal Plain and Piedmont ecoregions. Topography also contributed to these differences, with flatter wetlands generally having a higher concentration of nutrients and metals (possibly due to longer retention times), and also having more humic matter than bowl-shaped wetlands. Finally, clear differences between upland soil samples and wetland soil samples show that nutrients and metals accumulate in the headwater wetlands. The accumulation of metals and nutrients in the headwater wetlands also show how the wetlands serve as a sink for these and other pollutants and can improve the downstream water quality.

The correlation results show that several soil parameters correlate with disturbance measures. Copper and zinc correlated with all four measures of disturbance (and across all soil samples) with lower levels being associated with less disturbed or less developed areas. Phosphorus was also significantly different across all samples for ORAM, again lower levels associated with less disturbed sites. Manganese and nitrate-nitrogen had higher levels associated with less disturbed sites or less developed landscapes.

The results for the landscape ANOVA analysis show some similarities with the correlation results with disturbance measures, since higher levels of copper and zinc occurred in urban areas, which also correlated with all four measures of disturbance (ORAM and LDI). Higher levels of manganese correlated with less disturbed sites and in the landscape classes, higher levels occurred in natural areas, showing consistency. Generally, there were higher levels of nutrients in the natural and rural areas than in urban areas.

Finally, Table 6.7 show the soil classifications for each site based on the county soil maps. Some of the sites in the Piedmont appear to not have hydric soils, based on the county maps. However, these sites did have hydric soils which indicate that the mapping scale used by the soil maps did not pick up the hydric soils in these wetland sites. The Wagram soil class occurred at four Coastal Plain sites whereas Rains occurred at two sites. Sandy loam or Loamy sand were the predominant soil types in the Coastal Plain and largely in the Piedmont too. Several sites in the Coastal Plain had organic muck soils such as Nahunta, and Hog Farm Upper. The Piedmont also had largely sand loam with some silt soils showing up.

Table 6.1 Means for the Soil Parameters

Site Name - Coastal Plain	**Phosphorus (meq/ 100 cm^3)**	**Potassium (meq/ 100 cm^3)**	**Calcium (meq/ 100 cm^3)**	**Magneseium (meq/ 100 cm^3)**	**Sodium (meq/ 100 cm^3)**	**Weight/Volumne (g/cm^3)**	**pH**	**Buffer exchangeable acidity (AC) at pH6.6 (meq/ 100 cm^3)**	**Sum of the Cation (meg/L)**	**Cation Exchange Capacity (CEC) Buffer (meq/ 100 cm^3)**	**Base Saturation %**	**Maganese (meq/ 100 cm^3)**	**Zinc (meq/ 100 cm^3)**	**Copper (meq/ 100 cm^3)**	**Humic Matter (g/100 cm^3)**	**Nitrate Nitrogen (mg/ dm^3)**
Bachelor	7.192	0.074	0.658	0.259	0.108	1.083	3.825	5.400	1.099	6.375	17.167	7.033	2.117	0.583	4.434	20.333
Battle Park	18.979	0.131	2.125	0.757	0.116	1.296	4.684	2.111	3.128	5.121	56.263	20.411	3.237	0.742	0.463	25.053
Boddie Noell	69.972	0.136	1.382	0.501	0.072	1.303	4.439	2.978	2.091	5.000	40.222	3.333	2.211	0.656	0.691	16.222
Cox	4.068	0.131	1.282	0.420	0.084	1.186	4.563	2.963	1.917	4.805	34.789	2.442	0.668	0.253	0.828	9.053
East Fayetteville North	15.408	0.084	1.707	0.461	0.108	1.113	4.483	3.929	2.360	6.175	35.333	4.733	1.175	0.738	1.733	4.083
East Fayetteville South	23.218	0.119	1.284	0.413	0.123	1.194	4.223	3.841	1.938	5.659	31.318	3.209	1.368	0.495	1.212	25.409
Hog Farm Lower	53.708	0.103	1.055	0.448	0.100	1.271	4.467	3.596	1.706	5.204	32.000	6.542	2.608	0.763	3.003	12.292
Hog Farm Upper	55.368	0.212	4.022	2.611	0.240	1.120	5.146	3.500	7.085	9.854	56.542	16.000	3.952	0.472	3.417	19.040
Nahunta	59.436	0.152	4.049	1.924	0.121	1.192	4.993	3.829	6.246	9.964	57.571	7.671	3.486	0.679	4.970	35.714
PCS	13.420	0.130	0.982	0.338	0.160	0.996	3.840	6.680	1.610	8.120	20.200	1.300	2.680	0.500	6.568	11.400
Site Name-Piedmont																
Black Ankle Non-Powerline	0.070	0.125	0.765	0.304	0.080	1.060	4.460	3.230	1.273	4.425	26.950	7.585	1.185	0.920	0.827	23.600
Black Ankle Powerline	1.079	0.125	1.111	0.333	0.058	1.090	4.517	2.808	1.627	4.379	32.833	11.529	1.442	0.667	0.813	22.958
Duke Forest	1.240	0.159	11.842	7.451	0.295	1.175	6.155	1.665	19.747	21.115	90.850	167.57	1.200	2.025	0.311	10.700
East of Mason	3.168	0.195	3.167	1.471	0.186	1.180	4.482	3.077	5.020	7.927	59.318	23.768	3.391	0.450	0.498	32.773
Fire Tower	7.026	0.192	1.205	0.395	0.226	1.121	4.721	2.963	2.019	4.758	36.316	5.126	4.663	1.258	1.262	7.474
Kelly Rd	22.044	0.218	2.211	1.093	0.083	1.153	4.544	3.761	3.606	7.289	48.778	11.317	5.572	0.833	0.512	21.722
Moonshine	4.115	0.103	0.766	0.346	0.069	1.203	4.650	2.662	1.284	3.881	32.731	6.631	1.404	0.527	1.118	3.462
Pete Harris	8.655	0.210	1.530	0.851	0.110	1.682	4.910	1.995	2.700	4.580	54.800	81.315	1.105	0.835	0.589	18.650
Spring Garden	8.913	0.188	2.104	0.773	0.133	1.158	4.975	1.900	3.198	4.958	56.583	53.179	1.675	0.492	0.723	9.750
Troxler	24.720	0.145	3.158	1.530	0.135	1.270	5.235	1.310	4.968	6.145	72.600	99.445	14.175	2.795	0.268	15.500
Umstead	3.577	0.086	2.324	1.027	0.227	1.176	4.895	2.164	3.664	5.600	57.364	69.955	1.273	0.427	0.599	19.409
Walmart	4.378	0.124	1.421	0.407	0.078	1.235	4.948	2.189	2.031	4.141	46.741	9.311	7.511	1.085	0.887	5.333

Table 6.2a Means for soil data by sample location (stream, upland, wetland) for Phosphorus, Potassium, Calcium, and Magnesium

Site Name - Coastal Plain	Phosporus-Stream	Phosphorus-Upland	Phorsphours-Wetland	Potassium-Stream	Potassium-Upland	Potassium-Wetland	Calcium-Stream	Calcium-Upland	Calcium-Wetland	Magnesium-Stream	Magnesium-Upland	Magnesium-Wetland
Bachelor	12.933	4.100	6.750	0.060	0.070	0.090	0.460	0.970	0.415	0.183	0.362	0.188
Battle Park	17.100	26.780	15.945	0.173	0.142	0.115	2.383	1.534	2.323	0.777	0.362	0.931
Boddie Noell	29.850	159.220	38.222	0.115	0.136	0.146	1.275	1.804	1.194	0.458	0.400	0.577
Cox	2.940	9.275	2.550	0.124	0.078	0.156	2.672	0.890	0.743	0.522	0.268	0.430
East Fayetteville North	23.767	7.111	19.542	0.103	0.059	0.098	3.193	0.638	2.137	0.833	0.201	0.563
East Fayetteville South	24.975	30.643	17.855	0.120	0.077	0.145	1.605	0.846	1.445	0.508	0.339	0.425
Hog Farm Lower	78.150	30.443	55.182	0.088	0.076	0.128	0.897	1.066	1.135	0.407	0.330	0.545
Hog Farm Upper	101.525	62.210	32.364	0.368	0.164	0.200	6.108	1.422	5.627	3.100	0.544	4.312
Nahunta	40.100	156.267	28.986	0.128	0.367	0.074	5.515	4.170	3.159	3.033	1.490	1.476
PCS	3.100	13.450	18.550	0.120	0.055	0.210	1.250	0.740	1.090	0.330	0.240	0.440
Rough Rider	7.000	3.513	6.050	0.093	0.095	0.056	1.940	1.293	0.794	0.430	0.384	0.278
Site Name - Piedmont												
Black Ankle Non-Powerline	0.280	0.000	0.000	0.154	0.100	0.120	0.916	0.495	0.794	0.326	0.213	0.326
Black Ankle Powerline	0.000	1.680	1.011	0.124	0.111	0.140	0.740	1.482	0.904	0.298	0.296	0.394
Duke Forest	0.640	1.760	1.280	0.168	0.104	0.182	9.460	10.136	13.885	4.818	8.934	8.026
East of Mason	0.700	6.100	1.270	0.207	0.172	0.212	5.137	2.043	3.587	1.617	1.191	1.680
Fire Tower	1.850	4.138	13.286	0.283	0.086	0.261	1.140	1.158	1.297	0.400	0.278	0.527
Kelly Rd	14.840	59.167	14.510	0.250	0.143	0.225	2.728	0.907	2.344	1.218	0.473	1.216
Moonshine	3.220	6.867	2.425	0.090	0.131	0.088	0.706	1.007	0.611	0.382	0.404	0.287
Pete Harris	5.425	12.325	6.600	0.218	0.188	0.228	2.003	1.500	1.323	1.138	0.768	0.791
Troxler	19.067	0.933	39.236	0.113	0.250	0.095	2.470	5.238	2.211	0.990	3.023	0.863
Spring Garden	9.175	6.467	10.818	0.190	0.147	0.220	3.788	1.047	2.357	1.440	0.451	0.795
Umstead	6.375	3.300	2.783	0.110	0.080	0.081	3.300	0.992	2.664	1.193	0.393	1.288
Walmart	7.750	2.027	5.408	0.178	0.087	0.141	1.123	1.189	1.734	0.448	0.319	0.475

Table 6.2b Means for soil data by sample location (stream, upland, wetland) for Sodium, Weight/Volumn, pH, and Exchangable Acidity

Site Name - Coastal Plain	Sodium-Stream	Sodium-Upland	Sodium-Wetland	Weight/Volumne-Stream	Weight/Volumne-Upland	Weight/Volumne-Wetland	pH-stream	pH-upland	pH-wetland	Buffer exchangable acidity at pH 6.6-Stream	Buffer exchangable acidity at pH 6.6 - Upland	Buffer exchangable acidity at pH 6.6-Wetland
Bachelor	0.167	0.060	0.125	1.070	1.228	0.910	3.933	3.840	3.725	5.333	4.500	6.575
Battle Park	0.100	0.080	0.136	1.263	1.286	1.309	4.667	4.640	4.709	2.233	2.760	1.782
Boddie Noell	0.100	0.020	0.089	1.335	1.382	1.246	4.700	4.300	4.400	2.000	3.500	3.122
Cox	0.080	0.050	0.100	1.194	1.293	1.139	4.860	4.625	4.390	2.420	2.075	3.590
East Fayetteville North	0.233	0.056	0.117	0.617	1.456	0.981	4.367	4.578	4.442	6.167	1.922	4.875
East Fayetteville South	0.150	0.071	0.145	0.983	1.427	1.123	4.275	4.371	4.109	4.125	2.200	4.782
Hog Farm Lower	0.050	0.086	0.136	1.368	1.399	1.136	4.650	4.343	4.445	2.567	3.629	4.136
Hog Farm Upper	0.425	0.080	0.318	0.865	1.324	1.018	6.050	4.330	5.600	2.475	3.660	3.750
Nahunta	0.150	0.133	0.100	0.985	1.360	1.239	5.050	5.467	4.757	4.225	2.333	4.243
PCS	0.200	0.050	0.250	0.840	1.445	0.625	3.600	3.950	3.850	9.000	3.000	9.200
Rough Rider	0.133	0.088	0.088	1.283	1.246	1.345	5.167	4.463	4.838	1.933	2.875	1.575
Site Name - Piedmont												
Black Ankle Non-Powerline	0.100	0.025	0.091	0.974	1.073	1.094	4.420	4.350	4.518	3.140	3.775	3.073
Black Ankle Powerline	0.080	0.010	0.100	1.138	1.090	1.064	4.500	4.560	4.478	2.940	2.970	2.556
Duke Forest	0.220	0.240	0.360	1.188	1.208	1.151	6.040	5.680	6.450	1.320	2.720	1.310
East of Mason	0.300	0.144	0.190	1.017	1.239	1.175	4.433	4.678	4.320	3.433	2.611	3.390
Fire Tower	0.200	0.250	0.214	1.070	1.290	0.957	4.800	4.675	4.729	2.250	2.750	3.614
Kelly Rd	0.100	0.000	0.100	1.050	1.420	1.124	4.600	4.333	4.580	5.020	2.633	3.470
Moonshine	0.100	0.056	0.067	1.166	1.158	1.253	4.720	4.478	4.750	2.600	3.589	1.992
Pete Harris	0.150	0.088	0.113	1.173	2.455	1.163	4.925	5.038	4.775	1.650	1.963	2.200
Troxler	0.167	0.150	0.118	1.253	1.198	1.314	4.933	5.733	5.045	1.600	1.117	1.336
Spring Garden	0.150	0.122	0.136	1.065	1.284	1.087	5.300	4.878	4.936	1.325	1.922	2.091
Umstead	0.325	0.133	0.242	1.110	1.198	1.187	5.025	4.817	4.892	2.425	2.267	2.025
Walmart	0.125	0.036	0.100	1.145	1.320	1.187	5.125	5.018	4.825	2.650	1.682	2.500

Table 6.2c Means for soil data by sample location (stream, upland, wetland) for Sum Cation, CEC, Base Saturation, and Maganese

Site Name - Coastal Plain	Sum of Cation-Stream	Sum of Cation-Upland	Sum of Cation-Wetland	Cation Exchange Capacity buffer-Stream	Cation Exchange Capacity buffer-Upland	Cation Exchange Capacity buffer-Wetland	Base Saturation - Stream	Base Saturation - Upland	Base Saturation - Wetland	Maganese -Stream	Maganese -Upland	Maganese -Wetland
Bachelor	0.870	1.462	0.818	6.000	5.900	7.250	11.333	27.000	9.250	3.100	13.440	1.975
Battle Park	3.433	2.118	3.505	5.567	4.800	5.145	55.667	39.800	63.909	28.433	19.900	18.455
Boddie Noell	1.948	2.360	2.006	3.850	5.860	5.033	47.750	37.600	38.333	2.100	6.640	2.044
Cox	3.398	1.285	1.429	5.740	3.325	4.930	48.000	36.000	27.700	1.260	6.350	1.470
East Fayetteville North	4.363	0.953	2.913	10.300	2.822	7.658	39.333	33.667	35.583	6.200	6.633	2.942
East Fayetteville South	2.383	1.333	2.162	6.375	3.471	6.791	35.000	33.286	28.727	3.700	2.714	3.345
Hog Farm Lower	1.442	1.557	1.945	3.967	5.114	5.936	36.333	32.714	29.182	3.750	5.286	8.864
Hog Farm Upper	10.000	2.210	10.457	12.050	5.790	13.040	77.000	36.500	68.400	31.125	11.880	14.245
Nahunta	8.825	6.160	4.809	12.900	8.367	8.971	66.750	67.667	48.000	6.750	9.567	7.386
PCS	1.900	1.085	1.990	10.700	4.050	10.900	16.000	27.000	15.500	1.400	0.750	1.800
Rough Rider	2.597	1.859	1.215	4.400	4.638	2.700	60.333	34.375	44.625	6.067	9.475	1.563
Site Name - Piedmont												
Black Ankle Non-Powerline	1.496	0.833	1.331	4.520	4.575	4.327	30.400	17.500	28.818	6.120	3.550	9.718
Black Ankle Powerline	1.242	1.899	1.539	4.120	4.850	4.000	29.600	30.900	36.778	8.040	18.220	6.033
Duke Forest	14.666	19.414	22.453	15.760	21.900	23.400	91.800	85.400	93.100	153.720	87.340	214.610
East of Mason	7.260	3.551	5.669	10.400	6.033	8.890	65.000	54.444	62.000	41.233	28.811	13.990
Fire Tower	2.023	1.771	2.300	4.075	4.275	5.700	43.750	34.750	33.857	3.975	6.388	4.343
Kelly Rd	4.296	1.523	3.885	9.220	4.167	7.260	47.200	37.667	52.900	15.860	17.367	7.230
Moonshine	1.278	1.598	1.052	3.780	5.144	2.975	31.400	31.444	34.250	6.680	12.278	2.375
Pete Harris	3.508	2.543	2.454	5.025	4.400	4.538	66.750	52.000	51.625	142.250	106.263	25.900
Troxler	3.740	8.662	3.287	5.167	9.633	4.509	67.000	87.000	66.273	85.367	27.167	142.709
Spring Garden	5.568	1.767	3.508	6.750	3.556	5.455	79.250	42.667	59.727	44.200	97.278	20.364
Umstead	4.928	1.598	4.275	7.025	3.733	6.058	63.000	37.000	65.667	53.125	37.617	91.733
Walmart	1.873	1.632	2.450	4.400	3.282	4.842	38.750	47.455	48.750	3.525	9.373	11.183

Table 6.2d Means for soil data by sample location (stream, upland, wetland) for Zinc, Copper, Humic Matter, and Nitrate-Nitrogen

Site Name - Coastal Plain	Zinc-Stream	Zinc-Upland	Zinc-Wetland	Copper -Stream	Copper -Upland	Copper -Wetland	Humic Matter-Stream	Humic Matter-Upland	Humic Matter-Wetland	Nitrate nitrogen-Stream	Nitrate nitrogen-Upland	Nitrate nitrogen-Wetland
Bachelor	0.633	4.240	0.575	0.267	0.980	0.325	5.197	2.210	6.643	12.000	17.800	29.750
Battle Park	6.767	3.440	2.182	2.000	0.460	0.527	0.383	0.654	0.398	9.667	47.200	19.182
Boddie Noell	1.400	2.320	2.511	0.600	0.660	0.678	0.743	0.726	0.649	13.250	13.200	19.222
Cox	0.560	0.775	0.680	0.240	0.275	0.250	0.734	0.613	0.962	7.400	12.000	8.700
East Fayetteville North	2.000	0.767	1.275	0.833	0.678	0.758	3.540	0.431	2.258	3.333	4.778	3.750
East Fayetteville South	2.200	0.900	1.364	0.500	0.571	0.445	1.005	0.601	1.676	12.750	26.286	29.455
Hog Farm Lower	2.500	1.714	3.236	0.733	0.571	0.900	1.993	2.287	4.008	11.333	13.714	11.909
Hog Farm Upper	5.325	3.520	3.845	0.675	0.410	0.455	2.008	0.989	6.136	2.250	42.800	3.545
Nahunta	3.000	7.467	2.057	0.550	1.567	0.371	6.383	1.807	5.519	48.000	36.000	28.571
PCS	3.800	1.000	3.800	0.400	0.350	0.700	10.000	1.420	10.000	29.000	7.000	7.000
Rough Rider	1.200	1.088	0.488	0.000	0.200	0.038	1.517	1.091	0.851	9.667	17.125	19.375
Site Name - Piedmont												
Black Ankle Non-Powerline	1.440	0.800	1.209	0.700	0.475	1.182	1.484	0.593	0.614	32.000	15.000	22.909
Black Ankle Powerline	1.060	1.470	1.622	0.560	0.670	0.722	0.856	0.576	1.053	22.600	17.100	29.667
Duke Forest	1.060	0.920	1.410	2.700	1.000	2.200	0.422	0.252	0.284	10.000	5.400	13.700
East of Mason	4.700	2.344	3.940	0.367	0.356	0.560	0.700	0.537	0.403	66.667	20.111	34.000
Fire Tower	9.700	2.613	4.129	2.325	0.713	1.271	0.868	1.005	1.780	7.250	7.125	8.000
Kelly Rd	7.720	1.933	5.590	1.300	0.700	0.640	0.442	0.450	0.565	9.200	19.000	28.800
Moonshine	1.300	1.533	1.350	0.520	0.400	0.625	1.000	1.103	1.178	3.400	4.667	2.583
Pete Harris	1.425	0.913	1.138	1.150	0.513	1.000	0.765	0.448	0.641	34.000	15.625	14.000
Troxler	9.700	7.483	19.045	2.000	3.617	2.564	0.367	0.163	0.297	11.000	18.167	15.273
Spring Garden	2.025	1.500	1.691	0.800	0.133	0.673	0.465	0.528	0.975	5.750	11.556	9.727
Umstead	1.750	1.183	1.158	0.025	0.550	0.500	0.683	0.472	0.634	22.500	4.333	25.917
Walmart	5.775	3.845	11.450	1.950	0.927	0.942	1.873	0.704	0.726	4.750	8.818	2.333

Table 6.3 ANOVA p-values for Ecoregion, Sample Location, Topography, and Landscape Class

Soil Parameter	Ecoregion Comparison	Ecoregion: Wetland / Centerline samples	Sample Location: By Regions	Sample Location: Coastal Plain	Sample Location: Piedmont	Topography	Topography: Wetland / Centerline samples	Landscape Class
Phosporus	**0.0001**	**0.0001**	0.2849	**0.0846**	**0.4560**	**0.0001**	**0.0001**	**0.0001**
Potassium	**0.0018**	**0.0048**	**0.0202**	0.3706	**0.0391**	**0.0750**	**0.0307**	**0.0169**
Calcuim	**0.0114**	**0.0600**	**0.0116**	**0.0033**	0.2072	**0.0001**	**0.0004**	**0.0001**
Magnesium	**0.0137**	0.1542	0.1445	**0.0035**	0.7529	**0.0001**	**0.0001**	**0.0001**
Sodium	0.1245	0.5205	**0.0001**	**0.0001**	**0.0016**	0.4005	0.2324	**0.0001**
Weight/Volumn	0.9074	0.6147	**0.0002**	**0.0001**	**0.0654**	0.9121	0.1017	**0.0001**
Phosporus	**0.0001**	**0.0001**	**0.0850**	**0.0109**	0.8563	0.1245	**0.0002**	**0.0001**
pH	**0.0001**	**0.0001**	0.1087	**0.0178**	0.7429	**0.0026**	0.3249	**0.0001**
Sum Cation	**0.0092**	0.0765	**0.0255**	**0.0024**	0.3639	**0.0001**	**0.0001**	**0.0001**
CEC Buffer	0.6373	0.7815	**0.0071**	**0.0004**	0.3884	**0.0001**	**0.0001**	**0.0001**
Base Saturation	**0.0001**	**0.0001**	**0.0017**	**0.0103**	**0.0265**	0.2358	0.3635	**0.0001**
Maganese	**0.0001**	**0.0001**	0.7834	0.5561	0.6267	0.3064	0.8736	**0.0001**
Zinc	**0.0054**	**0.0027**	0.1239	0.5586	**0.0565**	**0.0043**	**0.0016**	**0.0001**
Copper	**0.0001**	**0.0001**	**0.0995**	0.5938	**0.0481**	**0.0114**	**0.0197**	**0.0027**
Humic Matter	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0612**	**0.0001**	**0.0001**	**0.0001**
Nitrogen	0.3446	0.2777	0.9885	0.1238	**0.0626**	0.1531	**0.0092**	**0.0015**

Red = Statistically Significant

Table 6.4 Headwater Wetland Sites Classified by Topography

Bowl	Flat
Battle Park	Bachelor
East Fayetteville North	Boddie Noell
East Fayetteville South	Cox
Fire Tower	Duke Forest
Kelly Rd	Hog Farm Lower
Black Ankle Non-Powerline	Hog Farm Upper
Pete Harris	Moonshine
Black Ankle Powerline	Nahunta
Spring Garden	PCS
Troxler	Rough Rider
Umstead	
East of Mason	
Walmart	

Table 6.5 Headwater Wetland Landscape Class

Natural	Rural	Urban
Bachelor	Duke Forest	Battle Park
Cox	Black Ankle Non-Powerline	Boddie Noell
Pete Harris	Black Ankle Powerline	Moonshine
PCS	East Fayetteville North	Troxler
Spring Garden	East Fayetteville South	Walmart
Umstead	East of Mason	
	Fire Tower	
	Kelly Rd	
	Nahunta	
	Hog Farm Lower	
	Hog Farm Upper	
	Rough Rider	

Table 6.6 Correlations between Soil Parameters and Disturbance Measures

Disturbance Variable	Soil Parameter	All Sample Location		Centerline Samples		Wetland Samples		Upland Samples	
		Correlation	p-value	Correlation	p-value	Correlation	p-value	Correlation	p-value
ORAM	Phosphorus	-0.2922	0.0001	-0.3734	0.0006	-0.3282	0.0001	-0.2932	0.0005
ORAM	Potassium	-0.0577	0.2471	-0.0856	0.4502	-0.0497	0.4996	-0.0396	0.6457
ORAM	Calicum	0.0044	0.9290	0.0968	0.3930	0.0203	0.7825	-0.0759	0.3781
ORAM	Magnesium	-0.0567	0.2558	-0.0036	0.9748	-0.1014	0.1674	0.0396	0.6457
ORAM	Sodium	0.0946	0.0574	0.2210	0.0488	0.0708	0.3359	0.0889	0.3014
ORAM	Weight/Volumne	-0.0320	0.5214	-0.3104	0.0051	-0.1161	0.1146	0.0105	0.9027
ORAM	pH	-0.0723	0.1473	-0.1859	0.0987	-0.0782	0.2885	0.0157	0.8558
ORAM	Buffer exchangable acidity at pH 6.6	-0.0351	0.4819	0.1421	0.2086	-0.0489	0.5078	-0.1053	0.2206
ORAM	Sum of Cation	-0.0161	0.7465	0.0698	0.5385	-0.0284	0.6993	-0.0435	0.6141
ORAM	Cation Exchange Capacity Buffer	-0.0244	0.6255	0.1234	0.2755	-0.0283	0.7014	-0.1021	0.2352
ORAM	Base Saturation	0.0783	0.1167	0.1012	0.3720	0.1618	0.0273	-0.0357	0.6792
ORAM	Maganese	0.3153	0.0001	0.2824	0.0111	0.3323	0.0001	0.3337	0.0001
ORAM	Zinc	-0.2654	0.0001	-0.2573	0.0212	-0.3349	0.0001	-0.1563	0.0682
ORAM	Copper	-0.1397	0.0049	-0.2333	0.0373	-0.0636	0.3870	-0.1506	0.0790
ORAM	Humic Matter	-0.1140	0.0219	0.0466	0.6815	-0.1616	0.0271	-0.1464	0.0878
ORAM	Nitrate-Nitrogen	0.1154	0.0204	0.2097	0.0620	0.2043	0.0050	-0.0675	0.4333
Watershed LDI	Phosphorus	0.0222	0.6565	0.0919	0.4175	0.0364	0.6209	-0.0048	0.9560
Watershed LDI	Potassium	-0.0393	0.4314	0.0665	0.5576	-0.0589	0.4232	-0.0794	0.3563
Watershed LDI	Calicum	-0.0680	0.1727	-0.1410	0.2122	-0.0685	0.3518	-0.0071	0.9347
Watershed LDI	Magnesium	-0.0713	0.1526	-0.0576	0.6117	-0.0609	0.4077	-0.1373	0.1097
Watershed LDI	Sodium	-0.1293	0.0093	-0.1407	0.2132	-0.1578	0.0311	-0.0895	0.2981
Watershed LDI	Weight/Volumne	0.0078	0.8764	0.0704	0.5348	0.0734	0.3193	-0.0242	0.7786
Watershed LDI	pH	0.1827	0.0002	0.2126	0.0583	0.1750	0.0169	0.1880	0.0278
Watershed LDI	Buffer exchangable acidity at pH 6.6	-0.0645	0.1963	-0.0671	0.5545	-0.0562	0.4458	-0.0686	0.4258
Watershed LDI	Sum of Cation	-0.0755	0.1298	-0.1174	0.2997	-0.0720	0.3275	-0.0486	0.5728
Watershed LDI	Cation Exchange Capacity Buffer	-0.0966	0.0527	-0.1313	0.2457	-0.0963	0.1909	-0.0729	0.3974
Watershed LDI	Base Saturation	-0.0591	0.2363	-0.1727	0.1255	-0.1113	0.1304	0.0813	0.3448
Watershed LDI	Maganexe	-0.2478	0.0001	-0.2796	0.0120	-0.2493	0.0006	-0.2535	0.0028
Watershed LDI	Zinc	0.3670	0.0001	0.2927	0.0084	0.5141	0.0001	0.2017	0.0181

Table 6.6 Correlations between Soil Parameters and Disturbance Measures

Disturbance Variable	Soil Parameter	All Sample Location		Centerline Samples		Wetland Samples		Upland Samples	
		Correlation	p-value	Correlation	p-value	Correlation	p-value	Correlation	p-value
Watershed LDI	Copper	**0.2450**	**0.0001**	**0.4159**	**0.0001**	**0.1751**	**0.0165**	**0.2350**	**0.0057**
Watershed LDI	Humic Matter	0.0597	0.2312	0.1275	0.2596	0.0490	0.5051	0.0733	0.3948
Watershed LDI	Nitrate-Nitrogen	**-0.2163**	**0.0001**	**-0.2457**	**0.0280**	**-0.3133**	**0.0001**	-0.0787	0.3604
50 M LDI	Phosphorus	0.0364	0.4656	0.0145	0.8985	0.0556	0.4494	0.0348	0.6866
50 M LDI	Potassium	-0.0062	0.9019	0.0723	0.5237	0.0134	0.8556	-0.0799	0.3535
50 M LDI	Calicum	-0.0391	0.4337	-0.1086	0.3374	-0.0471	0.5222	0.0386	0.6542
50 M LDI	Magnesium	-0.0927	0.0626	-0.0465	0.6823	-0.1172	0.1102	-0.0919	0.2855
50 M LDI	Sodium	-0.0866	0.0820	-0.1215	0.2830	-0.1189	0.1050	-0.0180	0.8345
50 M LDI	Weight/Volumne	0.0212	0.6713	0.1149	0.3104	0.0845	0.2517	-0.0105	0.9034
50 M LDI	pH	**0.1602**	**0.0013**	0.1558	0.1675	0.0825	0.2630	**0.2690**	**0.0015**
50 M LDI	Buffer exchangable acidity at pH 6.6	-0.0932	0.0615	-0.0604	0.5946	-0.0479	0.5163	**-0.1647**	**0.0544**
50 M LDI	Sum of Cation	-0.0618	0.2150	-0.0908	0.4233	-0.0783	0.2866	0.0004	0.9964
50 M LDI	Cation Exchange Capacity Buffer	-0.0929	0.0624	-0.1050	0.3537	-0.0800	0.2775	-0.1027	0.2325
50 M LDI	Base Saturation	0.0424	0.3955	-0.0656	0.5634	0.0024	0.9739	**0.1722**	**0.0442**
50 M LDI	Maganexe	**-0.1548**	**0.0018**	**-0.2154**	**0.0550**	-0.1203	0.1009	**-0.1696**	**0.0476**
50 M LDI	Zinc	**0.4134**	**0.0001**	**0.3763**	**0.0006**	**0.5795**	**0.0001**	**0.2091**	**0.0142**
50 M LDI	Copper	**0.2651**	**0.0001**	**0.4668**	**0.0001**	**0.1698**	**0.0202**	**0.2653**	**0.0017**
50 M LDI	Humic Matter	-0.0040	0.9360	0.1187	0.2944	-0.0474	0.5195	0.0222	0.7972
50 M LDI	Nitrate-Nitrogen	**-0.1311**	**0.0083**	-0.1246	0.2707	**-0.1611**	**0.0277**	-0.0960	0.2644
300 M LDI	Phosphorus	0.0771	0.1219	0.0620	0.5846	0.0499	0.4973	0.1038	0.2273
300 M LDI	Potassium	-0.0606	0.2242	-0.0235	0.8364	-0.1031	0.1602	-0.0107	0.9014
300 M LDI	Calicum	-0.0641	0.1988	-0.1540	0.1727	-0.0711	0.3338	0.0406	0.6379
300 M LDI	Magnesium	-0.0720	0.1488	-0.0639	0.5731	-0.0713	0.3320	-0.0818	0.3418
300 M LDI	Sodium	**-0.1968**	**0.0001**	-0.1443	0.2014	**-0.2177**	**0.0028**	**-0.2051**	**0.0162**
300 M LDI	Weight/Volumne	0.0198	0.6918	0.1318	0.2439	**0.1757**	**0.0165**	-0.0485	0.5734
300 M LDI	pH	**0.1516**	**0.0023**	**0.1868**	**0.0970**	**0.1479**	**0.0439**	**0.1533**	**0.0737**
300 M LDI	Buffer exchangable acidity at pH 6.6	**-0.1036**	**0.0377**	-0.1195	0.2909	**-0.1429**	**0.0518**	-0.0345	0.6886
300 M LDI	Sum of Cation	-0.0766	0.1242	-0.1320	0.2433	-0.0813	0.2688	-0.0018	0.9831
300 M LDI	Cation Exchange Capacity Buffer	**-0.1149**	**0.0210**	-0.1695	0.1329	**-0.1453**	**0.0479**	-0.0147	0.8648

Table 6.6 Correlations between Soil Parameters and Disturbance Measures

Disturbance Variable	Soil Parameter	All Sample Location		Centerline Samples		Wetland Samples		Upland Samples	
		Correlation	p-value	Correlation	p-value	Correlation	p-value	Correlation	p-value
300 M LDI	Base Saturation	-0.0280	0.5751	-0.1460	0.1963	-0.0549	0.4570	0.0997	0.2463
300 M LDI	Maganexe	-0.2420	0.0001	-0.2678	0.0163	-0.2701	0.0002	-0.2318	0.0064
300 M LDI	Zinc	0.3085	0.0001	0.1169	0.3019	0.4609	0.0001	0.1862	0.0294
300 M LDI	Copper	0.1664	0.0008	0.2618	0.0190	0.1101	0.1337	0.1901	0.0261
300 M LDI	Humic Matter	-0.0064	0.8976	0.0633	0.5772	-0.0317	0.6665	0.0292	0.7349
300 M LDI	Nitrate-Nitrogen	-0.1840	0.0002	-0.1980	0.0783	-0.2636	0.0003	-0.0699	0.4173

Red = Statistically Significant

Table 6.7 Soil Classification for each site based on NRCS county soil maps

Site Name Coastal Plain	Soil Classification	Soil Description	Hydric A or B
Cox	Mantachie	Loamy Sand	A
East Fayetteville South	Carteret	Fine Sand	
East Fayetteville North	Carteret	Fine Sand	
	Deloss	Loam	A
Hog Farm Lower	Rains	Sandy loam	A
	Norfolk	Loamy Sand	
Hog Farm Upper	Paxville	Fine Sandy loam	A
	Wagram	Loamy Sand	B
Batchlor	Wagram	Loamy Sand	A
	Blaney	Loamy Sand	B
Nahunta	Wagram	Loamy Sand	A
	Lynchburg	Sandy loam	B
Battle Park	Wedowee	Sandy loam	
	Grantham	Loam	B
Boddie Noell	Rains	Sandy loam	A
PCS	Leon	Sand	A
	Torhunta	Sandy loam	A
	Seabrook	Loamy Sand	B
Rough Rider	Goldsboro	Fine Sandy loam	B
Site Name Piedmont			
Black Ankle powerline	Herdon	Silt loam	
Black Ankle non-powerline	Herdon	Silt loam	
Duke Forest	Iredell	Gravelly loam	
	Chewacla	Loam	B
	Herdon	Silt loam	
East of Mason	Creedmore	Sandy loam	
Fire Tower	Vance	Sandy loam	B
	Bibb	Loam	A
Kelly Road	Mayoden	Sandy loam	
Moonshine	Appling	Gravelly Sandy loam	
	Colfax	Sandy loam	B
Pete Harris	Chastain	Silty clay loam	A
Spring Garden	Appling	Sandy loam	
Troxler	Cecil	fine Sandy loam	
Umsted	Cecil	gravely Sandy loam	
Walmart	Vance	Sandy loam	B

Hydric A = Hydric Soil, Hydric B = Upland soil with hydric inclusions

Section 7 – Amphibian Monitoring Section

Section 7.1 Amphibian Introduction and Background

Wetlands provide extremely important habitat for amphibians. Amphibians depend on wetlands during their aquatic life stages, especially for breeding habitat. Due to their abundance and diversity, amphibians play a very significant role in the wetland ecosystem (Dodd 1998). In addition, the environmentally sensitive nature of amphibians allows them to act as bioindicators of the surrounding wetland and water quality. Amphibians have been characterized as "a canary in the coal mine" for environmental disturbances (Richter 1999). Worldwide, populations of frogs and other amphibians are in a state of decline. The cause is a combination of environmental stressors, not all of which are known. However, habitat loss is considered to be the central factor in declines (Lannoo 1998). The health of amphibians as a whole is vital to wetland ecosystems, as they provide important links in food webs as well as between wetland and upland habitats (U.S. EPA 2002f).

While the causes of amphibian declines are not entirely known, several have been identified, including habitat loss and degradation, the spread of toxic substances, predator introduction, acid deposition, and global climate warming (U.S. EPA 2002f). Urbanization and habitat loss are considered to be the main cause of decline in amphibian abundance. As wetlands and nearby uplands are urbanized, breeding and terrestrial habitats become scarcer, and amphibian richness decreases (Orser and Shure 1972). Breeding amphibians are particularly susceptible to wetland urbanization (Richter 1999). It has also been found that salamander species richness or abundance in streams decreases as impervious surface area within the basin increases (Lannoo 1998, Jung 2004). Rapid development of North Carolina watersheds certainly has the potential to affect regional amphibian populations. North Carolina's population grew by 10.1%, or over 800,000 people, between 2000 and 2006, which is significantly higher than the national average of 6.4% (FedStats North Carolina 2007).

NC has a diverse community of 96 species of amphibians, including 54 species of salamanders, which is more salamanders than any other state (A. Braswell, pers. comm. 2006). However, like other places in the world, amphibians in North Carolina are unfortunately no exception to the trend of amphibian declines. Currently, three species of amphibians in North Carolina are listed as federal species of concern, one as state endangered, and four as state threatened. In addition, 11 are listed as a state special concern species (LeGrand *et al*. 2004). Protection of North Carolina's wetland habitat is important for supporting these amphibians as well as maintaining high species diversity.

Habitat requirements and home ranges of amphibians vary by species. Most amphibians are biphasic, spending part of their lives both in aquatic and terrestrial habitat. Typically, eggs are laid in a wetland, where they hatch into aquatic larvae that remain in the wetland until metamorphosis. At this point the juveniles emigrate towards terrestrial habitat, to return to the breeding pools as adults (Dodd 1998, Duellman and Trueb 1986). Many amphibians use upland foraging and over wintering sites that are substantially far from breeding areas (Dodd 1998). For example, some species of frogs, toads, and newts may move between 1000-1600m from aquatic habitats. In contrast, stream salamanders generally remain within 20-30m of streams. While the distances traveled to upland habitats vary, core terrestrial habitat for most amphibians has been found to range from 159-290 m from the edge of an aquatic site (Semlitsch and Bodie 2003). Because amphibians require both wetland and upland habitats, it is important to consider their habitat in terms of a broad landscape rather than just as the wetland.

In order to migrate between habitat types and have adequate terrestrial habitat, amphibians require corridors and a significant forested buffer (Harper 1999, Macdonald and Weinmann 1997). Forested buffers may be beneficial as contaminant sinks, protecting amphibians from pollutants such as fertilizers and pesticides (Hefting and De Klein 1998, Kuusemets 1999, Houlahan 2003). Absence of forest cover prohibits movement between wetlands as well as increases vulnerability to predation and desiccation (Houlahan 2003). While salamander abundance is affected by buffer presence, it is more closely related to the amount of undisturbed habitat within an entire watershed (Wilson and Dorcas 2003). A high correlation between salamander abundance and watershed disturbance strengthens the idea that salamanders are good indicators of environmental integrity (Welsh and Droege 2000, Wilson and Dorcas 2003).

Watershed disturbance is partially characterized by the amount of impervious surface present in the watershed. In watersheds with high impervious surface area, rainfall and runoff cause stream flow to increase. This is often the case in urbanized watersheds of North Carolina. High flow can wash away leaves and other protective cover as well as food sources for amphibians, making them unable to survive in this habitat (Orser and Shure 1972, Wilson and Dorcas 2003). In addition to decreasing salamander abundance, a high density of roads has been found to lessen both dispersal and genetic diversity (Reh and Seitz 1990, Gibbs 1998, Houlahan 2003, Lannoo 1998, Jung 2004). Research indicates that amphibian mortality increases exponentially with traffic volume (Hels and Buchwald 2001, Houlahan 2003). In rapidly urbanizing Wake County, North Carolina, dusky salamanders (*Desmognathus fuscus*), mud salamanders (*Pseudotriton montanus*), red salamanders (*Pseudotriton ruber*), and three-lined salamanders (*Eurycea guttolineata*) have had notable decreases in numbers over the years (A. Braswell, pers. comm. 2006). Also, in Wake County, a 2007 study discovered that ever-increasing amounts of impervious surfaces such as paved roads and rooftops have negative impacts on the abundance of larval two-lined salamander (*Eurycea cirregera*) populations (Miller and Hess 2007). Urbanization of terrestrial habitat required by amphibians should be minimized in order to maintain genetic diversity and allow adequate movement between nearby wetlands.

Apart from needing sufficient undisturbed aquatic and terrestrial habitats, amphibians also need a moist, shady environment in which to feed and hibernate. Many amphibians breathe through their skin and must keep it moist for gas exchange (Harper 1999, Richter 1999). As a result, they seek cool, damp conditions often created by a closed canopy and abundant leaf litter (Fischer 1999, Rudolph 1990). Salamanders generally prefer hardwood stands to conifers due to the presence of thicker leaf litter that retains moisture longer. A preference may also be shown for sites with northern and eastern aspects, which receive less direct sunlight and therefore remain damp (Harper 1999). Because amphibians are greatly affected by temperature and moisture levels, they are commonly found beneath rocks, leaf litter, and downed logs (Macdonald and Weinmann 1997). Cover such as this maintains humidity and is important in avoiding desiccation and predators. Density of prey is also higher in areas with organic debris. There is a positive correlation between salamander density and invertebrate density. Salamanders have been shown to search out sites with a high density of snails, as they are a vital calcium source (Harper 1999).

While some species of amphibians are able to reproduce in ponds, ditches, rivers, or lakes, more specialized species depend on mature forested wetland areas with high water quality. The type of wetlands habitat sought by most amphibians is a fishless, semi-permanent or ephemeral pond or wetland for breeding, which is connected by undisturbed uplands for terrestrial life stages (Lannoo 1998, Macdonald and Weinmann 1997). These characteristics often exist in rurally located headwater wetlands that drain into small perennial or intermittent streams that do not contain enough water for fish access. Wetlands lacking fish are important for successful reproduction, due to fish predation of eggs and larvae of frogs, salamanders, and other amphibians. Temporary wetlands are ideal breeding sites, as they lack fish and can support a large number of species even in small ponds (Dodd 1998). Permanent wetlands may also become suitable for breeding during droughts when water levels become too low to support fish (Lannoo 1998). Ideal wetlands for breeding have stable, medium-depth water levels that allow eggs to remain permanently or partially submerged from time of spawning through hatching. Amphibians that breed in slow-moving water require a low current velocity in order to prevent eggs from becoming dislodged from vegetation. A slight to modest current is optimal in order to provide oxygen flow to eggs and to avoid freezing (Macdonald and Weinmann 1997).

Amphibians depend greatly on isolated wetlands for habitat requirements, especially during breeding season. Isolated wetlands usually become dry at least once a year, while wetlands more connected to permanent water may dry only once or twice in a decade. Isolated wetlands and headwater wetlands, that drain into an intermittent or small perennial stream, provide important habitat that is free of predatory fish. In North Carolina, 53 species of amphibians are known to use fishless wetlands that have high water quality and a surrounding mature forest. These conditions are required exclusively by 31 of the 53 species, or nearly one-third of the amphibian species in North Carolina, in order to reproduce (A. Braswell, pers. comm. 2006). Included within the 31 species are those that are federally listed (3 federal species of concern), state-listed (1 state threatened, 5 special concern), and "NC significantly rare" (5 species) (North Carolina Natural Heritage Program 2006). Small and hydrologically isolated wetlands have high species diversity, and in addition are frequently home to rare, endemic species that have specialized habitat requirements, such as the Pine Barrens tree frog (Semlitsch and Bodie 2003).

Due to their nature, isolated wetlands are often surrounded by human disturbances and unsuitable habitat, and therefore disconnected from nearby wetlands. Small headwater wetlands can become isolated with respect to amphibians due to road crossings with poorly designed culverts for aquatic passage. Culverts that are not large enough or not placed at the correct elevation will clog thus causing water to pond near the road on the headwater side and not allow for aquatic species passage. Often, small isolated wetlands are the most prevalent type of wetland in a landscape. This makes their loss especially concerning since it reduces the breeding populations (Semlitsch and Bodie 2003). The number of individual wetlands in a landscape can be more important than the total area of wetlands present, because it is the abundance and distribution of individual populations that allows for species diversity as well as genetic diversity (Ricklefs and Schluter 1993, Futuyma 1998, Semlitsch and Bodie 1998). The loss of isolated wetlands causes an exponential increase in isolation as well as distance between remaining wetlands, which is significant because most amphibians are unable to migrate long distances due to moisture needs (Semlitsch and Bodie 2003). Conservation of isolated wetlands, even small pools, is important for maintaining high species diversity and connectivity between breeding populations.

The ability of amphibians to serve as bioindicators of water quality and wetland health is invaluable. Their sensitivity to surrounding contaminants and overall habitat conditions makes them sentinel species in recognizing water quality deterioration (Richter 1999). Cautionary signs provided by amphibians are especially important in instances of non-point source contamination, when it is not possible to locate sites for direct chemical monitoring (Gardiner *et al*. 2003). Non-point source pollution is the largest source of water quality problems in the US and NC (U.S. EPAd). Amphibians are especially vulnerable to accumulation of pollutants due to their permeable skin, unshelled eggs, and inability to disperse over long ranges (Richter 1999). This heightened exposure lets them act as indicators of water quality changes as well as changes related to hydrology, presence of pollutants in both air and water, and overall climate change (U.S. EPA 2002f).

Amphibians are highly susceptible to chemical contaminants within the environment. Pesticides and herbicides have been known to cause paralysis, developmental deformities, and death in amphibians. Intensive agriculture and the resulting chemical contamination of surface water have also been correlated to frog deformities in Canada (Ouellet 1997). Acid deposition created by acid rain impacts amphibians by lowering pH below ideal levels. While amphibians are somewhat tolerant of acidic conditions, responses may range from avoidance and developmental disorders to death. Wetlands that are most susceptible to acidification are seasonal or semipermanent wetlands, as are many headwater wetlands (Lannoo 1998). Ultraviolet B (UV-B) radiation has increased recently as a result of ozone depletion and has been implicated as a cause for amphibian decline. This form of radiation in sunlight can damage unshelled amphibian eggs by causing abnormal development and death, especially at high altitudes. Global warming as a whole is also affecting amphibians as it brings fluctuating temperatures and overall drier conditions. Wetlands may dry more quickly, thereby reducing breeding habitat. In addition, amphibians may breed prematurely and lose eggs to a freeze (Lannoo 1998, Richter 1999).

As mentioned previously, amphibians are sensitive to water quality declines that include increased acidity and pollution. The extent to which amphibians are affected is often influenced by the soil and hydrologic structure of a wetland. For most amphibians to thrive, they must exist in habitat with a pH level above 4.5 (Smith and Braswell 1994). Low pH levels have been found to inhibit fertilization and embryonic development in frogs (Beattie and Tyler-Jones 1992, Boyer and Grue 1995). In addition, the diversity of amphibians tends to be lower in acidic ephemeral ponds. The variability of amphibians with pH levels makes site-specific pH a useful way to estimate suitability of a habitat (Smith and Braswell 1994). Pollutants such as nitrogen and heavy metals have an adverse effect on sensitive amphibians (Smith and Braswell 1994, Wilson and Dorcas 2002). For example, chemicals used by agricultural and industrial practices may enter surrounding lakes, streams, and wetlands, leaving them unable to support amphibians. Specifically, high levels of ammonia in the form of nitrate and nitrite have a large impact on amphibian health (Marco *et al*. 1999). Nitrates themselves are not harmful, but when reduced to nitrites they become toxic. Even at the recommended drinking water level, nitrate and nitrite (10mg N-NO3/L and 1mg $N\text{-}NO_2$/L) can be moderately toxic for amphibians and may cause increased mortality rates for adults and larvae. Nitrate concentrations in agricultural areas are often much higher and therefore toxic. Research shows that when larval amphibians are exposed to water enriched with nitrate and nitrite ions, they reduce feeding and swimming activity, show paralysis and abnormalities, and eventually die (Marco *et al*. 1999). However, sensitivity varies among species, with some larvae being able to survive in areas containing more nitrate and nitrite. Bullfrog (*Rana catesbeiana*) tadpoles are relatively tolerant to nitrite and may also be more tolerant to nitrogen-based fertilizers than other amphibians. The lower nitrogen sensitivity of bullfrogs may contribute to the negative relationship between bullfrogs and other amphibians in landscapes with intense agriculture (Marco *et al*. 1999).

Frogs are strongly dependent on high water quality in order to remain healthy. Researchers believe that the increase in frog deformities and deaths in recent years is the result of a water-borne contaminant that has either appeared only recently or has reached a critical concentration (Gardiner *et al*. 2003). A dramatic increase in numbers of deformed amphibians has been seen since the early 1990s in both North America and Japan. This coincides with the decline of many amphibian species worldwide, especially those that are highly aquatic. Malformation rates of highly aquatic species, such as the green and mink frog, are much higher today than historically. In contrast, species that are predominantly terrestrial show little change in malformation rates over past years. The contaminant responsible for the deformations most likely exists within water used by frogs for breeding and larval development (Gardiner *et al*. 2003, Hoppe 1997). In Washington State, a recent study has indicated that the growing number of deformed frogs and parasitic infection of tadpoles is partly attributed to the presence of nitrogen and phosphorous in stormwater runoff (CNN.com Technology 2007). A National Institute of Environmental Health Sciences study conducted in Minnesota raised frogs in water taken from a pond where many deformed frogs were found. Deformities such as missing or extra legs were developed in 75% of embryos, compared with no deformities in embryos raised in ordinary water. Water samples from nearby homes also raised many deformed frogs (Gannon 1997). Researchers conducted a more recent study in contaminated Minnesota ponds, and concluded that it is highly likely that exposure to bioactive retinoids found in the water are causing deformations. Retinoids are essential in precise quantities for cellular processes including development of limbs and the central nervous system. If there is too much retinoid present, developmental defects and death can result (Gardiner *et al*. 2003). Their study is currently being repeated in other areas with frog malformations. The significant results of these studies demonstrate not only the ability of amphibians to act as bioindicators of water quality, but also the imperative nature of high water quality in amphibian survival.

The sensitive nature of amphibians to water quality also applies to wetland ecosystems. Because many species use both wetland and upland habitat, they often have unique behavioral requirements that make them effective biomonitors of wetland health (U.S. EPA 2002f). Monitoring of amphibian distribution as well as abundance and species richness allow for assessment of changes in the water quality and water regimes of wetlands. In addition, data may be provided on sedimentation and overall landscape stress levels (Richter 1999). Amphibian larvae are of specific use as bioindicators, as they may be more sensitive to environmental stressors than adults (Jung 2004).

The relative abundance and richness of amphibians is partially attributed to the soil characteristics and hydrologic structure of a wetland. The length of time for which a wetland remains inundated can dictate what species are found within a wetland. Short hydroperiod wetlands sustain a unique assembly of species, which are not found in wetlands with a long hydroperiod. While wetlands with short hydroperiods tend to be small, they remain crucial for conservation for this reason (Snodgrass 2000).

A strong relationship often exists between salamander population density and soil particle size of stream banks and beds. Research shows that as disturbance decreases, salamander density increases as does stream substrate silt and clay particles composition (Orser and Shure 1972). Changes in soil structure and hydrology resulting from deforestation and buffer removal have negative effects on amphibians. If soils have a limited buffering capacity, then human impacts on wetlands become higher. For example, rainfall and runoff from deforested land results in stream habitat that is increasingly urbanized due to bank and channel erosion. Salamander population density is closely related to both soil erosion and the extent of runoff. Runoff in urbanized areas causes heightened stream volume and velocity, as well as scouring and streambed disruption that decrease population levels (Orser and Shure 1972).

Similar to pH levels in water, adequate soil pH levels are extremely important for supporting a population of amphibians. If soil pH falls below 4.5, distribution of terrestrial salamanders becomes limited. A low pH can be lethal if exposure is continual. Soil pH is also affected by factors such as soil type, leaf litter, and amount of light reaching the wetland. An open canopy generally allows for a higher pH, as large amounts of light are able to reach the water, and leaf litter is not in excess (Smith and Braswell 1994). Increased acidity can result from acid rain. Following acid rain, the acid can continue to leach into ponds from surrounding soil, which remains more acidic than the actual water (Gannon 1997).

Numerous studies have shown that amphibians are bioindicators of ecosystem health at the habitat and landscape level. As discussed in the above section, the condition of the environment has the capacity to affect amphibian species richness, species assemblage, and population density and population health. While habitat loss and urbanization have had the greatest impact on amphibians, other adverse environmental factors have also had negative impacts. These include wetland size, presence of predatory fish (found in non-isolated wetlands), proximity, and corridor connectivity to other wetlands (especially isolated wetlands), forest type (hardwood or coniferous), hydrology, soil pH and particle size, water quality (including the presence of herbicides, pesticides, acidity, nutrients, and heavy metals) air pollutants, ultra-violet radiation and global warming. In order to develop an IBI specific to NC amphibians and headwater wetlands, NC DWQ has collected data on headwater wetland chemical and physical attributes, and amphibian species richness, species assemblages, and population density in 23 headwater wetland habitats of variable quality (see Section 2). The physical and chemical factors, as described in Sections 4, Section 5 and Section 6, include water quality, soil pH, hydrology, and watershed and buffer land-use. The amphibian IBI development is described further in the following sections.

Section 7.2.1 Amphibian Field Methods

A qualitative survey for amphibians was performed twice at each wetland site in February-March and May-early June of 2005. Approximately three man-hours of survey work per acre of study site were completed. Surveyors systematically walked the study sites and adjacent buffer areas searching for amphibians. D-shaped sweep nets were used to search for amphibians (frogs, tadpoles, egg masses, and larval salamanders) in wetland areas with standing water. These areas included isolated wetland pools, slow moving streams, or nearby ditches and ponded areas within the buffer (up to 150 meters) that were potential breeding grounds for amphibians. Pools of water were also carefully walked to search for egg masses floating at the surface of the water. Other areas of the wetland sites that had shallow puddles of standing water or saturated soil were searched with potato rakes. Leaf cover near standing water or moist soil was lightly scraped to search for salamanders. Logs or woody debris located in the wetland or adjacent upland buffer were carefully turned over and replaced to look for amphibians. Moss hummocks overhanging or within a few feet of water were searched for cavities containing nesting female salamanders (*Hemidactylium scutatum*). Crayfish holes were also searched for salamanders. Any auditory calls were recorded and identified when possible.

Field data sheets were kept for each amphibian survey event (see DWQ Headwater Wetland Amphibian Monitoring Project – Field Sheet in Appendix B). Information on the field data sheets included site name, county, observer names, date, start and stop time, water quality parameters, current air temperature, wind speed, percent cloud cover, air temperature range, rain in last 48 hours, comments on the hydrology of the site, and records for each separate observation. Each record included the species' scientific name and information on the life-stage, number observed (number of egg masses and eggs per mass), specimen number, photo number, and comments on microhabitat, behavior, malformations, type of observation (auditory or visual), and identification details such as size (head to tail for salamanders and head to anus for frogs and toads). The water temperature, dissolved oxygen, specific conductivity, pH, and air temperature were taken at the upstream and downstream water quality stations (See Section 4.0 for a description on water meters). The previous 48-hour precipitation and temperature minimum and maximum levels were taken from the nearest weather stations and recorded on field sheets. Qualitative amphibian surveys were not done if temperatures were below 4.4^{o}C (40^{o}F) the previous night or below 15.6^{o}C (60^{o}F) during the day of the scheduled survey. A specimen list sheet (see DWQ Headwater Wetland Amphibian Wetland Monitoring Project – Specimen List Appendix B) was kept with the records of each specimen collected. Specimens collected for identification were assigned a specimen number. Specimens were preserved in 10% formaldehyde solution and labeled with the specimen number, site name, and date. The "Distribution of Amphibians in North Carolina" (NC DENR 2003) draft document written by the NC State Museum of Natural Sciences was used for Genus species nomenclature.

A third amphibian survey was done in conjunction with the macroinvertebrate survey in 2006 (see Section 8). Amphibians that were inadvertently collected during the macroinvertebrate survey in the funnel traps, D-shaped sweep nets, or stove-pipe samplers were recorded on field sheets (see DWQ Headwater Wetland Amphibian Wetland Monitoring Project – Field Sheet Macroinvertebrate Stations Appendix B). The site name, date, observers, macroinvertebrate sample station ID, amphibian species, life stage, number observed, comments, specimen number, and photo number were recorded on these field sheets.

Section 7.2.2 Amphibian IBI Development and Analysis

In this study, seven biological attributes were tested for usage as metrics in the development of an amphibian Index of Biotic Integrity (IBI) for headwater wetlands. The biological attributes tested were an Amphibian Quality Assessment Index (AQAI), percent tolerant species, percent sensitive species, percent state-listed, percent ephemeral – headwater – seepage wetland (EW-HW-SW) species, species richness, and percent Urodela (Salamander / Newt Order). A description of how each potential metric was calculated is discussed later in this section. Wetland disturbance measures as determined by the Ohio Rapid Assessment Method (ORAM), Land Development Index (LDI) for the watershed and 300m and 50m buffers, water quality, and soil pH were used to test the seven metrics (see Section 3) for correlation with Spearman's rho non-parametric correlation test. Correlations were run using amphibian data results from both regions and from each region separately.

The field data observations were used to develop an amphibian database with Excel 2000 spreadsheets. In order to develop an amphibian IBI, each site's larvae and egg stage tally for each species needed to be converted to an adult tally. Table 7.1 shows the calculations used to convert each egg and larval species that were observed during the survey to adult species. In most cases 20% of the larvae were counted as one adult and every egg mass were counted as two adults (see Table 7.1). Amphibian C of C (Coefficient of Conservation) rankings for each species were assigned from 1-10 with "1" being species that were considered to be generalist with the least specific habitat requirements such as the American toad (*Bufo americanus*) and "10" being species that had the most specific habitat requirements and sensitivity to stress plus a state listing such as the four-toed salamander (*Hemidactylium scutatum*). Table 7.1 shows the C of C rankings for each species and gives an explanation for each C of C ranking. Species with a C of C $\leq$ 3 were considered tolerant while species with a C of C $\geq$ 6 were considered sensitive (see Table 7.1). Species that require ephemeral wetlands, headwater wetlands, or seepage wetlands (i.e. the absence of predatory fish) are also denoted in Table 7.1. Table 7.1, specifically the C of C ratings and adult conversion calculations, was developed with the assistance of Alvin Braswell in 2005, the Lab Director and Curator for Herpetology at the N.C. State Museum of Natural Sciences. It should be noted the adult conversion methodology as well as the C of C scores are not an exact science but rather based on the best professional judgement of an experienced herpetologist. For example, some female amphibians can lay more than one egg mass and 20% of all larvae do not always equal one adult, sometimes there is a better success rate, sometimes worse.

The number of adults for each site was determined and then used to calculate the AQAI value, species richness, percent tolerant species, percent sensitive species, percent EW-HW-SW species, percent state-listed, and percent Urodela species. The AQAI value for each site was determined using the following equation-

$$\text{AQAI} = \frac{\sum S_i * S_{i \text{ c of c}}}{N}$$

S_i = Adult number of species i
$S_{i \text{ c of c}}$ = C of C value for species i
N = Total number of adults

Spearman's rho correlation coefficient, a non-parametric correlation test, was used to test each candidate metric. Spearman's rho was used as the candidate metric data and disturbance measures were not normally distributed. Correlations were run with each candidate metric against each site's soil, Land Disturbance Index (LDI), Ohio Rapid Assessment Method (ORAM), and relative water quality parameter disturbance measures (see Section 3.1-3.4 for an in-depth description of the disturbance measures). The candidate metric correlations were tested using data from both regions and with the Coastal Plain and Piedmont regions separately. A p-value of 0.15 was considered significant.

Table 7.1 Amphibian Ratings and Adult Conversion Table

Species	Common Name	Amphibian C of C	Larvae = 1 Adult	Eggs or Egg Masses = 1 Adult	Tolerant Species (C of C ≤ 3)	Sensitive Species (C of C ≥ 6)	EW, HW, Seep Species Specific*	State-listed	Comments (Pied / CP)
Acris crepitans	Eastern Cricket Frog	2	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist- open grassy pond margins, ditches, marshy areas w/ shallow h2o (Pied)
Acris gryllus	Coastal Plain Cricket Frog	2	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist-grassy margins of ponds, streams or ditches (Pied / CP)
Ambystoma maculatum	Spotted Salamander	8	20% = 1 Adult	250 Eggs = 1 Adult		Y	0.5**		Spotted salamanders tend to use isolated or deeper headwater sites with semi permanent pools; will sometimes use other areas. (Pied)
Anura sp.	Frog or Toad species	1	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				generalist for non-identified frog calls (Pied / CP)
Bufo americanus	Eastern American Toad	1	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				generalist for non-identified frog calls (Pied)
Bufo americanus x *fowleri*	Eastern American Toad X Fowler's Toad	1	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist with short reproductive cycle and can tolerate disturbances; eggs can develop fast; can tolerate puddles, temperary pools, streams (Pied)
Bufo fowleri	Fowler's Toad	1	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist with fast-developing eggs; can tolerate disturbances; ponds, swales, streams & shallow water (Pied / CP)
Bufo sp.	Toad species	1	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist - eggs develop fast and can tolerate disturbances (Pied / CP)
Bufo terrestris	Southern Toad	1	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist- eggs develop fast and can tolerate disturbances;temporary pools, shallow water, sandy areas, flooded meadows (CP)
Desmognathus auriculatus	Southern Dusky Salamander	6	20% = 1 Adult	1 Egg Mass = 2 Adults		Y	Y		Site specific to seepage areas;do not tolerate poor water quality as well as other species do; under leaf litter logs, eggs in moss cavities in summer, small streams, eggs in cavities of rotten logs and under rock surfaces (CP)
Desmognathus fuscus	Northern Dusky Salamander	6	20% = 1 Adult	1 Egg Mass = 2 Adults		Y	Y		Site specific to seepage areas; do not tolerate poor water quality as well as other species do (Pied)
Eurycea chamberlaini	Carolina Dwarf Salamander	6	20% = 1 Adult	1 Egg Mass = 2 Adults		Y	Y		Site specific to seepage areas need better habitat (Pied / CP)
Eurycea cirrigera	Southern Two-lined Salamander	3	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Can be found in perennial streams, seem to have higher tolerance to lower water quality conditions (Pied/CP)
Hemidactylium scutatum	Four-toed Salamander	10	20% = 1 Adult	1 Egg Mass = 2 Adults		Y	Y	SC	Site specific to seepage area; needs mature forest & developed moss cavities to lay eggs; found in bogs; State SC (Pied)
Hyla chrysoscelis	Cope's Gray Tree Frog	5	20% = 1 Adult	1 Egg Mass = 2 Adults			Y		Site specific to ephemeral ponds or deeper water headwater wetlands; adults rarely found (CP)
Hyla squirella	Squirrel Treefrog	6	20% = 1 Adult	1 Egg Mass = 2 Adults		Y			Will use ephemeral wetlands & deeper water headwater wetlands; can also use ditches and other areas; found in urban settings (CP)
Plethodon cinereus	Eastern Red-backed Salamander	4	20% = 1 Adult	1 Egg Mass = 2 Adults					Not specific to needing headwater wetlands or ephemeral ponds; does need mature forested habitat, I.e. quality buffer; found under rocks and leaf litter/ logs in forested areas (CP)

Species	Common Name	Amphibian C of C	Larvae = 1 Adult	Eggs or Egg Masses = 1 Adult	Tolerant Species (C of C < 3)	Sensitive Species (C of C > 6)	EW, HW, Seep Species Specific*	State-listed	Comments (Pied / CP)
Plethodon glutinosus	Northern Slimy Salamander	4	20% = 1 Adult	1 Egg Mass = 2 Adults					Not specific to needing headwater wetlands or ephemeral ponds, does need mature forested habitat; I.e. quality buffer; found in wooded areas in burrows, under debris; ubiquitous; eggs hard to find in logs and among roots (Pied / CP)
Pseudacris crucifer	Northern Spring Peeper	3	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Uses ephemeral wetlands & deeper water headwater wetlands; can also use ditches and other areas, woodland areas, forest litter, brush areas, swamps, ponds , and ditches (Pied / CP)
Pseudacris feriarum	Upland Chorus Frog	4	20% = 1 Adult	1 Egg Mass = 2 Adults			Y		Site specific to ephemeral ponds or deeper water headwater wetlands; uses semi-permanent pools (Pied / CP)
Pseudacris ocularis	Little Grass Frog	6	20% = 1 Adult	1 Egg Mass = 2 Adults		Y	Y		Site specific to ephemeral ponds or deeper water headwater wetlands (CP)
Pseudacris sp.	Chorus Frog species	4	20% = 1 Adult	1 Egg Mass = 2 Adults		Y			If not identified to species, then 4 (Pied / CP)
Pseudotriton montanus	Eastern Mud Salamander	7	20% = 1 Adult	1 Egg Mass = 2 Adults		Y	Y		Site specific to seepage areas; need mature forest; muck soil beneath logs and stones on banks of seepages, springs, brooks, or swamps (Pied)
Pseudotriton ruber	Red Salamander	7	20% = 1 Adult	1 Egg Mass = 2 Adults		Y			Need seepage area or small perennial stream with quality habitat to reproduce in leaf litter accumulation, brooks, nearby crevices and burrows, under logs, stones and debris. (Pied)
Rana catesbeiana	American Bullfrog	1	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist (Pied / CP)
Rana clamitans	Northern Green Frog	2	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist (Pied / CP)
Rana palustris	Pickerel Frog	3	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Generalist (CP)
Rana sp.	Frog species	1	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Consider generalist if not identified to species (Pied / CP)
Rana sphenocephala	Southern Leopard Frog	3	20% = 1 Adult	1 Egg Mass = 2 Adults	Y				Ephemeral pond or other areas, ponds, ditches and swamps, lake and stream margins (Pied / CP)
Scaphiopus holbrookii	Eastern Spadefoot	8	20% = 1 Adult	1 Egg Mass = 2 Adults		Y	Y		Ephemeral pond quality habitat, sandy lowlands in burrows; needs temporary pools to breed (Pied)
Urodela sp.	Salamander or Newt species	4	20% = 1 Adult	1 Egg Mass = 2 Adults					If not identified to species, consider to be a 4 (Pied)

* EW = Ephemeral Wetland, HW = Headwater Wetland

** *Ambystoma maculatum* requires ephemeral, headwater, or seepage specific wetlands half the time, but can also be found in less pristine environments such as road-side ditches or small retention areas.

SC = Species of Special Concern

Pied = Species found in Piedmont During headwater wetland survey

CP = Species found in Coastal Plain During headwater wetland survey

Section 7.3 Amphibian Results and Conclusions

A total of 26 amphibians, 15 frogs and toads and 11 salamanders, were identified to species (see Table 7.1) during the amphibian monitoring survey. In the Coastal Plain, 17 species were identified; 12 frog species and 5 salamander species. In the Piedmont, 19 species were identified; 11 frog species and 8 salamander species. Of the 26 species identified, 8 were frog and toad species in the *Acris*, *Bufo*, and *Rana* genus that ranked as tolerant (having a C of C value < 3). Four salamander species were ranked as sensitive (having a C of C value >6), they were; spotted salamander (*Ambystoma maculatum*), four-toed salamander (*Hemidactylium scutatum*), eastern mud salamander (*Pseudotriton montanus*), and red salamander (*Pseudotriton ruber*). One toad species, the eastern spadefoot (*Scaphiopus holbrookii*), was also ranked as sensitive. The differences between the Piedmont and Coastal Plain results were partly related to individual species distribution. The *Acris, Bufo* and *Rana* species were found in both the Coastal Plain and Piedmont, while the spotted, four-toed, mud, and red salamanders and spadefoot toad were found only in the Piedmont. The spotted, four-toed, red, and mud salamanders are primarily distributed in the Piedmont; however, the spadefoot toad does have a heavier distribution in the Coastal Plain than in the Piedmont. The eastern cricket frog (*Acris crepitans*), American toad (*Bufo americanus*), and northern dusky salamander (*Desmognanthus fuscus*) are found primarily within the Piedmont. The Coastal Plain cricket frog (*Acris gryllus*), southern toad (*Bufo terrestris*), southern dusky salamander (*Desmognanthus auriculatus*) are found primarily within the Coastal Plain which was reflected in the survey results. Other species with primarily Coastal Plain distributions which were found include the squirrel tree frog (*Hyla squirella),* little grass frog (*Pseudacris ocularis*), and eastern red-backed salamander (*Plethodon cinereus*). Pickerel frog (*Rana palustris*) and Cope's gray tree frog (*Hyla chrysoscelis*), both of which can be found throughout the state, were only found in the Coastal Plain in our study. There were 9 species found in both the Piedmont and Coastal Plain; Carolina dwarf salamander (*Eurycea chamberlaini*), southern two-lined salamander (*Eurycea cirrigera*), northern slimy salamander (*Plethodon glutinosus*), Fowler's toad (*Bufo fowleri*), spring peeper (*Pseudacris crucifer*), upland chorus frog (*Pseudacris feriarum feriarum*), bull frog (*Rana catesbeiana*), green frog (*Rana clamitans*), southern leopard frog (*Rana sphenocephala*), and other unidentified amphibians.

The correlation analysis for both regions combined resulted in more significant results than for the correlation analysis of each region separately. Therefore, the development of an IBI for use in both the Piedmont and Coastal Plain regions seemed more logical than the development of an IBI for separate regions. Table 7.2 shows the significant results of the Spearman's rho correlation analysis of both regions. Species richness had the highest number of significant correlations (p-value < 0.15) with 14 of the 38 disturbance measures showing significant correlations, while percent state-listed had zero significant correlations. Water quality disturbance measures correlated with six of the seven candidate metrics; percent HW-EW-SW, percent sensitive, percent Urodela, AQAI, percent tolerant, and species richness. Soil disturbance measures correlated with four of the seven candidate metrics; percent sensitive, percent Urodela, AQAI, and species richness. ORAM and LDI disturbance scores, which are a more general indicator of disturbance, only correlated with percent HW-EW-SW (LDI only) and species richness (both ORAM and LDI at a p-value of < 0.05).

Table 7.2 shows that HW-EW-SW metric (headwater wetland-ephemeral wetland-seepage wetland) correlated with fecal coliform and NO_2+NO_3 at a p-value < 0.1, with dissolved oxygen at a p-value < 0.05 and more weakly with relative nutrients and watershed LDI (p-value = 0.14) (see Section 3.1-3.4 for a description of disturbance measures). Percent sensitive correlated with ammonia, relative nutrients, phosphorous, zinc, and relative nutrients-metals-fecal coliform-TSS-specific conductivity at a p-value < 0.05, with fecal coliform at p-value = 0.09, and with soils pH more weakly at p-value < 0.15. Percent Urodela correlated with relative Pb-Cu-Zn, turbidity, and zinc at p-value < 0.05, with lead, TSS, phosphorous at p-value < 0.10, and with soils pH and ammonia more weakly at p-value < 0.15. AQAI correlated with soils pH at p-value < 0.05, ammonia, phosphorous, TOC, pH, and dissolved oxygen at p-value $\leq$ 0.1, and more weakly DOC at p-value = 0.13. Percent tolerant correlated with pH at p-value = 0.04 and more weakly, dissolved oxygen at p-value < 0.15. Lastly, species richness correlated with LDI (watershed and 300m), ORAM, soils copper and zinc (wetland only) at a p-value < 0.05 and with soils pH, calcium, and magnesium at p-value < 0.1 (see Table 7.2).

Table 7.2 Amphibian Significant Correlation Results with Disturbance Measures

Candidate Metric	Disturbance Measurement	Spearman ρ	Prob>|ρ|
% HW-EW-SW	Relative Fecal Coliform	-0.3556	0.0959
% HW-EW-SW	Relative NO_2+NO_3	-0.3519	0.0996
% HW-EW-SW	Relative Nutrients	-0.3138	0.1448
% HW-EW-SW	Watershed LDI	-0.3189	0.1381
% HW-EW-SW	Relative Dissolved Oxygen (%)	0.5298	0.0093
% HW-EW-SW	Relative Dissolved Oxygen (Mg)	0.5104	0.0128
% Sensitive	Relative Ammonia	-0.4356	0.0377
% Sensitive	Relative Fecal Coliform	-0.3607	0.0909
% Sensitive	Relative Nutrients	-0.4197	0.0462
% Sensitive	Relative NutrientsCuPbZnFCTSSCondo	-0.4299	0.0406
% Sensitive	Relative NutrientsMetalsFCTSSCondo	-0.381	0.0728
% Sensitive	Relative Phosphorous	-0.4142	0.0494
% Sensitive	Relative Zinc	-0.4774	0.0212
% Sensitive	Soils (pH, wetland)	0.3128	0.1462
% Sensitive	Soils Mean (pH)	0.3179	0.1394
% Urodela	Relative Ammonia	-0.3171	0.1403
% Urodela	Relative Lead	-0.3612	0.0903
% Urodela	Relative PbCuZn	-0.4597	0.0273
% Urodela	Relative Phosphorous	-0.3617	0.0899
% Urodela	Relative TSS	-0.3815	0.0725
% Urodela	Relative Turbidity	-0.5142	0.0144
% Urodela	Relative Zinc	-0.5159	0.0117
% Urodela	Soils (pH, stream)	0.3285	0.126
AQAI	Relative Ammonia	-0.3608	0.0908
AQAI	Relative DOC	-0.3281	0.1265
AQAI	Relative Phosphorous	-0.3583	0.0932
AQAI	Relative Toc	-0.3513	0.1002
AQAI	Relative Dissolved Oxygen (%)	0.3513	0.1002
AQAI	Relative Dissolved Oxygen (Mg)	0.3607	0.0909

Table 7.2 Amphibian Significant Correlation Results with Disturbance Measures

Candidate Metric	Disturbance Measurement	Spearman ρ	Prob>|ρ|
AQAI	Relative pH	0.3553	0.0962
AQAI	Soils (pH, stream)	0.4142	0.0495
AQAI	Soils (pH, wetland)	0.4537	0.0297
AQAI	Soils Mean (pH)	0.5299	0.0093
% Tolerant	Relative Dissolved Oxygen (%)	-0.3106	0.1492
% Tolerant	Relative Dissolved Oxygen (Mg)	-0.319	0.1379
% Tolerant	Relative pH	-0.4393	0.036
Species Richness	Soils (pH, stream)	-0.4118	0.0509
Species Richness	Soils (pH, wetland)	-0.3575	0.094
Species Richness	Soils (Zn, stream)	-0.341	0.1113
Species Richness	Soils (Zn, wetland)	-0.4292	0.041
Species Richness	Soils (Cu, stream)	-0.5966	0.0027
Species Richness	Soils (Cu, wetland)	-0.35	0.1016
Species Richness	Soils Mean (Zn)	-0.3774	0.0758
Species Richness	Soils Mean (Cu)	-0.4401	0.0356
Species Richness	ORAM (no outliers)	0.5786	0.0038
Species Richness	Relative Calcium	-0.3655	0.0864
Species Richness	Relative Magnesium	-0.3694	0.0827
Species Richness	Watershed LDI	-0.5975	0.0026
Species Richness	300 M LDI	-0.5532	0.0062

Based on the results shown in Table 7.2, five of seven candidate metrics were chosen for the IBI; percent HW-EW-SW, percent Sensitive, percent Urodela, AQAI, and species richness. Percent state-listed, which had no significant correlations, and percent tolerant, which only correlated with dissolved oxygen and pH, were not chosen. The distribution (excluding outliers) and natural gaps in the data of the metric results were used to determine the metric score assignments for each metric set of results. Table 7.3 shows the metric scores assigned for each metric result. For example, the metric scores results for species richness ranged between 0 and 11 therefore less than three types of species were assigned a metric score of "0", three to four species were assigned a metric score of "3", five to seven species were assigned a metric score of "7" and eight or greater species were assigned a metric score of "10" (see Table 7.3).

Table 7.3 Metric Score Assignment for Amphibians

Metric	0	3	7	10
AQAI	<3	<5	<7	≥7
% Sensitive	<5	<10	<25	≥25
% HW-EW-SW	<20	<50	<75	≥75
% Urodela	<10	<30	<50	≥50
Species Richness	<3	<5	<8	≥8

The metric results, metric scores, and final amphibian IBI score is shown in Table 7.4. The final IBI scores ranged between 0 and 27 in the Coastal Plain and 7 and 37 in the Piedmont. Battle Park and Boddie Noell, two highly urban sites, had the lowest IBI scores of 0, and East Fayetteville North had the third lowest IBI score of 3. East Fayetteville North is a fairly natural site so the low IBI score was unexpected. Only four species, all frogs and toads, were found at this site. East Fayetteville South had the highest score of 27, followed by Nahunta and PCS with 19 and 17, respectively. East Fayetteville South is a more natural site with an intact buffer, so the high score was not surprising. Ten species of amphibians were found during the survey at East Fayetteville South, including four species of salamanders. Nahunta and PCS are both mature forests, although Nahunta is surrounded by agricultural development and PCS has a large forested buffer.

In the Piedmont, the Moonshine, Kelly Road, Fire Tower, and Pete Harris sites had the lowest IBI scores of 7, 10, 13, and 13, respectively. Duke Forest and Walmart had the highest scores of 37 and 30, respectively. Spring Garden, East of Mason, and Black Ankle Non-Powerline tied for third with a score of 23. Moonshine is an urban site located near I-40/440 in Raleigh and is not as wet as some of the other sites so the low score was not surprising. No HW-EW-SW species or sensitive species were found at this site. Kelly Road is a mature forest with a number of invasive plant species, located directly downstream of Old US 1. A number of green and bull frog (*Rana clamitans* and *Rana catesbeiana*) tadpoles were found in the ponded area on the northwestern side of the site adjacent to a farm pond berm. Green frogs and bull frogs are tolerant species that indicate this ponded area was not isolated from the adjacent farm pond. Fire Tower and Pete Harris both have mature forests, but Pete Harris has nearby agricultural lands and Fire Tower is adjacent to a car junkyard, downstream of a mobile home park, and is also bisected by Bensalem Church Road. Pete Harris did have two four-toed salamanders (*Hemidactylium scutatum*) which are state-listed species of special concern and have a C of C rating of 10; however, a number of upland chorus frog eggs (*Pseudacris feriarum*) which are more tolerant species, were found on this site. Three of the sites, Duke Forest, East of Mason, and Troxler had small retention areas or large persistent puddles that were located in the adjacent wetland buffer. These ponded areas located in the buffer had spotted salamander eggs (*Ambystoma maculatum*). The Duke Forest site had a large quantity of egg masses in the retention area located next to Eubanks Road, resulting in close to 25 spotted salamander adults being found at this site. This large quantity of spotted salamanders was the main reason the Duke Forest site had the highest rating. Duke Forest is a mature forest with a mature forested buffer on three sides, representing good habitat for spotted salamanders. However, the site is not very wet in general and therefore may not provide the best habitat for other species of amphibians. Walmart is the most urban of the Piedmont sites with high-density development located in much of the watershed and adjacent buffer. The Walmart site itself has mature forest and did have the lowest value for relative nutrients – metals – TSS – Fecal Coliform – Conductivity, indicating reasonably good water quality (see Table 3.2). Only two individual salamanders were found at this site during the entire survey; the eastern mud salamander (*Pseudotriton montanus*) and the red salamander (*Pseudotriton ruber*). Both were considered to be sensitive species with C of C ratings of “7”. Spring Garden is a high-quality Piedmont site with a mature forested wetland and buffer, so it was not unexpected for this site to receive one of the higher scores. East of Mason, like Kelly Road, is a mature forest with a forested buffer located downstream of Old US 1; however, this site does not have nearly as many invasive plant species as Kelly Road and there is a more developed microhabitat of moss-covered hummocks. The better habitat resulted in 11 species being found at the East of Mason site, including four salamanders, one of which was the state-listed four-toed salamander. Black Ankle Non-Powerline is also a mature forested wetland, although with some agricultural influences upstream. The high number of upland chorus frogs found at Black Ankle Non-

Powerline (112 adults based on egg mass counts) resulted in a 90% EW-HW-SW metric, giving Black Ankle Non-Powerline one of the higher IBI scores.

The more general disturbance measures, ORAM and LDI, were not as good at predicting correlations with candidate amphibian metrics. The results of the metric correlations suggest that amphibian populations are more influenced by water quality and soil chemistry than by surrounding land cover or general wetland assessments. Some IBI results, like a high scoring value for reference site Spring Garden, were expected. Less expected was the even higher IBI score for Duke Forest. Duke Forest rarely has adequate water to yield water quality samples. Due to these unpredictable results, the limitations in the methodology should be noted here. Amphibian surveys based on time tend to be more qualitative than quantitative, although the amphibians that were inadvertently collected in sweep nets, stove-pipe samples, and funnel traps during the macroinvertebrate survey are more representative of a quantitative survey. In this study, the majority of the amphibian observation records used in the analysis were taken during the qualitative amphibian survey and not the more quantitative macroinvertebrate survey. Using time-surveys as opposed to a more quantitative method (like pit-traps with silk fencing), made more sense as quantitative amphibian surveys can be highly time-consuming. Such time-consuming surveys would not be practical if the NC Amphibian IBI were ever to be implemented into a state wetland monitoring program. In addition, a quantitative survey might not capture as many species thereby potentially missing sensitive or state-listed amphibians. A second limitation of the survey was the recording of amphibians found within buffer ponded areas. These ponded areas were typically man-made and provided additional habitat for amphibians. These tiny ponded areas generally do not affect the LDI or ORAM score and it is questionable if they would affect soil and water quality of the nearby wetland, although they did affect the amphibian survey results.

Further testing of the NC Headwater Wetland Amphibian IBI is needed in order to completely determine the accuracy of this method and what other wetland land ecosystems types this method would be applicable to. The additional testing of the chosen amphibian metrics on a larger number of sites than the 23 used in this study would add credence to the Amphibian IBI developed for this study.

Table 7.4 Metric Results, Metric Scores, and Amphibian IBIs

Region	Site Name	Metric Results					Metric Scores					IBI
		AQAI	% Sensitive	% HW-EW- SW	% Urodela	Species Richness	Metric AQAI	Metric % Sensitive	Metric % HW-EW-SW	Metric % Urodela	Metric Score Species Richness	Amphib IBI
Coastal Plain	Battle Park	0	0	0	0	0	0	0	0	0	0	0
	Boddie Noell	0	0	0	0	0	0	0	0	0	0	0
	East Fayetteville North	2.6	0	0	0	4	0	0	0	0	3	3
	Cox	2.63	0	0	2.5	7	0	0	0	0	7	7
	Hog Farm Lower	2	0	0	33.33	3	0	0	0	7	3	10
	Bachelor	2.18	9.09	18.18	9.09	9	0	3	0	0	10	13
	Hog Farm Upper	4	0	0	50	2	3	0	0	10	0	13
	Rough Rider	2.92	7.69	0	15.38	8	0	3	0	3	10	16
	PCS	3.22	0	0	33.33	5	3	0	0	7	7	17
	Nahunta	4	7.14	92.86	7.14	3	3	3	10	0	3	19
	East Fayetteville South	3.07	18.52	18.52	30.86	10	3	7	0	7	10	27
Piedmont	Moonshine	2.71	0	0	8.47	5	0	0	0	0	7	7
	Kelly Road	2.08	0	18.07	0	8	0	0	0	0	10	10
	Fire Tower	2	14.29	14.29	28.57	3	0	7	0	3	3	13
	Pete Harris	3.52	2.41	68.67	2.41	4	3	0	7	0	3	13
	Umstead	2.33	8.84	25.41	8.84	8	0	3	3	0	10	16
	Troxler	4.08	6.32	93.91	0.47	4	3	3	10	0	3	19
	Black Ankle Powerline	3.89	1.67	93.1	1.67	7	3	0	10	0	7	20
	Black Ankle Non-Powerline	3.85	2.39	90.22	3.97	8	3	0	10	0	10	23
	East of Mason	4	2.27	95.13	2.27	11	3	0	10	0	10	23
	Spring Garden	3.94	4.8	84.8	16	5	3	0	10	3	7	23
	Walmart	7	100	16.67	100	2	10	10	0	10	0	30
	Duke Forest	6	52.78	69.32	52.78	4	7	10	7	10	3	37

Section 8 – Aquatic Macroinvertebate Monitoring Section

Section 8.1 Aquatic Macroinvertebrates Introduction and Background

Wetlands provide important habitat for a large variety of aquatic macroinvertebrates. Many of these aquatic macroinvertebrates complete their life cycles within wetlands while others utilize wetlands during part of their life cycle (U.S. EPA 2002d). As was discussed earlier, North Carolina water quality has been affected by rapid watershed development. Basinwide reports of some of the major NC basins (e.g. Catawba and Tar-Pamlico) have shown that macrobenthos bioclassification ratings in streams and rivers have shown a trend to decrease over time (NC DENR 1999a, 1999b, 2004a, 2004b). This is potentially related to agriculture and urbanization within these watersheds. Aquatic macroinvertebrates have proven to be useful bioindicators of aquatic environments due to their ubiquitous presence and sensitivity to environmental stressors (U.S. EPA 2002d). The following section will discuss basic information about macroinvertebrates and how they are affected by environmental stressors. Information in this introduction and background section will include the advantages and disadvantages of using macroinvertebrates as bioindicators.

Macroinvertebrates are aquatic invertebrates such as insects, crustaceans, molluscs, and worms that dwell in nearly all of our aquatic habitats. Though macroinvertebrates occupy all vertical stratas of the water column, they are most common in the benthic zone of a body of water, i.e. the bottom layer of sediment, substrate, and organic matter (USGS 1999). The majority of macroinvertebrates found in streams and wetlands are found in the form of pre-adults. These immature insects spend their time on the bottom of wetlands and streams but as adults leave the water to live the rest of their life on land, and in the case of some families, only for a few hours.

Aquatic insects usually develop in one of two ways. One way is by complete metamorphosis, wherein development consists of four stages; eggs, larvae, pupa, and adult. The other way is by incomplete metamorphosis. Except for the mayfly that has two winged growing stages, incomplete metamorphosis has three main stages of development; eggs, nymph, and adult. Metamorphosis is often severe and drastic, and the immature insects bear no resemblance to their adult stage. The difference between these two evolutionary strategies lies in how the middle stage of development transforms the immature into an adult. In complete metamorphosis larvae wrap themselves in a cocoon-like structure and then gradually reconstitute themselves into adults. In incomplete metamorphosis immature insects are called nymphs and they reach adulthood by shedding their skin a number of times until they finally emerge as adults. In this case the immatures often do resemble the adults they will become except that they will not get their wings until reaching adulthood (McDonald *et al*. 1990).

Macroinvertebrates are important to aquatic foodwebs. The primary food source of macroinvertebrates are phytoplankton, algae, bacteria and other micro-organisms floating on the water surface (biofilms), and organic material that falls or washes into the water from the above vegetation. Macroinvertebrates in turn are consumed by other macroinvertebrates, fish, and waterfowl (Mulholland *et al*. 2000, Hubert and Krull 1973). Midge larvae, or bloodworms, spend their life cycle buried in wetland sediment and or benthic organic matter where they become food for fish, frogs, and birds. When these pupae leave the water as adults, they become food for fish and birds who feed on the water surface (Weller 1981). Waterfowl managers place a premium on scientific data as it regards insect ecology because in the 1960's and 1970's it was discovered that insects were important waterfowl food as well as indicators of polluted water (Murkin *et al*. 1987). According to Bellrose (1980) and Weller (1999), taxonomic diversity is an indicator of the potential for supporting a variety of game and non-game birds and species composition indicates the presence of those particular taxa that are important in wetland bird diets.

Macroinvertebrates, particularly those of the feeding group known as shredders, are important to the breakdown of organic matter in streams and wetlands. For instance, researchers in North Carolina applied an insecticide to a southern Appalachian Mountain headwater stream. This thinning of the macroinvertebrate population resulted in 25-28% decrease in the breakdown of leaf litter annually. This in turn reduced fine particulate organic matter to 33% of its normal annual production. This fine particulate organic matter would have been made available to other larger invertebrates and fishes as energy had the macroinvertebrate population not been thinned (Bouchard 2004, Cuffney *et al*. 1990).

There are many factors that can affect the diversity and/or biomass of macroinvertebrates within wetland environments. These factors include plant biomass, frequency and duration of flooding, time of year, salinity, physical alterations through mowing, and water quality (Higgins *et al*. 1990, Neckles *et al*. 1990, Hubert and Krull 1973, Kreis and Johnson 1968, Kaminski and Prince 1981, U.S. EPA 2002c).

In Midwestern prairie wetlands, invertebrate densities are positively linked to the biomass of vegetation because plants provide submersed habitats for invertebrates much more than open water (McCrady *et al*. 1986, Engel 1990); however, if vegetation gets too dense, species richness declines, possibly because of the development of anoxia, or the absence of oxygen (Kaminski and Prince 1981a,b). In a southeastern study of macroinvertebrates in the Okefenokee Swamp, Kratzer and Batzer (2007) found little variation of macroinvertebrate species among the five vegetation types they sampled. However, this was not the case in a study of macroinvertebrate wetlands in another southeastern study located in southwest Georgia depressional wetlands where Battle and Golladay (2001) found that marsh habitats had greater invertebrate taxon richness and density than forested habitats.

Hydroperiod length greatly affects macroinvertebrate densities. Seasonally flooded freshwater wetlands have remarkable similarities in community structure to each other across a wide range of criteria. Depressions, which flood for short durations during the year, have high densities of aquatic invertebrates with low taxonomic diversities (Wiggins *et al*. 1980). This also holds true for temporary ponds, regardless of physiographic region, season of flooding, substrate type, water chemistry, or vegetative cover (Neckles *et al*. 1990). The effects of water regime are of the utmost importance in maintaining distinct communities in these habitats. Early in the growing season in an undisturbed seasonal wetland in North Dakota, invertebrate densities were much higher than a flooded summer-fallow wetland (Swanson *et al*. 1974). Regular flooding and drying is essential to maintaining high densities of macroinvertebrates in seasonal wetlands such as North Carolina headwater wetlands. One reason for the breeding success of macroinvertebrates in temporary rather than permanent waters is the abundance of organic food material created when floodwaters wash over already dead vegetation and organic matter. Also, frequent drying of the wetland results in a reduction of the number of predators on macroinvertebrates during all stages of their life cycle. Semipermanent flooding as opposed to temporary flooding can cause dramatic reductions in densities of total invertebrates and the dominant taxa (Neckles *et al*. 1990).

The usefulness of species composition for inferring hydrologic conditions of prairie wetlands has been demonstrated with macroinvertebrates (Neckles *et al*. 1990, Bataille and Baldassarre 1993), and species composition is used as an indicator of how long and in what seasons a wetland has surface water. A shift from herbivorous to detrivorous species of macroinvertebrates, and in the ratio of open-water forms to forms that live in vegetation suggests that a prairie wetland has recently undergone inundation (Murkin and Kadlec 1986, Murkin *et al*. 1991). In particular, densities of non-predatory midges (*Chironomidae*) increase greatly during the first year after flooding, and within this family, species characterized by the greatest tolerance for low oxygen levels increase the most (Murkin and Kadlec 1986b). Data from North Dakota indicate that even the wetlands that are flooded only temporarily have many more species than non-wetland areas (Euliss *et al*. 1993). Within wetlands, flooding can increase invertebrate richness somewhat, but perhaps only during the initial year of flooding.

Temporal considerations also play a part in macroinvertebrate numbers. In surveys of macroinvertebrates in a greentree reservoir in Tennessee there were significant differences in populations across seasons. The diversity was highest in early autumn with amphipods and isopods prevalent and insect species declining. Diversity was lowest in winter with isopods and amphipods being most numerous (Hubert & Krull 1973).

Water salinity can also affect the specific assemblages within a wetland. In the Midwest certain invertebrate assemblages are found in hypersaline prairie wetlands. Macroinvertebrates tolerant of salt in wetlands are certain species of midges, mosquitoes, aquatic worms, dragonflies, and water bugs (Kreis and Johnson 1968, Swanson *et al*. 1974).

A study of physical alteration through mowing of delta marsh wetlands in Manitoba Canada actually showed there was a positive effect on the variety of invertebrate families found in wetlands. In this study, the variety of invertebrate families was usually greater in wetlands that had been mowed than in otherwise similar wetlands that had not been mowed, especially if the cut vegetation was not removed. In addition, wetlands whose emergent vegetation had been rototilled had a greater variety of invertebrates than an otherwise similar undisturbed wetland (Kaminski and Prince 1981b).

The water quality of aquatic habitats can affect the diversity, species assemblages, and biomass of benthic macroinvertebrates. Benthic macroinvertebrates are good indicators of pollution and water quality because they live in the water for all or most of their life, stay in areas suitable for their survival, are easy to collect, are relatively easy to identify in a laboratory, and differ in their tolerance to amount and types of pollution. Pollutants and physical changes that affect water quality which have been shown to impact aquatic macroinvertebrate taxa include nutrients such as nitrogen, phosphorous, and potassium, sediments, oxygen levels, and man-made chemicals

(Rosenberg and Resh 1993, Murkin et. al. 1991, Welch et. al. 1991, U.S. EPAc, Kaller and Kelso 2007).

Certain assemblages of macroinvertebrates are useful indicators of the trophic, or nutrient level of a lake, and may also be useful for identifying wetlands with excessive nutrient levels. Species from the functional feeding group known as “scrapers” (macroinvertebrates such as the *Heptagenid* and *Baetid* mayflies that graze on algae) tend to increase with eutrophication, at least in the early stages of enrichment (Rosenberg and Resh 1993). Eutrophication brought on by the input of chemical nutrients also generally increases the abundance of macroinvertebrates (N.H. DES). The density of midges increases with larger increases in wetland fertility (Murkin *et al*. 1991). In addition, the density of midges has been recommended as an efficient indicator in some situations of secondary production in lakes (Welch *et al*. 1988). Agricultural practices that increased nutrient levels of potassium and phosphorous in wetlands have been shown to strongly negatively correlate with species diversity and Chironomidae abundance while positively correlate with Culicidae biomass (Chipps *et. al*. 2006). In addition, polluted wastewater with excessive amounts of nutrients, sediments, and toxic metals was found to cause the macroinvertebrate trophic structure to become less complex (Reiss and Brown 2005).

Another direct link between excessive nutrient loads in a system and macroinvertebrate populations has to do with periphyton. Periphyton are benthic algae, bacteria, and associated organic material that attaches itself to submerged surfaces in most aquatic systems (Lamberti *et al*. 1983). Wherever periphyton mats are found, they are vital to macroinvertebrates as a food source and as habitat structure. In the Florida Everglades, periphyton is responsible for more than 50% of the primary producer standing stock. Nutrients, mainly phosphorus, that empty into the Everglades ecosystem from farms near Lake Okeechobee are negatively impacting periphyton levels. While low levels of phosphorus stimulate periphyton productivity, high levels of phosphorus cause mats of periphyton to break up and completely disappear (Smith 2004).

A shift from herbivorous and filter-feeding species to sediment-burrowing species may signal that major turbidity and sedimentation changes have happened or are occurring in an aquatic system. This happens because a reduction in light penetration kills submersed plants and their attached algae, and these plants are home to a characteristic assemblage of herbivorous species, while burrowing species can continue to exploit the ever-increasing soft sediments associated with sedimentation of the wetland or stream benthos. Broadly speaking, reductions in the variety of invertebrates may mean that turbidity and sedimentation have been severe (U.S. EPAc).

Oxygen levels have also proven to be a factor that can affect macroinvertebrate populations. In the absence of excessive amounts of organic matter, flowing water has lots of oxygen available for macroinvertebrates. This use as an "indicator" of water quality has been occurring for many years. For example, stoneflies are often considered to be excellent examples of macroinvertebrates that need clean water and high levels of dissolved oxygen to thrive. But macroinvertebrates such as worms and midges are usually indicators of dirty water and low levels of dissolved oxygen (Kaller and Kelso 2007).

Agricultural chemicals such as insecticides have been shown to be detrimental to mayflies and amphipods while midges and adult water beetles are less sensitive. In general, herbicides are not as acutely lethal to invertebrates as are insecticides (Buhl and Faerber 1990). In a study in The

Netherlands, macroinvertebrate species were shown to have pollutant-specific tolerance levels to chemical compounds. However, interpretation of the effects of a mixture of numerous chemical compounds can be difficult since species have tolerance levels that are pollution specific. Therefore, using macrobenthos species as bio-indicators to classify surface waters polluted with a variety of chemical pollutants is less feasible (Sloof 1983).

Macroinvertebrates have proven to be useful bioindicators of the health of an aquatic system due to their sensitivity to water quality and changes in their environment. While there are many works on using macroinvertebrates as health indicators of aquatic habitats such streams, rivers and lakes the body of work on the equivalent analyses of macroinvertebrates in wetlands is considerably less extensive, mainly because the use of macroinvertebrates in wetlands as bioindicators is in its infancy (Rader *et al*. 2001). Biological assessments in lakes and/or streams and rivers with the use of macroinvertebrates has been intiated in 48 states including Florida, Minnesota, Montana, North Dakota, Ohio and North Carolina (Reiss and Brown 2005, NC DWQ 2006). Wetland aquatic macroinvertebrate communities differ from stream communites due to the differences in substrate, dissolved oxygen levels in the water column, hydroperiod, lack of flow, and annual water fluctuations. Wetland communities include most of the major aquatic groups of macroinvertebrates and it has been speculated that macroinvertebrates may be usable as appropriate indicators of environmental integrity (Reiss and Brown 2005). Already, states such as Ohio, Minnesota, Maine and Florida have developed macroinvertebrate IBIs for wetland usage (U.S. EPA 2002d). There are a number of notable advantages to using macroinvertebrates as bioindicators in wetlands including: 1) macroinvertebrates have a wide distribution and are ubiquitous; 2) there are a large number of macroinvertebrate species that have a wide range of responses to pollution and contaminants; 3) the sampling methods of macroinvertebrates are often simple procedures and is a skill easily learned; 4) macroinvertebrates can easily be used in experimental studies (e.g., bioassays) (Rader *et al*. 2001).

While there are notable advantages to using macroinvertebrates as bioindicators of wetland quality, there are also a number of disadvantages that need to be addressed. The disadvantages of using macroinvertebrates as bioindicators in wetlands are much the same as for other aquatic habitats. The following summarizes the disadvantages of using macroinvertebrates as bioindicators: 1) many taxa are difficult to identify to a low enough taxonomic level to be useful as bioindicators, especially at the different developmental stages of macroinvertebrates like instars or larvae; 2) many macroinvertebrates are short-lived, their life spans being measured in terms of days and weeks, not months or years. Therefore, sampling times during the year are limited and must reflect known aquatic macroinvertebrate life cycles; 3) sampling and processing that goes into obtaining macroinvertebrate site data can be time-consuming and expensive. The proper sorting, sub-sampling and enumeration of specimens are labor intensive, and some families have to be mounted on slides for identification; 4) additional monetary expenses may occur with macroinvertebrate identification needs when outsourcing to independent labs is necessary for proper identification of macroinvertebrates (Lane *et al*. 2003); 5) wetland macroinvertebrates such as water bugs and water beetles are highly mobile and while responses to pollution for aquatic macroinvertebrates are well known, the tolerances of wetland taxa to pollution are largely unknown (Batzer *et al*. 1999); and finally, 6) sampling is difficult during dry years when there is no water in wetlands (Rosenberg and Resh 1993).

Even with the known difficulties of using macroinvertebrates as bioindicators, a number of studies have been done which effectively identified macroinvertebrate metrics within aquatic habitats, including wetlands. The "EPT" metric has been found to be highly useful as a bioindicator of poor water quality and has been commonly used. "EPT" are those taxa of aquatic macroinvertebrates that are intolerant of pollution in streams and wetlands and refers to three insect orders; the Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (Lenat and Penrose 1996). These three taxa were first recognized as being intolerant to pollution in 1928 at the same time that scientists also first recognized the use of macroinvertebrates to monitor water quality. The NC DENR, Division of Water Quality Biological Assessment Group has found that the EPT taxa richness correlates with stream and water quality in the different regions of North Carolina (Eaton and Lenat 1991). The EPT metric has also been used to assess low-gradient stream quality in 5 other mid-Atlantic states (Maxted et. al. 2000). The use of the EPT metric in depressional wetlands in Minnesota was also found to be a useful indicator of wetlands that had been influenced by agricultural and urban stormwater runoff. Another wetland study in Montana used a similar metric, POET, (Plecoptera, Odonata, Ephemeroptera and Trichoptera) which included another sensitive order, dragonflies (Odonata) (Rader *et al*. 2001). Currently, monitoring groups throughout the US have adopted EPT taxa richness and percent abundance as a useful measure of stream water quality (Lenat and Penrose 1996).

There are a number of other metrics that have been identified as correlating with water quality in aquatic systems. The most common pollution-tolerants are the aquatic worms of the sub-order *Oligochaeta*, the leeches of the sub-class *Hirudinea*, and members of the *Chironomidae* family, commonly referred to as "blood worms", or non-biting midges (Kratzer and Batzer 2007). Percent Chironomidae has been used as a metric to indicate poor water quality (Rader *et al*. 2001). Some of the other metrics that have been used in the development of IBIs include family diversity and richness, taxa richness, abundance of individuals, percent leech / sponge / clam, percent crustacea / mollusca, percent dominance of the most dominant three taxa, percent predators and percent intolerant/tolerant taxa etc (U.S. EPA 2002c, Rader *et al*. 2001).

Aquatic macroinvertebrates are diverse and play an important role in NC wetlands. As was previously discussed, studies have shown that macroinvertebrate diversity and abundance (biomass) is affected by both natural and human induced influences such as vegetation, hydrology, season, salinity and modifications to the physical (e.g. mowing or logging) and chemical (water quality) wetland conditions. NC wetland water quality has been affected by surrounding land-use. Studies in North Carolina, similar to other regions of the US, have developed metrics and standard sampling procedures for use in river and stream aquatic habitats to detect stressors related to water quality (NC DWQ 2006) but this has not been done for NC wetlands. The following methodology and results sections will describe the field sampling and sample processing procedures used in headwater wetlands for the North Carolina Wetland Monitoring Program grant, biological attributes to be used as potential metrics, and the results of the development of a macroinvertebrate IBI for headwater wetlands.

Section 8.2.1 Macroinvertebrate Field Methods

A pilot sampling study for macroinvertebrates was done in March 2006 at one Piedmont site, Kelly Road, and one Coastal Plain site, Nahunta. The other sites were surveyed the following month in April. Each site was scouted for appropriate sample station locations in order to choose variable microhabitats and areas that meet the requirements of each sample method. Optimally, two stations for funnel traps, two stations for sweeping, and one station for taking a stove-pipe sample were chosen. Due to the lack of standing water, three sites (Duke, Troxler, and Battle Park) could not be surveyed at all, and only 11 of the 20 sites had five (or more for the pilot study sites) macroinvertebrate stations surveyed. Table 8.1 summarizes the sampling stations located at each site. Funnel traps, sweep stations, and stovepipes were sampled in different locations (i.e. upstream near the head of the wetland, mid-stream, and downstream) as well as microhabitats such as adjacent to the bank, in open water, over roots, among vegetation etc. Figure 8.2 shows an example of a map of the macroinvertebrate sample stations at the Hog Farm Upper site. Water levels were $\geq$ 5" for the funnel trap while sweeps were taken in water as shallow as 1". The stove-pipe sampler was placed anywhere there was 2-3" of water and in a different location and microhabitat than sweep and funnel station locations when possible.

A "DWQ Headwater Wetland Macroinvertebrate Sampling Field Sheet" was completed for each site sampled (see Appendix B). The site name, county, sampler's initials, Station ID Numbers, sample technique, date, start time, funnel trap deployment time, water quality, and station description were recorded on the field sheet. The physical water quality parameters (temperature, dissolved oxygen [percent and mg/L], specific conductivity, and pH) were taken at one to three locations within the general area of the sample stations. Water quality parameters were recorded on the macroinvertebrate field sheet next to the appropriate Station ID Number. Station description information was recorded on each macroinvertebrate field sheet. Station description information included the appropriate Sample ID Number, location (upstream – close to the well at the wetland head, downstream – close to the 200' downstream water sample station [see Section 4], mid-stream somewhere in between), flow rate, pool / stream, stream width, depth, percent vegetation cover, percent shade, and substrate texture. Flow Rate (No Flow, Slow, Med, Fast) at most sites was "No Flow" or "Slow". For pools, the width x length was estimated and for streams only the width was recorded (i.e. continuous water in stream bed). The "% vegetation", "% shade", and "substrate texture" solely referred to the microhabitat where the macroinvertebrate sample stations were located. Station ID numbers were labeled at the corresponding field station with yellow pin flagging. GPS was used to record the location of the sampling stations. Photos were also taken of each sample station.

Figure 8.1 Macroinvertebrate Sample Stations at Hog Farm Upper Site

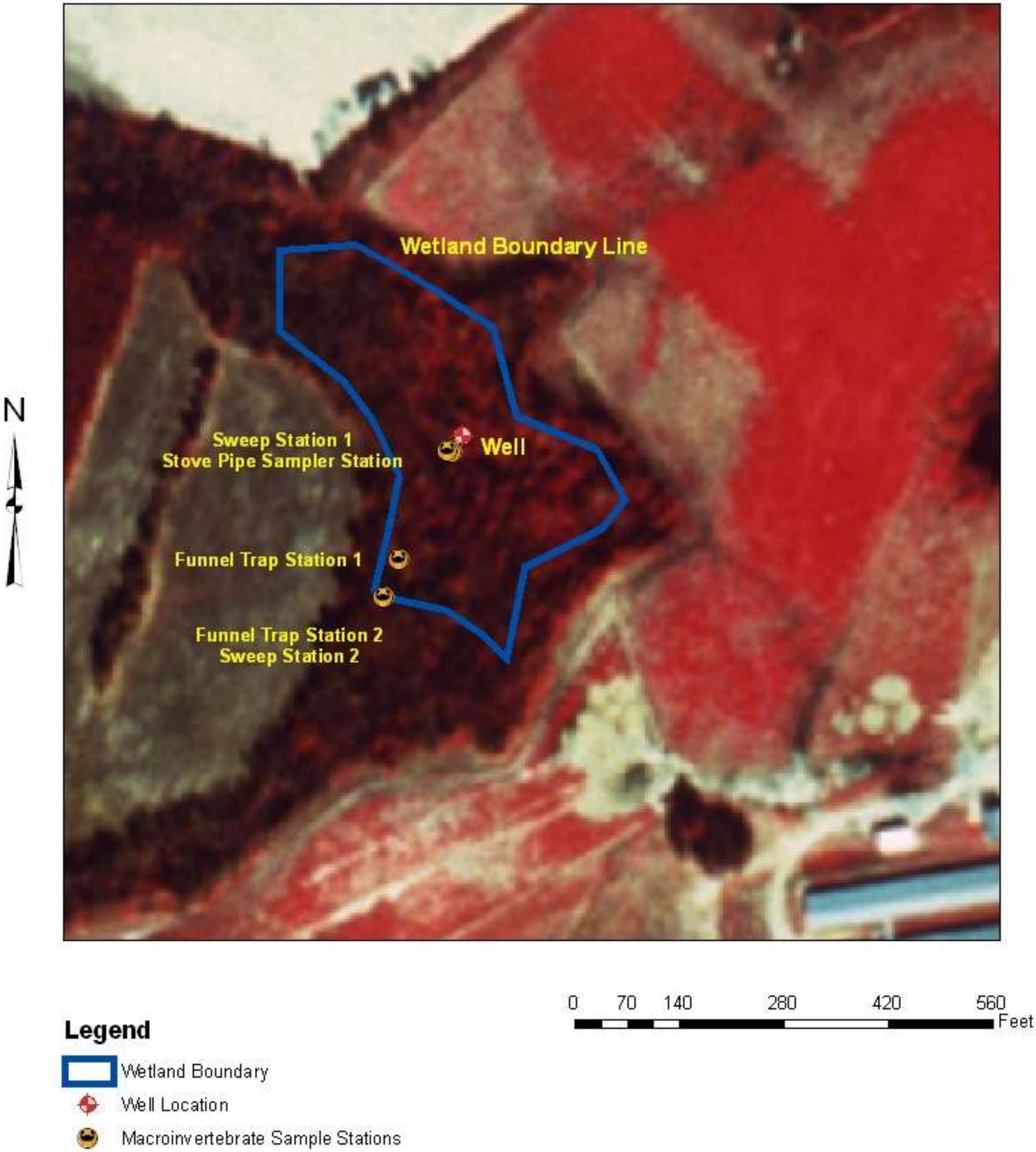


Table 8.1 Macroinvertebrate Sample Stations

	Site Name	Funnel Stations	Sweep Stations	Stove-pipe Stations	Total Stations
Piedmont	Black Ankle Non-Powerline	2	2	1	3
	Black Ankle Powerline	0	2	0	2
	Duke Forest	0	0	0	0
	East of Mason	2	1	2	3
	Fire Tower	2	2	1	3
	Kelly Rd	6	4	2	6
	Moonshine	1	1	0	1
	Pete Harris	0	0	1	1
	Spring Garden	0	3	1	4
	Troxler	0	0	0	3
	Umstead	2	2	1	3
	Walmart	2	2	1	3
Coastal Plain	Bachelor	2	2	1	3
	Battle Park	0	0	0	0
	Boddie Noell	0	1	0	1
	Cox	2	2	1	3
	East Fayetteville North	2	2	1	3
	East Fayetteville South	1	1	1	2
	Hog Farm Lower	2	2	1	3
	Hog Farm Upper	2	2	1	3
	Nahunta	6	3	2	5
	PCS	0	0	1	1
	Rough Rider	1	1	0	1

SAMPLE METHODS

FUNNEL TRAP STATIONS

The funnel trap is a semi-quantitative method used for sampling macroinvertebrates. Funnel traps are easy to use activity traps that collect a clean sample and require little processing time; however, funnel traps do not collect as wide a range of taxa as some of the other methods. Logistically, they are difficult to plan. They require two site visits approximately 24 hours apart, higher water levels than for the other methods, and predation may occur in the trap by macroinvertebrates or amphibians (U.S. EPA 2002d).

The funnel traps used at the headwater wetland sample stations were 18 x 6 inch cylinders with inverse funnels located on either side with 2" openings to allow macroinvertebrates easy entry (See Figures 8.2a and 8.2b). Each trap was made with a layer of window screen and 300-micron nitex netting. Funnel traps were deployed for approximately 24 hours (+/-2 hours). Care was taken when deploying the funnel traps to ensure air pockets existed for any amphibian that might enter the trap and that the openings remained open and were completely under water. As needed, sediment and debris were removed to ensure the traps were placed deep enough in the water to be effective. Traps were kept horizontal when retrieving and then placed vertically in the washbasin where water was used to rinse the macroinvertebrates from the traps into the washbasin. The contents of the washbasin were then decanted through a sieve (250-micron or smaller) to remove excess water or sediment from the sample. Lastly, the sample was put in a labeled container. Funnel traps were rinsed thoroughly between site usages.

SWEEP STATIONS

Sweep nets, or dip nets, are another semi-quantitative method that is quick and easy to use. They can collect a diverse array of representative taxa and are usable in very shallow water. Unlike funnel traps, sweep nets are not as useful for collecting motile and nocturnal species, require a longer processing time, and may result in user variability (U.S. EPA 2002c). In order to ensure more semi-quantitative results, D-shaped nets (600-micron) were used to sweep a 1-meter area with 3-4 sweeps per station (see Figures 8.3a and 8.3b). The leaf and woody materials were then elutriated from the net, and a visual search of leaf packs and woody debris was made before discarding. The sample was then put in a labeled container. Sweep nets were rinsed thoroughly between sites.

STOVE-PIPE STATIONS

The stove-pipe sampler, similar to core samples and Gerking box samples, is a quantitative method useful for collecting benthic taxa; however, this method surveys a smaller area, does not pick up more mobile species, and is extremely time-consuming to process (U.S. EPA 2002d). The stove-pipe sampler methodology used in this study was modeled after methods designed by Fritz *et al*. (2006) to monitor headwater streams in Ohio.

The stove-pipe sampler used in this study was composed of a 5-gallon bucket with a cut-off jagged edge bottom and a weighted nylon skirt fitted around the lower half of the bucket prior to deployment (see Figures 8.4a and 8.4b). Once the nylon skirt was in place, the stove-pipe sampler was carefully placed in the water while lifting the lower weighted end of the skirt above the lower jagged edge of the bucket. The bottom edge of the bucket was then inserted vertically 1-2" into the substrate while keeping the skirt out from underneath the lower edge of the bucket. The lower weighted end of the skirt was then pressed into the sediment tight against the bucket and adjusted as necessary to achieve a good seal. Rocks and woody debris were removed in some situations in order to properly install the stove-pipe sampler. A trowel was then used to stir the water column and top 1-2" of sediment substrate for 10 seconds inside the sampler. Stirring of the sediment substrate released the benthic macroinvertebrates into the water column so they could more easily be netted. The stove-pipe sampler was swept with a 600-micron hand net through the water column and sediment substrate immediately following the stirring procedure. Netting was continued until the loose material had been removed from the stove-pipe sampler. The sample was then placed into a washbasin and water was added. Sample contents were mixed with the water and decanted through a 250-micron sieve. Sieved material was put into a labeled container when the sieve mesh clogged. This sieving procedure was repeated two more times and then the residual material was discarded.

SAMPLE CONTAINERS

All sample containers were labeled in pencil with the site name, date, sample ID, container number, dye, field crew initials, sample-processing initials, and date processed. Rose bengal dye was used when there was excessive sediment in the sample, which included all stove-pipe samples, and some sweep-net samples and a few funnel trap samples. For preservation, 70 percent non-denaturized ethanol alcohol was added to each sample bottle.

Section 8.2.2 Sample Processing Procedure

Macroinvertebrate samples were picked randomly under a light by using a picking tray with 12 grid cells (see Figure 8.5). Sample contents were stirred and then deposited evenly on a 14 x 17 inch tray. All macroinvertebrates that were >1 cm were picked from the sample first to ensure that predators and species higher on the food chain were included in the processed sample. Grid cells were randomly chosen for picking after the >1 cm taxa were removed from the sample. Each grid cell was entirely picked prior to starting the next randomly chosen grid cell. A total of 200 individuals or the entire sample (if <200 individuals found) was picked for each sample. Processed specimen sample jars were labeled with the site name, station ID, number of individuals picked, date of collection, and picker's initials.

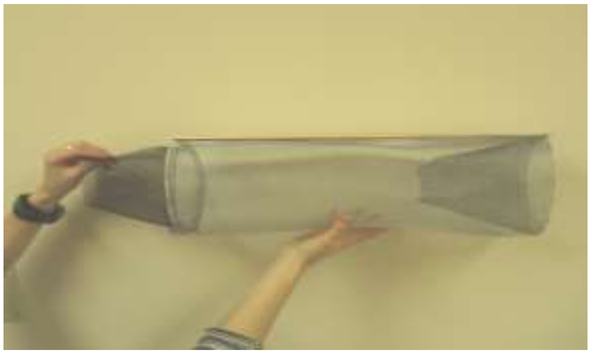


Figure 8.2a Funnel Trap

Figure 8.2b Funnel Trap in Field

Figure 8.3a Sweep Net

Figure 8.3b Sweep Net in Field

Figure 8.4a Stove-pipe sampler
in Field

Figure 8.4b Stove-pipe sampler
with net and trowel

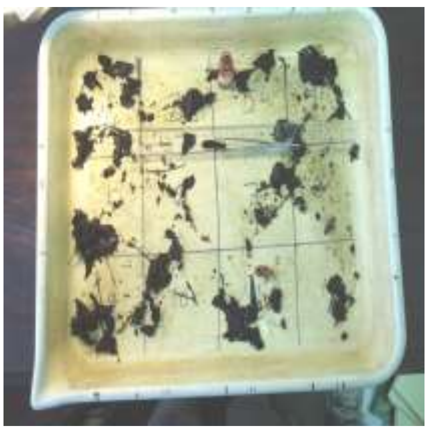


Figure 8.5 Picking Tray

Section 8.2.3 Sample Identification and Enumeration

Rhithron Associates of Missoula, Montana was contracted to enumerate and identify taxa to the lowest practical taxonomic level. A macroinvertebrate sample-tracking sheet was also sent to Rhithron Associates that contained the same information on the specimen sample jar label and sample collection and processing dates. Rhithron Associates entered the identification and enumeration results into a database containing the following fields for each record; sample ID, site name, collection date, sample methods, order, family, taxon, count, life stage, additional comments on the key, specimen condition, QA/QC procedure, and specimen habitat type (terrestrial species were denoted). The Rhinthron QA/QC procedures are outlined in Appendix E. There was no NC DWQ QA/QC of the Rhinthron identification work due to time constraints.

Section 8.2.4 Sample Method Evaluation

Total species richness and abundance was calculated for each sample method type; sweep, funnel trap, and stove pipe. The ratio of species richness : sample type number and abundance : sample type number was also calculated so a relative comparison of the three sample types could be made.

Section 8.2.5 Macroinvertebrate IBI Development and Analysis

A total of 36 biological attributes were identified for use as potential metrics for the NC headwater wetland Index of Biotic Integrity. The candidate metrics were chosen by reviewing data with the assistance of NC DWQ aquatic macroinvertebrate biologist Larry Eaton and a literature review of other stream and wetland IBI development studies by Rader *et al*. (2001), Ohio EPA (2004), U.S. EPA (2002c), Reiss and Brown (2005), Chirhart (2003), and Stribling *et al*. (1998). Wetland disturbance measures as determined by the Ohio Rapid Assessment Method (ORAM), Land Development Index (LDI) for the watershed and 300m buffer, water quality, soil pH, zinc, and copper were used to test the 36 candidate metrics (see Section 3). Table 8.2.1 lists the candidate metrics and the expected response (positive or negative) with the various disturbance measures. Candidate metrics are listed in Table 8.2.1 according to metric type: Taxonomic Richness, Taxonomic Composition, Trophic Structure, and Tolerance / Sensitive.

Table 8.2.1 Candidate Macroinvertebrate Metrics with Expected Response to Disturbance measures

Metric Type	Candidate Metric	LDI, Water Quality, Soils Metals	ORAM, soil and water pH, DO
Taxonomic Richness	Species Richness	Negative	Positive
	Genera Richness	Negative	Positive
	Family Richness	Negative	Positive
	Chironomidae Richness	Negative	Positive
	EPT Richness	Negative	Positive
	OET Richness	Negative	Positive

Table 8.2.1 Candidate Macroinvertebrate Metrics with Expected Response to Disturbance measures

Metric Type	Candidate Metric	LDI, Water Quality, Soils Metals	ORAM, soil and water pH, DO
	POET Richness	Negative	Positive
Taxonomic Composition	Percent Decapoda	Negative	Positive
	Percent Oligochaeta	Positive	Negative
	Percent Chironomidae	Positive	Negative
	Percent Coleoptera	Negative	Positive
	Percent Corixidae	Positive	Negative
	Percent Crustacea	Negative	Positive
	Percent Diptera	Positive	Negative
	Percent Dytiscidae	Negative	Positive
	Percent Hemiptera	Positive	Negative
	Percent Leech	Positive	Negative
	Percent Microcrustacea	Variable	Variable
	Percent Mollusk	Negative	Positive
	Percent Orthocladiinae	Positive	Negative
	Percent Terrestrial	Variable	Variable
	Percent Trichoptera	Negative	Positive
	Percent Trombidiformes	Negative	Positive
	Percent EPT*	Negative	Positive
	Percent OET**	Negative	Positive
	Percent POET***	Negative	Positive
	Percent of Top 3 Dominants	Positive	Negative
	Evenness	Negative	Positive
	Simpson's Index of Diversity	Negative	Positive
	Site Abundance	Negative	Positive
Trophic Structure	Percent Predators	Negative	Positive
	Predator Richness	Negative	Positive
Tolerance / Sensitive	Percent Sensitive	Negative	Positive
	Percent Tolerant	Positive	Negative
	Sensitive : Tolerant	Negative	Positive
	Macroinvertebrate Biotic Index Score****	Positive	Negative

*EPT=Ephemeroptera, Plecoptera, Trichoptera

**OET=Odonata, Ephemeroptera, Trichoptera

***POET=Plecoptera, Odonata, Ephemeroptera, Trichoptera

**** The Macroinvertebrate Biotic Index metric uses a method created by David Lenat of the NC DENR Division of Environmental Management for use in southeastern streams (Lenat 1993). The Macroinvertebrate Biotic Index is calculated as follows:

$$MBI = \frac{\sum TV_i N_i}{N}$$

MBI = Macroinvertebrate Biotic Index
TV_i = Tolerance Value of *i*th taxa
N_i = Abundance of *i*th taxa
N = Total Number of individuals in taxa

Metrics were developed using "all" the sample data collected at each site and using just two sample stations (in most cases see Table 8.1) at each site. Primarily the two samples chosen were "sweep" samples (see Table 8.1). The two-sample station or "sweep" metric development provided a more comparable sampling effort between sites. The two sets of metrics, "all" and "sweep", were tested for normality using the Shapiro-Wilk W Goodness of Fit Test (see Section 3.1). The results of this test are shown below in Table 8.2.2. The Normality test showed that for "all" the raw data only eight out of 36 metric data sets had a normal distribution while for the "sweep" data sets seven out of 35 metric data sets had a normal distribution. Metrics using "all" the data and "sweep" data were tested against the disturbance measures using both Spearman's rho and Pearson's Correlation Coefficient with pairwise comparisons. Both sets of metrics (all and sweep) were transformed prior to calculating the Pearson's Correlation Coeffiecient with pairwise comparisons. Transformed data sets had better results for normal distribution resulting in 24 out of 36 and 25 out of 34 metric data sets being normally distributed for the transformed "all" and "sweep" data sets respectively. Correlations were performed on both sets of regional macroinvertebrate data and the Piedmont and Coastal Plain data separately.

Table 8.2.2 Macroinvertebrate Metric Test for Normality

	All Raw Data		All Data Transformed		Sweep Raw Data		Sweep Data Transformed	
Y All raw data	Prob<W	Normal Distribution?	Prob<W	Normal Distribution?	Prob<W	Normal Distribution?	Prob<W	Normal Distribution?
Biotic Index	0.3644	Yes	0.0000	No	0.0176	No	0.0000	No
Chironomidae Richness	0.0017	No	0.3362	Yes	0.0005	No	0.0124	No
EPT Richness	0.0000	No	0.0589	Yes	0.0000	No	*	*
Evenness	0.0049	No	0.0001	No	0.0004	No	0.0000	No
Family Richness	0.9339	Yes	0.0510	Yes	0.1194	Yes	0.2491	Yes
Genera Richness	0.8735	Yes	0.0239	No	0.4144	Yes	0.2394	Yes
OET Richness	0.0003	No	0.0141	No	0.0001	No	0.0034	No
Percent Coleoptera	0.0000	No	0.3167	Yes	0.0000	No	0.5070	Yes
Percent Crustraceae	0.0488	No	0.0157	No	0.0319	No	0.0370	No
Percent Dominance of Top 3 Taxa	0.9103	Yes	0.9586	Yes	0.4704	Yes	0.6416	Yes
Percent Predator	0.0061	No	0.5734	Yes	0.0092	No	0.1181	Yes
Percent Sensitive	0.0000	No	0.6377	Yes	0.0000	No	0.8848	Yes
Percent Tolerant	0.4823	Yes	0.0003	No	0.7241	Yes	0.0037	No
Percent Chronomidae	0.0085	No	0.1702	Yes	0.0094	No	0.4298	Yes
Percent Corixidae	0.0000	No	0.3494	Yes	*	*	*	*
Percent Corixidae+Coleoptera	0.0000	No	0.4845	Yes	0.0000	No	0.5070	Yes
Percent Decapoda	0.0043	No	0.1504	Yes	0.0290	No	0.2030	Yes
Percent Diptera	0.1642	Yes	0.0301	No	0.0680	Yes	0.0487	No
Percent Dytiscidae	0.0000	No	0.4779	Yes	0.0000	No	0.2037	Yes
Percent EOT	0.0000	No	0.3757	Yes	0.0000	No	0.1942	Yes
Percent EPT	0.0000	No	0.5699	Yes	0.0000	No	0.8207	Yes
Percent Hemiptera	0.0000	No	0.8384	Yes	0.0000	No	0.6185	Yes
Percent Leech	0.0000	No	0.8662	Yes	0.0000	No	0.1905	Yes
Percent Microcrustaceae	0.0004	No	0.0963	Yes	0.0000	No	0.5295	Yes
Percent Mollusk	0.0000	No	0.2208	Yes	0.0000	No	0.9427	Yes
Percent Oligochaets	0.0109	No	0.0208	No	0.0003	No	0.2425	Yes

Percent Orthocladiinae	0.0017	No	0.4874	Yes		0.0000	No	0.4852	Yes
Percent POET	0.0000	No	0.0364	No		0.0000	No	0.6975	Yes
Percent Terrestrial	0.0000	No	0.5922	Yes		0.0000	No	0.7212	Yes
Percent Tricoptera	0.0000	No	0.4293	Yes		0.0000	No	0.4868	Yes
Percent Trombidiformes	0.0000	No	0.9337	Yes		0.0000	No	0.3395	Yes
POET Richness	0.0004	No	0.0364	No		0.0001	No	0.0234	No
Predator Richness	0.5000	Yes	0.1114	Yes		0.0562	Yes	0.5409	Yes
Sensitive :Tolerant	0.0000	No	0.5736	Yes		0.0000	No	0.8700	Yes
Simpson's Index of Diversity	0.0000	No	0.0000	No		0.0002	No	0.0000	No
Species Richness	0.2007	Yes	0.0265	No		0.1194	Yes	0.2491	Yes

Section 8.2.6 Multiple Regression Methods for Macroinvertebrates

Multiple regression was also used to evaluate candidate macroinvertebrate metrics (biological attributes) for all the data (not sweep data, see Section 8.2.5) against disturbance measurements (see Table 8.2.1). Regression equations were developed using the various candidate macroinvertebrates metrics as predictor variables (rather than dependent variables as were used for the development of the macroinvertebrate IBI's). The dependent variables (what is being predicted) were the various measures of disturbance; ORAM, LDI, water quality, and soils (see Section 3). Therefore, macroinvertebrate metrics were used to build a regression model to predict disturbance in the wetland.

A stepwise regression technique was used to build the regression equations. The stepwise approach uses several passes through the data to build the equations. This statistical technique takes each predictor variable one at a time and uses the least squares method to get the best fit with that particular variable. When all of the predictor variables have been evaluated, the predictor variable with the best fit is selected for the model. The second pass takes two predictor variables at a time, again using least squares to determine the best fit. The resulting variable of the first pass may drop out if two other variables have a better fit. The third pass uses three predictor variables and so forth until the criteria for building the regression model has been satisfied.

Each step of the stepwise regression technique used established criteria to determine when a predictor variable was accepted into the equation or rejected for inclusion. The criteria used in this analysis were that a predictor variable had to be significant at a p-value of ≤ 0.1 and account for at least 5% of the variance. Therefore, for each pass of the stepwise regression, the predictor variables had to satisfy the established criteria to be accepted into the equation and that was true for one predictor variable in the first pass, two predictor variables in the second pass, and so forth. When the predictor variable no longer satisfied the criteria, the stepwise regression procedure was stopped, and the result was the final regression equation.

Section 8.3.1 Macroinvertebrate Sample Method Analysis Results and Conclusions – IBI Development

Table 8.3 shows the results of the analysis of the three sample methods. The sweep method had the highest number of species and highest abundance at 189 and 3517, respectively. The stovepipe had the least at 105 and 2117, respectively. A relative comparison of the sample methods was also made by dividing both the species richness and abundance totals for each sample method by the total number of samples collected for each method (e.g. sweep relative species richness = 189/35) . When the number of samples collected per method is taken into account (i.e. a "relative" comparison of the samples based on sample size) the stovepipe had the highest species richness and abundance at 5.8 and 117.6, respectively, and the funnel trap had the least at 3.7 and 76.8, respectively. These results show the stovepipe was the most versatile at collecting both the highest number of species and highest quantity of individuals. This method required more disturbance of the wetland substrate than the other two methods which may have resulted in the collection of benthic taxa not found in the water column or on or near the surface of the wetland substrate. Stove-pipe samples were also the most labor-intensive to process.

The macroinvertebrate survey methods that were tested; sweep, stovepipe, and funnel trap, indicated that the stove pipe sampler collected the highest number of species and individuals and the funnel trap collected the least according to the relative comparison of the different methods (see Table 8.3). The stovepipe is also the most quantitative of the three methods and also the most labor intensive. The funnel traps appear to be the least effective methodology for use in monitoring headwater wetlands. This is primarily due to the fact that it was difficult to find deep enough water to deploy the traps at a number of the sites. The stove-pipe methodology also has limitations, as a few inches of standing water are required to utilize this method. The sweep method, however, can be used in very shallow or very deep locations and processing samples is not as labor intensive as the stove-pipe method. The sweep method does seem to be the best method for monitoring headwater wetlands although the sweep method did not collect as many taxa or individuals. Therefore, the sweep method is the most applicable for headwater wetland monitoring due to its versatility and ability to be used in shallow areas and the ability to process samples relatively easily.

Table 8.3 Macroinvertebrate Sample Method Analysis Results

Sample Method	Number of Samples per Method	Species Richness	Abundance	Relative Species Richness	Relative Abundance
Funnel	34	127	2612	3.7	76.8
Stove	18	105	2117	5.8	117.6
Sweep	35	189	3517	5.4	100.5

Relative Species Richnes = Species Richness / Sample Number
Relative Abundance = Abundance / Number of Samples

Section 8.3.2 Macroinvertebrate Metrics Results and Conclusions

The Piedmont and Coastal Plain correlations had variable results therefore it seemed more logical to develop separate Piedmont and Coastal Plain macroinvertebrate IBIs. In the Piedmont, predator richness, percent tolerance, percent Coleoptera, percent mollusk, family richness, Plecoptera, Odonata, Ephemeroptera, Trichoptera (POET) richness, and Chironomidae richness had the most significant correlations. In the Coastal Plain percent POET, POET richness, percent Crustacea, percent Diptera, percent Orthocladiinae, and percent Coleoptera had the most significant correlations. The following paragraphs detail how these metrics were chosen and which disturbance measures correlated with the them.

Table 8.4 shows the Piedmont and Coastal Plain results for the four different tests; all data with Spearman's rho correlation, sweep data with Spearman's rho correlation, all data with Pearson's coefficient, and sweep data with Pearson's coefficient (see Section 8.2.5 for a description of "all" and "sweep" samples). Table 8.4 is a summary table that shows the number of significant correlations for each test. There were 38 total disturbance measures tested for correlation with the 36 candidate metrics. The complete significant results for the Piedmont and Coastal Plain region candidate metrics and disturbance measures are listed in Appendix E. In order to more clearly interpret the results of Table 8.4, a test for autocorrelation of the different disturbance measures was run. Disturbance measures that correlated with each other (i.e. autocorrelation) at a p-value < 0.05 were grouped together, resulting in 12 "grouped" disturbance measures rather than 38 (see Table 8.5). The number of significant correlations for grouped disturbance measures are shown in Table 8.6 for each statistical test (all data with Spearman's rho correlation, sweep data with Spearman's rho correlation, all data with Pearson's coefficient, and sweep data with Pearson's coefficient). Candidate metrics that had four or more significant correlations with grouped disturbance measures were evaluated for use in the regional macroinvertebrate headwater wetland IBI.

As previously discussed, in the Coastal Plain, six IBI metrics were chosen; percent Coleoptera, percent Crustacea, percent Diptera, percent Orthocladiinae, percent POET, and POET Richness . These correlated with disturbance measures at a p-value $\leq$ 0.15 for one or more of the correlation tests (all results using Spearman's rho, sweep results using Spearman's rho, all results using Pearson's correlation coefficient, and sweep results using Pearson's correlation coefficient). The following summarizes which disturbance measures significantly correlated with the chosen Coastal Plain metrics (see Section 3 for a description of disturbance measures). Exact p-values for each metric's statistical test results are listed in Appendix E.

Percent Coleoptera - significantly correlated with soils zinc and copper, ORAM, and for water quality, relative fecal coliform, zinc, lead, metals, nutrients, and nutrients-metals-fecal coliform-TSS-conductivity.

Percent Crustacea – significantly correlated with soils zinc, ORAM, 300m LDI, and for water quality, relative calcium, zinc, specific conductivity, and nutrients-metals-fecal coliform-TSS-conductivity.

Percent Diptera – significantly correlated with soils zinc, ORAM, and for water quality, relative calcium, zinc, fecal coliform, metals, nutrients, and nutrients-metals-fecal coliform-TSS-conductivity.

Percent Orthcladiinae – significantly correlated with soils zinc and copper, watershed LDI, and for water quality, water temperature, relative calcium, magnesium, metals, fecal coliform, nutrients, and nutrients-metals-fecal coliform-TSS-conductivity.

Percent POET (Plecoptera, Odonata, Ephemeroptera, Trichoptera) – significantly correlated with water quality relative lead, copper, metals, TOC, turbidity, phosphorous, TKN, fecal coliform, and dissolved oxygen.

POET Richness – significantly correlated with water quality relative lead, copper, metals, TOC, turbidity, phosphorous, TKN, fecal coliform and dissolved oxygen.

In the Piedmont, seven metrics were chosen; percent Coleoptera, percent mollusk, percent tolerant, family richness, Chironomidae richness, predator richness, and POET richness, all of which correlated with disturbance measures at a p-value $\leq$ 0.15 for one or more of the correlation tests (all results using Spearman's rho, sweep results using Spearman's rho, all results using Pearson's correlation coefficient, and sweep results using Pearson's correlation coefficient). The following summarizes which disturbance measures significantly correlated with the chosen Piedmont metrics (see Section 3 for a description of disturbance measures). Exact p-values for each metric's statistical test results are listed in Appendix E.

Percent Coleoptera - significantly correlated with soils copper and zinc, ORAM, and 50m LDI, and for water quality relative NO_2+NO_3, fecal coliform, dissolved oxygen, turbidity, and pH.

Percent Mollusk - significantly correlated with soils pH, and for water quality, relative metals, fecal coliform, specific conductivity, dissolved oxygen, ammonia, TKN, phosphorous, nutrients, and nutrients-metals-fecal coliform-TSS-conductivity.

Percent Tolerant – significantly correlated with soils pH, and for water quality relative copper, zinc, lead, magnesium, metals, ammonia, phosphorous, TKN, nutrients, DOC, TOC, TSS, turbidity, specific conductivity, and nutrients-metals-fecal coliform-TSS-conductivity.

Family Richness - significantly correlated with soils pH, and for water quality relative ammonia, phosphorous, TKN, nutrients, fecal coliform, specific conductivity, dissolved oxygen, and nutrients-metals-fecal coliform-TSS-conductivity.

Chironomidae Richness - significantly correlated with soils pH, water quality relative copper, zinc, lead, metals, ammonia, phosphorous, TKN, nutrients, DOC, specific conductivity, and nutrients-metals-fecal coliform-TSS-conductivity.

Predator Richness - significantly correlated with soils pH and for water quality relative copper, lead, metals, ammonia, phosphorous, TKN, DOC, turbidity, specific conductivity, and nutrients-metals-fecal coliform-TSS-conductivity.

POET Richness (Plecoptera, Odonata, Ephemeroptera, Trichoptera) - significantly correlated with soils pH, water quality relative copper, lead, metals, ammonia, phosphorous, TKN, nutrients, fecal coliform, DOC, TOC, specific conductivity, turbidity, TSS, and nutrients-metals-fecal coliform-TSS-conductivity.

Metric results were assigned metric score values of "0", "3", "7", and "10" based on natural breaks in the metric data distribution results. For example, sites in the Piedmont that had greater than or equal to 60% tolerant individuals had a metric score value assignment of "0" (see Table 8.7). Table 8.7 shows the metric score value assignments. The metric results, metric scores, and resulting macroinvertebrate IBI values are shown in Table 8.8a and 8.8b for the Piedmont and Coastal Plain evaluation of all of the data and the sweep data alone. In the Coastal Plain, the IBI results of all of the data and the sweep data alone had some differences, with results ranging from 10 to 36 for all the data and 13 and 40 for the sweep data. Boddie Noell, one of the most urban Coastal Plain sites, and PCS, located near an active phosphate mine, had the two lowest scores for the analysis of all the data at 10 and 13, respectively. East Fayetteville North and South ranked lowest for the analysis of the sweep data, both scoring 13. East Fayetteville North, which ranked lowest, was unexpected as this site appears to be less disturbed. East Fayetteville South is also more natural; however, all the samples were taken downstream of Rock Hill Road. During the study, our team lost access to the upper portion of the site upstream of Rock Hill Road. The highest-ranking site for both sets of data was Bachelor, with a score of 40. Bachelor is another high-quality site with a mostly intact buffer. Rough Rider and Nahunta scored 34 for the analysis of all the data and Rough Rider and Hog Farm Upper scored 24 for the analysis of the sweep data. Rough Rider is a more natural site with mature trees and a sizeable forested buffer. Nahunta and Hog Farm Upper's scores were unexpected. Nahunta, which scored 34 for all the data and 23 for the sweep data, appears to be a fair quality site, but it is surrounded by agricultural lands. Hog Farm Upper, which scored 16 for all the data and 24 for the sweep data, has lower quality habitat and receives runoff from a nearby hog operation.

The Piedmont IBIs also had some differences. The analysis of all the data ranged from 6 to 57 and the analysis of the sweep data ranged from 3 to 50. In the Piedmont, Pete Harris, at 6, followed by East of Mason, at 13, were the lowest ranked for the macroinvertebrate IBIs for all the data. Pete Harris does have agricultural influence in the surrounding area, but the site has an intact buffer present. East of Mason appears to have a mature and varied vegetative community; however, there is a narrower buffer in the upstream direction where Old US 1 exists just to the south of the site. Pete Harris and East of Mason were also the lowest ranked sites for the sweep data at 3 and 10, respectively. The top three ranking sites were Spring Garden (top for both sweep and all data analysis), Walmart, and Fire Tower. Spring Garden is a high-quality site with an intact forested buffer, so the resulting score of 67 and 57 for the analysis of all the data and sweep data, respectively, was not surprising. The results for Fire Tower, and especially Walmart, were more unexpected. Fire Tower and Walmart were the other two top-ranked sites for the Piedmont, respectively scoring 44 and 47 for the analysis of all the data, and 41 and 40 for the analysis of the sweep data. Fire Tower is a quality site with a narrow buffer bordered by a car-junkyard and mobile home park. Bensalem Church Road also bisects the site, causing road runoff to the southwest portion of the site where sweep and funnel samples were collected. Walmart is an extremely urban site (named for the adjacent Walmart) with a narrow buffer and developed watershed, although the habitat appears to be of reasonable quality.

The results of the analysis of the 10 sites in the Coastal Plain and 10 sites in the Piedmont have provided significant results using the Spearman's rho and Pearson's correlations. Overall, water quality parameters and soil parameters correlated with more of the candidate metrics (both metrics chosen for the macroinvertebrate IBI and metrics not chosen for the macroinvertebrate IBI) metrics that had significant results than did ORAM and LDI. Appendix E shows over 1250 significant (p-value < 0.15) results for the four statistical tests (Spearman's rho on all the data, Spearman's rho on the Sweep data, Pearson's correlation on all the transformed data, and Pearson's correlation on sweep transformed data) that were run on the candidate metrics against the disturbance measures (see Section 3). Of these 1250 results, 22 were significant results for ORAM, 58 were significant results for LDI (13 for watershed, 12 for 300m, and 33 for 50m), 365 were significant for soils (74 for zinc, 59 for copper, and 232 for pH), and the rest were significant for water quality parameters (see Appendix E). Please refer Section 3.6 on statistical concerns on the high number of results. The ORAM disturbance measurement correlated with four of the 13 chosen metrics while the LDI disturbance measures correlated with three (one 300m, one watershed, and one 50m) of the 13 chosen metrics (see above). Soils correlated with 11 of the 13 chosen metrics; five of the 13 for zinc, three of the 13 for copper, and six of the 13 for pH. Water quality correlated with 12 of the 13 chosen metrics; 12 of the 13 for metals (calcium, magnesium, copper, zinc, lead), 12 of the 13 for nutrients (ammonia, phosphorous, NO_2+NO_3, and TKN), nine of the 13 for fecal coliform, seven of the 13 for specific conductivity, 5 of the 13 for dissolved oxygen, 4 of the 13 for TSS and turbidity, 5 of the 13 for organic carbon (TOC and DOC), and 9 of the 13 for the combination disturbance measurement, nutrients-metals-fecal coliform-TSS-conductivity (see Section 3).

The results of the statistical correlation tests suggest that macroinvertebrate communities are more likely to be influenced by water quality and soils rather than surrounding land cover or general wetland characteristics. It is possible that LDI and ORAM scores do affect some water quality parameters (see Section 4), but these disturbance measures seemed to be a limited indicator of the health of the macroinvertebrate community as opposed to water quality and soil chemistry. Some results of the macroinvertebrate IBI were anticipated, i.e. the high score of reference site Spring Garden in the Piedmont or the low score of Boddie Noell, an urban site in the Coastal Plain. Unexpected results were the low score of East Fayetteville North and South in the Coastal Plain, and the high score of an urban site, Walmart, in the Piedmont. Further refinement, development, and testing in headwater wetlands and other wetland types are needed for the NC headwater wetland macroinvertebrate IBI. A larger number of sites are essential to test the methodology and ensure precision. Ohio EPA (2004), Minnesota Pollution Control Agency (2002), and Brown *et al*. (2003) reported studies with wetland sample sizes that were 83, 44, and 70, respectively. This macroinvertebrate study, completed on 10 headwater wetlands in the Piedmont and 10 headwater wetlands in the Coastal Plain, has provided the basis for, and necessary steps towards, the development of an accurate NC wetland macroinvertebrate IBI.

Table 8.4 Piedmont and Coastal Plain Number of Significant Correlations for Macroinvertebrates

Metric	Coastal Plain				Piedmont			
	ALL Spearman's rho	Sweep Spearman's rho	All Pearson's Correlation	Sweep Pearson's Correlation	ALL Spearman's rho	Sweep Spearman's rho	All Pearson's Correlation	Sweep Pearson's Correlation
Percent Crustacea	4	0	6	7	4	2	5	4
Percent Dominance of Top 3 Taxa	5	3	5	4	2	0	2	0
Percent Predator	7	8	4	9	7	5	3	4
Percent Sensitive	0	0	0	0	4	5	3	3
Percent Tolerant	2	0	0	0	19	16	12	14
Percent Chironomidae	5	0	1	1	6	2	4	2
Percent Coleoptera	4	5	11	4	7	5	8	4
Percent Corixidae	0	0	0	0	2	0	0	0
Percent Decapoda	3	4	4	4	2	3	3	4
Percent Diptera	7	7	11	5	7	0	7	0
Percent Dytiscidae	4	3	3	1	6	4	6	4
Percent OET**	6	8	7	8	2	4	4	6
Percent EPT*	6	6	5	5	5	2	5	2
Percent Hemiptera	0	0	0	0	7	5	7	6
Percent Leech	0	0	1	2	1	2	0	1
Percent Microcrustacea	2	3	4	3	7	5	11	7
Percent Mollusk	3	4	3	4	12	5	15	6
Percent Oligochaeta	1	1	2	2	6	1	5	1
Percent Orthocladiinae	10	6	3	4	4	0	3	0
Percent POET***	6	8	7	8	2	4	3	5
Percent Terrestrial	4	2	1	1	5	6	1	4
Percent Trichoptera	6	6	5	5	5	2	4	2
Percent Trombidiformes	1	1	0	0	0	0	0	0
Macroinvertebrate Biotic Index	1	1	0	0	3	4	2	2
Chironomidae Richness	1	6	3	5	11	14	9	1
EPT Richness*	6	6	7	7	7	5	5	9
Evenness	2	0	3	5	2	3	2	2
Family Richness	5	4	5	4	8	6	7	4
Genera Richness	5	4	5	4	10	7	7	4
OET Richness**	7	7	7	7	5	9	6	9
POET Richness***	7	8	7	7	12	13	4	9

Table 8.4 Piedmont and Coastal Plain Number of Significant Correlations for Macroinvertebrates

Metric	Coastal Plain				Piedmont			
	ALL Spearman's rho	Sweep Spearman's rho	All Pearson's Correlation	Sweep Pearson's Correlation	ALL Spearman's rho	Sweep Spearman's rho	All Pearson's Correlation	Sweep Pearson's Correlation
Predator Richness	7	5	4	5	12	7	7	4
Sensitive :Tolerant	0	0	0	0	6	10	4	11
Simpson's Index of Diversity	4	2	4	5	3	0	4	2
Site Abundance	2	2	4	3	12	3	6	2
Species Richness	6	4	6	4	10	8	7	4

*EPT=Ephemeroptera, Plecoptera, Trichoptera

**OET=Odonata, Ephemeroptera, Trichoptera

***POET=Plecoptera, Odonata, Ephemeroptera, Trichoptera

Table 8.5 Grouped Disturbance Measures that Correlated with each other each other at P-value < 0.05 for Macroinvertebrates

Disturbance measurement	Grouped Disturbance measures
300 M LDI	1
50 M LDI	1
Watershed LDI	1
Soils Mean(Cu)	2
Soils Mean(Cu, stream)	2
Soils Mean(Cu, wetland)	2
Soils Mean(pH)	3
Soils Mean(pH, stream)	3
Soils Mean(pH, wetland)	3
Relative pH	3
Soils Mean(Zn, stream)	4
Soils Mean(Zn, wet)	4
Soils Mean(Zn)	4
ORAM	5
Relative Ammonia	6
Relative DOC	6
Relative NO_2+NO_3	6
Relative Nutrients	6
Relative NutrientsCuPbZnFCTSSCondo	6
Relative NutrientsMetalsFCTSSCondo	6
Relative Phosphorous	6
Relative TKN	6
Relative Toc	6
Relative Calcium	7
Relative Copper	7
Relative Lead	7
Relative Magnesium	7
Relative Metals	7
Relative PbCuZn	7
Relative Zinc	7
Relative Dissolved Oxygen (%)	8
Relative Dissolved Oxygen (Mg)	8
Relative Fecal Coliform	9
Relative Specific Conductivity	10
Relative TSS	11
Relative Turbidity	11
Relative WaterTemp	12

Table 8.6 Piedmont and Coastal Plain Number of Significant Correlations of Grouped Disturbance Measures for Macroinvertebrates

Metric	Coastal Plain				Piedmont			
	ALL Spearman's rho	Sweep Spearman's rho	All Pearson's Correlation	Sweep Pearson's Correlation	ALL Spearman's rho	Sweep Spearman's rho	All Pearson's Correlation	Sweep Pearson's Correlation
Percent Crustacea	3	0	4	4	3	3	1	2
Percent Dominance of Top 3 Taxa	4	2	3	2	2	1	0	0
Percent Predator	3	3	2	3	4	2	2	2
Percent Sensitive	0	0	0	0	3	2	3	2
Percent Tolerant	1	0	0	0	5	4	5	5
Percent Chironomidae	3	0	1	1	3	2	1	1
Percent Coleoptera	3	4	6	3	4	5	4	3
Percent Corixidae	0	0	0	0	1	0	0	0
Percent Decapoda	1	2	2	2	2	3	2	2
Percent Diptera	4	4	5	3	4	4	0	0
Percent Dytiscidae	3	2	2	1	3	3	3	3
Percent OET**	3	5	3	4	2	3	3	3
Percent EPT*	3	3	2	2	3	2	2	2
Percent Hemiptera	0	0	0	0	4	3	3	3
Percent Leech	0	0	1	2	1	0	2	1
Percent Microcrustacea	2	3	2	3	5	5	3	4
Percent Mollusk	2	2	1	2	5	5	3	3
Percent Oligochaeta	1	1	2	2	3	2	1	1
Percent Orthocladiinae	6	4	3	4	3	2	0	0
Percent POET***	3	5	3	4	2	3	3	3
Percent Terrestrial	3	2	1	1	3	1	3	1
Percent Trichoptera	3	3	2	2	3	2	2	2
Percent Trombidiformes	1	1	0	0	0	0	0	0
Macroinvertebrate Biotic Index	1	1	0	0	2	1	2	1
Chironomidae Richness	1	2	3	2	4	3	4	1
EPT Richness*	3	3	3	4	4	2	3	3
Evenness	2	0	3	3	2	2	1	1
Family Richness	3	1	2	2	5	2	3	2
Genera Richness	3	1	2	2	3	2	3	2

Table 8.6 Piedmont and Coastal Plain Number of Significant Correlations of Grouped Disturbance Measures for Macroinvertebrates

Metric	Coastal Plain				Piedmont			
	ALL Spearman's rho	Sweep Spearman's rho	All Pearson's Correlation	Sweep Pearson's Correlation	ALL Spearman's rho	Sweep Spearman's rho	All Pearson's Correlation	Sweep Pearson's Correlation
OET Richness**	3	4	3	4	3	3	3	3
POET Richness***	3	4	3	4	4	3	4	3
Predator Richness	2	2	1	2	5	4	4	3
Sensitive :Tolerant	0	0	0	0	3	2	4	4
Simpson's Index of Diversity	4	2	3	3	3	3	0	1
Site Abundance	2	2	2	1	4	3	2	2
Species Richness	3	1	3	2	3	2	3	2

*EPT=Ephemeroptera, Plecoptera, Trichoptera
**OET=Odonata, Ephemeroptera, Trichoptera
***POET=Plecoptera, Odonata, Ephemeroptera, Trichoptera

Table 8.7 Metric Score Assignment for Macroinvertebrates

Metric	0	3	7	10
Coastal Plain Metric Results				
Percent Coleoptera	<1	<2	<5	≥5
POET Richness	<1	<3	<10	≥10
Percent POET	<1	<2	<5	≥5
Percent Crustaceae	<20	<40	<70	≥70
Percent Diptera	≥60	<60	<35	<15
Percent Orthocladiinae	≥20	<20	<10	<2
Piedmont Metric Results				
Percent Tolerant	≥60	<60	<40	<15
Percent Mollusk	<2	<10	<20	≥20
Percent Coleoptera	<2	<10	<20	≥20
POET Richness	<1	<2	<5	≥5
Family Richness	<6	<11	<21	≥21
Chironomidae Richness	<3	<9	<16	≥16
Predator Richness	<3	<6	<13	≥13

POET=Plecoptera, Odonata, Ephemeroptera, Trichoptera

Table 8.8a Coastal Plain Metric Results, Metric Scores, and Macroinvertebrate IBIs

Site Name	Metric Results						Metric Scores						Coastal Plain Macro Invertebrate IBI Score
	% Coleoptera	% Crustraceae	%Diptera	%Ortho-cladiinae	%POET	POET Richness	% Coleoptera	% Crustacea	% Diptera	% Ortho-cladiinae	% POET	POET Richness	
	Coastal Plain All Data						Coastal Plain All Data						
Boddie Noell	0	7.14	85.71	0	0	0	0	0	0	10	0	0	10
PCS	0	30.77	53.85	3.85	0	0	0	3	3	7	0	0	13
East Fayetteville South	0.26	68.32	30.89	23.56	0	0	0	7	7	0	0	0	14
Hog Farm Upper	0	23.95	57.98	30.46	1.26	3	0	3	3	0	3	7	16
Cox	0.29	44.38	49.64	4.09	0	0	0	7	3	7	0	0	17
East Fayetteville North	1.45	36.71	31.88	8.7	0.48	1	3	3	7	7	0	3	23
Hog Farm Lower	0	72.01	20.75	10.06	0.31	1	0	10	7	3	0	3	23
Nahunta	2.11	63.34	17.52	16.11	2.32	4	3	7	7	3	7	7	34
Rough Rider	21.53	63.89	3.47	2.08	0	0	10	7	10	7	0	0	34
Bachelor	1.98	83.66	2.48	0	0.5	1	3	10	10	10	0	3	36
	Coastal Plain Sweep Data						Coastal Plain Sweep Data						
East Fayetteville North	0	22.41	24.14	3.45	0	0	0	3	3	7	0	0	13
East Fayetteville South	0.3	70.83	28.27	20.83	0	0	0	10	3	0	0	0	13
PCS	0	30.77	53.85	3.85	0	0	0	3	7	7	0	0	17
Boddie Noell	0	7.14	85.71	0	0	0	0	0	10	10	0	0	20
Cox	0.24	31.59	64.61	5.46	0	0	0	3	10	7	0	0	20
Hog Farm Lower	0	74.24	13.64	3.03	1.52	1	0	10	0	7	3	3	23
Nahunta	2.8	33.18	34.58	34.11	3.74	3	3	3	3	0	7	7	23
Hog Farm Upper	0	6.28	73.22	32.64	2.51	3	0	0	10	0	7	7	24
Rough Rider	21.53	63.89	3.47	2.08	0	0	10	7	0	7	0	0	24
Bachelor	5.26	63.16	21.05	0	5.26	1	7	7	3	10	10	3	40

POET=Plecoptera, Odonata, Ephemeroptera, Trichoptera

Table 8.8b Piedmont Metric Results, Metric Scores, and Macroinvertebrate IBIs

Site Name	Metric Results							Metric Scores							
	Predator Richness	Chironomidae Richness	% Tolerant	%Mollusk	% Coleoptera	POET Richness	Family Richness	Predator Richness	Chironomidae Richness	% Tolerant	Percent Mollusk	Percent Coleoptera	Poet Richness	Family Richness	Invertebrate IBI Score
	Piedmont All Data							Piedmont All Data							
Pete Harris	2	5	68.75	0	0	0	10	0	3	0	0	0	0	3	6
East of Mason	3	5	75.05	0.86	0.86	0	14	3	3	0	0	0	0	7	13
Moonshine	4	4	49.15	0	11.86	1	9	3	3	3	0	7	3	3	22
Black Ankle Non-Powerline	9	2	44.74	0	2.63	2	11	7	0	3	0	3	7	7	27
Umstead	10	8	43.48	2.81	1.79	0	22	7	7	3	3	0	0	10	30
Black Ankle Powerline	8	4	51.02	2.04	28.57	0	18	7	3	3	3	10	0	7	33
Kelly Rd	11	8	38.16	1.5	0.92	2	24	7	7	7	0	0	7	10	38
Fire Tower	16	29	36.11	6.49	0.81	3	19	10	10	7	3	0	7	7	44
Walmart	10	26	10.08	38.71	0.2	1	18	7	10	10	10	0	3	7	47
Spring Garden	12	21	36.19	30.36	2.74	6	30	7	10	7	10	3	10	10	57
	Piedmont Sweep Data							Piedmont Sweep Data							
Pete Harris	2	2	68.75	0	0	0	10	0	0	0	0	0	0	3	3
East of Mason	3	1	71.98	1.1	0.82	0	12	3	0	0	0	0	0	7	10
Black Ankle Non-Powerline	3	1	45.45	0	9.09	0	7	3	0	3	0	3	0	3	12
Kelly Rd	3	1	84.27	3.23	0.81	1	11	3	0	0	3	0	3	7	16
Moonshine	3	0	49.15	0	11.86	1	9	3	0	3	0	7	3	3	19
Umstead	5	3	58.1	10.48	2.86	0	16	3	3	3	7	3	0	7	26
Black Ankle Powerline	8	2	51.02	2.04	28.57	2	18	7	0	3	3	10	7	7	37
Walmart	9	7	9.11	49.22	0.26	1	14	7	3	10	10	0	3	7	40
Fire Tower	13	8	25.96	9.62	1.28	2	16	10	7	7	3	0	7	7	41
Spring Garden	11	7	34.14	34.14	3.63	6	27	7	3	7	10	3	10	10	50

POET=Plecoptera, Odonata, Ephemeroptera, Trichoptera

Section 8.3.3 Macroinvertebrate Sample Method Results and Conclusions - Multiple Regression Analysis

Regression equations were developed separately for the Coastal Plain sites and the Piedmont sites. This decision was based on the macroinvertebrate correlation results previously discussed in this section, which showed differences between the two ecoregions. The disturbance dependent variables (what was being predicted) were divided into 3 groups: 1) overall disturbance as indicated by ORAM and the three types of LDI (50 meter, 300 meter, and watershed LDI); 2) soil disturbance measurements; and, 3) water quality disturbance measurements (see Section 3.1 for details on disturbance measurements).

This analysis developed 34 regression equations, 17 for the Coastal Plain and 17 for the Piedmont, all highly statistically significant at $p < 0.02$. Most of the regression models had only three predictors whereas a few equations had as many as five predictor variables. All 34 regression equations are presented in Appendix E. The equations are presented with the y-intercept and the weights of the predictor variables. The R-squared result is also presented with its associated p-value. Each predictor variable is listed with the percent of the total variance accounted for in the model and their associated p-values.

Table 8.9.a presents the four regression equations for the Coastal Plain that predict overall wetland disturbance (ORAM and LDI). All four regression equations were highly significant at $p \leq 0.0043$ and the percent of variance accounted for ranged from 96% to 99% for the four models. These results clearly indicate that various biological attributes for macroinvertebrate that can be used to predict headwater wetland disturbance. Unfortunately, the predictor variables are not very consistent across the four equation. Percent macrocrustaceae was the most consistent variable and was in three of the equations. Percent tolerance and Simpson's Index of Diversity were both used in two equations.

Table 8.9.b presents the four regression equations for the Piedmont that predicted overall wetland disturbance (ORAM and LDI). Again, all four regression equations were highly significant at $p \leq 0.0059$, with the percent of variance accounted for ranging from 92% to 96%. The various measures of biological attributes for macroinvertebrate again show that they can be used to predict headwater disturbance (via the disturbance measurements), this time in the Piedmont ecoregions. Like the Coastal Plain equations, predictor variables were not consistent. Percent tolerance occurred in three equations for the Piedmont, which was also a consistent predictor for the Coastal Plain. In addition, percent Oligochaetes occurred in more than one equation, which was different from the Coastal Plain.

The resulting regression equations for soil disturbance measurements for the Coastal Plain are presented in Table 8.9.c. The equations were all statistically significant at $p \leq 0.0127$ and the variance accounted for ranged from 71% to 96%. For the three equations predict Soil pH, percent Mollusk occurred in all three and percent Hemiptera was in two equations. The equations predicting soil zinc had percent Sensitive occurring in all three equations. For soil copper, the predictor equations resulted in percent Hemiptera and percent Dytiscidae occurring in two of the three equations. Across all nine equations predicting soil disturbance, percent Hemiptera occurred in five equations and percent Sensitive occurred in four equations, indicating that these two predictors may be the most consistent in predicting soil disturbance. The various measures of biological attributes for macroinvertebrate show that they can be used to predict soil disturbance in headwater wetlands in the Coastal Plain. The consistency of the predictor variables was a little better for the soil disturbance than for overall disturbance.

The Piedmont regression equations predicting soil disturbance are presented in Table 8.9.d. The equations were all statistically significant at $p \leq 0.0185$ and the variance accounted for ranged from 80% to 96%. The three equations predicting soil pH had percent Mollusk in all three equations and percent Predator and percent Crustaceae occurred in two equations. Percent Mollusk was in all six equations predicting soil pH (three in Coastal Plain and three in the Piedmont), which strongly indicated that mollusks were very sensitive to pH levels in the soil. For predicting levels of zinc in soil, percent Predator was in two equations as was percent Sensitive. Percent Sensitive was also a major predictor of soil zinc in the Coastal Plain. Percent Dytiscidae predicted soil copper disturbance measurements for two equations in the Piedmont and Coastal Plain. Overall, percent Predator occurred in four equations and percent Sensitive, percent Hemiptera, and percent Mollusk occurred in three equations. For the Piedmont, the various measures of biological attributes for macroinvertebrate again show that they can be used to predict soil disturbance in headwater wetlands.

The regression equations predicting water quality disturbance measurement for the Coastal Plain are shown in Table 8.9.e. The equations were all statistically significant at $p \leq 0.0022$ and the variance accounted for ranged from 90% to 98%. One predictor, percent Orthocladiinae, occurred in three of the four equations that predicted water quality disturbance while percent leech was a significant predictor in two equations as was percent Diptera. While there were some consistent predictor variables in the relative nutrients, relative metals, and the copper, zinc, and lead equations, the regression equation predicting pH in water had predictor variables that only occurred in that equation. Again, these regression equations show that the macroinvertebrate biological attributes, used as predictor variables, can successfully predict water quality disturbance in headwater wetlands.

The results of the Piedmont regression equations predicting water quality disturbance are presented in Table 8.9.f. The equations were all statistically significant at $p \leq 0.053$ and the variance accounted for ranged from 80% to 94%. Percent Mollusk as a predictor variable occurred in two equations, relative nutrients and pH. Percent Mollusk was a significant predictor for pH in five of the six regression equations predicting pH (four equations for soil pH and two equations for pH in water). For the two regression equations predicting water quality disturbance, four of the five predictor variables were identical which would be expected since relative metals (relative cu, pb, zn, mg, and ca) and relative CuPbZn are very similar, plus there are low levels of mg and ca in the Piedmont. Predictions of wetland water quality disturbance for the Piedmont can again be predicted by using the biological attributes of macroinvertebrates.

All of the regression equations successfully used macroinvertebrate biological attributes (candidate metrics) to predict wetland disturbance at a general level (Level 1 LDI and Level 2 ORAM) and a more specific level (Level 3) water quality and soil disturbance measurements). The resulting regression equations all had statistically significant results where the criteria were met (see section 8.2.6). However, the consistency of the predictor variables is not as strong as would be desired, but there are some consistencies such as percent Mollusk that was very sensitive to pH both in soil and water.

Finally, it is important to note that these equations have not been validated which is the next step to finalizing any regression predictive model. Strictly speaking, until validated, these equations cannot be generalized beyond headwater wetlands or even the current sample. However, the future of using regression analysis to predict disturbance measurements does look promising as indicated by these results.

TABLE 8.9.a Macroinvertebrate Regression Equations for the Coastal Plain – Predictions of Overall Wetland Disturbance.

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1 .) **Regression equation to predict ORAM**
Rsq = 0.983 p = 0.0013

ORAM = 99.179376-0.129885 (Site Abundance)+ 0.9852465 (Species Richness) + 0.7440127 (%Microcrustaceae) -0.708794 (%Diptera) -0.647804(%Decapoda)

2.) **Regression Equation to predict 50m LDI (50 meter buffer)**
Rsq = 0.968 p = 0.0043

LDI 50m = 270.72654-173.3369 (Simpson's Index of Diversity) -49.21813 (EPT Richness) + 17.720607 (Biotic Index) -1.634921 (% Tolerant) + 106.85764 (%Tricoptera)

3.) **Regression Equation to predict 300m LDI (300 meter buffer)**
Rsq = 0.994 p = 0.0001

LDI 300m = 412.27448 + 25.912912 (OET Richness) -3.278049 (% Tolerant) – 2.005671 (% Microcrustaceae) -1.102924 (%Chironomidae)

4.) **Regression Equation to predict watershed LDI**
Rsq = 0.959 p = 0.0001

Watershed LDI = 262.54681-194.3378 (Simpson's Index of Diversity) + 4.909616 (Genera Richness) -1.219932 (%Microcrustaceae)

TABLE 8.9.b Macroinvertebrate Regression Equations for the Piedmont - Predictions of Overall Wetland Disturbance.

1.) **Regression Equation to predict ORAM disturbance**

Rsq = 0.92 p = 0.0059

ORAM = 49.131448 + 7.1666937 (POET Richness) -4.32693 (Predator Richness) + 1.4741468 (%Oligochaetes) + 0.4428189 (%Diptera)

2.) **Regression Equation to predict 50m LDI (50 meter buffer)**

Rsq = 0.955 p = 0.0002

LDI 50m = -114.6837+5.6601461 (% Dominance of Top 3 Taxa) -3.220687 (% Tolerant) + 5.0517224 (%Chironomidae)

3.) **Regression Equation to predict 300m LDI (300 meter buffer)**

Rsq = 0.961 p = 0.001

LDI 300m = 510.53529-40.87017 (POET Richness) + 41.309687 (Biotic Index) - 7.311557 (% Tolerant) -6.286723 (%Oligochaetes)

4.) **Regression Equation to predict watershed LDI**

Rsq = 0.921 p = 0.001

LDI Watershed = 967.37539-16.92829 (Family Richness) -9.063873 (% Tolerant) – 54.07238 (%Terrestrial)

TABLE 8.9.c Macroinvertebrate Regression Equations for the Coastal Plain – Predictions of Soil Disturbance in the Wetland.

5.) **Regression Equation to predict Soils pH**
Rsq = 0.96   p = 0.0001

Soils pH = 4.4966502-0.010187 (% Tolerant) + 0.3563166 (%Hemiptera) + 0.1761529 (%Mollusk)

6.) **Regression Equation to predict Soils zinc levels**
Rsq = 0 .872   p = 0.0043

Soils Zn = 4.8099518 - 6.377977 (Evenness) + 0.3731323 (Biotic Index) + 0.3043475 (% Sensitive)

7.) **Regression Equation to predict Soils copper levels**
Rsq = 0.874   p = 0.0043

Soils Cu = 0.736893 - 0.000424 (Site Abundance) + 0.1171743 (POET Richness) - 0.279286 (%Leech) - 0.004775 (%Chironomidae)

8.) **Regression Equation to predict Soils pH from the downstream samples only**
Rsq = 0.713   p = 0.0127

Soils PH Stream = 4.3988878-4.870031 (Sensitive:Tolerant) + 0.4262148 (%Mollusk)

9.) **Regression Equation to predict Soils pH from the wetland samples only**
Rsq = 0.923   p = 0.001

Soils pH Wetland = 4.2343377 - 0.075291 (Predator Richness) + 0.514346 (%Hemiptera) + 0.3320336 (%Mollusk)

10.) **Regression Equation to predict Soils Zinc levels from the stream samples only**
Rsq = 0.909   p = 0.0016

Soils Zn Stream = 0.4572185 + 0.1450827 (% Predator) + 0.2189366 (%Sensitive) – 0.93052 (%Hemiptera)

11.) **Regression Equation to predict Soils Zinc levels from the wetland samples only**
Rsq = 0.913   p = 0.0014

Soils Zn Wetland = 2.25760140 + 2337053 (% Sensitive) -0.046287 (%Microcrustaceae) – 8.33224 (% Coleoptera)

TABLE 8.9.c Macroinvertebrate Regression Equations for the Coastal Plain Predicting Soil Disturbance in the Wetland cont.

12.) **Regression Equation to predict Soils copper levels in stream sample only**
Rsq = 0.942 p = 0.0027

Soils Cu Stream = 0.6072002 - 0.035888 (Predator Richness) + 0.4126272 (%EPT) + 0.3563769 (%Hemiptera) - 0.141344 (%Dytiscidae)

13.) **Regression Equation to predict Soils copper levels in wetland sample only**
Rsq = 0.959 p = 0.0012

Soils Cu Wetland = - 0.373625 + 0.0104502 (% Dominance of Top 3 Taxa) + 0.0509195 (%Sensitive) + 0.4156877 (%Hemiptera) – 0.151937 (%Dytiscidae)

TABLE 8.9.d Macroinvertebrate Regression Equations for the Piedmont - Predictions Soil Disturbance in the Wetland.

5.) **Regression Equation to predict soils pH**
Rsq = 0 .933 p = 0.0185

Soils pH = 5.076375 - 0.000329(Site Abundance) - 0.009911(% Predator) – 0.005199 (% Crustaceae) + 0.0097319 (%Microcrustaceae)+ 0.0091859 (%Mollusk)

6.) **Regression Equation to predict soils zinc level**
Rsq = 0.821 p = 0.0116

Soils Zn = 20.068034-24.12724 (Simpson's Index of Diversity) + 0.1683005 (Chironomidae Richness) + 0.0626826(% Predator)

7.) **Regression Equation to predict soils copper level**
Rsq = 0.963 p = 0.0001

Soils Cu = 1.4534378 - 0.235413 (Biotic Index) + 0.0099185 (%Decapoda) + 0.0139295 (%Chironomidae)

8.) **Regression Equation to predict soils pH stream sample only**
Rsq = 0.797 p = 0.0169

Soils pH Stream = 5.453887 - 0.017668 (% Predator) - 0.009429 (% Crustaceae) + 0.0069794 (%Mollusk)

9.) **Regression Equation to predict soils pH wetland sample only**
Rsq =0 .923 p=0.001

Soils pH Wetland = 4.2343377-0.075291(Predator Richness)+ 0.514346(%Hemiptera)+ 0.3320336(%Mollusk)

10.) **Regression Equation to predict soils zinc stream sample only**
Rsq = 0.909 p=0.0016

Soils Zn Stream = 0.4572185 + 0.1450827 (% Predator) + 0.2189366 (% Sensitive) – 0.93052 (%Hemiptera)

11.) **Regression Equation to predict soils zinc wetland sample only**
Rsq = 0 .913 p = 0.0014

Soils Zn Wetland = 2.2576014+0.2337053 (% Sensitive) - 0.046287 (%Microcrustaceae) – 8.33224 (% Coleoptera)

TABLE 8.9.d Macroinvertebrate Regression Equations for the Piedmont Predicting Soil Disturbance in the Wetland cont.

12.) **Regression Equation to predict soils copper stream sample only**
Rsq = 0.868 p = 0.0048

Soils Cu Stream = 0.4824544 + 0.1505997 (OET Richness) - 0.405319 (%Dytiscidae) + 12.152903 (% Coleoptera)

13.) **Regression Equation to predict soils copper wetland sample only**
Rsq = 0.961 p = 0.0063

Soils Cu Wetland = -0.548113 + 0.0122942 (%Dominance of Top 3 Taxa) + 0.0023945 (Chironomidae Richness) + 0.0558515 (%Sensitive) + 0.4460519 (%Hemiptera) -0.153573 (%Dytiscidae)

TABLE 8.9.e Macroinvertebrate Regression Equations for the Coastal Plain – Predictions of Water Quality Disturbance in the Wetland.

14.) **Regression Equation to predict levels of relative nutrients**
Rsq = 0.969 p = 0.0006

Relative Nutrients = -0.678765+43.758807 (%Leech) + 0.4394038 (%Diptera)+ 1.6949256 (%Orthocladiinae) -366.1841 (% Coleoptera)

15.) **Regression Equation to predict levels of relative metals**
Rsq = 0.946 p= 0.0022

Relative Metals = 19.708689 + 62.145478 (Sensitive:Tolerant) -0.926467 (%Oligochaetes) + 0.4774804 (%Diptera) + 0.7706454 (%Orthocladiinae)

16.) **Regression Equation to predict levels of relative levels of copper, zinc, and lead**
Rsq = 0.981 p=0.0002

Relative CuPbZn = 48.194558-1.658801 (Family Richness) -34.53216 (%Leech) + 0.4454163 (%Orthocladiinae) + 7.9220009

17.) **Regression Equation to predict levels of relative pH**
Rsq = 0.906 p = 0.0018

Relative pH = 9.7715575 +1.0705927 (EPT Richness) -0.042449 (% Tolerant) + 1.1897936 (%Hemiptera)

TABLE 8.9.f Macroinvertebrate Regression Equations for the Piedmont – Predictions of Water Quality Disturbance in the Wetland.

14.) **Regression Equation to predict relative nutrient levels**
Rsq = 0.926 p = 0.0009

Relative Nutrients = 8.9304523 + 0.5064651 (% Tolerant) +0.5539664 (%Chironomidae) – 0.704052 (%Mollusk)

15.) **Regression Equation to predict relative levels of metals**
Rsq = 0.939 p = 0.0153

Relative Metals = -405.4503 + 0.0733023 (Site Abundance) +
558.67276 (Simpson's Index of Diversity) -13.13607 (OET Richness) –
12.47724 (Predator Richness) + 2.1925262 (Genera Richness)

16.) **Regression Equation to predict relative levels of copper, lead, and zinc**
Rsq = 0.877 p = 0.0583

Relative CuPbZn = -239.2771 + 0.0571027 (Site Abundance) + 354.16033 (Simpson's Index of Diversity) -19.21104 (OET Richness) +13.819083 (EPT Richness) –
6.103286 (Predator Richness)

17.) **Regression Equation to predict relative pH**
Rsq = 0.806 p = 0.0497

Relative pH = 1.1307087 + 6.1000638 (Evenness) + 0.0183574 (% Crustaceae)
+ 0.0352938 (%Oligochaetes) + 0.0479021 (%Mollusk)

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Section 9 – Plant Monitoring Section

Section 9.1 Wetland Plant Introduction and Background Information

Plants are a key component of wetland ecosystems. Wetland plants provide a critical link for the ecological processes of the abiotic and biotic factors of a wetland. Wetland trees, shrubs, and herbaceous species provide habitat structure for other organisms, filter pollutants from the water, and influence hydrological and sediment regimes. The abundant presence of wetland plants in most types of wetlands have also enabled wetland scientists and managers to use this taxon type for wetland classification, identification of wetland boundaries, and as bioindicators of both natural and anthropomorphic derived impacts (Cronk and Fennessy 2001, U.S. EPA 2002e). This section of this report will define wetland plants, discuss the importance of wetland plants in wetland communities, wetland classification, and wetland identification, and evaluate the usefulness of wetland plants as bioindicators. The types of anthropomorphic stressors and how these affect wetland plant communities and the development of floristic quality indexes and other types of metrics used to quantify the integrity of wetlands will be a focal point of this section.

Cronk and Fennessy (2001) define wetland plants as “those species that are normally found growing in wetlands, i.e., in or on the water, or where soils are flooded or saturated long enough for anaerobic conditions to develop in the root zone, and that have evolved some specialized adaptations to an anaerobic condition.” Wetland vegetation can be both vascular and non-vascular and has generally been categorized into four groupings; emergent, submerged, floating-leaved, and floating (Cronk and Fennessy 2001). For the headwater wetland vegetation survey performed for this study, most species have fallen into the emergent (i.e., woody) category due to the hydrological conditions of this type of wetland. Most of the sites had seepage flow that resulted in seasonally saturated or shallow flooded conditions that generally did not support submerged, floating-leaved, or floating aquatic plants.

The presence of plants in wetland ecosystems is vital for wetland function, structure, and the survival of other species (Reiss and Brown 2005). Wetland plants are at the base of the trophic pyramid and therefore are a direct “conduit” of energy flow from inorganic to organic parts of the ecosystem. Wetland plants not only provide food for species higher on the food chain, they also provide critical habitat structure for macroinvertebrates and wildlife species such as fish, amphibians, and birds. Epiphytic bacteria and phytoplankton cling to submerged wetland vegetation while other species of wetland plants such as mosses or tree seedlings utilize damp and rotten fallen logs to germinate. Tree branches also provide structure for epiphytic bromeliads and orchids (Cronk and Fennessy 2001, U.S. EPA 2002e).

Wetland plants have been documented to influence water chemical and physical traits through respiration, photosynthesis, shading and through the uptake of harmful pollutants such as nutrients and metals. Wetland plants can influence the hydrological and sediment regimes of a wetland. Evapotranspiration of forested wetlands during summer months helps to dry these systems while the lack of it during colder months helps to flood them. Wetland vegetation aids in filtering sediments out of water by slowing currents and allowing sediments to accumulate.

Wetland vegetation also stabilizes shorelines and influences soil characteristics (Cronk and Fennessy 2001, U.S. EPA 2002e).

Wetland scientists and managers use plant species type and physiognomy (i.e. whether the wetland is dominated with herb, shrub, or tree species) in combination with other characteristics such as soil or parent material, landscape location, connectivity, topography, hydrology, and region to classify wetlands. Classification systems have ranged from very detailed and specific to more general. Schafale and Weakley's (1990) Classification of the Natural Communities of North Carolina identifies 57 types of wetlands in North Carolina. This classification method places an emphasis on community vegetation but also considers region, soil characteristics, topography, assemblages of animals or other organisms, substrate, hydrology, and other abiotic factors. The North Carolina Wetland Functional Assessment Team (2007) has recently developed a coarser classification, the North Carolina Wetland Assessment Method (NCWAM) system for wetlands that identifies 16 general types, including headwater wetlands as a separate type. Other classification systems for wetlands have been developed by The Nature Conservancy (Anderson *et al*. 1998), the US Fish and Wildlife Service (Cowardin *et al*. 1979), local state agencies such as the Ohio Environmental Protection Agency, Florida Natural Areas Inventory (FNAI 1990), and California (Radovich 1993).

In North Carolina, the Piedmont and Coastal Plain regions of the state vary considerably in geology, soils, topography, hydrology, and plant community types. The Piedmont is the non-mountainous section of the old Appalachian Highlands and is a transitional area between the Appalachian Mountains, located to the northeast, and the primarily flat, sandy Coastal Plain, located to the southeast. The parent material of this region is a complex mosaic of Precambrian and Paleozoic metamorphic and igneous rocks with rolling hills and plains. Soils of the Piedmont are finer in structure and the higher elevation affords fewer wetlands than the Coastal Plain. The sandy Coastal Plain is composed of two main sections; the Southeastern Plains located to the east of the Piedmont, and the Middle Atlantic Coastal Plain located along the coast to the east of the Southeastern Plains. The Southeastern Plains have irregular plains with broad interstream areas and is composed of a mosaic of cropland, pasture, and forested natural areas. The Middle Atlantic is composed of low elevation flat plains with numerous swamps, marshes, and estuaries dotting the landscape (Griffith *et al*. 2002).

The US Fish and Wildlife Service (Reed 1988, Reed 1997) has developed a wetland indicator status for 7500 species of plants based on the probability a particular wetland species has of occurring within a wetland. The wetland indicator status types and their wetland occurrence rates used to define these 7500 species are: obligate (OBL) – greater than 99%; facultative wetland (FACW) – 67%-99%; facultative (FAC) – 34%-66%; facultative upland (FACU) – 1%-33%; and upland (UPL) – less than 1%. Additionally, a "+" or a "-" assignment (e.g. FAC+ or FAC-) indicates that a wetland species is more likely to be found in a wetland, "+", or less likely to be found in a wetland "-".

Wetland plant species have a cumulative response to a wide array of chemical, physical, and biological wetland alterations (Cronk and Fennessy 2001). Wetland alterations that affect plant populations can come in the form of natural disturbances or human derived impacts. Natural disturbances can be at a small scale, such as a downed tree or gopher mound, or at a large scale such as catastrophic blow downs, natural fire, or lack of natural fire (Taft *et al*. 1997). In North

Carolina, certain wetland systems like pine savannahs require fire to maintain species composition (Schafale and Weakley 1990). Human derived stressors can alter the land cover in the vicinity of the wetland and immediate surrounding buffer, the hydrological and sediment regimes, and the quality of the water (both point source and stormwater) that enters the wetland (Lopez and Fennessy 2002, U.S. EPA 2002e). Hydrological alterations can cause a decrease in plant species richness, the decline of mutualistic interactions (such as mycorrhizae fungi), the removal of sensitive species, and the dominance of invasives. Vegetation composition can become dominated solely by one or two species that can result in the presence of either dense or sparse stands of vegetation. Nutrient enrichment can cause algal blooms, while sediment loading and turbidity can influence light penetration and, therefore, plant growth (U.S. EPA 2002e). One study in Ohio showed plant species composition correlated positively with water quality levels of total organic carbon, total phosphorous, and total calcium, and negatively with soil pH (Lopez and Fennessy 2002). Specific examples of human impacts that affect wetland plant vigor and composition include grazing by livestock, draining for irrigation, flooding from stormwater runoff, timber harvesting, urbanization, and agriculture development (Herman 2005). The diminishment of wetland integrity ultimately can alter ecological processes and allow for the invasion of adventive taxa (Taft *et al*. 1997).

Wetland plants effectively respond to stressors and therefore the monitoring and evaluation of a wetland's plant community can be used by wetland managers to determine the ecological integrity of a wetland, evaluate best management practices, assess restoration or mitigation sites, prioritize wetland related resource management decisions, and establish aquatic life use standards for wetlands. Wetland plants have a conspicuous and dominant presence in most classes of wetlands (including headwater wetlands). Plant monitoring is an easier task to accomplish than the monitoring of other taxonomic groups because of the conspicuous nature of plants. The advantages and disadvantages to utilizing wetland plants as bioindicators have been examined by Cronk and Fennessy (2001) and Reiss and Brown (2005) and is summarized below:

ADVANTAGES

1. Plants are a ubiquitous component of wetland ecosystems.
2. Plants are immobile (mostly) and integrate the temporal, spatial, chemical, and physical attributes of a system and are therefore useful as an indication of long-term chronic stress.
3. Taxonomy is known and many regional identification keys exist.
4. Species are diverse.
5. The ecological tolerances of many species are known and therefore changes in the community composition can diagnose the stressors (e.g. hydrology alterations).
6. Sample techniques are documented and known and can be used in fresh and saltwater systems.
7. Functionally or structurally based guilds have been proposed for some regions.
8. Wetland plant community type and changes can be evaluated with aerial interpolation.

DISADVANTAGES

1. Wetland plants, especially long-lived woody species, have a lag time response to some stressors.
2. The identification of some species can be difficult and limited to a narrow season (i.e., grasses and sedges).
3. Some plant assemblages are difficult to sample (submerged species or high-density individuals).
4. Sampling is limited to the growing season.
5. Many species are insensitive to contaminants such as insecticides and heavy metals.
6. Research and literature on plant species response to specific stressors such as insecticides and metals is not well developed.
7. Herbivory patterns can make quantifying vegetation coverage difficult.

Floristic Quality Assessments (FQA) or vegetation Indices of Biotic Integrity (IBIs) have been developed by states in other regions of the country, including; Ohio (Andreas and Lichvar 1995, Lopez and Fennessy 2002), Michigan (Herman *et al*. 2001), Missouri (Ladd 1993), southern Ontario (Oldham *et al*. 1995), Mississippi (Ervin *et al*. 2006), Illinois (Taft *et al*. 1997), North Dakota (Mushet *et al*. 2002), and Florida (Cohen *et al*.). Taft *et al*. (1997), Reiss and Brown (2005), Rader *et al*. (2001), and Wisconsin (Bernthal 2003). The U.S. EPA (2002e) has suggested the use of several vegetative parameters, or metric types, for the development of a more effective vegetative IBI. According to these documents, vegetative IBIs or FQAs should include:

1. Community balance metrics (e.g., species richness, evenness, diversity).
2. Community structure (e.g., sapling density).
3. Auto-ecological metrics that explore previously described relationships between taxa and environmental gradients.
4. Quality or tolerance metrics (e.g., floristic quality index, percent tolerant species, percent sensitive species, average site coefficient of conservation scores).
5. Functional groups (e.g., guild diversity, annual to perennial ratio, moss coverage).
6. A wetness characteristic metric that utilize wetland indicator status (e.g., percent obligate or submersed aquatic).

Researchers have used various disturbance measurements to develop vegetative metrics such as water quality, hydrology, surrounding land cover type, and rapid assessment methods. Rapid assessment and land cover type comparable disturbance measurements will be used in developing the headwater plant IBIs (see Section 9.2.2). Rader *et al*. (2001) used the water quality parameter results of reference, agricultural, and stormwater wetlands in Minnesota to develop metrics. Regression statistics found correlations between vegetation metrics and concentrations of chloride, phosphorous, and copper. Lopez and Fennessy (2002) used land cover change in the vicinity of the wetland site, presence of a vegetative buffer between the adjacent land cover and the wetland, and hydrological condition for the IBI development of depressional Ohio wetlands. Ervin (2005) points out that the use of hydrological disturbance measurements can be problematic in forested wetlands as trees have a slow rate of response to hydrological alterations. Altered hydrology can indicate improved growth conditions due to alleviations of stress from saturated anoxic soils. Land Development Indexes (see Section 3.2) have been used as disturbance measurements in Florida (Cohen *et al*. 2004), while another study in Mississippi used a three-tiered ranking approach that also rated wetlands based on surrounding land cover type (Lopez and Fennessy 2002). The Ohio EPA (Andreas *et al*. 2004) used a semi-quantitative rapid wetland assessment method, ORAM (See Section 3.3), as a disturbance measurement to test a Floristic Quality Assessment Index in six different types of wetlands.

Floristic Quality Assessment Indexes (FQAI) is a vegetation metric that has been used alone or in combination with other metrics to assess the integrity of wetlands by a number of states (Andreas and Lichvar 1995, Lopez and Fennessy 2002, Herman *et al*. 2001, Ladd 1993, Ervin *et al*. 2006, Taft *et al*. 1997, and Mushet *et al*. 2002, Bernthal 2003, Reiss and Brown 2005). This assessment method has been designed to minimize subjectivity and create an "objective standard of quality" that is useable by any scientist with basic botanical skills. FQAI was first developed by Swink and Wilhelm (1979) to evaluate plant community condition in the Chicago Region and later revised by Wilhelm and Ladd (1988) and Wilhelm and Masters (1995). FQAI (also referred to as FQI and FQA) is a "weighted index of species richness (N) and is the arithmetic product of the average coefficient of conservatism and the square root of species richness of an inventory unit". FQAI is calculated as follows (Taft *et al*. 1997, Cohen *et al*. 2004).

$$FQAIj = \sum C_{ij} / \sqrt{N_j} \quad \text{or} \quad \bar{C}_j * \sqrt{N_j}$$

C_{ij} = Coefficient of Conservatism for species *i*
At site *j*
$\bar{C}_j$ = Average Coefficient of Conservatism at site *j*
N_j = Species richness at site *j*

The Coefficient of Conservatism, or C of C rank, is an estimated probability that a species is likely to occur in the landscape that is relatively unaltered to what is believed to be the pre-settlement condition (Bernthal 2003). C of C rank is an *a priori* assignment to each species that is based on each species' affinity to "natural areas" in a given region of the country. C of C ranks range from 0-10, with 0 representing non-native species adapted to severe disturbance, and 10 representing a species with the highest "fidelity" to natural areas (Taft *et al*. 1997). Rapid changes to the landscape have caused the reduction of conservative plants (i.e. sensitive) and allowed for the increasing establishment of less conservative and non-native invasives that are suited to these changed habitats. A vast proportion of the landscape has been severely degraded and fragmented and what remains has various levels of ecological integrity (Swink and Wilhelm 1979).

Studies utilizing the FQAI metric have proven this method to be useful for evaluating wetland integrity (Andreas *et al*. 2004, Cohen *et al*. 2004, Lopez and Fennessy 2002, Mushet *et al*. 2002); however, flaws do exist in the FQAI metric that could result in a misrepresentation of wetland quality. FQAI is strongly influenced by species richness (Ervin *et al*. 2006). Species richness can be affected by habitat heterogeneity, wetland size, and survey effort; therefore, survey methods must be standardized in wetland studies that use FQAI (Taft *et al*. 1997). The influence of species richness on the FQAI equation could result in a lower FQAI score for more natural and pristine sites with a lower number of native species than more disturbed sites that are heterogeneous and have a higher number of native weedy species. The limitation that species richness has on FQAI is a clear reason why this metric should not be used solely as a wetland evaluation method. Additionally, FQAI mathematically neglects non-native species in calculation of the equation (Ervin 2005). Invasive exotics are assigned a C of C value of zero.

Ervin *et al*. (2006) developed a wetland indicator metric called Floristic Assessment Quotients for Wetlands, or FAQWet indices, that were designed to evaluate the "relative effectiveness of floristic indices depicting both 'wetness' and 'nativeness' of the wetland plant assemblages" in Mississippi wetlands. This study developed four equations that are variations of the Wetland Index developed by Herman *et al*. (1997). Two FAQWet equations (shown below) had the highest correlation with site study disturbance measurements and were not correlated with species richness.

$$\text{FAQWet} = \sum WC/\sqrt{S} * N/S; \quad \text{FAQWet} = \sum WC/\sqrt{S} * \sum f/\sum F$$

WC = Wetness Coefficient
S = All species
N = Native Species
F = Frequency of all species
f = Frequency of native species

Wetland coefficient values in the above equations are calculated as follows: OBL = + 5, FACW = + 3, FAC = 0, FACUP = -3, UPL = - 5.

The FAQWet equations incorporate non-native species and wetland indicator status. The second equation provides the most information by weighting results based on native and non-native species frequencies. Both FAQWet equations may also evaluate "indirectly the interactive ecological effects of anthropogenic watershed stressors such as water quality degradation" (Ervin 2005). Similarly, to FQAI, the FAQWet metric also has the potential to misrepresent wetland integrity since wetland indicator status was not designed to provide information on the condition of a wetland. For example, there are obligate native wetland species (e.g., *Typha* spp.) that are invasive and indicate degraded integrity but would result in a higher FAQWet score (U.S. EPA 2002e).

FQAI C of C classifications will vary with regional plant distributions and affinities for natural areas. The majority of C of C regional assignments have been developed for Midwestern states. In recent years, FQAI and other metrics have been tested on studies in the southeast (Mississippi, Herman *et al*. 2005 and Florida, Cohen *et al*. 2004) and mid-Atlantic (Virginia, Nichols *et al*. 2006). At this time, vegetative IBIs including FQAI and C of C ranking assignments or FAQWet have not been developed for North Carolina. With the help of botanists at the University of North Carolina at Chapel Hill, NC DWQ has developed C of C assignments for the 217 plant species identified at all of the headwater wetland sites and tested various vegetative metrics including FQAI and FAQWet. Disturbance measurements (see Section 3) similar to the ones reviewed in the literature and already discussed in this section were used to test the candidate metrics. The following sections discuss the field methods chosen to quantify the vegetation community of each headwater wetland site, statistical methods used to test the metrics, and the results of the vegetation monitoring section of the report.

Section 9.2.1 Plant Survey Field Methods

Section 9.2.1.1 Presence-Absence Species Lists

In order to generate a species list for the site, all vascular plant species located within the study area boundary were identified to species, if possible. Species lists were recorded in field notebooks and transferred to a database. Voucher specimens were obtained for identification. All taxa were identified to the lowest taxonomic level practical. Voucher specimens were collected and identified resulting in the modification of site species lists, field survey sheets, and the plant list database as needed. Voucher specimens were processed, labeled, and catalogued for future reference. The University of North Carolina Herbarium was contracted to identify some of the more difficult voucher specimens such as grass and sedge species. The "Manual of the Vascular Flora of the Carolinas" (Radford *et al*. 1968) was used for genus and species nomenclature for all survey-related field research or databases used for this project.

Section 9.2.1.2 Community Plant Survey

The headwater wetland monitoring methods were developed to have a similar survey design as the "The North Carolina Vegetative Survey Protocol (Peet *et al*. 1997), also known as the Carolina Vegetative Survey (CVS). CVS was developed by experienced North Carolina botanists and ecologists for the purpose of providing a quantitative description of the vegetation in a variety of habitats throughout the Carolinas. A modification of the CVS protocol was used to develop the three sections of the DWQ plant survey; presence, cover, and woody stem DBH. Plant surveys were completed on all sites except for Black Ankle Powerline, resulting in a sample size of 22. The plant survey was not done on Black Ankle Powerline due to time constraints, the close proximity and similarity this site had to Black Ankle Non-Powerline, and the narrowness of the site.

<u>PLOT LAYOUTS – NORMAL AND VARIED</u>

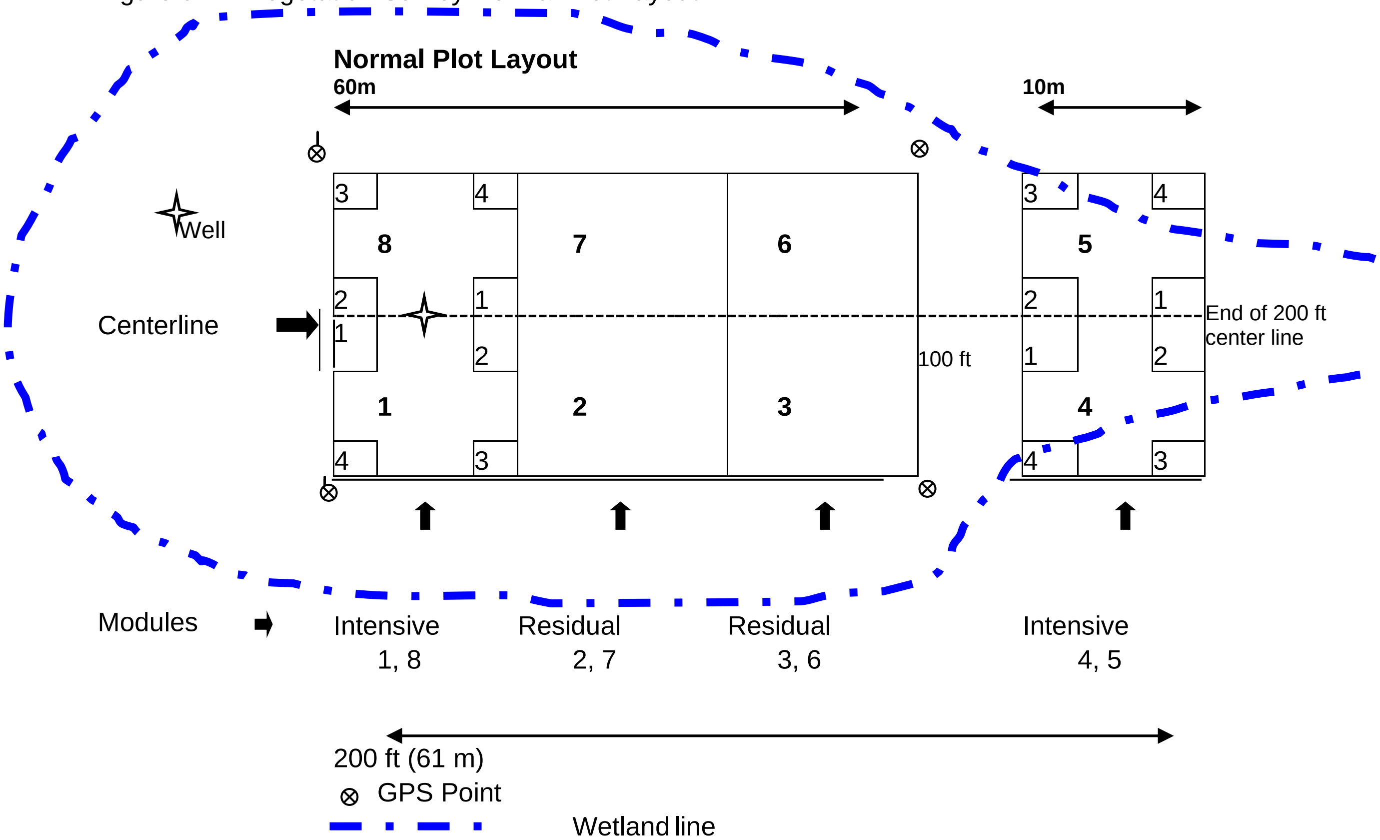
Figure 9.2.1 shows a diagram of the vegetation plot layout. Vegetation survey plots consisted of 8 modules (or subplots) that were 10 x 10 m in size and numbered counterclockwise from 1-8 (see Figure 9.2.1). A 200 ft (61m) centerline ending at the approximate location of the downstream water quality station (see Section 4.0) runs down the center of the plot between Modules 1-4 and 5-8. This center-line was oriented in the field so that 0 m was located at the head of the wetland, the well was located at approximately 5 m along the center-line, and the 200 ft (61 m) end of the centerline was located near the downstream water quality station (see Section 4). The 10x10 array of modules was arranged such that there was a 3 x 2 array of Modules at the head of the wetland (Modules 1, 2, 3, 6, 7, and 8) located 0-30 m along the centerline and at the 200 ft downstream location there was a 1 x 2 array of Modules at the 200 ft downstream location (Modules 4 and 5) located at 51-61 m along the centerline (see Figure 9.2.1). Therefore, a total of 20 x 80 m divided into eight 10 x 10 modules were surveyed. There is a gap of 21 m along the centerline between Modules 3 and 6 and Modules 4 and 5 that was not

surveyed It did not seem cost-effective or necessary to survey the plant community at each entire site, however, a survey that represented site diversity was desirable. This is why modules 4 and 5 were placed at the most downstream location of the centerline, thus the 21 m gap. Labeled survey flags were placed at 0 m, 10 m, 20 m, 30 m, 51 m, and 61 m along the centerline and all Module corners. The outermost corners of the plot (see Figure 9.2.1) were recorded with GPS.

Some of the study sites do not have a well installed in the center part of the head of the wetland due to the specific hydrology and topography of the site. Cox, Duke, Bachelor, and Moonshine have the well installed closer to the head of the wetland; PCS and Walmart have the well installed off to one side rather than centered. In these situations, the well was usually installed closer to the edge of the site boundary; therefore, the plot centerline did not cross over the well. Due to the well location, using the normal plot layout would potentially result in Modules 1 and 8 being located in upland areas. To rectify this situation a new centerline was established along the approximate center of the study site and oriented in a downstream direction. Modules were established along the centerline in the same fashion as shown in Figure 9.2.1.

The "DWQ Headwater Wetland Plot Layout and Slope Field Sheet"(see Appendix B) was completed after each plot was set up. The slope section of the study is described in Section 5.0. The direction of the centerline was taken with a compass and recorded for the appropriate plot layout diagram (normal or varied). The approximate location of the site delineation line was also drawn on the appropriate plot layout diagram (normal or varied). Delineation lines that cross the inside of the vegetation survey plot, as is the situation for narrow sites, or downstream Modules in the Piedmont especially (see Figure 9.2.1) indicate the potential presence of upland plants in the plot survey.

Figure 9.2.1 Vegetation Survey Normal Plot Layout



PLOT PLANT SURVEY METHODS

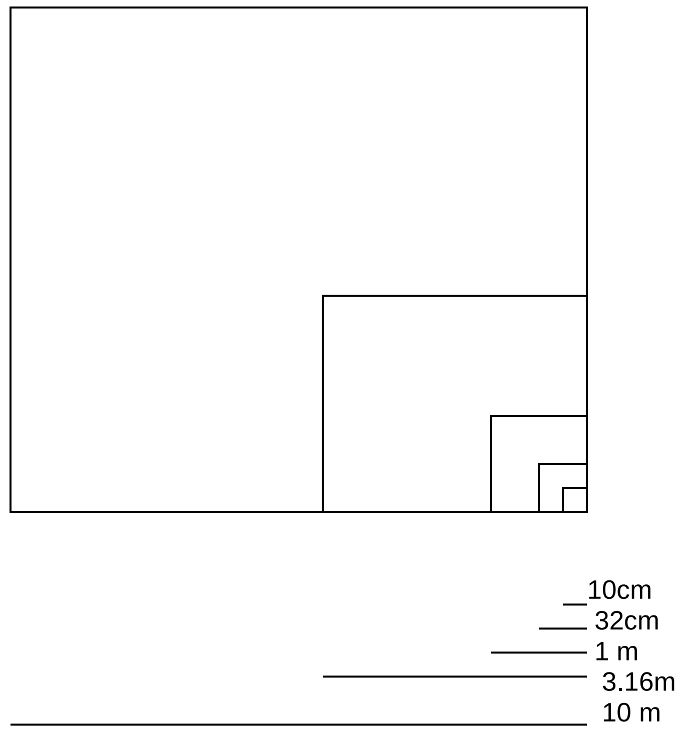
The "Headwater Wetland Plant Survey Species Cover Field Sheet" and the "Headwater Wetland Woody Stem Survey Field Sheet" were completed for the plant survey. The first column refers to the species code, which was used later in the plant database. The species code was typically the first four letters of the genus followed by the first four letters of the species (e.g. *Acer rubrum* = acerrubr). For species identified to genus (or family) only, the code was the first four letters of the genus (or family) followed by "spp" (e.g. *Acer* species = acerspp or Poaceae species = poacspp). Plants that could not be identified in the field were recorded with a brief descriptive name in the species column and marked as collected in the appropriate column. Collected specimens were tied with flagging and marked with the Module number and the brief descriptive name. Similar to the presence-absence survey, voucher specimens were identified to the lowest practical taxonomic level, processed, labeled, and catalogued for future reference.

PLANT SPECIES PRESENCE AND COVERAGE SURVEY

Modules 1 and 8 (located at the head of the wetland), and Modules 4 and 5 (located at the most downstream portion of the study area), were intensively surveyed since these two sets of paired Modules were located the farthest apart and would potentially be the most variable (see Figure 9.2.1). Modules 2, 3, 6, and 7 were considered residual Modules and were surveyed for woody stem DBH only, which is discussed later in the field method section. It did not seem necessary or cost effective to complete intensive surveys on all modules. The “DWQ Wetland Species Plant Survey Species Cover Sheet” was completed for the intensive Modules only (see Appendix B). Each intensive Module had corners numbered from 1 to 4 counterclockwise in which a series of nested quadrats were surveyed (see the labeled corners in Figure 9.2.1 and nested quadrats in Figure 9.2.2). First, species presence was determined at one chosen corner within each intensive Module, and then cover classes were assigned to each species present within the Module. One corner was chosen in the field for each intensive Module to be surveyed for presence. Adjacent corners of adjacent Modules such as Module-1, corner-1 and Module-8, corner-2 or Module-4, corner-1 and Module 5, corner-2 were not chosen (see Figure 9.2.1). Vegetation within the chosen corner was considered to be fairly representative of the plot. Therefore, corners with localized disturbances, such as downed trees, were not chosen for the presence survey.

A series of nested quadrats (see Figure 9.2.2) were surveyed for presence at the chosen survey corner. The nested quadrats were composed of five nested quadrats that increased exponentially in size from 10 x 10 cm to 10 x 10 m. “Presence” for a plant species was defined as being rooted within the boundary of the survey quadrat. “Presence class” was defined by the smallest of the nested quadrats the plant was rooted in. The quadrat size and presence class were as follows: class 5 – 10 cm x 10 cm, class 4 – 32 x 32 cm, class 3 – 1 m^2, class 2 – 3.16 x 3.16 m, and class 1 – the entire 10 x 10m Module (see Figure 9.2.2). Each nested quadrat was surveyed in order by size from the smallest quadrat (10cm x 10cm or presence class 5) to the largest quadrat (10m x 10m or presence class 1). Any individual plant species that over-hung the intensive Module, but was not rooted within the Module, was given a presence class of “0”. The presence class of “0”, “1”, “2”, “3”, “4”, or “5” was recorded under the appropriate corner number (c#) and Module number.

Figure 9.2.2. Nested Quadrats Diagram



A cover class was assigned to every species rooted in or overhanging the intensive Module after all presence values were assigned. Cover was defined as “The percentage of ground surface obscured by the vertical projection of all above ground parts of a given species onto that surface” (Peet et al. 1997). Cover classes were: trace (1-2 individuals only), 0-1% ($1m^2$), 1-2%, 2-5%, 5-10%, 10-25%, 25-50% (5m x 10m), 50-75%, 75-95%, 95-100% ($10m^2$). The cover class was recorded in the percent cover (%cov) column for each species under the appropriate Module number. The overall cover for the herb (H), shrub (S), and Canopy (C) vertical stratums for each Module were recorded last, directly under the Module number. The vertical stratums classes are herb = 0-1m, shrub = 1-6m, and canopy = >6m in height. The residual Modules were surveyed for any species not present in the intensive Modules after the intensive Module survey was completed. The species code, genus species, and collected (when applicable) columns were completed for any new species surveyed in the residual Modules. In addition, the letter “R” was recorded in the last column, labeled “RES” on the “DWQ Wetland Species Plant Survey Species Cover Sheet”. Species sited in the residual modules, including new species, were not surveyed for cover just presence. Survey interpretation of cover classes varied between project coordinators at the module level and estimating the cover class of multiple modules or the entire plot would have increased the likely hood of overestimating or under estimating a species cover class. New species sited in the residual modules were included in the calculation of metrics that utilized species richness but not species cover.

Woody Stem Survey

Woody plants (primarily trees, shrubs and vines) were recorded on the "DWQ Headwater Wetland Woody Stem Survey Field Sheet" (see Appendix B). Every plant that was rooted within the plot and reached DBH level (1.37m) was surveyed and tallied on this field sheet. A separate tally was kept for each intensive Module and a combined tally was kept for the residual Modules. Therefore, two separate lines were used if the same species occurred in two separate intensive Modules (one for each Module). Each individual stem was measured and tallied as one of the following size classes: <2.5cm, 2.5-5cm, 5-10cm, 10-15cm, 15-20cm, 20-25cm, 25-30cm 30-35cm, >35cm. The DBH rounded to the nearest centimeter was recorded for trees >35cm. For bifurcated saplings or shrubs, "Individual stems" were defined as stems that split below 1 meter. All stems were surveyed for bifurcated saplings or shrubs that split below one meter while only the largest stem was surveyed for bifurcated saplings or shrubs that split above one meter. The Module number was recorded for intensive Modules (1, 4, 5, and 8 tallied separately) and the letter "R" was recorded for residual Modules (2, 3, 6, and 7 tallied together). A sub-sample of half the plot was taken in situations that had particularly dense woody vegetation. In these situations, all woody stems located within 5 m of the centerline within intensive and residual modules were surveyed.

Section 9.2.2 Plant Survey Data Analysis Methods

An overall species list database was developed. The "Species list" database contained fields for the species code (see section 9.2.1.2), genus species, common name, family, NWI Region 2 Wetland Indicator Status (Resource Management Group, Inc. 1999), physiognomic form (fern, forb, grass, moss, sedge, shrub, small tree, tree, and vine), habit (annual, perennial, cryptogram, woody species), group (monocot or dicot), shade tolerance (shade species, light species, partial light species, or adventive) and coefficient of conservative value (C of C). Two botanists from the University of North Carolina, Chapel Hill, were contracted to evaluate each plant species and assign C of C values based on Taft *et al*. (1997), which is summarized in Table 9.2.1 below. An average value of the C of C ratings of the two botanists was calculated for the species list database.

Information from the "DWQ Headwater Wetland Woody Stem Survey Field Sheet" and "DWQ Wetland Species Plant Survey Species Cover Sheet" was also entered into a "Coverage and woody stem survey" database in Excel. The median cover value for each cover class (see Table 9.2.2) was calculated for all coverage records on the "DWQ Wetland Species Plant Survey Species Cover Sheet" and entered in the database. Voucher species identifications were used to modify and correct the field sheets and databases prior to analysis.

Table 9.2.1 Floristic Quality Index Coefficient of Conservation Value Assignments (Taft et. al. 1997)

C of C Value Assignment	Criteria used to define C of C assignment
0-1	Taxa that are adapted to severe disturbances, particularly anthropogenic. Disturbance occurs so frequently that often only brief periods are available for growth and reproduction, generally considered ruderal species/opportunistic invaders.
2-3	Taxa within this category are associated with more stable, though degraded habitat. Generally considered ruderal-competitive species, found in a variety of

C of C Value Assignment	Criteria used to define C of C assignment
	habitats.
4-6	Taxa that have a high consistence of occurrence within a given community type and will include many dominant or matrix species for several habitats. Species will persist under moderate disturbance.
7-8	Taxa associated mostly with natural areas but can persist where the habitat has been somewhat degraded. Increases in the intensity or frequency of disturbance may result in reduction in population size or taxa may be subject to local extirpation.
9-10	Taxa exhibiting a high degree of fidelity to a narrow range of synecological parameters. Species within this category are restricted to relatively intact natural areas.

Table 9.2.2 Median Wetland Plant Class Coverages

%Cov m^2 =	Median Cover m^2
T	0.25 m^2
0-1 m^2	0.5 m^2
1-2 m^2	1.5 m^2
2-5 m^2	3.5 m^2
5-10 m^2	7.5 m^2
10-25 m^2	17.5 m^2
25-50 m^2	37.5 m^2
50-75 m^2	62.5 m^2
75-95 m^2	85 m^2
95-100 m^2	97.5 m^2

CANDIDATE METRICS

A total of 41 candidate metrics was identified for use as potential metrics for the North Carolina headwater wetland Plant Index of Biotic Integrity. The candidate metrics assessed for the study were different types of vegetative parameters (or different types of metrics): community balance metrics, floristic quality metrics, wetness metrics, functional group metrics, or community structure metrics (see Section 9.1 for further detail on vegetative parameters). All metrics were calculated and statistically tested with JMP v. 6.0 software. Spearman's Rho correlation coefficient, a non-parametric correlation test, was used to test each candidate metric. Plant metrics were tested for normality using the Shapiro-Wilk W Goodness of Fit test (see Section 3.1). The results of the normality test are shown in Appendix F, 21 of the 41 metrics were normally distributed. Spearman's Rho was used since the candidate metric data and disturbance measures were not always normally distributed. The ORAM and LDI disturbance measurements were used to test the candidate metrics (see Section 3). The candidate metric correlations were tested using data from both regions and with the Coastal Plain and Piedmont regions separately. A p-value of 0.15 was considered significant. ORAM and LDI are a better overall indicator of site disturbance then water quality and soil characteristics and were therefore used to test plant metrics. Soil disturbance metrics using trace metals, nutrient level or other characteristics were not used to develop IBI as significant correlations were identified using ORAM and LDI (see Plant Survey Results and Conclusions).

Water quality disturbance scores were not used for this section of the report as most headwater wetlands were not inundated with water therefore many of the individual plants surveyed were not rooted in standing water for all or most of the year. The following is a list and description of each metric. The metrics are organized according to vegetative parameter (or metric type). Table 9.2.3 lists the candidate metrics and the expected correlation (positive or negative) with the various disturbance measurements.

Community Balance Candidate Metrics

Simpson's Diversity Index and *Native Species Simpson's Diversity Index Metrics* – Simpson's Index (Simpson 1949) considers the number of species, the number of individuals, and the proportion of the total of each species. A higher value of D_s correlates with higher diversity within the survey area. The first equation is the standard Simpson's diversity equation (D_s) and the second equation (D_{cov}) uses coverage instead of abundance and was used as a candidate metric in this study. The Simpson's diversity using cover (D_{cov}) and just native species was also calculated and tested as a candidate metric.

$$D_s = 1 - [\sum n_i (n_i - 1) / N (N - 1)] \quad D_{cov} = 1 - [\sum n_{icov} (n_{icov} - 1) / N_{cov} (N_{cov} - 1)]$$

D_s – Simpson's Diversity Index
D_{cov} – Simpson's Diversity Index using Cover
N – Total individuals
n_i –Total individuals of species $_i$
N_{cov} – Total cover for all species
n_{icov} - Total cover for species $_i$

Evenness and *Native Species Evenness Metrics*– Evenness is the distribution of individuals among species. If all species are equal in distribution, then evenness is high. The first equation (E_s) is the standard Evenness equation (Brower and Zar 1977) and the second equation (E_{cov}) uses coverage instead of abundance and was used as a candidate metric in this study. Evenness using coverage and just native species was also calculated and tested as a candidate metric.

$$E_s = D_s / D_{max}$$

$$E_{cov} = D_{cov} / D_{max\text{-}cov}$$

$$D_{max} = (s - 1 / s) * (N / N - 1) \qquad D_{max\text{-}cov} = (s - 1 / s) * (N_{cov} / N_{cov} - 1)$$

E_s - Evenness
D_{max} – Maximum D_s
$D_{max\text{-}cov}$ – Maximum D_s using cover
s - number of species
N – Total Individuals
D_s – Simpson's Diversity Index
N_{cov} – Total cover for all species

Dominance metric – This metric incorporates the "distribution or concentration" of the three most dominant species cover class values for shrub and herb classified individuals.

$$D = (Cov_{a+b+c} / Ncov)$$

Cov_{a+b+c} - Total herb or shrub cover species *a*, *b*, or *c*.
Ncov – Total cover for all herb and shrub species

Species Richness Metric – Total Number of Species

Vascular Plant Genera Richness Metric – Total number of vascular plant genera.

Floristic Quality Candidate Metrics

FQAI and *FQAI Cover Metrics* - Floristic Quality Assessment Index (FQAI) is an evaluation of ecological integrity that incorporates the affinity a species has for occurring in a natural habitat and the total number of species at the site into the calculation of the index (Taft *et al*. 1997). The metric used in this study also includes non-natives in the species total (Fennessy *et al*. 1998a and 1998b, Lopez and Fennessy 2002, Mack 2004). A second FQAI metric, $FQAI_{cov}$, which incorporates species cover into the equation, was also tested.

$$FQAI = \sum C_i / \sqrt{N} \qquad FQAI_{cov} = \sum C_i * Cov_i / \sqrt{N} * Cov_{tot}$$

C_i - Coefficient of Conservatism for species i
N - Species richness (including non-natives)
Cov_i - Cover of species i
Cov_{tot} – Total Coverage including non-native species

Average C of C Metric – Average Coefficient of Conservation value (see Appendix F).

Percent Tolerant Metric – Total relative coverage of all species, including non-natives, with a C of C value ≤ 2.

Percent Sensitive Metric - Total relative coverage of all species, including non-natives, with a C of C value ≥ 7.

Invasive Coverage Metric – Total relative cover of all non-native invasive species.

Invasive Shrub Coverage Metric – Total relative cover, within the shrub stratum only, of non-native invasive shrubs.

Invasive Grass Coverage Metric – Total relative cover, within the herb stratum only, of non-native invasive grasses.

<u>Wetness Characteristics</u>

FAQWet Metrics (FAQWet Equation 3 Metric and *FAQWet Cover Metric)* – The Floristic Assessments for Wetland Plants index equations "3" and "4" were devised by Ervin *et al*. (2006). These equations incorporate species wetness, number of species, number of native species, and frequency of native species. For this study, the FAQWet equation "3" was tested; however, the FAQWet equation "4" was revised to include coverage (FAQWet Cover Metric) rather than frequency as a factor in the equation. Frequency values are typically calculated by the number of times a specific plant species occurs within survey plots. Therefore, the more survey plots in a study the more variable the value for frequency. FAQWet equation "4" was not used in this study since there were only four large survey plots (i.e., four intensive modules). The FAQWet metric equations are as follows:

$$\text{FAQWet equation 3} = \sum WC/\sqrt{S} * N/S$$
$$\text{FAQWet equation 4} = \sum WC/\sqrt{S} * \sum f/\sum F$$
$$\text{FAQWet Cover} = \sum WC/\sqrt{S} * \sum \text{Cov}_{\text{nat}}/\sum \text{Cov}_{tot}$$

WC = Wetness Coefficient
S = All species
N = Native Species
F = Frequency of all species
f = Frequency of native species

Wetland coefficient values in the above equations are calculated as follows: OBL = + 5, FACW = + 3, FAC = 0, FACUP = -3, UPL = - 5.

Wetland Plant Species Richness Metric – Number of native herb species with a FACW or OBL wetland indicator status.

Wetland Plant Cover Metric – Coverage of native herb species with a FACW or OBL wetland indicator status.

Wetland Shrub Species Richness Metric – Number of native wetland shrubs with a FACW or OBL wetland indicator status.

Wetland Shrub Cover Metric – Coverage of native wetland shrubs with a FACW or OBL wetland indicator status.

Functional Groups

Cryptogram Richness Metric – Number of fern or fern ally species.

Cryptogram Coverage Metric – Total relative cover of fern and fern allies.

Annual : Perennial Metric – Annual + Biennial species / Perennial species.

Bryophyte Coverage Metric – Total relative coverage of moss.
Carex Richness Metric – Total number of *Carex* species.

Carex Coverage Metric – Total relative cover of *Carex* species.

Cyperaceae, Poaceae, and Juncaceae Metric – Total number of native Cyperaceae, Poaceae, Juncaceae.

Cyperaceae, Poaceae, and Juncaceae Coverage Metric – Total relative cover of native Cyperaceae, Poaceae, and Juncaceae.

Dicot Richness Metric – Total number of native dicot herb species.

Dicot Coverage Metric – Relative percent cover of native dicot herb stratum species.

Community Structural

Native Herb Species Richness – Total number of native herb species.

Native Herb Cover Metric – Total herb cover for native species.

Total Herb Species Richness (Native and Exotic) Metric –Total herb richness for both native and exotic species.

Total Herb Cover (native and exotic) Metric –Total herb cover for both native and exotic species.

Shade Metric – Number of native species (not including adventives or trees) with a shade rating of "shade" or "partial shade".

Sapling Density Metric – Relative density of canopy and small tree sapling species and small tree species in the <1 cm, 1-2.5 cm, 2.5-5 cm, and 5-10 cm DBH size classes. Relative density was calculated for each size class by dividing the total number of stems per size class for canopy and small tree species by all stems for canopy and small tree species. The relative density of the four size classes (<1 cm, 1-2.5 cm, 2.5-5 cm, and 5-10 cm) was then summed to equal the *Sapling Density Metric*.

Large Tree Density Metric – Relative density of trees ≥ 25 cm DBH. The relative density of trees ≥25 cm was calculated by dividing the total number of ≥ 25 cm DBH canopy and small tree species stems by the total number of all canopy and small tree species stems.

Pole Timber Density Metric – Relative density of trees in the 10-15, 15-20, and 20-25 cm DBH size class. Relative density of pole timber trees was calculated for each size class (10-15, 15-20, 20-25) by dividing the total number of stems per size class for canopy and small tree species by all stems for canopy and small tree species. The relative density of the three size classes (10-15, 15-20, and 20-25 cm) was then summed to equal the *Pole Timber Density Metric*.

Canopy Importance Metric - The *Canopy Metric* is the average relative importance value of native canopy species. The relative importance value is equal to the sum of relative density, relative dominance, and relative frequency. Relative density for each species was calculated by dividing the total number of canopy stems per species by the total number of canopy stems for all species. Species dominance per size class for size classes 0-1 cm to 30-35 cm DBH was calculated by multiplying the number of canopy stems in each species size class by the midpoint of the size class. The 0-1 cm to 30-35 cm dominance size class for each species was calculated by summing the dominance for size classes 0-1 cm to 30-35 cm. The species dominance for size classes >35 cm DBH was calculated by summing the total DBH for each canopy species >35 cm. Therefore, if two red maples equal to 45 cm DBH and one red maple equal to 60 cm DBH were recorded during the woody vegetation survey the >35 dominance size class would be equal to 150 cm. The total dominance for each species was calculated by summing the 0-1 cm to 30-35 cm dominance and > 35 cm species dominance species size classes. Relative dominance was calculated by dividing total dominance of each canopy species by the total dominance of all canopy species. Relative frequency was calculated by dividing the number of size classes each canopy species occurred in by the total number of size classes, which were 12 (0-1, 1-2.5, 2.5-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45, >45). For example, if red maple occurred in the 0-1, 1-2.5, 2.5-5, 5-10, 10-15, 20-25, 35-40, and >45 the frequency would be 8 / 12 or 0.67.

Average Importance Shrub Metric - The *Average Importance Shrub Metric* is the sum of the average importance value for native shade-tolerant and partial shade-tolerant shrubs and small trees. The average importance values for all native shade shrubs and small trees and all native partial shade shrubs and small trees were calculated separately. The relative importance value is equal to the sum of the relative density, relative dominance, and relative frequency. Relative density for each species (shade or partial shade) was calculated by dividing the total number of shrub and small tree stems per species by the total number of woody stems for all species. Species dominance per size class was calculated by multiplying the number of shrub and small tree stems in each species size class by the midpoint of the size class. The dominance of each size class was then summed to equal total species dominance. Relative species dominance was calculated by dividing total dominance of each native shade or partial shade shrub and small tree species by the total dominance of all woody species. Relative species frequency was calculated by dividing the number of size classes each native shade or partial shade shrub or small tree species occurred in by the total number of size classes, which were 12.

Table 9.2.3 Candidate Plant Metrics and expected Correlation with Disturbance Measurements

Candidate Metric	ORAM Score	LDI Scores
Community Balance Candidate Metrics		
Simpson's Diversity Index Metric	Positive	Negative
Native Species Simpson's Diversity Index Metric	Positive	Negative
Evenness Metric	Positive	Negative
Native Species Evenness Metric	Positive	Negative
Dominance Metric	Negative	Positive
Species Richness Metric	Positive	Negative
Vascular Plant Genera Richness Metric	Positive	Negative
Floristic Quality Candidate Metrics		
FQAI Metric	Positive	Negative
FQAI Cover Metric	Positive	Negative
Average C of C Metric	Positive	Negative
Percent Tolerant Metric	Negative	Positive
Percent Sensitive Metric	Positive	Negative
Invasive Coverage Metric	Negative	Positive
Invasive Shrub Coverage Metric	Negative	Positive
Invasive Grass Coverage Metric	Negative	Positive
Wetness Characteristic Metrics		
FAQWet Equation 3 Metric	Positive	Negative
FAQWet Cover Metric	Positive	Negative
Wetland Plant Species Richness Metric	Positive	Negative
Wetland Plant Cover Metric	Positive	Negative
Wetland Shrub Species Richness Metric	Positive	Negative
Wetland Shrub Cover Metric	Positive	Negative
Functional Groups		
Cryptogram Richness Metric	Positive	Negative
Cryptogram Coverage Metric	Positive	Negative
Annual : Perennial Metric	Negative	Positive
Bryophyte Coverage Metric	Positive	Negative
Carex Richness Metric	Positive	Negative
Carex Coverage Metric	Positive	Negative

Table 9.2.3 Candidate Plant Metrics and expected Correlation with Disturbance Measurements

Candidate Metric	ORAM Score	LDI Scores
Cyperaceae, Poaceae, and Juncaceae Metric	Positive	Negative
Cyperaceae, Poaceae, and Juncaceae Coverage Metric	Positive	Negative
Dicot Richness Metric	Positive	Negative
Dicot Coverage Metric	Positive	Negative
Community Structural		
Native Herb Richness Metric	Positive	Negative
Native Herb Cover Metric	Positive	Negative
Total Herb Richness (Native and Exotic) Metric	Positive	Negative
Total Herb Cover (Native and Exotic) Metric	Positive	Negative
Shade Metric	Positive	Negative
Sapling Density Metric	Negative	Positive
Large Tree Density Metric	Positive	Negative
Pole Timber Density Metric	Negative	Positive
Canopy Importance Metric	Positive	Negative
Average Importance Shrub Metric	Positive	Negative

Section 9.3 Plant Survey Results and Conclusions

Headwater wetlands in the Piedmont and Coastal Plain are primarily with hardwood forests. In the Piedmont and Coastal Plain the three most dominant canopy species were red maple (*Acer rubrum*), tulip tree (*Liriodendron tulipifera*) and sweet gum (*Liquidambar styraciflua*). Another common dominant in the Piedmont was black gum (*Nyssa sylvatica*), which was replaced by swamp tupelo (*Nyssa sylvatica* var. *biflora*) in the Coastal Plain. Other common Piedmont canopy species were willow oak (*Quercus phellos*), sourwood (*Oxydendrum arboreum*), loblolly pine (*Pinus taeda*), and green ash (*Fraxinus pennsylvanica*). Species such as white oak (*Quercus alba*), American beech (*Fagus grandifolia*), and various hickories also occurred in transitional areas at the upland edge of the wetland in the Piedmont and Coastal Plain. Loblolly pine and sweetbay magnolia (*Magnolia virginiana*) were more common in the Coastal Plain, while willow oak, green ash, and sourwood were not.

Sub-canopy and shrub stratum at some of the Coastal Plain sites was denser than in the Piedmont. Ironwood (*Carpinus caroliniana*), flowering dogwood (*Cornus florida*), common persimmon (*Diospyros virginiana*) and (less dominantly), American holly (*Ilex opaca*) occurred in the sub-canopy at most of the Piedmont sites. However, American holly and red bay (*Persea borbonia*) were far more prevalent at the Coastal Plain sites. The shrub cover in the Piedmont, although sparser, was more diverse with 43 species as opposed to the 34 species found in the

Coastal Plain. Tag alder (*Alnus serrulata*) was the most commonly occurring and dominant shrub species in the Piedmont. Other species like highbush blueberry (*Vaccinium fuscatum*), highbush blackberry (*Rubus argutus*), winter berry (*Ilex verticellata*), Chinese privet (*Ligustrum sinense*), and strawberry bush (*Euonymus americanus*) were commonly occurring but not dominant. A few Piedmont sites were dominated with northern spicebush (*Lindera benzoin*), American hazelnut (*Corylus americana),* and sweet pepperbush (*Clethra alnifolia*). In the Coastal Plain, the exotic invasive Chinese Privet was more prevalent. Other dominant and commonly occurring shrubs were evergreen gallberry (*Ilex coriacea*), coastal dog-hobble (*Leucothoe axillaris*), and fetterbush (*Lyonia lucida*), and deciduous horse sugar (*Symplocos tinctoria*), sweet pepperbush, titi (*Cyrilla racemiflora*), and highbush blueberry. Wax myrtle (*Myrica cerifera*), possum-haw (*Viburnum nudum*), and beautyberry (*Callicarpa americana*), were commonly occurring but not dominant in the Coastal Plain.

Vines occurred at all the Coastal Plain and Piedmont sites. Vines were dominant where there were gaps in the canopy caused by natural disturbance. Muscadine grape (*Vitis rotundifolia*), common greenbriar (*Smilax rotundifolia*), and the exotic invasive Japanese honeysuckle (*Lonicera japonica*) commonly occurred and were fairly dominant in both the Piedmont and Coastal Plain. Laurel-leaf greenbriar (*Smilax laurifolia*) was far more dominant in the Coastal Plain, while poison ivy (*Toxicodendron radicans*), although dominant at some sites in the Coastal Plain, was still more prevalent in the Piedmont. Other commonly occurring but less dominant vine species in both Coastal Plain and Piedmont include the trumpet creeper (*Campsis radicans*), yellow jessamine (*Gelsemium sempervirens*), climbing hempweed (*Mikania scandens*), and Virginia creeper (*Parthenocissus quinquefolia*).

The herbaceous stratum was also variable between the Piedmont and Coastal Plain Regions. Overall, the Piedmont headwater wetlands had higher diversity and herbaceous coverage than the Coastal Plain, most likely due to the dominance of acid tolerant shrub species in the Coastal Plain. In the Piedmont there were 70 forb species, 9 fern species, and 40 grass, sedge, and rush species. In the Coastal Plain, there were 33 forb species, 9 fern species, and 14 grass, sedge, and rush species. The fern species that occurred in both regions were primarily the same species; however, there were more ferns, such as netted chain fern (*Woodwardia areolata*), lady fern (A*thyrium filix-femina*), and cinnamon fern (*Osmunda cinnamomea*) as well in the Coastal Plain. Sphagnum moss mats were also more common in the acidic soils of the Coastal Plain. There were no dominant or commonly occurring forb species, although lizard tail (*Saururus cernuus*) was fairly dominant at a few of the sites. Some of the more commonly occurring forb species in the Piedmont were Jack-in-the-pulpit (*Arisaema triphyllum*), rough-stemmed golden-rod (*Solidago rugosa*), Virginia bugleweed (*Lycopus virginicus*), snakeroot (*Sanicula canadensis*). False nettle (*Boehmeria cylindrica*) was common in both the Coastal Plain and Piedmont. In 10 out of 12 Piedmont sites, the exotic invasive Nepalese brown top grass (*Microstegium vimineum*) was the most dominant species within the herbaceous layer; however, this species had only a minor presence in the Coastal Plain. Switchcane (*Arundinaria gigantea*) was common in both the Coastal Plain and Piedmont. Spike Chasmanthium (*Chasmanthium laxum*), *Panicum* and *Dichanthelium* species also occurred at some of the sites in the Coastal Plain and Piedmont. Sedges in the *Carex* genus commonly occurred in the Piedmont and at a few sites in the Coastal Plain, while rushes were uncommon in the Piedmont and Coastal Plain.

The Spearman's Rho correlation analysis resulted in nearly half of the candidate metrics yielding significant results that correlated with ORAM and one or more of the LDI (50 M, 300 M, or watershed) disturbance measurements for the 22 wetland sites on which vegetative surveys were completed. The 20 significant Spearman's Rho correlation results (p-value $\leq$ 0.15) for the 41 candidate metrics are shown in Table 9.3.1. A Pearson's correlation was also run to see if the results would be similar to the Spearman's Rho analysis. The two statistical tests did have similar results. ORAM, 50 M LDI, 300 M LDI, and watershed LDI correlated with 17, 8, 8, and 6 of the candidate metrics for the Spearman's Rho analysis (see Table 9.3.1). The community balance metrics with significant results were Simpson's Diversity Index (native and all species), Evenness (native and all species), Dominance, and Species Richness. The floristic quality metrics with significant results were FQAI, Average C of C, Percent Tolerant, Invasive Cover, and Invasive Shrub Cover. Only one wetland characteristic metric had a significant result, which was Native Wetland Plant Richness. There were also limited results for functional group metrics with the Poaceae, Cyperaceae, and Juncaceae Richness and Cover metrics having significant results. The significant results for community structure metrics were Native Herb Richness, Total Herb Species Richness (native and exotic), Total Herb Cover (native and exotic), Shade, Pole Timber Density, and Average Importance Shrub metric (see Table 9.3.1).

Spearman's Rho correlation analyses were also run on the individual regions, resulting in 20 significant results in the Coastal Plain and 15 significant results in the Piedmont. Although the Coastal Plain did have the same number of significant results as the analysis of both regions,it still seemed more logical to develop one IBI for both regions rather than for each region separately. The dataset for the analysis of both regions together was 22, whereas the datasets for the regional analysis were half that size (11); therefore, the analysis of both regions together provided more statistically robust results. Additionally, an IBI that is usable in more than one region of the state seemed more versatile and would require less training if ever implemented for regulatory usage.

A combination of ten metrics for the Headwater Wetland Plant IBI was chosen from the 20 significant results. Since there were 20 significant results, the metric's p-value, disturbance measurements the metric correlated with, type of metric (vegetative parameter), and metric similarity with other metrics were all factors that were evaluated by DWQ when choosing 10 metrics for the final Plant IBI. Metrics with lower p-values were considered over similar metrics (e.g., Poaceae, Cyperaceae, and Juncaceae Richness and Cover metrics were similar) as the lower p-value indicated a more significant correlation effect with the disturbance measurement. In other words, the lower p-value gives greater confidence in rejecting the null hypothesis as opposed to the higher p-value. The ORAM disturbance measurement is a more accurate representation of the wetland's condition than is LDI disturbacne measurement, which is an evaluation of the surrounding land cover disturbance. LDI is more of an indirect measurement of disturbance, therefore, metrics that only correlated with LDI, especially just watershed LDI, were not chosen for the Plant IBI. Metrics from each type of metric; community balance, floristic quality, wetness characteristic, functional group, and community structure were chosen so that the final IBI was representative of the five different community characteristics: balance, floristic quality, wetness, functional group, and structure, and not just one or two community characteristics. Lastly, when possible, metrics that were similar to each other and had the potential to correlate with each other (autocorrelation) were not chosen (e.g., the Native Species

Evenness metric and Evenness metric). The discussion describes in more detail which metrics were chosen and why.

Table 9.3.2 lists the chosen metrics and the site results for each of those metrics. Native Species Evenness was the only metric chosen for the Community Balance type of metrics. The Native Species Evenness metric correlated with ORAM, the 300 M LDI, and the Watershed LDI. ORAM and the 300 M LDI correlated at p-values of 0.0321 and 0.0782, respectively, which were slightly better than the Evenness Metric calculated from both native and non-native species which had p-values of 0.0366 and 0.1237 for ORAM and the 300 M LDI respectively (see Table 9.3.1). The p-value for the correlation of the Native Species Evenness and Watershed LDI was 0.1318. Evenness was derived from Simpson's Diversity Index, causing the metrics to correlate with each other and have similar results. The Native Species Evenness metric also had slightly lower p-values than the Native Simpson's Diversity Index metric and was therefore chosen for use in the IBI rather than the Native Species Simpson's Diversity Index. Simpson's Diversity Index, calculated from both native and non-native species, only correlated significantly with ORAM at a p-value of 0.0466. The Dominance metric also correlated only with ORAM, but at a less significant p-value of 0.1419, and the Species Richness metric only correlated with the 50 M LDI, at a p-value of 0.0958, and not ORAM.

The FQAI metric, Average C of C metric and Invasive Shrub Cover metric, were chosen from the floristic quality metrics to be used in the Plant IBI (see Tables 9.3.1 and 9.3.2). The Invasive Shrub Cover metric was one of the two metrics out of 19 that correlated with ORAM and all three LDI disturbance measurements (50 M- p-value = 0.0697, 300 M – p-value = 0.0018, and Watershed – p-value = 0.0023). The ORAM score for the Shrub Cover metric also had the lowest p-value of all the significant metric results, at 0.0002, and the FQAI metric had the second lowest ORAM p-value of 0.007. Additionally, FQAI correlated with 300 M LDI at a p-value of 0.1121. The Average C of C metric was chosen for use in the Plant IBI even though the C of C value is used in the FQAI metric calculation (see Section 9.2.2). The Average C of C metric had a p-value of 0.0326 and 0.1463 for ORAM and the 300 M LDI, respectively. Both the site FQAI and the Average C of C values are highly representative of floristic quality; however, FQAI is weighted by species richness, therefore sites that are not as diverse but have high quality species may not score as high an FQAI result as sites with lower floristic quality but higher diversity. For example, Bachelor which tied with Hog Farm Lower for the lowest species richness at 37, had a more average FQAI result at 32.55 (the range was 22.46 to 41.72 with an average of 31.71) and the highest Average C of C metric result at 5.67 while Spring Garden had the highest species richness at 82 and the highest FQAI result at 41.72 but only the fourth highest Average C of C score at 4.95 (the range for Average C of C was 3.28 to 5.67 with and average of 4.55, see Table 9.3.2).

Native Wetland Plant Richness was chosen for use in the Plant IBI as this metric was the only wetland characteristic metric with significant results at a p-value = 0.0471 and 0.1409 for ORAM, and 50 M LDI, respectively. This metric's significant results possibly had more to do with site diversity correlating with the disturbance measurements rather than the wetness factor. As was discussed in Section 9.1, FAQWet was not designed to provide information on the "condition" of the wetland, therefore, it was not surprising the FAQWet equations did not have significant results. It is plausible that the FAQWet results would correlate with hydrological site measurements. Table 9.3.3 shows the FAQWet results, which indicate the Coastal Plain had wetter sites with an average of 9.15 for the FAQWet Equation 3 metric and 8.53 for the FAQWet Cover metric, while the Piedmont had 3.89 for the FAQWet Equation 3 metric and 4.12 for the FAQWet Cover metric. This result is not surprising as many of the Piedmont sites were small, bowl-shaped wetlands that graded into streams, so the vegetation survey recorded upland plants adjacent to the streams.

The Coastal Plain sites tended to be flatter and wider, thus more wetland plants were recorded during the survey. Three sites had low FAQWet scores that were hydrologically representative: 1) Boddie-Noell, a drier urban site in the Coastal Plain; 2) Troxler, an urban Piedmont site; and 3) Duke Forest, a mature, but marginal wetland. Bachelor, a very wet Coastal Plain site that had pocosin-like vegetation, and Walmart, another urban Piedmont site, had the highest FAQWet scores. A Spearman's correlation of just the ORAM hydrology metric against the FAQWet metrics was run to see if there would be a significant result, but there was not. The ORAM hydrology metric was designed to measure the wetness of the site and impacts to the hydrology of the site (e.g. ditching or stormwater input). The ORAM form located in Appendix B, gives further information on the hydrology metric. We have found that performing a rapid assessment of wetland hydrology can sometimes result in inaccuracies especially during times of extreme drought. The hydrology metric, in particular, in a rapid assessment form can be difficult to accurately access. One or both of the FAQWet metrics may still have a future use in monitoring the success of a mitigation site in regards to wetness, although this metric does not appear to be useful for assessing wetland condition at this time. Hydrological data from transducers was available for only 12 of the sites and may have correlated in some way with the FAQWet metrics but was not assessed in this study.

The Poaceae, Cyperaceae, and Juncaceae Cover metric had significant p-value of 0.0542 for ORAM, and 0.0275 for the 50 M LDI. The Poaceae, Cyperaceae, and Juncaceae Richness metric had less significant p-values of 0.133 for ORAM and 0.0684 for the 50 M LDI. The Poaceae, Cyperaceae, and Juncaceae Cover metric was chosen since this metric had lower p-values and both metrics were biological attributes (richness and cover) for the same guild or functional group and, therefore, were related.

The Native Herb Richness metric, Shade metric, Pole Timber Density Metric, and Average Importance Shrub metric were chosen for use in the Plant IBI. The Native Herb Richness Metric correlated with ORAM at a p-value of 0.1031 and 50 M LDI at p-value of 0.0684. The shade metric was the other metric that correlated with all four disturbance measurements at p-values of 0.0738, 0.0406, 0.0409, and 0.134 for ORAM, 50 M LDI, 300 M LDI, and watershed LDI, respectively. The Pole Timber Density Metric only correlated with ORAM at a p-value of 0.057; however, this was the only metric that took into account canopy tree DBH and was therefore chosen for use in the plant IBI. The Average Importance Shrub Canopy metric correlated with ORAM, 300 M LDI, and watershed LDI at p-values of 0.0447, 0.0691, and 0.1036, respectively, and was chosen for use in the Plant IBI. The Total Herb Cover (native and exotic) Metric only correlated with watershed LDI at a p-value of 0.1133 and no other metrics, and the Total Herb Richness (native and exotic) only correlated with the 50 M LDI at a p-value of 0.0140 and no other metrics.

The results of the 10 metrics chosen for usage in the plant IBI, and regional and overall maximum, minimum, and averages, are shown in Table 9.3.2. Additionally, Figures 9.3.1 – 9.3.10, located at the end of this section, graphically show the correlation of each metric separately with the ORAM disturbance measurement. Table 9.3.2 shows that Native Species Evenness ranged from 0.74 to 0.94 with the average being 0.86 in the Coastal Plain and 0.88 in the Piedmont (see Figure 9.3.1). The FQAI metric ranged from 22.46 to 41.72, with the average being 30.6 in the Coastal Plain and 32.65 in the Piedmont (see Figure 9.3.2). The Average C of C metric ranged from 3.28 to 5.67, with the average being 4.72 in the Coastal Plain and 4.44 in the Piedmont (see Figure 9.3.3). The Invasive Shrub Cover Metric ranged from 0 at 11 different sites to 85.14 at the Hog Farm Upper site due to the dominant presence of Chinese Privet (*Ligustrum sinense)*. The Coastal Plain average was 22.16 and the Piedmont average was 6.66 for the Invasive Shrub Cover metric (see Figure 9.3.4). The Native Wetland Plant Richness metric ranged from 2 to 15 with the average being 5.82 in the Coastal Plain and 8.27 in the Piedmont (see Figure 9.3.5). The Poaceae, Cyperaceae, and Juncaceae cover metric ranged from zero to 76.5, with the average being 9.55 in the Coastal Plain and 19.76 in the Piedmont (see Figure 9.3.6). The Native Herb Species Richness metric ranged from 6 to 40, with the average being 12.09 in the Coastal Plain and 24.27 in the Piedmont (see Figure 9.3.7). The shade metric ranged from 13 to 43, with the average being 17 in the Coastal Plain and 24.45 in the Piedmont (see Figure 9.3.8). The Pole Timber Density metric ranged from 0.0798 to 0.04513, with the average being 0.1951 in the Coastal Plain and 0.20 in the Piedmont (see Figure 9.3.9). Lastly, the Average Importance Shrub metric ranged from zero to 0.0553, with the average being 0.0222 in the Coastal Plain and 0.02 in the Piedmont (see Figure 9.3.10).

Spring Garden, a high-quality Piedmont site, had 4 of the best results with a FQAI metric of 41.72, Invasive Shrub Cover metric of zero, Native Plant Richness metric of 15. and shade metric of 43. Troxler, a low-quality Piedmont site, had three of the worst results with an FQAI metric of 22.46, Average C of C metric of 3.26, and Native Wetland Plant Richness metric of 2. In the Coastal Plain Bachelor had two of the best results, with the highest overall Average C of C value of 5.67 and an Invasive Shrub Cover of 0, while Hog Farm Upper had the two worst results for Native Species Evenness (0.74) and Invasive Shrub Cover (85.14).

Table 9.3.4 shows the metric score assignment for plant metrics and Table 9.3.5 shows the metric score values assigned for each of the site's metrics and final Headwater Wetland Plant IBI score results organized by region. For example, Table 9.3.4 shows an FQAI Metric result of < 28 scores "0", ≥ 28 and < 33 scores "3", ≥ 33 and < 35 scores "7", and ≥ 35 scores "10". Therefore, Table 9.3.5 shows that Battle Park and Boddie Noell, which both had FQAI Metric values < 28 scored "0". Kelly Road and Moonshine, which had FQAI Metric results of 28.88 and 32.31, respectively, scored "3". Rough Rider and Black Ankle Non-Powerline, which had FQAI Metric results of 33.7 and 34.47, respectively, scored "7". Lastly, Spring Garden and Cox, which had FQAI Metrics results of 41.72 and 36.95, respectively, scored "10". The overall distribution of the metric results and natural breaks in the data were used to assign the metric score values shown in Table 9.3.4.

The final Headwater Wetland Plant IBI scores ranged from 6 to 66, with an average of 39.91 in the Coastal Plain and 19 to 84, with an average of 46.95 in the Piedmont. In the Coastal Plain, Boddie Noell, Hog Farm Upper, and Hog Farm Lower had the three lowest Plant IBI scores of 6, 12, and 15, respectively. Cox, Rough Rider, and East Fayetteville South had the three highest scores of 66, 61, and 60, respectively. Boddie Noell was an urban site located in Rocky Mount that was not as wet or as diverse as some of the other sites and had a dominance of poison ivy (*Toxicodendron radicans*) in the understory. The Hog Farm sites are located adjacent to intensive agricultural land use. The presence of old disposal piles caused disturbance to the substrate, especially at Hog Farm Upper, enabling the establishment of Chinese privet. Additionally, it is likely there was historic grazing at both sites and sediment erosion was also noted at Hog Farm Lower. Chinese privet (*Ligustrum sinense*), which is a very aggressive exotic invasive in North Carolina, will dry wetland sites and shade out native vegetation. The low Plant IBI scores seemed fairly representative of the condition of these three sites, which also had the three lowest Coastal Plain ORAM scores. Cox, Rough Rider, and East Fayetteville South are all located in fairly natural settings with mature forested vegetation. Cox does have a clear-cut located to the east of the site, but this disturbance occurred during the study and was noted in Section 9.1. As noted, before, one of the disadvantages to using plants as indicators of wetland condition is that plants have a lag-time response to stressors (Cronk and Fennessy, 2001). Rough Rider is a mature forested system with an intact buffer that is 50 feet on all sides and > 200 feet around 80% of the study area. Rock Hill Road bisects the East Fayetteville South site west of the location of the vegetation survey plot so the plant survey may not have picked up some of the edge effect of the road. East Fayetteville South otherwise is a mature forested system with a diverse wetland understory and 100 foot wide intact buffer.

In the Piedmont, Troxler, Kelly Rd, and Moonshine had the three lowest scores of 19, 36, and 47, respectively. Spring Garden, Umstead, and Black Ankle Non-Powerline had the three highest scores of 84, 70, and 64, respectively. Troxler and Moonshine are both urban sites, though Moonshine has a more mature forest and a wider buffer than Troxler, which had a number of invasive species including a dominance of poison ivy. Kelly Road is less of an urban site, though Old US 1 is located to the southeast and the buffer located along the northeastern portion of the site appears to be only 10-15 years old. There is also a dominance of golden bamboo (*Phyllostachys aurea*) located along the edge of the study area and in the buffer, in addition to other exotics such as Bradford pear (*Pyrus calleryana*) and Nepalese brown top (*Microstegium vimineum*). Additionally, the downstream section of the site has been dredged to create a berm for a farm pond. The dredged area was dominated solely with lizard's tail (*Saururus cernuus*) at the time of the vegetation survey. It was not surprising that Spring Garden had the highest overall Plant IBI score of 84, as this site is a mature forested high-quality wetland with a diverse understory, and also had the highest overall ORAM score of 74.33. Umstead, which is not as diverse as Spring Garden, is also a very mature forested system and located in the middle of Umstead State Park in Wake County. Umstead also had the second highest Piedmont ORAM score of 70. Black Ankle Non-Powerline is located on Nature Conservancy property, and like Spring Garden has high understory diversity. This site does have more of an edge effect than Spring Garden as Black Ankle Road is located to the north. Overall, the Plant IBI scores overall seem to be fairly representative of the wetland condition as measured by ORAM and LDI. Figures 9.4.1 to 9.4.4 show a graphical representation of the headwater wetland plant IBI scores versus ORAM and the watershed, 300 m, and 50 m LDI values.

The results of the vegetative monitoring effort have provided a usable Headwater Wetland Plant IBI that has the potential to be applicable in other wetland types. In future studies, DWQ also plans to determine if the Headwater Wetland Plant IBI can be applied in other types of North Carolina wetlands. It is probable that some of the chosen plant metrics, like the FQAI and Average C of C metrics, which have already proven usable in other regions of the country, are more versatile in different types of North Carolina wetlands than other metrics chosen for the Headwater Wetland Plant IBI. The development of a vegetative IBI that is applicable for the entire state is most desirable and would be the easiest to implement in regulatory practices. The Headwater Wetland Plant IBI was also developed for a forested system and would need to have some adjustments to account for naturally non-forested wetlands and wetlands that have little shrub cover like salt and freshwater marshes. Metrics such as Pole Timber Density, Shade, Invasive Shrub Cover, and Average Importance Shrub metric would need to be removed or revised for the Headwater Wetland Plant IBI to be usable for non-forested or shrub covered wetland systems.

In this vegetation study, similar to the Amphibian and Macroinvertebrate monitoring efforts, there is a size limitation of only 22 sites. There are other comparable studies with small sample sizes, including a study done on 26 depressional wetlands in Minnesota by Helgen and Gernes (Rader *et al*. 2001), and 20 depressional wetlands in Ohio by Lopez and Fennessy (2002). Larger studies have been completed by Ervin et. al (2006) on 52 Mississippi wetlands, Cohen at al. (2004) on 75 isolated depressional Florida wetlands, Reiss and Brown (2005) on 118 isolated depressional forested Florida wetlands, and Andreas *et al*. (2004) on 156 Ohio wetlands. The analysis results indicate there is strong correlation between wetland condition, as assessed by ORAM (and as assessed indirectly by LDI) and the quality of the wetland vegetative community, although study sample size was rather small. Future wetland monitoring and further testing and development of the Plant IBI should result in a Plant IBI that is usable in other types of North Carolina wetlands; however, it is probable at least two types of IBIs will need to be developed for both forested and non-forested systems.

Table 9.3.1 Plant Significant Correlation Results with Disturbance Measurements

Candidate Metric	Disturbance measurement	Spearman ρ	p-value
Community Balance Significant Metric Results			
Simpson's Diversity Index Metric	ORAM	0.4286	0.0466
Native Species Simpson's Diversity Index Metric	300 M LDI	-0.3642	0.0956
Native Species Simpson's Diversity Index Metric	ORAM	0.4512	0.0351
Native Species Simpson's Diversity Index Metric	Watershed LDI	-0.3348	0.1277
Evenness Metric	300 M LDI	-0.3382	0.1237
Evenness Metric	ORAM	0.4478	0.0366
Native Species Evenness Metric	300 M LDI	-0.3834	0.0782
Native Species Evenness Metric	ORAM	0.4579	0.0321
Native Species Evenness Metric	Watershed LDI	-0.3315	0.1318
Dominance Metric	ORAM	-0.3235	0.1419
Species Richness Metric	50 M LDI	-0.364	0.0958
Floristic Quality Significant Metric Results			
FQAI Metric	300 M LDI	-0.3484	0.1121
FQAI Metric	ORAM	0.5573	0.007
Average C of C Metric	300 M LDI	-0.3202	0.1463
Average C of C Metric	ORAM	0.4568	0.0326
Percent Tolerant Metric	ORAM	-0.4128	0.0562
Invasive Cover Metric	ORAM	-0.3635	0.0963
Invasive Shrub Cover Metric	300 M LDI	0.6271	0.0018
Invasive Shrub Cover Metric	50 M LDI	0.3939	0.0697
Invasive Shrub Cover Metric	ORAM	-0.718	0.0002
Invasive Shrub Cover Metric	Watershed LDI	0.6156	0.0023
Wetness Characteristic Significant Metric Results			
Native Wetland Plant Richness	50 M LDI	-0.3243	0.1409
Native Wetland Plant Richness	ORAM	0.4277	0.0471
Functional Group Significant Metric Results			
Poaceae, Cyperaceae, and Juncaceae Richness	50 M LDI	-0.3956	0.0684
Poaceae, Cyperaceae, and Juncaceae Richness	ORAM	0.3305	0.133
Poaceae, Cyperaceae, and Juncaceae Cover	50 M LDI	-0.4696	0.0275
Poaceae, Cyperaceae, and Juncaceae Cover	ORAM	0.4159	0.0542
Community Structural Significant Metric Results			
Native Herb Richness Metric	50 M LDI	-0.5491	0.0081
Native Herb Richness Metric	ORAM	0.3568	0.1031
Total Herb Richness (native and exotic) Metric	50 M LDI	-0.5159	0.014
Total Herb Cover (native and exotic) Metric	Watershed LDI	-0.3473	0.1133
Shade Metric	300 M LDI	-0.4391	0.0409
Shade Metric	50 M LDI	-0.4396	0.0406
Shade Metric	ORAM	0.3887	0.0738
Shade Metric	Watershed LDI	-0.3297	0.134
Pole Timber Density Metric	ORAM	-0.4116	0.057
Average Importance Shrub Metric	300 M LDI	-0.3947	0.0691
Average Importance Shrub Metric	ORAM	0.432	0.0447
Average Importance Shrub Metric	Watershed LDI	-0.3563	0.1036

Table 9.3.2 Plant Metric Results for Coastal Plain and Piedmont Headwater Wetland Sites

Region	Site Name	Native Species Evenness Metric	FQAI Metric	Average C of C Metric	Invasive Shrub Cover	Native Wetland Plant Richness	Poaceae, Cyperaceae, and Juncaceae Cover	Native Herb Richness Metric	Shade Metric	Pole Timber Density Metric	Average Importance Shrub Metric
Coastal Plain	Bachelor	0.93	32.55	5.67	0	5	7.5	8	14	0.1614	0.008
	Battle Park	0.84	24.48	3.73	6.63	7	8.75	18	17	0.1389	0.0553
	Boddie Noell	0.74	25.22	4.04	37.5	4	1.5	8	13	0.2422	0
	Cox	0.94	36.95	5.03	0	5	0.75	18	26	0.0954	0.0115
	East Fayetteville North	0.89	37.81	5.29	0	7	2.75	10	18	0.0798	0.0194
	East Fayetteville South	0.9	32.6	4.76	2.24	4	76.5	9	17	0.0837	0.0322
	Hog Farm Lower	0.81	26.88	4.54	75.13	6	0	9	14	0.2788	0.0181
	Hog Farm Upper	0.74	27.82	4.51	85.14	5	0.5	13	15	0.42	0.0089
	Nahunta	0.88	30.14	4.31	37.14	9	1.5	15	18	0.1528	0.0357
	PCS	0.91	28.48	5.2	0	4	0.75	6	15	0.3148	0.025
	Rough Rider	0.93	33.7	4.86	0	8	4.5	19	20	0.1787	0.0298
	Maximum	0.94	37.81	5.67	85.14	9	76.5	19	26	0.42	0.0553
	Minimum	0.74	24.48	3.73	0	4	0	6	13	0.0798	0
	Average	0.86	30.60	4.72	22.16	5.82	9.55	12.09	17.00	0.1951	0.0222
Piedmont	Black Ankle Non-Powerline	0.91	34.47	4.45	20.52	14	75.25	37	25	0.1507	0.0105
	Duke Forest	0.93	33.27	4.45	1.12	3	11.25	26	26	0.2099	0.0296
	East of Mason	0.89	33.4	4.87	0	7	33.5	21	23	0.2	0.0173
	Fire Tower	0.86	33.91	4.7	4.68	5	8.25	14	19	0.1878	0.0119
	Kelly Rd	0.79	28.88	4.21	5	7	6.5	17	21	0.1667	0.0214
	Moonshine	0.86	32.31	4.48	5.56	10	73	20	24	0.4513	0.0068
	Pete Harris	0.88	34.63	4.43	0.2	7	3.5	24	29	0.2133	0.0367
	Spring Garden	0.91	41.72	4.95	0	15	7.5	40	43	0.1223	0.0307
	Troxler	0.89	22.46	3.28	32.79	2	2.5	17	17	0.1404	0.0121
	Umstead	0.88	30.5	4.36	0	11	52.25	36	24	0.1633	0.0239
	Walmart	0.9	33.65	4.62	2.26	10	4.75	15	18	0.1915	0.0074
	Maximum	0.93	41.72	4.95	32.79	15	75.25	40	43	0.4513	0.0367
	Minimum	0.79	22.46	3.28	0	2	2.5	14	17	0.1223	0.0068
	Average	0.88	32.65	4.44	6.56	8.27	25.30	24.27	24.45	0.20	0.02
Overall	**Maximum**	0.94	41.72	5.67	85.14	15	76.5	40	43	0.4513	0.0553
	Minimum	0.74	22.46	3.28	0	2	0	6	13	0.0798	0
	Average	0.86	31.71	4.55	18.44	7.09	19.76	17.73	21.50	0.2162	0.0204

Table 9.3.3 FAQWet Metric Results

Region	Site Name	FAQWet Equation 3 Metric	FAQWet Cover Equation Metric
Coastal Plain	Bachelor	16.81	16.81
	Battle Park	2.55	2.93
	Boddie Noell	3.45	3.76
	Cox	9.98	9.98
	East Fayetteville North	11.97	12.2
	East Fayetteville South	5.82	6.19
	Hog Farm Lower	9.56	5.74
	Hog Farm Upper	8.22	4.88
	Nahunta	14.09	13.03
	PCS	10.78	10.78
	Rough Rider	7.42	7.56
	Average	**9.15**	**8.53**
Piedmont	Black Ankle Non-Powerline	9.81	9.66
	Duke Forest	-4.93	-4.03
	East of Mason	4.48	4.56
	Fire Tower	6.93	7.27
	Kelly Rd	4.27	4.13
	Moonshine	6.22	6.67
	Pete Harris	0.85	0.87
	Spring Garden	3.32	3.39
	Troxler	-1.36	-1.53
	Umstead	1.87	1.84
	Walmart	11.33	12.54
	Average	**3.89**	**4.12**

Table 9.3.4 Metric Score Assignment for Plant Metrics

Metric	0	3	7	10
Native Species Evenness Metric	< 0.85	< 0.9	< 0.93	≥ 0.93
FQAI Metric	< 28	< 33	< 35	≥ 35
Average C of C Metric	< 4.3	< 4.6	< 5.0	≥ 5.0
Invasive Shrub Cover	≥ 20	< 20	< 10	< 5
Native Wetland Plant Richness	< 10	< 20	< 30	≥ 30
Poaceae, Cyperaceae, and Juncaceae Cover	< 5	< 10	< 40	≥ 40
Native Herb Richness Metric	<10	< 20	< 30	> 30
Shade Metric	< 16	< 22	< 27	≥ 27
Pole Timber Density Metric	≥ 0.30	< 0.30	< 0.20	< 0.10
Average Importance Shrub Metric	< 0.01	< 0.02	< 0.03	≥ 0.03

Table 9.3.5 Plant Metric Score and IBI Results for Coastal Plain and Piedmont Headwater Wetland Sites

Region	Site Name	Native Species Evenness Metric	FQAI Metric	Average C of C Metric	Invasive Shrub Cover	Native Wetland Plant Richness	Poaceae, Cyperaceae, and Juncaceae Cover	Native Herb Richness Metric	Shade Metric	Pole Timber Density Metric	Average Importance Shrub Metric	Plant IBI Result
Coastal Plain	Bachelor	10	3	10	10	3	3	0	3	7	0	49
	Battle Park	0	0	0	7	3	3	3	3	7	10	36
	Boddie Noell	0	0	0	0	0	0	0	3	3	0	6
	Cox	10	10	10	10	3	0	3	7	10	3	66
	East Fayetteville North	3	10	10	10	3	0	3	3	10	3	55
	East Fayetteville South	7	3	7	10	0	10	0	3	10	10	60
	Hog Farm Lower	0	0	3	0	3	0	0	3	3	3	15
	Hog Farm Upper	0	0	3	0	3	0	3	3	0	0	12
	Nahunta	3	3	3	0	7	0	3	3	7	10	39
	PCS	7	3	10	10	0	0	0	3	0	7	40
	Rough Rider	10	7	7	10	7	0	3	3	7	7	61
Piedmont	Black Ankle Non-Powerline	7	7	3	0	10	10	10	7	7	3	64
	Duke Forest	10	7	3	10	0	7	7	7	3	7	61
	East of Mason	3	7	7	10	3	7	7	7	3	3	57
	Fire Tower	3	7	7	10	3	3	3	3	7	3	49
	Kelly Rd	0	3	0	7	3	3	3	3	7	7	36
	Moonshine	3	3	3	7	7	10	7	7	0	0	47
	Pete Harris	3	7	3	10	3	0	7	10	3	10	56
	Spring Garden	7	10	7	10	10	3	10	10	7	10	84
	Troxler	3	0	0	0	0	0	3	3	7	3	19
	Umstead	3	3	3	10	10	10	10	7	7	7	70
	Walmart	7	7	7	10	7	0	3	3	7	0	51

Figure 9.3.1 Native Species Evenness Metric versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont)

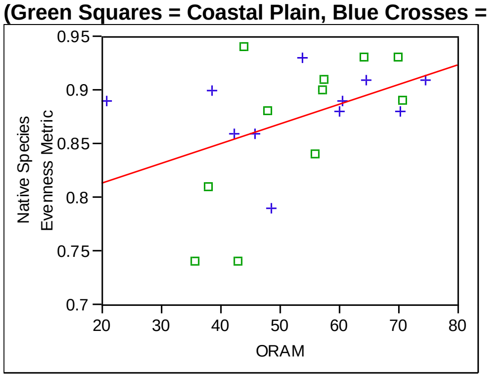


Figure 9.3.2 FQAI Metric versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

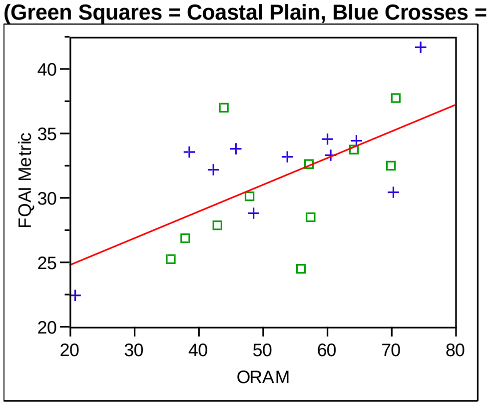


Figure 9.3.3 Average C of C Metric versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

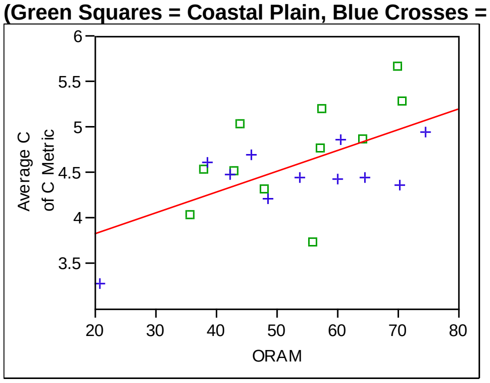


Figure 9.3.4 Invasive Shrub Cover Metric versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

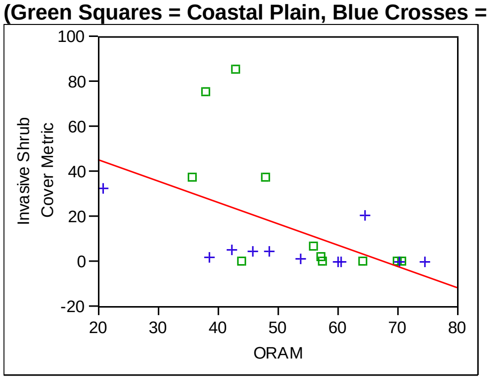


Figure 9.3.5 Wetland Plant Richness versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

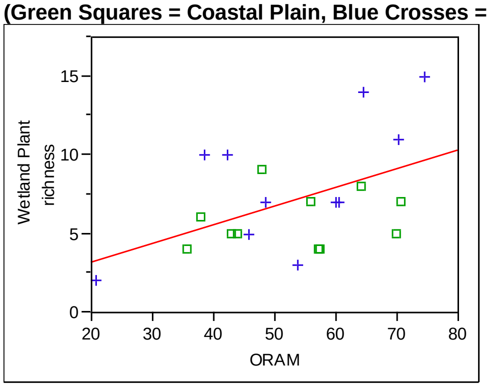


Figure 9.3.6 Poaceae, Cyperaceae, and Juncaceae Cover versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

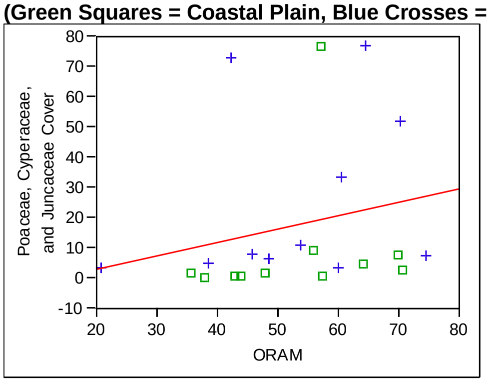


Figure 9.3.7 Native Herb Richness Metric versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

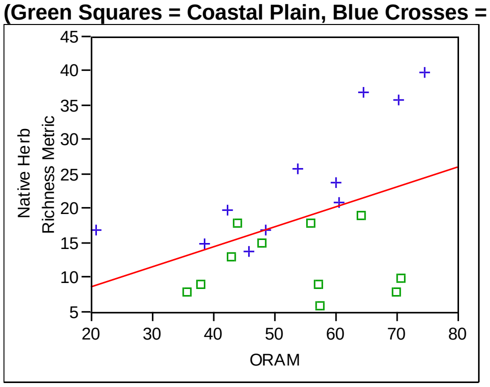


Figure 9.3.8 Shade Metric versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

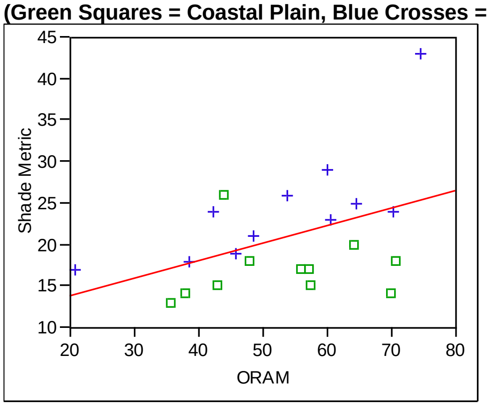


Figure 9.3.9 Pole Timber Density Metric versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

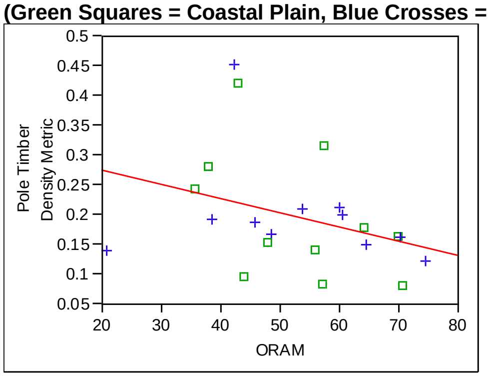


Figure 9.3.10 Average Importance Shrub Metric versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont

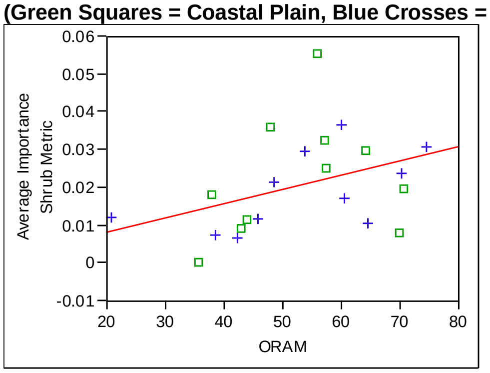


Figure 9.4.1 Headwater Wetland Plant IBI versus ORAM
(Green Squares = Coastal Plain, Blue Crosses = Piedmont)

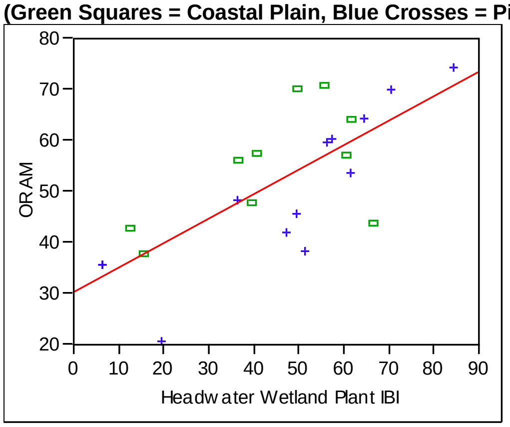


Figure 9.4.2 Headwater Wetland Plant IBI versus Watershed LDI
(Green Squares = Coastal Plain, Blue Crosses = Piedmont)

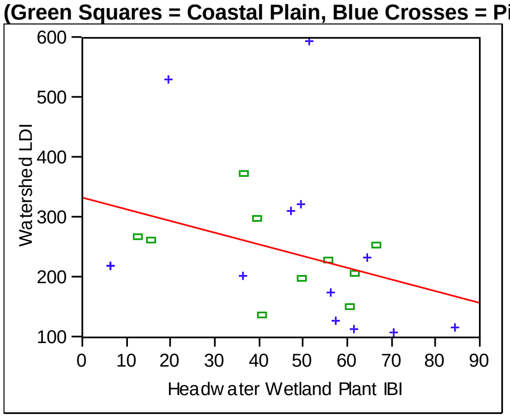


Figure 9.4.3 Headwater Wetland Plant IBI versus 300 M LDI
(Green Squares = Coastal Plain, Blue Crosses = Piedmont)

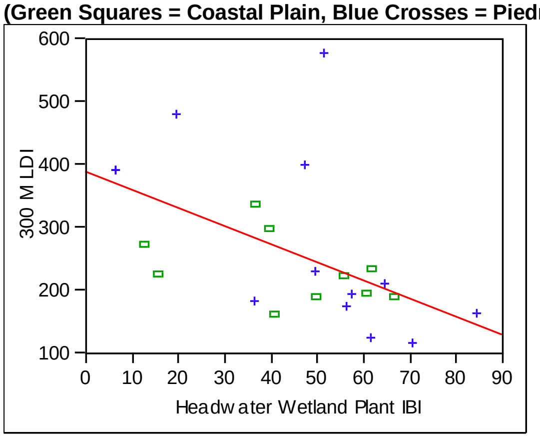
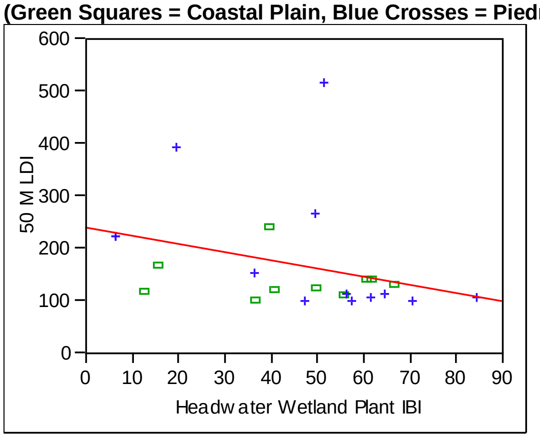


Figure 9.4.4 Headwater Wetland Plant IBI versus 50 M LDI
(Green Squares = Coastal Plain, Blue Crosses = Piedmont)



Section 10 – Headwater Wetland Summary Discussion and Final Conclusions

Section 10.1 Headwater Wetland Summary Discussion

Headwater wetlands are quite diverse and variable in nature both within and between regions. The following discussion is based on the field research of the 23 sites used in this study, observations of other headwater wetlands located during the site reconnaissance stage of this study, and research on headwater wetlands. The purpose of this discussion is to provide a general description on the physiography, water quality, hydrology, soils and amphibian, macroinvertebrate, and plant communities of these unique systems.

The monitoring of these 23 headwater wetland sites has enabled the NC DWQ to characterize the attributes of the physiography, water quality, soils, hydrology, macroinvertebrates, amphibians and plants of this wetland type. In the Piedmont, headwater wetlands are typically bowl-shaped features in the landscape that grade into first order ephemeral, intermittent, or small perennial streams. Streams often originated with shallow braided channels dissecting the bowl-shaped wetland. The headwater wetlands in the Piedmont tend to be narrower than wide and usually less than half to three-quarters of an acre in size (the average was 0.61 acre in this study). The "bowl-shaped" headwater wetland is less prevalent in the Coastal Plain, although areas with more topographical relief (e.g., sandhill region) can still form this bowl shape. Coastal Plain headwater wetlands in many situations are better described as headwater swamps that are fairly flat and larger in size than Piedmont headwater sites (the average was 2.2 acres in this study). Many Coastal Plain wetlands, especially in rural agricultural areas have been ditched and the stream straightened so the natural grading of wetland to stream is absent. Another frequent impact to headwater wetlands was roads that were usually built prior to wetland regulations often bisect headwater wetlands either at the very head or right at the base of the headwater wetland.

Headwater wetlands are located in the upper reaches of watersheds and therefore have the capacity to influence downstream water quality and aquatic resources. Headwater wetland water quality in North Carolina is variable and affected by stormwater runoff, ditching, ecoregion, soils, topography, and vegetation coverage. Activities such as urban development, agriculture, livestock operations, and silviculture can cause pollutants such as metals, nutrients, fecal coliform, sediments, oils, and pesticides to drain into headwater wetlands via stormwater runoff. Headwater wetlands act as a natural filter by removing, reducing, or transforming these pollutants. Ditching of stormwater into a headwater wetland can increase the flow rate of stormwater and therefore pollutants entering the wetland while ditching through a headwater wetland will decrease the water retention time in the headwater wetland and therefore cause higher levels of pollutants to exit the system. Regional differences can cause variability in the soils, topography and plant communities, which have the potential to cause differences in the water quality. In this headwater wetland study, the acidic soils of the Coastal Plain caused lower pH than in the Piedmont. In addition, calcium and magnesium in Coastal Plain soils were significantly higher than in the Piedmont. The dense plant coverage and organic soils of the Coastal Plain also probably caused the total and dissolved organic carbon (TOC and DOC) to be higher than in the Piedmont. NO_2+NO_3, phosphorous, total Kjeldahl (TKN), and specific conductivity were also significantly higher in the Coastal Plain than Piedmont. Topographical relief and colder water allowed for significantly higher oxygen levels in the Piedmont as compared to the Coastal Plain. Copper was also significantly higher in the Piedmont than Coastal Plain. The presence of vegetation in headwater wetlands is also extremely important for water quality. Wetland plants filter out pollutants such as sediments and absorb other harmful pollutants through their roots.

Headwater wetland hydrology varies according to season, rainfall, ecoregion, topography, the condition of the surrounding watershed, and human impacts such as ditching and road construction. Headwater wetlands show definite seasonal trends. Headwater wetlands have pockets of inundation and saturation during the wet season, from November to May. Surface water in many headwater sites will dry up during the growing season due to evapotranspiration. The hydrological connection to downstream waters is usually a small perennial or intermittent stream. In some situations that stream connection can be ephemeral in nature. Headwater wetlands may lose their surface connection to downstream waters during drier seasons, but it is unlikely the groundwater connection is lost. This was indicated by the fact that most of the headwater wetlands in this study continue to have measurable water levels in the shallow groundwater levels throughout the growing season. Headwater wetlands have water levels within a foot of the surface during most of the growing season. While the sites may appear to be dry on the surface, the water levels are not far below the surface. The Coastal Plain sites water levels were within a foot of the surface 75% of the growing season and Piedmont sites were 72% of the growing season. Urban site water levels were within a foot of the surface 62% of the growing season while rural sites were at 75% and natural sites at 84%. These results may be useful for establishing mitigation success criteria. The bowl-shaped Piedmont topography and flat Coastal Plain topography can affect the hydrology of headwater wetlands. The downhill gradient of headwater wetlands promotes groundwater seepage even during drier months when there is no surface water. For example, in this study, the bowl-shaped headwater wetlands, because of their steeper slopes and smaller size have more frequent changes in water level (spikes) during storm events while the flatter Coastal Plain wetlands exhibit smoother transitions. The study results also showed that urban headwater wetlands have definite flashy trends primarily due to the density of development increasing runoff. Human impacts to the hydrology are common in headwater wetlands and can be caused by ditching which lowers the water table. Increased impervious surface in the watershed has the potential to cause flashiness. Additionally, roads built at the base of headwater wetlands with poorly placed culverts cause ponding. Logging which decreases the evapotranspiration that would normally be at a headwater wetland site can also cause increased ponding.

The soils in headwater wetlands are variable. Coastal Plain headwater wetland soils can be mineral or organic while Piedmont headwater wetland soils are usually always mineral. In this study, the Coastal Plain headwater wetlands generally had higher levels of phosphorus, exchangeable acidity, and humic matter while the Piedmont had higher levels of metals such as manganese, zinc, and copper. Metals and nutrients are leeched out of adjacent upland soils and accumulate in the headwater wetlands, which act as a natural sink for pollutants. Headwater wetland soils in this study were mapped as hydric, upland with hydric inclusions, and in a few situations, upland. Coastal Plain soil types mapped in this study included: Matachie, Carteret, Deloss, Rains, Norfolk, Paxville, Wagram, Blaney, Lynchburg, Wedowee, Grantham, Leon, Torhunta, Seabrook, and Goldsboro. Piedmont soil types mapped in this study included: Herdon, Iredell, Chewacla, Creedmore, Vance, Bibb, Mayoden, Appling, Colfax, Chastain, and Cecil.

The hydrological connection of headwater wetlands through a small perennial or intermittent stream keeps predatory fish out of headwater wetland areas and thus provides excellent breeding habitat for many amphibian species. Headwater wetlands that have deeper pools can mimic conditions found in isolated ephemeral spring ponds, which are utilized by many amphibian species for habitat and breeding. The seepage areas with saturated soils also attract a number of amphibian species such as the dusky salamander, the mud salamander or the four-toed salamander. In this headwater wetland study, 5 of the 26 amphibian species surveyed require headwater, seepage, or ephemeral wetland conditions that are void of predators. In North Carolina, more than half (53 out of 96) of the amphibian species will use seepage ephemeral headwater wetlands and nearly one-third (31) will use these systems exclusively (Braswell 2006). Headwater wetland amphibian species in the Piedmont and Coastal Plain include *Ambystoma* species such as the spotted, mabee's (*A. mabeei*) and marbled salamanders (*A. opacum*), southern (in the Coastal Plain) and northern dusky (in the Piedmont) salamanders, *Eurycea* species such as the Carolina dwarf salamander and southern two-lined salamander, Eastern (in the Piedmont) and Coastal Plain cricket (in the Coastal Plain) frogs, eastern mud-salamanders, red salamanders, four-toed salamanders, *Pseudacris* species such as upland chorus frogs and spring peepers, and leopard frogs. Additionally, various *Bufo*, *Hyla*, and *Plethodon* species can be found in headwater wetlands and associated forested buffers in the Coastal Plain and Piedmont regions.

Many aquatic macroinvertebrates occur within Coastal Plain and Piedmont headwater wetlands. In this study, we detected 33 orders, 43 families, and 160 individual taxa in the Coastal Plain and 27 orders, 19 families, and 175 individual taxa in the Piedmont. This shows that Coastal Plain wetlands are more variable at the order and family level and the Piedmont wetlands were more variable at the taxon level. The most common orders in both regions were *Amphipoda*, *Cyclopoida*, *Diptera*, *Haplotaxida*, and *Isopoda* while *Podocopida* was also common in the Coastal Plain and *Veneroida* was also common in the Piedmont. The most common families in both regions were *Asellidae*, *Chironomidae*, and *Crangonyctidae* while *Naididae* and Ostracods were more common in the Coastal Plain and *Pisidiidae* and *Tubificidae* were more common in the Piedmont.

Headwater wetlands in a natural state are forested with mature trees in both the Piedmont and Coastal Plain with the most dominant tree species being red maple, sweet gum, and tulip poplar in both regions. Other common canopy tree species in the Piedmont include black gum, green ash, and willow oak while swamp tupelo, loblolly pine and sweet bay are more common in the Coastal Plain. Coastal Plain headwater systems tend to have a denser sub-canopy and shrub layer than Piedmont wetlands with species such as American holly, redbay, Chinese privet, gallberry, coastal dog-hobble, fetterbush, horse sugar, and sweet pepper bush dominating. Chinese privet is a frequent invader of the edges of headwater wetlands, especially in Coastal Plain areas that have been disturbed by agricultural and urban development; however, there is higher diversity but more sparse coverage of the Piedmont sub-canopy and shrub layers than in the Coastal Plain. Common piedmont sub-canopy and shrub species include ironwood, flowering dogwood, tag alder and highbush blueberry. The density of shrubs in the Coastal Plain are probably related to the flatter topography and acidic organic soils that provide habitat for acid tolerant species such as those found in the Ericaceae family like fetterbush and coastal dog-hobble. Vine species such as muscadine grape, common greenbriar, trumpet creeper, Japanese honeysuckle, laurel-leaf greenbriar (more in the Coastal Plain), and poison ivy (more in the Piedmont) commonly occur within the headwater wetland sites. Vines are more predominant in areas where there are naturally occurring gaps in the canopy or near the edge where there is excess light generated by the removal of a historic forested buffer due to development. Fern species coverage with species such as cinnamon fern, lady fern, and netted chain fern and sphagnum moss mats are more common in Coastal Plain sites than in the Piedmont. Other herbaceous Coastal Plain species include switch cane, lizard tail, and false nettle. The herbaceous stratum in Piedmont headwater wetlands is generally denser and more diverse than in the Coastal Plain, most likely due to less competition for light and space or more acidic conditions. Various species of sedges, grasses, forbs, and ferns occur in the herbaceous stratum such as *Carex* species, switch cane, Nepalese browntop, *Panicum* species, *Dichanthelium* species, spike chasmanthium, jack-in-the-pulpit, rough-leaved goldenrod, snakeroot, lizard's tail, false nettle, Virginia bugleweed, cinnamon fern, lady fern, and netted chain fern. In this study, the exotic invasive Nepolese browntop unfortunately seemed to be prevalent throughout much of the Piedmont headwater wetland sites, even in natural areas.

Section 10.2 Final Conclusions

The purpose of this EPA Wetland Program Development Grant was to study a sample of headwater wetlands along a disturbance gradient in order to examine the differences and similarities of amphibians, water quality, soils, hydrology, aquatic macroinvertebrates, and plants. Our long-term goal is to continue monitoring a portion of the sites and to use the data collected in this study and during future long-term monitoring to continue to assess the condition of NC headwater wetlands and other types of NC wetlands and to develop a set of baseline data that can be used toward implementing mitigation criteria and the support of 404 and 401 regulations. In order to achieve this goal, the NC DWQ devised monitoring methods for the biotic portions of the wetland ecosystem; amphibians, macroinvertebrates, and plants and for the abiotic portions; water quality, hydrology, and soils of headwater wetlands. Study sites were selected at 11 locations within the Coastal Plain and 12 locations within the Piedmont, primarily in 2004. Headwater wetland monitoring information was collected from 2005-2007. A GIS assessment and rapid wetland assessment were completed for the sites in addition to the intensive monitoring surveys. A Land Development Index (LDI, Brown and Vivas 2003) was used for a GIS survey and the Ohio Rapid Assessment Method (ORAM, Mack 2001) was used for the rapid survey. Indices of Biotic Integrity (IBIs) were developed with the survey results from the intensive surveys to see how amphibians, macroinvertebrates, and plant communities vary across disturbance gradients. Intensive survey monitoring data was examined to identify biological attributes that could be used as candidate metrics. Candidate metrics were then tested individually with Spearman's Rho and Pearson's Correlation analyses against site disturbance measurements to see if there was a significant correlation ($p\text{-value} < 0.15$). The GIS and rapid survey results, LDI and ORAM, were used as disturbance measurements. In addition, the intensive survey results of the soil survey (pH, copper, and zinc only) and water quality were also used as disturbance measurements to test the biotic candidate metrics (see Section 3.0 for further detail). The final conclusions of the abiotic sections of the headwater monitoring study will be discussed followed by the biotic conclusions in the following paragraphs.

Extensive monitoring – of the abiotic portions of headwater wetland ecosystems – the water quality, hydrology, and soils were completed in addition to the biotic portions of the study. The water quality monitoring was of particular importance since states are required to protect the quality of navigable waters under Section 401 of the Clean Water Act (U.S. EPA 1989). In addition, the EPA and U.S. Army Corps of Engineers has provided guidance for "non-navigable relatively permanent tributaries" pursuant to the June 2007 Rapanos and Carabell Supreme Court Cases. These relatively permanent tributaries are defined as being connected to traditionally navigable waters with continuous flow at least seasonally (three months) which is comparable to the streams flowing from the headwater wetlands in this study (U.S. EPA, 2008). Headwater wetlands are located in the headwater areas of watersheds and ultimately flow downstream to navigable waters. This post Rapanos and Carabell guidance also requires a "significant nexus analysis" that will assess the functions of the tributary and all adjacent wetlands (like headwater wetlands) to determine if there are significant effects on the chemical, physical and biological integrity of downstream navigable waters (U.S. EPA, 2008). The water quality analysis was done to gain a better understanding of the impact that watershed development and the decrease in the quality of storm water runoff has on headwater wetlands in the Piedmont and Coastal Plain regions of North Carolina. The water quality analysis completed for this report can also be applied to the "significant nexus analysis" as described by the EPA and ACOE guidance document (U.S. EPA, 2008). The goals the water quality section of this study were to determine if: 1) headwater wetlands located in more urban and agricultural watersheds have lower water quality than wetlands located in more natural watersheds; 2) headwater wetlands filter out pollutants; and, 3) headwater wetlands have a better filtering capacity in more natural watersheds than in more developed watersheds.

The results indicated that there is a direct correlation between headwater wetland water quality and the condition of the watershed. Disturbance values for the wetland needed to be determined in order to figure out if headwater wetlands located in more developed watersheds have lower water quality than wetlands located in more natural watersheds. Correlation analyses were run to determine if there was a significant correlation between the site's ORAM and watershed LDI scores and the site's water quality parameter results. The results of these analyses suggested there was a significant correlation (p-value < 0.10) for fecal coliform, magnesium, and NO2+NO3 with both the ORAM and LDI scores and a significant correlation for ammonia, calcium, specific conductivity, and zinc with just the ORAM score.

The results also indicated that wetlands reduce the amount of pollutants entering downstream waters. In order to determine if headwater wetlands are effectively filtering out pollutants, the mean water quality parameter results of the three stations were compared: upstream to downstream (UP-DN), upstream to further downstream (UP-FD), and downstream to further downstream (DN-FD). The mean value for each regional station's water quality parameter was compared to determine if there was "improvement" or "no improvement" at the downstream station. For the regional analysis by station of all the water quality data, 42 of 55 mean station comparisons improved in the Coastal Plain (10 of 19, 16 of 18, and 16 of 18 for UP-DN, UP-FD, and DN-FD respectively) and 14 of 19 mean station comparisons (UP-DN) improved in the Piedmont. For the regional analysis of the "no dig" data 35 of 55 mean station comparisons improved (4 of 19, 16 of 18, and 15 of 18 for UP-DN, UP-FD, and DN-FD respectively) in the

Coastal Plain and 9 of 19 mean and station comparisons improved in the Piedmont. The mean value for each site station's water quality parameters was also compared to determine if there was "improvement" or "no improvement" at the downstream station. For the site station analysis of all the water quality, 256 of 385 mean station comparisons improved (117 of 205, 73 of 90, and 66 of 90) for UP-DN, UP-FD, and DN-FD respectively) in the Coastal Plain and 130 of 224 mean station comparisons improved in the Piedmont. For the site station analysis of the "no dig" data, 222 of 385 mean station comparisons improved (104 of 205, 55 of 90, and 63 of 90 for UP-DN, UP-FD, and DN-FD respectively) in the Coastal Plain and 104 of 195 mean station comparisons improved in the Piedmont. A preliminary analysis of the UP-DN mean station comparisons indicated there was better water quality improvement in the Piedmont than in the Coastal Plain from headwater wetlands. It was then hypothesized that water may need to travel further in the flatter Coastal Plain sites to show improvement. Therefore, further down monitoring stations were established at five of the Coastal Plain sites and monitored for the last two quarters of the study. This analysis showed that there were significantly better results for water quality improvement in the Coastal Plain UP-FD and DN-FD station comparisons than the UP-DN station comparison.

The ANOVA and Ranks sums statistical tests were used to identify significant differences between stations for the comparison of upstream, downstream, and further downstream stations within regions and within sites (p-value ≤ 0.10 was considered significant, only the Ranks sum test was used for site station comparisons). In the Coastal Plain region, there was significant "no improvement" for fecal coliform for UP-FD (all data and no dig) and significant "improvement" for copper for DN-FD ("no dig" only). In the Piedmont region, there were notably more significant improvement results, this may potentially be due to the physiographic differences between regions. For the Piedmont, there was significant "no improvement" for lead (all data), and there was significant "improvement" for dissolved oxygen mg/L, TKN, turbidity (both data sets), copper, percent dissolved oxygen, phosphorous, TOC, and Zinc ("no dig" only). The Ranks sum test found significant results at the site level comparison of the parameters for all parameters except NO2+NO3 and turbidity. The parameters that showed the most significant improvements within sites were dissolved oxygen (five sites), copper (four sites), TKN (six sites), copper (four sites), and TOC (four sites). Walmart, an urban site, and Fire Tower located adjacent to a car junkyard and mobile home park, had the highest number of significant improvements at 12 and 11 respectively. One reason why these two sites had the highest number of significant improvements may be because these sites received the highest rates of pollutants in the headwater areas thereby allowing for greater difference between headwater and downstream stations.

For regional and site station comparisons, a Chi-square test was performed on the categorical nature of the water quality station comparisons (improved or not improved) to determine if the number of station comparisons that improved was significantly different than the number of station comparisons that did not improve. The following comparisons showed significant (p-value < 0.05) improvement for the regional chi-square test: Piedmont UP-DN (all data), Coastal Plain UP-FD and DN-FD (all data), and Coastal Plain UP-DN, UP-FD and DN-FD ("no dig" data). The following comparisons showed significant (p-value < 0.05) improvement for the site chi-square test: Piedmont (UP-DN) (all data), Coastal Plain UP-DN, UP-FD and DN-FD (all data), and Coastal Plain UP-DN, UP-FD and DN-FD ("no dig" data). The overall results of the regional and site station comparison and Chi-square test analyses indicate that headwater wetlands do have the capacity to filter out pollutants and therefore improve the quality of the water entering streams and river systems in their watershed.

Finally, it was determined that higher quality headwater wetlands do not have a better filtering capacity than lower quality headwater wetlands. This conclusion was reached by performing a correlation analysis of the wetland site percent improvement capacity with the wetland site ORAM score. The wetland site percent improvement capacity was calculated by determining the percent of station comparisons that improved for each site. The results of this correlation indicate the importance of preserving headwater wetlands even if the immediate surrounding area is developed and the wetland does not rate as high quality. These lower quality headwater wetlands are still functioning properly and effectively, removing pollutants.

The surface water and pore water quality results were variable in this study as was determined during preliminary analyses. In future studies DWQ will only sample surface water or review and potentially implement a different method for obtaining a cleaner sampler of soil pore water such as with the use of ground wells or lysimeters.

The hydrology data showed that there was a tendency for urban areas to be flashy during rain events. This was shown by comparing the hydroperiods graphs of the urban sites with the more rural sites. Another trend was that the flatter headwater wetlands, typical of the Coastal Plain, showed slower changes in water levels, even seasonally, when compared to the more bowl-shaped wetlands, more typical of the Piedmont. The Piedmont sites, being smaller and more bowl shaped generally showed some flashiness, but less than the more urban sites.

The soils data had several statistically significant results. Most of the results showed mostly obvious trends, with the wetland areas containing significantly more nutrients and metals than the surrounding upland. This result confirms the filtering functions of the wetland, to accumulate potential pollutants and improve water quality. There were some differences in soil composition between the Coastal Plain and Piedmont, mostly in terms of more humic matter and a higher base saturation in the Coastal Plain. Topography differences are also noted in the results in terms of flatter headwater wetlands versus the more bowl-shaped wetlands. Flatter headwater wetlands tended to have more humic matter.

Seven candidate metrics tested for the amphibian IBI with the Spearman's Rho correlation analysis, which resulted in five of those metrics being chosen for the IBI; Amphibian Quality Assessment Index (AQAI), Percent Sensitive, Percent Headwater Wetland-Ephemeral Wetland-Seepage Wetland (HW-EW-SW), Percent Urodela, and Species Richness. The correlations were as follows: water quality disturbance measurements correlated with all five chosen candidate metrics; soil disturbance measurements correlated with four of the five chosen candidate metrics; LDI correlated with two of the five chosen candidate metrics, and lastly, ORAM only correlated with one of the chosen five candidate metrics. The final Headwater Wetland Amphibian IBI scores ranged from 0-27 in the Coastal Plain and 7-37 in the Piedmont. The range of scores was expected as the sites yielded varying success rates during the amphibian survey. However, some of the high scoring and low scoring sites were more unexpected, e.g. the Walmart site, a highly urban site, placed second in the Piedmont while East Fayetteville North, a fairly natural site, scored only “3” in the Coastal Plain. It should be noted that there were some limitations in the study; sample size, qualitative survey methods, buffer features separate from the wetland that provided amphibian breeding habitat, and the adult conversion methods (see Section 7 for further detail). The sample size was only 23 (i.e. number of sites) and survey methods limited by time available. Buffer areas were surveyed and found to sometimes have features like small retention areas or deep puddles. These features provided additional, and in some cases more usable, amphibian breeding habitat than the actual wetland. The conversion of larvae observations to adult observations (typically 20% of the larvae equaled one adult) for survey records is an estimate and therefore not an accurate representation of the number of adults found during a survey.

Thirty-six metrics were tested for the macroinvertebrate IBI with the Spearman’s Rho and Pearson’s correlation analyses. The results between the regions were different so six metrics were chosen for the Coastal Plain; percent Coleoptera, POET (Plecoptera, Odonata, Ephemeroptera, Trichoptera) Richness, percent POET, percent Crustacea, percent Diptera, and percent Orthocladiinae. Seven metrics were chosen for the Piedmont: percent Tolerant, percent Mollusk, percent Coleoptera, POET Richness, Family Richness, Chironomidae Richness, and Predator Richness. GIS disturbance measurement, LDI, correlated with two of the Coastal Plain metrics but none of the Piedmont metrics, while the rapid disturbance measurement, ORAM, correlated with three of the Coastal Plain metrics and one of the Piedmont metrics. The soil disturbance measurements correlated with four of the Coastal Plain and all of the Piedmont metrics and water quality disturbance measurements correlated with all of the Coastal Plain and all of the Piedmont metrics. Two sets of correlation analyses were performed: 1) all the samples taken at every site with the four types of disturbance measurements (LDI, ORAM, soil and water); 2) just two samples (usually sweep samples) with the four types of disturbance measurements. In the Coastal Plain, the Headwater Wetland Macroinvertebrate IBI results ranged from 10 to 36 for all the data and 13 to 40 for the just sweep data (with six metrics) and in the Piedmont the IBI results ranged from 6-57 for all the data and 3-50 for the just sweep data (with seven metrics). Similarly, to the Amphibian IBI, there were some unexpected results, which is not surprising as macroinvertebrates responded more noticeably to intensive water quality and soil chemistry disturbance measurements than to GIS, LDI and rapid, ORAM disturbance measurements. The Macroinvertebrate IBI will need to be further tested with a larger data set and completely equal sampling efforts between sites to more accurately assess the Macroinvertebrate IBI. The sweep samples were a more comparable sample set than the analysis of all the data samples; however, the sample effort was still not completely consistent.

Both the amphibian and macroinvertebrate IBI candidate metric correlation analysis results showed that these communities responded more directly to water quality and soil chemistry rather than the more general GIS, LDI and rapid, ORAM disturbance measurements. GIS and rapid assessments are an easier and more practical assessment for regulatory purposes, however, the correlation results with the candidate metrics indicate that these more general and faster surveys are only partially reflective of the health of the amphibian and macroinvertebrate populations. Water quality and soil chemistry appear to be a better indicator of the health of the amphibian and macroinvertebrate communities which is not surprising. Future wetland monitoring in other types of North Carolina wetlands should verify this assumption.

The Carolina Vegetative Survey (Peet *et. al*. 1997) was used as a template to devise a quantitative survey method for the herbaceous and woody vegetation. The 41 candidate metrics assessed for the Headwater Wetland Plant IBI included community balance, floristic quality, wetness, functional group and community structure types of metrics (see Section 9.0 for further details). Only ORAM and LDI were used as disturbance measurements to test the candidate plant metrics with Spearman's Rho correlation analyses. The water quality and soils disturbance measurements used in the amphibian and macroinvertebrate IBI development sections were not used to test the candidate plant metrics. Headwater wetlands are generally not inundated with water; therefore, many of the individual plants surveyed were not rooted in standing water for long periods. The root system of plants takes up some harmful metals like copper and zinc but are not necessarily harmed by lower dosages and soil pH levels will effect the types of plants the grow in a wetland, but not the quality unless levels are very extreme.

The Spearman's correlation analyses showed that 20 of the 41 plant candidate metrics correlated significantly (p-value $\leq$ 0.15) with ORAM and or one of more of the LDI (50M, 300M, and watershed) disturbance measurements for both regions together. The p-values, type of disturbance measurement that correlated, type of candidate metric, and candidate metric similarity with other metrics were evaluated for the 20 significant results in order to pare down the 20 candidate metrics to the 10 final metrics that were used in the Plant IBI. The final Headwater Plant IBI was composed of the Native Species Evenness, FQAI (Floristic Quality Assessment Index), Average C of C (Coefficient of Conservation), Invasive Shrub Cover, Native Wetland Plant Richness, Poaceae, Cyperaceae, and Juncaceae Cover, Native Herb Richness, Shade, Pole Timber Density, and Average Importance Shrub metrics. The final Headwater Wetland Plant IBI scores ranged from 6 to 66 in the Coastal Plain and 19 to 84 in the Piedmont. In the Piedmont, Spring Garden (a high quality and diverse natural site) had the highest score, and Troxler (an urban site located in an industrial setting in Burlington) had the lowest score. In the Coastal Plain, Cox (a mature forested site that does have recent impacts in the northeastern portion of the buffer) had the highest score, and Boddie Noell (an urban site located in Rocky Mount) had the lowest score. Plants, especially woody species, have a lag time response to stressors so it is possible the Cox site may go through some future changes that could alter the vegetation score due to recent buffer disturbance and therefore change the Plant IBI.

Overall, the results of the vegetation section of this study indicate there is a strong correlation between wetland condition as represented by the disturbance measurements, ORAM and LDI, and the quality of the vegetative community. It should be noted that, a larger dataset, as some other studies have had, would still provide more robust results of the Headwater Plant IBI. Further testing of the Headwater Wetland Plant IBI is also need on other types of wetlands. It is likely that some of the metrics chosen for the Headwater Wetland Plant IBI, like the FQAI, Average C of C metrics, Invasive species cover, etc, which have proven to be usable in other types of wetlands and in other regions of the country, will prove to be useable in a Plant IBI developed for other types of wooded North Carolina wetlands.

In conclusion, it should be noted that there are other factors that could have influenced the results of this study other than the small sample size and the survey methodology previously discussed. The study sites had a lot of natural site variability that occurred outside the influence of human disturbance as is the case with natural systems such as soil type, topography, precipitation and wetland contour. Some of the sites also seemed to have more marginal wetland characteristics, especially during the dry season; like Moonshine, Duke Forest, and Troxler. Having sites that had marginal wetland characteristics, not having a large enough sample size, semi-quantitative survey methods, and not having sites that were highly impacted (although some of the sites had highly impacted buffers) may have been problematic in the IBI development. The aforementioned issues are all reasons why further IBI testing and development is needed. Due to the reality of financial limitations it is unlikely that further testing of the IBI on new headwater sites will happen; however, it is likely these survey methodologies and IBIs can be tested on other types of NC wetlands.

The results of the monitoring and analysis of this study indicate there are significant differences between the amphibian, macroinvertebrate, and plant communities located in headwater wetlands of variable quality. The IBIs developed for the macroinvertebrate, amphibian, and plant communities of headwater wetlands have provided a basis for future monitoring and IBI development on other types wetlands. Further work on additional headwater wetland sites and other types of wetlands is really needed to more accurately test and refine these IBIs. The NC DWQ is currently in the process of completing the fieldwork of the “Field Verification of Wetlands Functional Assessment Methods Grant” (CD 96422105-0), which will provide additional opportunity to test these IBIs and refine the field survey methodologies for riverine swamp wetlands, bottomland hardwood wetlands, and small basin wetlands in the Coastal Plain and Piedmont regions. Additionally, three Piedmont and three Coastal Plain sites have been chosen for long-term wetland monitoring.

The relevant wetland monitoring for the 401 regulatory process is of continual importance in terms of avoidance and minimization, establishment of more accurate mitigation criteria, and preservation. Wetland monitoring of headwater wetlands has provided a scientific reason that supports the protection of these wetlands through minimization of impacts, avoidance, and preservation. Headwater wetlands tend be small but have a highly significant position in the landscape which results in a critical water quality function through filtration of pollutants. Headwater wetlands also provide necessary habitat for breeding amphibians and other species. Wetland monitoring of headwater wetlands have the potential to be used for 401 mitigation criteria in a number of capacities. This study could be used to indicate mitigation success in terms of the hydrological function of headwater wetlands which in this study showed that headwater wetlands have a water table within one foot of the surface for > 50% of the growing season. Further developed IBIs could also be used to determine success criteria of mitigation site vegetation, amphibian, and macroinvertebrate communities. Applying the wetland monitoring results to the 401 regulatory process is necessary to join the science to the real-world issues and practices related to wetland protection.

LITERATURE CITED

Agricultural Statistics. USDA, 1988; North Carolina Department of Natural Resources, Division of Parks and Recreation; NC. Department of Commerce, Division of Travel and Tourism; and NC. Division of Marine Fisheries.

(AGU) American Geophysical Union. Beaver Dams Create Healthy Downstream Ecosystems. 5 December 2007. ScienceDaily. 6 June 2006. <http://www.sciencedaily.com /releases/2006/06/060605120417.htm>.

Alley, W.M., R.W. Healy, J.W. LaBaugh, and T.E. Reilly. 2002. Flow and storage in groundwater systems. Science 296:1985-1990.

Almon, J.M. 1998. Plant Communities of Some Southern Appalachian Bog-Forest Complexes. Master's Thesis. NC State University, Department of Forestry. November 1998.

Anderson, M., P. Bourgeron, M.T. Bryer, R. Crawford, L. Engelking, D. Faber-Langendoen, M. Gallyoun, K. Goodin, D.H. Grossman, S. Landaal, K. Metzler, K.D. Patterson, M. Pyne, M. Reid, L. Sneddon, and A.S. Weakley. 1998. Terrestrial vegetation of the United States. Volume II: List of vegetation types. The Nature Conservancy, Arlington, VA.

Andreas, B.K., J.J. Mack, and J.S. McCormac. 2004. Floristic quality assessment index (FQAI) for vascular plants and mosses for the State of Ohio. Wetland Ecology Group, Division of Surface Water, Ohio Environmental Protection Agency.

Andreas, B.K. and R.W. Lichvar. 1995. Floristic index for establishing assessment standards: a case study for northern Ohio. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, USA. Technical Report WRP-DE-8.

Azous, A.L. and R.R. Horner, eds. (2001). Wetlands and Urbanization. Boca Raton, FL: Lewis Publishers.

Babbit, K.J. 2005. The relative importance of wetland size and hydroperiod for amphibians in southern New Hampshire, USA. Wetlands Ecology and Management 13:269–279.

Baker, W.L. 1987. Recent Changes in the Riparian Vegetation of the Montane and Subalpine Zones of Western Colorado, U.S.A. PhD Dissertation. University of Wisconsin. Madison, WI.

Bataille, K.J. and G.A. Baldassarre. 1993. Distribution and abundance of aquatic macroinvertebrates following drought in three prairie pothole wetlands. Wetlands 13:260-269.

Battle, J.M. and S.W. Golladay. 2002. Aquatic invertebrates in hardwood depressions of southwest Georgia. Southeastern Naturalist 1:149-158.

Batzer, D.P., R.B. Rader, and S.A. Wissinger (eds.). 1999. Invertebrates in freshwater wetlands of North America: ecology and management. John Wiley and Sons, New York, NY, USA.

Batzer, D.P. and S.A. Wissinger. 1996. Ecology of insect communities in nontidal wetlands. Annual Review of Entomology 41:75-100.

Beattie, R.C. and R. Tyler-Jones. 1992. The effects of low pH and aluminum on breeding success in the frog *Rana temporaria*. Journal of Herpetology 26:353-360.

Beck, W.M., Jr. 1953. Studies in stream pollution biology. Florida Academy of Sciences 16: 211-227.

Bedford, B.L., M.R. Walbridge, and A. Aldous. 1999. Patterns in Nutrient Availability and Plant Diversity of Temperate North American Wetlands. Ecology 80:2151-2169.

Bellrose, F.C. 1980. Ducks, geese and swans of North America. Wildlife Management Institute. 540 pp.
Bernthal, T.W. 2003. Development of a floristic quality assessment methodology for Wisconsin. Wisconsin Department of Natural Resources, Bureau of Integrated Science Services, Madison, Wisconsin, USA. PUB-SS-986 2003.
Beschta, R. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. Water Resources Research 14:1011–1016.
Bilby, R.E., K. Sullivan, and S.H. Duncan. 1989. The generation and fate of road-surface sediment in forested watersheds in southwestern Washington. Forest Science 35:453–468.
Blackmer, A.M. and J.M. Bremner. 1976. Potential of soil as a sink for atmospheric nitrous oxide. Geophysical Research Letters 3:739–742.
BMWD (Berrenda Mesa Water District). Water Related Terms / Glossary. 4 December 2007. Terminology. 29 January 2004. http://www.bmwd.org/Terminology.htm
Bouchard, R.W., Jr. 2004. Guide to aquatic macroinvertebrates of the Upper Midwest. Water Resources Center, University of Minnesota, St. Paul, MN. 208pp.
Bowden, W.B. 1984. Nitrogen and phosphorus in the sediments of a tidal, freshwater marsh in Massachusetts. Estuaries 7:108–118.
Boyd, C.E. 1970. Production, mineral accumulation and pigment concentrations in *Typha latifolia* and *Scirpus americanus*. Ecology 51:285–290.
Boyer, R. and C.E. Grue. 1995. The need for water quality criteria for frogs. Environmental Health Perspectives 103:352-357.
Branson, F.A., G.F. Gifford, K.G. Renard, and R.F. Hadley. 1981. Rangeland Hydrology, Second Edition. Society for Range Management. pp. 61-62, 85-88.
Braswell, A., Lab Director and Curator for Herpetology, NC State Museum of Natural Sciences Research Laboratory (NCDENR). Personal interview. 28 March 2006.
Brinson, M.M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology 58:601-609.
Brower, J.E. and J.H. Zar. 1977. Field and laboratory methods for general ecology. Wm. Brown Company, Dubuque, Iowa.
Brown, M.T. and M.B. Vivas. 2003. A Landscape Development Intensity Index. Center for Environmental Policy, Department of Environmental Engineering Sciences, University of Florida. Technical Report Submitted to the Florida Department of Environmental Protection.
Buhl, K.J. and N.L. Faerber. 1990. Acute toxicity of selected herbicides and surfactants to larvae of the midge, *Chironomus riparius*. Abstract *in* "Environmental contaminants and their effects on biota of the Northern Great Plains". U.S. Department of the Interior, Fish and Wildlife Service, Bismarck, ND.
Bullock, A. and M. Acreman. 2003. The role of wetlands in the hydrological cycle. Hydrology and Earth System Sciences 7:358-389.
Busch, D.E. and J.C. Trexler (eds.). 2003. Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, DC 384 pp.
Chescheir, G.M., M.E. Lebo, D.M. Amatya, J. Hughes, J.W. Gilliam, R.W. Skaggs, and R.B. Herrmann. 2003. Hydrology and water quality of forested lands in eastern North Carolina. Technical Bulletin 320, North Carolina Agricultural Research Service, North Carolina State University, Raleigh, North Carolina

Chipps, S.R., D.E. Hubbard, K.B. Werlin, N.J. Haugerud, K.A. Powell, J. Thompson, and T. Johnson. 2006. Association between wetland disturbance and biological attributes in floodplain wetlands. Wetlands 26:497-508.

Chirhart, J. 2003. Development of a Macroinvertebrate Index of Biological Integrity (MIBI) for Rivers and Streams of the St. Croix River Basin in Minnesota. Minnesota Pollution Control Agency Biological Program. St. Paul, MN.

CNN.com Technology. Nutrient runoff deforming frogs. 25 September 2007. CNN. 8 November 2007 http://www.cnn.com/2007/TECH/science/09/25/deformed.frogs.ap/index.html

Cohen M.J., S. Carstenn, and C.R. Lane. 2004. Floristic quality indices for biotic assessment of depressional marsh condition in Florida. Ecological Applications 14:784–794.

Collier, M., R.J. Webb, and J.C. Schmidt. 1996. Dams and rivers: A primer on the downstream effects of dams. US Geological Survey, Circular 1126. 94 pp

Colorado State University. Glossary of Water Terminology. 27 November 2007. Colorado State University Extension-Agriculture. October 2004. http://www.ext.colostate.edu/PUBS/crops/04717.html

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND.

Cronk, J.K. and M.S. Fennessy. 2001. Wetland plants: biology and ecology. CRC Press, Boca Raton, FL.

CSI (Conservation Science Institute). Dam removal. 4 December 2007. Conservation Science Institute. Date unknown. http://www.conservationinstitute.org/damremoval.htm

Cuffney, T.E, J.B. Wallace, and G. J. Lugthart. 1990. Experimental evidence quantifying the role of benthic invertebrates in organic matter dynamics of headwater streams. Freshwater Biology 23:281-299.

Cunningham, J.M., A.J.K. Calhoun, and W.E. Glanz. 2006. Patterns of beaver colonization and wetland change in Acadia National Park. Northeastern Naturalist 13:583-596.

Davidsson, T.E. and M. Stahl. 2000. The influence of organic carbon on nitrogen transformations in five wetland soils. Soil Science Society of America Journal 64:1129-1136.

Davidsson, T.E., R. Stepanauskas, and L. Leonardson. 1997. Vertical patterns of nitrogen transformations during infiltration in two wetland soils. Applied and Environmental Microbiology. 63:3648–3656.

Davie. T. 2003. Fundamentals of hydrology. Routledge, New York, New York. 169pps.

Delorme (ed.). North Carolina Atlas & Gazeteer. 6th Edition. Yarmouth, Maine, Delorme Mapping Company. 2003.

Despres, A.D. and G.R. Whittecar. 2004. Hydrologic variations between mineral soil flat wetlands, southeastern Virginia. Presentation to the Geological Society of America, Northeastern- Southeastern Section meeting, Tysons Corner, Virginia. March 25, 2004

Dodd, C.K. and B.S. Cade. 1998. Movement patterns and the conservation of amphibians breeding in small, temporary wetlands. Conservation Biology 12:331-339.

Duellman, W.E. and L. Trueb. 1986. Biology of amphibians. McGraw-Hill, New York.

Eaton, L.E. and D.R. Lenat. 1991. Comparison of a rapid bioassessment method with North Carolina's macroinvertebrate collection method. Journal of the North American

Benthological Society 10: 335-338.
Engel, S. 1990. Ecosystem responses to growth and control of submerged aquatic macrophytes: A literature review. Technical Bulletin No. 170. Wisconsin Department of Natural Resources, Madison, WI. 20 pp.
Environmental Defense Fund. Environmental impacts of hog factories in North Carolina. 13 December 2007. Publications. 11 December 2002 http://www.environmentaldefense.org/documents/2537_Hogwatch_EnviroImpacts.pdf
Environmental Laboratory. 1987. US Army Corps of Engineers Wetlands Delineation Manual. U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS.
EOSAT/LandSat Thermatic Mapper (TM) (1996). Land Use/Land Cover – TM. Raleigh, NC: EOSAT/LandSat TM. Available: http://cgia.cgia.state.nc.us/corpmeta.dir/corplayer.html.
Ervin, G.N., B.D. Herman, J.T. Bried, and D.C. Holly. 2006. Evaluating non-native species and wetland indicator status as components of wetlands floristic assessment. Wetlands 26:1114-1129.
Ervin, G.N., B.D. Herman, and J.T. Bried. 2005. Evaluation of wetland floristic quality indices as indicators of ecological integrity in north Mississippi wetlands. Technical completion report to the USGS Water Resources Research Institute for grant project 01HQGR0088.
Euliss, N.H., Jr., D.M. Mushet, and D.H. Johnson. 1993. Use of macroinvertebrates to identify and delineate temporary and seasonal wetlands in the Prairie Pothole Region. Abstract *in* Prairie ecosystems: Wetland ecology, management, and restoration. Northern Prairie Science Center, Jamestown, ND.Evans, R.O., J.W. Gilliam, R.W.
Evans, R.W., J.W. Gilliam, and W. Skaggs. 1996. Controlled drainage management guidelines for improving drainage water quality. North Carolina Cooperative Extension Service, Publication Number: AG 443.
Faber, S. 1996. On borrowed land: public policies for floodplains. Cambridge (MA): Lincoln Institute of Land Policy.
FAO (Food & Agriculture Organization of the United Nations). Natural Resources Management and Environment Department. 3 December 2007. Chapter 1: Introduction to agricultural water pollution. Date unknown. http://www.fao.org/docrep/W2598E/w2598e04.htm
FedStats, North Carolina. "MapStats, North Carolina". 31 July 2007. 9 November 2007 http://www.fedstats.gov/qf/states/37000.html
Fennessy, M.S., J.J. Mack, A. Rokosch, M. Knapp, and M. Micacchion. 2004. Integrated wetland assessment program. Part 5: Biogeochemical and hydrological investigations of natural and mitigation wetlands. Ohio EPA Technical Report WET/2004-5. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.
Fennessy, M.S., R. Geho, B. Elifritz, and R.D. Lopez. 1998a. Testing the floristic quality assessment index as an indicator of riparian wetland quality. Final Report to U.S. EPA. Ohio Environmental Protection Agency, Division of SurfaceWater, Columbus, Ohio, USA.
Fennessy, M.S., M. Gray, R.D. Lopez, and J.J. Mack. 1998b. An ecological assessment of wetlands using reference sites. Final Report to U.S. EPA. State of Ohio Environmental Protection Agency, Columbus, Ohio, USA.

Fischer, R.A., C.O. Martin, K. Robertson, W.R. Whitworth, and M.G. Harper. 1999. Management of bottomland hardwoods and deepwater swamps for threatened and endangered species. Technical Report SERDP-99-5, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

FMNH. Ichthyology Glossary. 9 November 2007. Florida Museum of Natural History. No date. http://www.flmnh.ufl.edu/fish/southflorida/glossary.html#H

(FNAI) Florida Natural Areas Inventory. 1990. Guide to the natural communtities of Florida. Florida Department of Natural Resources.

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207.231.

Frederick, P. and J.C. Ogden. 2003. Monitoring wetland ecosystems using avian populations: Seventy years of surveys in the Everglades, *in* "Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives".Busch, D.E. and J.C. Trexler (eds.). Island Press, Washington, DC pp. 321-350.

Fritz, K.M., B.R. Johnson, and D.M. Walters. 2006. Field operations manual for assessing the hydrologic permanence and ecological condition of headwater streams. EPA/600/ R-06/126. U.S. Environmental Protection Agency, Office of Research and Development, Washington DC. Pp. 114-122.

Futuyma, D.J. 1998. Evolutionary biology. Third edition. Sinauer Associates, Sunderland, Mass.

Gannon, R. 1997. Frogs in peril. Popular Science, V.251 issue 6, p.84.

Gardiner, D., A. Ndayibagira, F. Grun, and B. Blumberg. 2003. Deformed frogs and environmental retinoids. Pure Applied Chemistry 75:2263-2273.

Gaufin, A.R. and C.M. Tarzwell. 1952. Aquatic invertebrates as indicators of stream pollution. Public Health Reports 67: 57-64.

Gibbs, J.P. 1998. Amphibian movements in response to forest edges, roads, and streambeds in southern New England. Journal of Wildlife Management 62:584-589.

Gifford, G.F. and R.H. Hawkins. 1978. Hydrologic impact of grazing on infiltration: a critical review. Water Resources Research 14:305-313

Gilbert, K.M., J.D. Tobe, R.W. Cantrell, M.E. Sweeley, and J.R. Cooper. 1995. The Florida wetlands delineation manual. The Florida Department of Environmental Protection, Tallahassee, Florida 197pps.

Gilliam, J.W. 1994. Riparian wetlands and water quality. Journal of Environmental Quality 23:896-900.

Graf, W.L. 1999. Dam nation: A geographic census of American dams and their large-scale hydrologic impacts. Water Resources Research 35:1305-1311.

Gregory, J.D. 2005. Growing season: Definitions and dates for wetland delineation in North Carolina. Course in Wetland Determination and Delineation.

Griffith, G.E., J.M. Omernik, J.A. Comstock, M.P. Schafale, W.H. McNab, D.R. Lenat, T.F. MacPherson, J.B. Glover, and V.B. Shelburne. 2002. Ecoregions of North Carolina and South Carolina (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey map scale 1:1,500,000).

Group Three Taxa - Pollution Tolerant Organisms. No date. The Kentucky Natural Resources and Environmental Protection Cabinet (NREPC). 6 November 2007. http://www.state.ky.us/nrepc/water/group3.htmater/group1.htm

Gruelich, S., S. Franklin, T. Wasklewicz, and J. Grubaugh. 2007. Hydrogeomorpholgy and forest composition of Sunrise Towhead Island in the lower Mississippi River. Southeastern Naturalist 6:217-234.

Gurnell, A. 1997. The hydrological and geomorphological significance of forested floodplains. Global Ecology and Biogeography Letters 6:219–229.

Hansen, Larry. Wetland: Status & Trends. Publications. 21 July 2006. 11 November 2007. USDA http://www.ers.usda.gov/publications/arei/eib16/Chapter2/2.3/

Harper, C.A. and D.C. Guynn. 1999. Factors affecting salamander density and distribution within four forest types in the Southern Appalachian Mountains. Forest Ecology and Management 14:245-252.

Harpstead, M.I. , T.J. Sauer, and W.F. Bennett. 2001. Soil science simplified, Fourth edition. Iowa State University Press, Ames, Iowa. 225pps.

Harr R.D., W.C. Harper, J.T. Krygier, and F.S. Hsieh. 1975. Changes in storm hydrographs after road building and clear-cutting in the Oregon Coast Range. Water Resources Research 11:436–444.

Hefting, M.M. and J.J.M. De Klein. 1998. Nitrogen removal in buffer strips along a lowland stream in the Netherlands: a pilot study. Environmental Pollution 102:521-526.

Heimann, D.C. and Mettler-Cherry, P.A., 2004. Hydrologic, soil, and vegetation gradients in remnant and constructed riparian wetlands in West-Central Missouri, 2001–04. U.S. Geological Survey Scientific Investigations Report 2004-5216, 160 p.

Hels, T. and E. Buchwald. 2001. The effect of road kills on amphibian populations. Biological Conservation 99: 331–340.

Hemond, H.F. and J. Benoit. 1988. Cumulative impacts on water quality functions of wetlands. Environmental Management 12:639-653.

Herman, B.D. 2005. Testing the floristic quality assessment index in natural and cretaed wetlands in Mississippi, USA. M.S. Thesis. Mississippi State University, Mississippi State, MS, USA.

Herman, K.D., L.A. Masters, M.R. Penskar, A.A. Reznicek, G.S. Wilhelm, W.W. Brodovich, and K.P. Gardiner. 2001. Floristic quality assesssment with wetland categories and examples of computer applications for the state of Michigan. Revised, Second edition. Michigan Department of Natural Resources, Wilidlife Division, Natural Heritage Program.

Herman, K.D., L.A. Masters, M.R. Penskar, A.A. Reznicek, G.S. Wilhelm, and W.W. Brodowicz. 1997. Floristic quality assessment: development and application in the state of Michigan (USA). Natural Areas Journal 17:265-279.

Hirsch, R.M., J.F. Walker, J.C. Day, and R. Kallio. 1990. The influence of man on hydrologic systems, *in* “The Geology of North America”, v, 0-1, Surface Water Hydrology: Boulder, Colo., Geological Society of America Special Publication, p. 329-359.

Holechek, J.L., R.D. Pieper, and C.H. Herbel. 2004. Range management, principles and practice, Fifth Edition. Pearson Prentice Hall. pp. 325-370, 379-385.

Holland, M.M., E.R. Blood, and L.R. Shaffer (eds.). 2003. Achieving Sustainable Freshwater Systems: A Web of Connections. Island Press, Washington, DC. 312pp.

Holm, L.G., L.W. Weldon, and R.D. Blackburn. 1969. Aquatic weeds. Science 166:699-709.

Hoppe, D.M. 1996. Historical observations and recent species diversity of deformed anurans in Minnesota. North American Amphibian Monitoring Program III Conference. http://www.im.nbs.gov/naamp3/naamp3.html

Houlahan, J.E. and C.S. Findlay. 2003. The effects of adjacent land use on wetland amphibian species richness and community. Canadian Journal of Fisheries and Aquatic Sciences 60:1078-1094.

Hubert, W.A., and J.N. Krull. 1973. Seasonal fluctuations of aquatic macroinvertebrates in Oakwood Bottoms Greentree Reservoir. American Midland Naturalist 90:177-185.

Hummel, O.C. and T. Caplan. 2007. Saltcedar control and riparian restoration – be careful with generalizations. Southwest Hydrology 6:26-27.

IJC (International Joint Commission). 1974. Management programs, effects of research, and present land use activities on water quality of the Great Lakes (2 vols.). Pollution from Land Use Activities Reference Group (PLUARG), International Joint Commission, Windsor, Ontario.

Johnston, C.A. 1991. Sediment and nutrient retention by freshwater wetlands: Effects on surface water quality. Critical Reviews in Environmental Control 21:491-565.

Jones, C.G., J.H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. Oikos 69:373–386.

Jones, J.A., F.J. Swanson, B.C Wemple, and K.U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14:76–85.

Jones J.A. and G.E. Grant. 1996. Peak flow responses to clearcutting and roads in small and large basins, Western Cascades, Oregon. Water Resources Research 32:959–974.

Jung, R.E., P. Nanjappa, and E.H.C. Grany. 2004. Stream salamander monitoring: Northeast refuges and parks. USGS Northeast amphibian research and monitoring initiative.

Kaminski, R.M. and H.H. Prince. 1981a. Dabbling duck activity and foraging responses to aquatic macroinvertebrates. The Auk 98:115126.

Kaminski, R.M. and H.H. Prince. 1981b. Dabbling duck and aquatic macroinvertebrate responses to manipulated wetland habitat. Journal of Wildlife Management 45:1-15.

Keddy. P.A. 2000. Wetland Ecology: Principles and conservation. Cambridge Univ. Press, Cambridge, United Kingdom. 614 pp.

Kirby-Smith, W.W. and R.T. Barber. 1979. The water quality ramifications in estuaries of converting forest to intensive agriculture. Report No. 148. North Carolina Water Resources Research Institute, Raleigh. 70 p.

Kratzer, E.B. and D.P. Batzer. 2007. Spatial and temporal variation in macroinvertebrates in the Okefenokee Swamp, Georgia, USA, Wetlands 27:127-140.

Kreis, R.D., and W.C. Johnson. 1968. The response of macrobenthos to irrigation return water. Water Pollution Control Federation Journal 40:1614-1621

Kuusemets, V. 1999. Nitrogen and phosphorus transformation in riparian buffer zones of agricultural landscapes in Estonia. Diss. Geogr. Univ. Tartuensis. Inst. of Geogr., Faculty of Biol. and Geogr., Univ. of Tartu, Estonia.

Ladd, D.M. 1993. Coefficients of conservatism for Missouri vascular flora. The Nature Conservancy, St. Louis, MO, USA.

La Marche, J.L. and D.P. Lettenmaier. 2000. Effects of forest roads on flood flows in the Deschutes River, Washington. Earth Surface Processes and Landforms 26:115-134.

Lamberti, G.A. and V.H. Resh. 1983. Stream periphyton and insect herbivores: An experimental study of grazing by a caddisfly population. Ecology 64:1124-1135.

LandSat. 1996. Distributed by NC Center for Geographic Information and Analysis.

Lane, C.R., M.T. Brown, M. Murray-Hudson, and M.B. Vivas. 2003. The Wetland Condition Index (WCI): Biological Indicators of Wetland Condition for Isolated Depressional Herbaceous Wetlands in Florida. Submitted to the Florida Department of Environmental Protection under Contract #WM-683.

Lannoo, M.J. 1998. Status and conservation of midwestern amphibians. Iowa City, IA: University of Iowa Press.

Lee, D.C., J.R. Sedell, B.E. Rieman, R.F. Thurow, J.E. Williams, D. Burns, J.L. Clayton, L. Decker, R. Gresswell, R. House, P. Howell, K.M. Lee, K. Macdonald, J. McIntyre, S. McKinney, T. Noel, J.E. O'Connor, C.K. Overton, D. Perkinson, K. Tu, and P. Van Eimeren. 1997. Broadscale assessment of aquatic species and habitats. *In* "An assessment of ecosystem components in the interior Columbia Basin and portions for the Klamath and Great Basins". Volume III, TM Quigley, SJ Arbelbide (eds) USDA Forest Service General Technical Report PNWGTR-405. Portland, Oregon: 1057–1713.

LeGrand, H.E., S.P. Hall, S.E. McRae, and J.T. Jinnegan. 2006. Natural Heritage Program list of the rare animal species of North Carolina. North Carolina Natural Heritage Program, Office of Conservation and Community Affairs, N.C. Department of Environment and Natural Resources.

Lenat, D.R. and D.L. Penrose. 1996. History of the EPT taxa richness metric. Bulletin of the North American Benthological Society 13(2).

Lenat, D.R. 1990. A biotic index for the southeastern United States: derivation and list of tolerance values, with criteria for assigning water quality ratings. Journal of North American Benthological Society 12(3):279-290.

Lenat, D.R. 1983. Chironomid taxa richness: natural variation and use in pollution assessment. Freshwater Invertebrate Biology (now Journal of the North American Benthological Society) 2: 192-198.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. San Francisco: Freeman

Lopez, R.D. and M.S. Fennessy. 2002. Testing the Floristic Quality Assessment Index as an indicator of wetland condition. Ecological Applications 12:487-497.

Luce, C.H.. and B.C. Wemple. 2001. Introduction to special issue on hydrologic and geomorphic effects of forest roads. Earth Surface Processes and Landforms 26:111-113.

Luce, C.H. 1995. Forests and wetlands, *in* "Environmental Hydrology". Ward, A.D. and W.E. Elliot (eds.). Lewis Publishers, Boca Raton, FL, pp. 253-283.

Macdonald, K.B. and F. Weinmann (eds.) 1997. Wetland and riparian restoration: Taking a broader view. Contributed Papers and Selected Abstracts. Society for Ecological Restoration, 1995 International Conference. September 14-16, 1995. University of Washington. Seattle, Washington, USA. Publication EPA 910-R-97-007, USEPA, Region 10, Seattle, Washington.

Mack, J.J. 2004. Integrated wetland assessment program. Part 9: Field manual for the vegetation index of biotic integrity for wetlands v. 1.3. Ohio EPA Technical Report WET/2004-9. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Mack, J.J. 2001. Ohio Rapid Assessment Method for Wetlands, Manual for Using Version 5.0. Ohio EPA Technical Bulletin Wetland/2001-1-1. Ohio Environmental Protection Agency, Division of Surface Water, 401 Wetland Ecology Unit, Columbus, Ohio.

Magilligan, F.J. and K.H. Nislow. 2005. Changes in hydrologic regime by dams. Geomorphology 71:61-78.
Marco, A., C. Quilchano, and A.R. Blaustein. 1999. Sensitivity to nitrate and nitrite in pond-breeding amphibians from the Pacific Northwest, USA. Environmental Toxicology and Chemistry 18:2836–2839.
Masser, M. 2007. Impacts of invasive aquatic plants. Southwest Hydrology 6:22-23 & 33.
Mathias, M.E. and P. Moyle. 1992. Wetland and aquatic habitats. Agriculture, Ecosystems, and Environment 42:165-176.
Maxted, J.R., M.T. Barbour, J. Gerritsen, V. Poretti, N. Primrose, A. Silvia, D. Penrose, and R. Renfrow. 2000. Assessment framework for mid-Atlantic coastal plain streams using benthic macroinvertebrates. Journal of the North American Benthological Society 19:128-144.
McConkey, S., A. Kingsley, and B. Pollock. 1994. 1993 Mississippi River record stages and levee failures along the Illinois border. Illinois State Water Survey, Hydrology Division, Champaign, Illinois, Office of Surface Water Resources: Systems, Information, & GIS, Miscellaneous Publication 163.
McCrady, J.W., W.A. Wentz, and R.L. Linder. 1986. Plants and invertebrates in a prairie wetland during duck brood-rearing. The Prairie Naturalist 18:23-32.
McDonald, B., W. Borden, and J. Lathrop.1990. Citizen stream monitoring: A manual for Illinois. Illinois Department of Energy and Natural Resources, ILENR/RE-WR-90/18. Springfield, Illinois. Found at http://www.epa.gov/bioiweb1/html/lifecycle.html
Mid-Atlantic Hydric Soils Committee. 2004. A guide to hydric soils in the Mid-Atlantic Region, ver. 1.0. L.M. Vasilas and B.L. Vasilas (eds.). USDA, NRCS, Morgantown, WV. www.epa.gov/reg3esd1/hydricsoils/
Miller, J.E. and G.R. Hess. 2007. Southern two-lined salamanders in urbanizing watersheds. Urban Ecosystems 10:73-85.
Minnesota Pollution Control Agency. Indexes of Biological Integrity (IBI) for Large Depressional Wetlands in Minnesota. Biological Monitoring Program. Environmental Outcome Division. May 2002.
Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands, Third edition. John Wiley and Sons, New York, New York.
Mitsch, W.J., X. Wu, R.W. Nairn, P.E. Weihe, N. Wang, R. Deal, and C.E. Boucher. 1998. Creating and restoring wetlands. A whole ecosystem experiment in self-design. BioScience 48:1019–1030.
Mitsch, W.J., J.R. Taylor, and K.B. Benson. 1991. Estimating primary productivity of forested wetland communities in different hydrologic landscapes. Landscape Ecology 5:75-92.
Moore, S.E. 1999. Forests, hydrology, and water quality: impacts of silvicultural practices. University of Florida Extension, Institute of Food and Agricultural Sciences, Document CR 1185.
Mulholland, P.J., J.L. Tank, D.M. Sanzone, W.M. Wollheim, B.J. Peterson, J.R. Webster, and J.L. Meyer. 2000. Food resources of stream macroinvertebrates determined by natural-abundance stable C and N isotopes and a 15N tracer addition. Journal of North American Benthological Society 19:145–157.
Munsell Soil Color Charts. 1994. Macbeth Division of Kollmorgen Instruments Corporation. New Winsor, NY

Murkin, H.R., M.P. Stainton, J.A. Boughen, J.B. Pollard, and R.D. Titman. 1991. Nutrient status of wetlands in the Interlake region of Manitoba, Canada. Wetlands 11:105-122.

Murkin H.R. and B.D.J. Batt. 1987. The interactions of vertebrates and invertebrates in peatlands and marshes. Memoirs of the Entomological Society of Canada 140:15-30.

Murkin, H.R. and J.A. Kadlec. 1986b. Responses by benthic macroinvertebrates to prolonged flooding of marsh habitat. Canadian Journal of Zoology 64:65-72.

Mushet, D.M., N.H. Euliss, Jr., and T.L. Shaffer. 2002. Floristic quality assessment of one natural and three restored wetland complexes in North Dakota, USA.Wetlands 22:126–138.

Naiman, R.J., C.A. Johnston, and J.C. Kelley. 1988. Alteration of North American streams by beaver. Bioscience 38:753-762.

National Technical Committee for Hydric Soils. 1985. Hydric Soils of the United States. USDA Soil Conservation Service, Washington, DC.

Natural Resources Conservation Service. 1994. Changes in hydric soils of the United States. Federal Register, 59(133): 35680.

NatureServe. 2005. Laurentian-acadian conifer-hardwood acid swamp ecological system. Ecological Integrity Assessment. Prepared by Don Faber-Langendoen. December 15, 2005. www.natureserve.org/getData/pdf/new_england/Laurentian-Acadian_Conifer-Hardwood_Acid_Swamp_assessment.pdf

Neckles, H.A., H.R. Murkin, and J.A. Cooper. 1990. Influences of seasonal flooding on macroinvertebrate abundance in wetland habitats. Freshwater Biology 23:311-322.

Nelson, W.M., A.J. Gold, and P.M. Groffman. 1995. Spatial and temporal variation in groundwater nitrate removal in a riparian forest. Journal of Environmental Quality 24:691-699.

Nichols, J.D., J.E. Perry, and D.A. DeBerry. 2006. Using a Floristic Quality Assessment Technique to Evaluate Plant Community Integrity of Forested Wetlands in Southeastern Virginia, USA . Natural Areas Journal 26:360-369**.**

Niering, W.A. 1997. Wetlands. Alfred A. Knopf, Inc., New York, New York.

(NCDA&CS) N.C. Department of Agriculture and Consumer Services, Soil Testing Section. Soil Sample Information Lab Sheet. http://www.ncagr.com/agronomi/pdffiles/issoil.pdf. Oct 2007.

(NCDA&CS) N.C. Department of Agriculture and Consumer Services, Soil Testing Section. http://www.ncagr.com/agronomistmethod.htm. July 2006.

(NC DENR) N.C. Department of the Environment and Natural Resources. 2003. NC Museum of Natural Sciences. Distribution of amphibians in North Carolina draft document. January 2003.

(NC DENR) N.C. Division of Water Quality. Standard operating procedures for benthic macroinvertebrates. 20 November 2007. Division of Water Quality Environmental Sciences Section. 26 July 2006. http://h2o.enr.state.nc.us/esb/BAUwww/benthossop.pdf

(NC DENR) N.C. Department of the Environment and Natural Resources. 2004a. Basin Planning Program: September 2004 Catawba River Basinwide Water Quality Plan. N.C. Division of Water Quality. September 2004. http//h2o.enr.state.nc.us/basinwide/draft2004CatawbaRiverBasinWaterQualityPlan.htm

(NC DENR) N.C. Department of the Environment and Natural Resources. 2004b. Basin Planning Program: 2004 Tar-Pamlico River Basinwide Water Quality Plan. N.C. Division of Water Quality. 2004. http//h2o.enr.state.nc.us/basinwide/tarpam2004.htm

(NC DENR) N.C. Department of the Environment and Natural Resources. 1999a. Basin Planning Program: 1999 Catawba River Basinwide Water Quality Plan. N.C. Division of Water Quality. December 1999. http//h2o.enr.state.nc.us/basinwide/catawba/catawba_wq_management_plan.htm

(NC DENR) N.C. Department of the Environment and Natural Resources. 1999b. Basin Planning Program: 1999 Tar-Pamlico River Basinwide Water Quality Plan. N.C. Division of Water Quality. July 1999. http//h2o.enr.state.nc.us/basinwide/tarpam/tarpam_wq_management_plan.htm

(NC WAM) N.C. Wetland Assessment Method Draft User Manual, Draft Version 5.0. 15 May 2007. Accessed 13 December 2007. http://h2o.enr.state.nc.us/ncwetlands/documents/NCWAMDUMv5.pdf

(NCDWQ) North Carolina Division of Water Quality (2006). Water Quality Assessment and Impaired Waters List (2006 Integrated 305(b) and 303(d) Report) Public Review Draft February 2006. Raleigh NC North Carolina Division of Water Quality (2004). Ambient Monitoring System. Environmental Sciences Section, Raleigh, NC. 4 January 2007. Available: http://h2o.enr.state.nc.us/esb/ams.html

(NCDWQ) North Carolina Division of Water Quality (2005). Laboratory Section: Sample Submission Guidance Document. North Carolina Division of Water Quality, Raleigh, NC. June 1. Available: http://h2o.enr.state.nc.us/lab/qa.htm.

(NCDWQ) North Carolina Division of Water Quality (2003). Intensive Survey Unit Standard Operating Procedures. North Carolina Division of Water Quality, Raleigh, NC. Available: http://h2o.enr.state.nc.us/esb/isu.html.

(NCDWQ) North Carolina Division of Water Quality (2003b). Quality Assurance Manual for the North Carolina Division of Water Quality Laboratory Section. Available: http://h2o.enr.state.nc.us/esb/qapp/labqam.pdf.

N.C. WSWA (North Carolina Water Supply Watershed Administrators. Streamlines. A Newsletter for North Carolina Water Supply Watershed Administrators. Volume 1, Number 5. 3 December 2007. Limiting impervious surfaces protects water quality. July 1996. http://h2o.enr.state.nc.us./wswp/SL/v1n5.html#top

N.H. DES (New Hampshire Department of Environmental Services). Lake Eutrophication. 6 November, 2007. New Hampshire Department of Environmental Services. 1995. http://www.des.state.nh.us/factsheets/bb/bb-3.htm.

Noon, B.R. 2003. Conceptual issues in monitoring ecological resources, *in* Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives. Busch, D.E. and J.C. Trexler (eds.). Island Press, Washington, DC pp. 27-71.

(NRC) National Research Council. 1992. Restoration of aquatic systems: science, technology, and public policy. Washington (DC): National Academy Press.

NRCD. 1982. Chowan River water quality management plan. Division of Environmental Management, North Carolina Department of Natural Resources and Community Development, Raleigh.

NRCD. 1987. Surface water quality concerns in the Tar-Pamlico River basin. Report no. 87-04. Division of Environmental Management, North Carolina Department of Natural Resources and Community Development. Raleigh.

Odum, E.P. 1985. Trends expected in stressed ecosystems. Bioscience 35:419–422.

Odum, W.E., T.J. Smith III, J.K. Hoover, and C.C. McIvor. 1984. The ecology of tidal freshwater marshes of the United States east coast: A community profile, U.S. Fish and Wildlife Service, Washington, DC, USA. FWS/OBS-87/17.

Ohio EPA (Environmental Protection Agency). Wetlands and Water Quality. Edited January 1997. 31 March 2006. Available http://www.epa.state.oh.us/pic/facts/wetqual.html.

Ohio EPA (Environmental Protection Agency). 2004. Integrated Wetland Assessment Program. Part 8: Initial Development of Wetland Invertebrate Community Index for Ohio. Ohio EPA Technical Report WET/2004-8. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Oldham, M., W. Bakowsky, and D. Sutherland. 1995. Floristic quality assessment for southern Ontario. Natural Heritage Information Centre, Ontario Ministry of Natural Resources, Peterborough, Ontario.

Orser, P.N. and D.J. Shure. 1972. Effects of urbanization on the salamander *Desmognathus fuscus fuscus*. Ecology 53:1148-1154.

Ouellet, M., J. Bonin, J. Rodrigue, J.-L. DesGranges, and S. Lair. 1997. Hindlimb deformities (Ectromelia, Ectrodactyly) in free-living anurans from agricultural habitats. Journal of Wildlife Diseases 33:95-104.

Paerl, H.W., L.M. Valdes, A.R. Joyner, B.L. Peierls, M.F. Piehler, S.R. Riggs, R.R. Christian, L.A. Eby, L.B. Crowder, J.S. Ramus, E.J. Clesceri, C.P. Buzzelli, and R.A. Luettich Jr. 2006. Ecological response to hurricane events in the Pamlico Sound system, North Carolina, and implications for assessment and management in a regime of increased frequency. Estuaries and Coasts 29:1033-1045.

Paerl, H.W., J.D. Bales, L.W. Ausley, C.P. Buzzelli, L.B. Crowder, L.A. Eby, J.M. Fear, M. Go, B.L. Peierls, T.L. Richardsoni, and J.S. Ramus. 2001. Ecosystem impacts of three sequential hurricanes (Dennis, Floyd, and Irene) on the United States' largest lagoonal estuary, Pamlico Sound, NC. Proceedings of the National Academy of Sciences 98:5655-5660.

Parker, D.L., M. Renz, A. Fletcher, F. Miller, and J. Gosz. 2005. Strategy for long-term management of exotic trees in riparian areas for New Mexico's five river systems, 2005-2014. USDA Forest Service and New Mexico Energy, Minerals and Natural Resources Department.

Pate, P.P. and R. Jones. 1981. Effects of upland drainage of estuarine nursery areas of Pamlico Sound, North Carolina. Working paper no. 81-10. UNC Sea Grant, Raleigh.

Peet R.K., T.R. Wentworth, R.P. Duncan, and P.S. White. 1997. The North Carolina vegetation survey protocol: A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63:262–274.

Peterson, B.J., W.M. Wollheim, P.J. Mulholland, J.R. Webster, J.L. Meyer, J.L. Tank, E. Martí, W.B. Bowden, H.M. Valett, A.E. Hershey, W.H. McDowell, W.K. Dodds, S.K. Hamilton, S. Gregory, and D.D. Morrall. 2001. Control of nitrogen export from watersheds by headwater streams. Science Magazine 292:86-89.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg . The natural flow regime: A paradigm for river conservation and restoration. BioScience 47:769-784.

Preiner, S., I. Baart, A.P. Blaschke, E. Bondar, C. Habereder, I. Zsuffa, and T. Hein. 2006. Impact of hydrological connectivity on primary production patterns of large river floodplains. Proceedings 36th International Conference of IAD. Austrian Committee DanubeResearch / IAD, 04.-08.2006, Vienna, 200-202.

Pringle, C.M. 2003. Interacting effects of altered hydrology and contaminant transport: Emerging ecological patterns of global concern, *in* Achieving Sustainable Freshwater Systems: A Web of Connections. Holland, M.M., E.R. Blood, and L.R. Shaffer (eds.). Island Press, Washington, DC. pp. 85-107.

Raben, C.F. and N. Wang. 2001. Bioassessment of streams using macroinvertebrates: Are the Chironomidae necessary?. Environmental Monitoring and Assessment 71:177-185.

Rader, R.B., D.P. Batzer, and S.A. Wissinger (eds.). 2001. Bioassessment and management of North American freshwater wetlands. John Wiley and Sons, New York, NY, USA.

Radford, A.E., H.E. Ahles, and C.R. Bell. 1968. Manual of the vascular flora of the Carolinas. University of North Carolina Press, Chapel Hill, N.C.

Radovich, R.A. 1993. An identification and generalized classification of the wetlands of California (with accompanying key). California Department of Fish and Game, Environmental Services Division. Administrative Report 93-2.

Reed, P.B. 1997. Revison of the national list of plant species that occur in wetlands. Department of the Interior, U.S. Fish & Wildlife Service, Washington, D.C. 209pp.

Reed, P.B. 1988. National list of plant species that occur in wetlands: North Central (Region 3). Biological Report 88 (26.3). Washington D. C.: U. S. Fish and Wildlife Service.

Reh, W. and A. Seitz. 1990. The influence of land use on the genetic structure of populations of the common frog *Rana temporaria*. Biological Conservation 54:239-249.

Reinelt, L.E. and R.R. Horner. Pollutant removal from stormwater runoff by palustrine wetlands based on comprehensive budgets. Ecological Engineering 4 (1995).

Reinhardt, R.D., M.C. Reinhardt, M.M. Brinson, and K.E. Faser, Jr. 1999. Application of reference data for assessing and restoring headwater ecocsystems. Restoration Ecology 7:3:241-251.

Reiss, K.C. and M.T. Brown. 2005. The Florida Wetland Condition Index (FWCI): Developing biological indicators for isolated depressional forested wetlands. Final Report to the Florida Department of Environmental Protection, under contract #WM-683.

Resource Management Group, Inc., 1999. National list of plant species that occur in wetlands, Region 2, Southeast, B.J. Sabine (ed.), Dickinson Press, USA, 90 pp.

Richardson, J.L. and M.J. Vepraskas. 2001. Wetland soils: genesis, hydrology, landscapes, and classification. CRC Press. Boca Raton, FL. 85-126.

Richardson, R.E. 1928. The bottom fauna of the Illinois River, 1913-1925. Illinois Natural History Survey Bulletin 17:387-475.

Richter, K.O. and E.C. Ostergaard. 1999. King County wetland-breeding amphibian monitoring program: 1993-1997 Summary Report. King County Department of Natural Resources, Water and Land Resources Division, Seattle, WA, USA.1997.

Ricklefs, R.E. and D. Schluter (editors). 1993. Species diversity in ecological communities: historical and geographical perspectives. University of Chicago Press, Chicago, IL, USA.

Riley, L.M and R.K. Aikens. 2007. The Quaggas have arrived. Southwest Hydrology 6:18-19.

Rodrigue, P.B. and K.M. Wright. 2003. Wetland restoration: Applications on the land in the Lower Mississippi alluvial valley, *in* "Achieving Sustainable Freshwater Systems: A Web of Connections". Holland, M.M., E.R. Blood, and L.R. Shaffer (eds.). Island Press, Washington, DC. pp. 173-191.

Rosenberg, D.M. and V.H. Resh. 1993. Introduction to freshwater biomonitoring and benthic macroinvertabrates. Pages 1-9 in D.M. Rosenberg and V.H. Resh (eds.), Freshwater biomonitoring and benthic macroinvertebrates. Chapman & Hall, New York.

Rudolph, D.C. and J.G. Dickson. 1990. Streamside zone width and amphibian and reptile abundance. Southwestern Naturalist 35:472–476.

Sauer, V.B., E.O. Thomas, Jr., V.A. Stricker, and K.V. Wilson. 1982. Magnitude and frequency of urban floods in the United States. Transportation Research Record 896:30–33.

Schafale, M.P. and A.S. Weakley. 1990. Classification of the natural communities of North Carolina. Third approximation. North Carolina Department of Environment, Health, and Natural Resources, Division of Parks and Recreation, Natural Heritage Program, Raleigh. 325 pp.

Scorecard. Pollutants or Environmental Stressors Impairing Water Quality. 2005. 1 January 2007. Available: http://www.scorecard.org/env-releases/def/cwa_cause_class_def.html.

Semlitsch, R.D. and J.R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology 17:1219-1228.

Semlitsch, R.D. and J.R. Bodie. 1998. Are small, isolated wetlands expendable? 1998 Conservation Biology 12:1129-1133.

Shafike, N., S. Bawazir, and J. Cleverly. 2007. Native versus invasive – plant water use in the Middle Rio Grande Basin. Southwest Hydrology 6:28-29.

Simpson, E.H. 1949. Measurement of diversity. Nature 163:688.

Simpson, R.L., R.E. Good, M.A. Leck, and D.F. Whigham. 1983. The ecology of freshwater tidal wetlands. BioScience 33:255–259.

Skaggs, R.W., J.W. Gilliam, T.J. Sheets, and J.S. Barnes. 1981. Effect of agricultural land development on drainage waters in the North Carolina tidewater region. Environmental Protection Agency Project Summary EPA-600/S3-80-087 July 1981.

Skidds, D.E. and F.S. Golet. 2005. Estimating hydroperiod suitability for breeding amphibians in southern Rhode Island seasonal forest ponds. Wetlands Ecology and Management 13:349– 366

Sleavin, W.J., D.L. Civoc, S. Prisloe, and L. Giannotti. 2000. Measuring impervious surfaces for non-point source pollution modeling. Proceedings, 2000 ASPRS Annual Conference. May 22– 26, Washington, DC, 11 pp.

Sloof, W. 1983. Benthic macroinvertebrates and water quality assessment: Some toxicological considerations. Aquatic Toxicology 4:73-82.

Smith, N.P. 2001. Seasonal-scale transport patterns in a multiinlet coastal lagoon. Estuarine Coastal and Shelf Science 52:15–28.

Smith, S.D. and A.L. Braswell. 1994. Preliminary investigation of acidity in ephemeral wetlands and the relationship to amphibian usage in North Carolina. Report submitted to NC Wildlife Resources Commission, Nongame and Endangered Wildlife Program, Raleigh, NC. 57 pages.

Smith, S.E.L. 2004. Poster: Understanding the role of eutrophication on aquatic food web interactions in the Florida Everglades. EPA Science Forum).

Snodgrass, J.W., M.J. Komoroski, A.L. Bryan Jr., and J. Burger. 2000. Relationships among isolated wetland size, hydroperiod, and amphibian species richness: Implications for wetland regulations. Conservation Biology 14:414-419.

Sorenson, E., R. Popp, M. Lew-Smith, B. Engstrom, M. Lapin, and M. Ferguson. 2004. Hardwood swamps of Vermont: distribution, ecology, classification, and some sites of ecological significance. Vermont Fish and Wildlife Department, Agency of Natural Resources, Nongame and Natural Heritage Program. Waterbury, Vermont. 55 pp.

Sparks R.E. 1992. Risks of altering the hydrologic regime of large rivers. Pages 119-152 in Cairns J, Niederlehner BR, Orvos DR, eds. Predicting ecosystem risk. Vol XX. Advances in modern environmental toxicology. Princeton (NJ): Princeton Scientific Publishing Co.

Stanturf, J.A., E.S. Gardiner, and M.L. Warren, Jr. Restoring forested wetland Ecosystems , *in* Achieving Sustainable Freshwater Systems: A Web of Connections. Holland, M.M., E.R. Blood, and L.R. Shaffer (eds.). Island Press, Washington, DC. pp. 193-220.

Steward, J.S., R.W. Virnstein, M.A. Lasi, L.J. Morris, J.D. Miller, L.M. Hall, and W.A. Tweedale. 2006. The impacts of the 2004 hurricanes on hydrology, water quality, and seagrass in the Central Indian River Lagoon, Florida. Estuaries and Coasts 29:954-965.

Stewart, K.G. and M. Roberson. 2007. Exploring the geology of the Carolinas: A field guide to favorite places from Chimney Rock to Charleston. University of North Carolina Press, Chapel Hill, NC. 298 pps.

Streamlines. A Newsletter for North Carolina Water Supply Watershed Administrators Volume 1, Number 5. 3 December 2007. Limiting impervious surfaces protects water quality. July 1996. http://h2o.enr.state.nc.us./wswp/SL/v1n5.html#top

Stribling, J.B., B.K. Jessup, J.S. White, D. Boward, and M. Hurd. 1998. Development of a Benthic Index of Biotic Integrity for Maryland streams. Prepared by Tetra Tech, Inc., Owings Mills, MD and Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Program. CBWP-MANTA-EA-98-3.

Stromberg, J.C. 2007. Hydrologic changes and riparian forests: the saltcedar story. Southwest Hydrology 6:30-32.

Stromberg, J.C., S.J. Lite, R. Marler, C. Paradzick, P.B. Shafroth, D. Shorrock, J. White, and M. White. 2007. Altered stream flow regimes and invasive plant species: the *Tamarix* case. Global Ecology and Biogeography 16: 381-393.

Stromberg, J.C., S.J. Lite, and C. Paradzick. 2005. *Tamarix* and river restoration along the San Pedro and Gila Rivers. Presented at Connecting Mountain Islands and Desert Seas: Biodiversity and Management of the Madrean Archipelago II, May 11-15, 2004, Tucson, AZ.

Surber, E.W. 1953. Biological effects of pollution in Michigan waters. Sewage & Industrial Wastes 25: 79-86.

Swanson, G.A., M.I. Meyer, and J.R. Serie. 1974. Feeding ecology of breeding blue-winged teal. Journal of Wildlife Management 38:396-407.

Swink, F.A. and G.S. Wilhelm. 1979. Plants of the Chicago region, revised and expanded edition with keys. Morton Arboretum, Lisle, IL, USA.

Taft, J.B., G.S. Wilhelm, D.M. Ladd, and L.A. Masters. 1997. Floristic quality assessment for vegetation in Illinois, a method for assessing vegetation integrity. Erigenia 15:3-95.

Tegart, W., G. Sheldon, and D. Griffiths (Eds.). 1990. Climate change: The IPCC impacts assessment. Prepared by the Intergovernmental Panel on Climate Change (IPCC). Australian Governmental Publishing Service. Canberra.

Thien, S. J. 1979. A flow diagram for teaching texture by feel analysis. Journal of Agronomy Education 8:54-55.

Thompson, W.L. and D.C. Lee. 2000. Modeling relationships between landscape level attributes and snorkel counts of chinook salmon and steelhead parr in Idaho. Canadian Journal of Fisheries and Aquatic Sciences 57:1834–1842.

Timmer, C.E. and L.W. Weldon. 1967. Evapotranspiration and pollution of water by water hyacinth. Hyacinth Control Journal 6:34–37.

Timmons, F.L. 1960. Weed control in western irrigation and drainage systems. U.S. Department of Agriculture Service, ARS 34-14. 22 pp. 81.

Tiner, R.W. 1999. Wetland indicators: A guide to wetland identification, delineation, classification, and mapping. CRC Press, 127.

Tiner, R.W. Technical aspects of wetlands, wetland definitions and classifications in the United States. 9 November 2007. United States Geological Survey Water Supply Paper 2425. 7 March 1997. http://www.water.usgs.gov/nwsum/WSP2425/definitions.html.

Toth, L.A. 1995. Principles and guidelines for restoration of river/floodplain ecosystems-Kissimmee River, Florida. Pages 49-73 in Cairns J, ed. "Rehabilitating damaged Ecosystems". Second ed. Boca Raton (FL): Lewis Publishers/CRC Press.

University of California, Agriculture and Natural Resources. Pesticides and water quality. 2004. 2 January 2007. Available: http://www.ipm.ucdavis.edu/WATER/U/watqual.html.

U.S. Army Corps of Engineers. 2000. Installing Monitoring Wells/Piezometers in Wetlands. Wetland Regulatory Assistance Program. http://el.erdc.usace.army.mil/elpubs/pdf/tnwrap-2.pdf

U.S. Army Corps of Engineers. 2000. Installing Monitoring Wells/Piezometers in Wetlands. Wetland Regulatory Assistance Program. http://el.erdc.usace.army.mil/elpubs/pdf/tnwrap-2.pdf

U.S. Census Bureau. 2006. Annual Population Growth – NC/US. 10 January 2007. Available: http://demog.state.nc.us/demog/ncsuagr6.html.

U.S. Drought Monitor (US Department of Agriculture, US Geological Survey and the USEnvironmental Protection Agency. 6 June 2008. USDA. 3 June 2008. http://www.drought.unl.edu/dm/monitor.html)

U.S. EPA (U.S. Environmental Protection Agency). Clean Water Act, Section 401 Certification. 1989. http://www.epa.gov/OWOW/wetlands/regs/sec401.html

U.S. EPAa (U.S. Environmental Protection Agency). Functions and values of wetlands. 3 December 2007. Office of Wetlands, Oceans and Watersheds. September 2001. http://www.epa.gov/owow/wetlands/pdf/fun_val.pdf

U.S. EPAb (U.S. Environmental Protection Agency). Threats to Wetlands. 3 December 2007. Office of Wetlands, Oceans and Watersheds. September 2001. http://www.epa.gov/owow/wetlands/pdf/threats.pdf

U.S. EPAc (U.S. Environmental Protection Agency). Invertebrates as Indicators of Prairie Wetland Integrity. 6 November 2007. U.S. Environmental Protection Agency. September 1995. http://www.epa.gov/owow/wetlands/wqual/pph2_4.html#4.4.4.

U.S. EPAd (U.S. Environmental Protection Agency). Polluted Runoff (Nonpoint Source Pollution). What is nonpoint source (NPS) pollution. 29 November 2006. U.S. Environmental Protection Agency. 8 November 2007. http://www.epa.gov/owow/nps/qa.html

U.S. EPA (U.S. Environmental Protection Agency). 2002a. Methods for Evaluating Wetland Condition: Introduction to Wetland Biological Assessment. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-014.

U.S. EPA (U.S. Environmental Protection Agency). 2002b. Methods for Evaluating Wetland Condition: Study Design for Monitoring Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-015.

U.S. EPA (U.S. Environmental Protection Agency). 2002c. Methods for Evaluating Wetland Condition: Developing Metrics and Indexes of Biological Integrity. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-016.

U.S. EPA (U.S. Environmental Protection Agency). 2002d. Methods for Evaluating Wetland Condition: Developing an Invertebrate Index of Biological Integrity for Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-019.

U.S. EPA (U.S. Environmental Protection Agency). 2002e. Methods for Evaluating Wetland Condition: Using Vegetation To Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-020.

U.S. EPA (U.S. Environmental Protection Agency). 2002f. Methods for Evaluating Wetland Condition: Using Amphibians in Bioassessments of Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-022.

U.S. EPA (U.S. Environmental Protection Agency). 2000. Ambient Water Quality Criteria Recommendations for Rivers and Streams in Nutrient Ecoregion IX and XIV. EPA-822-B-00-019. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

U.S. EPA (U.S. Environmental Protection Agency). 1998. Assessing Biological Integrity of Surface Waters. EPA-843-F-98-001a. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

U.S. EPA (U.S. Environmental Protection Agency). 1994. Clean Water Act Fact Sheets: Controlling Agriculture Sources of Water Pollution. Office of Water (WH-4105F), May, 1994.

U.S. EPA (U.S. Environmental Protection Agency) and U.S. ACOE (U.S. Army Corps of Engineers). 2008. Clean Water Jurisdiction Following the U.S. Supreme Court's Decision in Raponos v. United States & Carabell v. United States.

USFWS (U.S. Fish and Wildlife Service). Peregrine Falcon. 10 January 2007. Available: http://www.fws.gov/chesapeakebay/Peregr.htm

USFWS (U.S. Fish and Wildlife Service). 2000. The value of headwater streams: results of a workshop. State College Pennsylvania, April 13, 1999. State College PA. Sponsored by the Pennsylvania Field Office. April 2000

USGS (U.S. Geological Survey). The Water Cycle. 26 November 2007. Water Science for Schools. 27 November 2007. http://ga.water.usgs.gov/edu/watercycle.html

USGS (U.S. Geological Survey). L.I. Briel. 1997. Water Quality in the Appalachian Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces, Eastern United States.

USGS (U.S. Geological Survey). 1999. Ecological status and trends of the Upper Mississippi River System 1998: A report of the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin.

van Dijck, S.J.E. and T.W.J. van Asch. 2002. Compaction of loamy soils due to tractor traffic in vineyards and orchards and its effect on infiltration in southern France. Soil and Tillage Research 63:141-153.

Varney, R.W. Wetlands can help reduce flooding. 30 November 2007. U.S. Environmental Protection Agency. 1 June 2006. http://epa.gov/region01/ra/column/archive/2006/wetlands_20060601.html

Verhoeven, J.T.A., D.F. Whigham, R. van Logtestijn, and J. O'Neill. 2001. A Comparative Study of Nitrogen and Phosphorous Cycling in Tidal and Non-Tidal Riverine Wetlands. Wetlands. 21:2:210-222.

Vigil, K.M. 2003. Clean Water: An Introduction to Water Quality and Water Pollution Control. Oregon State University Press, Corvallis, Oregon. 192pps.

Virginia Cooperative Extension. Pesticides and Aquatic Animals: A Guide to Reducing Impacts on Aquatic Systems, 1996. Available: http://www.ext.vt.edu/pubs/waterquality/420-013/420-013.html.

Von Stackelberg, N.O. 2005. Simulation of the hydrologic effects of afforestation in the Tacuarembo River Basin, Uruguay. A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Master of Science, Raleigh, North Carolina 2005.

Waggoner, P.E. (Ed.). 1990. Climate Change and U.S. Water Resources, John Wiley, New York.

Ward, A.D. and W.E. Elliot (eds.). 1995. Environmental hydrology. Lewis Publishers, Boca Raton, FL, 422pp.

Ward, A.D. 1995. Surface runoff and subsurface drainage, *in* "Environmental Hydrology". Ward, A.D. and W.E. Elliot (eds.). Lewis Publishers, Boca Raton, FL, pp. 133-174.

Watson, R.T., M.C. Zinyowera, and R.H. Moss (Eds.), Climate Change, I995: Impacts, adaptations, and mitigation of climate change, Cambridge Univ. Press, New York, 1996.

Weber, C.I. (ed.) 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA-670/4-73-001. US Environmental Protection Agency, Cincinnati, OH.

Welch, H.E., J.K. Jorgenson, and M.F. Curtis. 1988. Measuring abundance of emerging Chironomidae (Diptera): Experiments on trap size and design, set duration, and transparency. Canadian Journal of Fisheries and Aquatic Sciences 45:738-741.

Weller, M.W. 1999. Wetland birds: habitat resources and conservation implications. Cambridge University Press, Cambridge, New York. 271 pages.

Weller, M.W. 1981. Freshwater Marshes. University of Minnesota Press, Minneapolis, Minn., 146p.

Welsh, H.H., Jr. and S. Droege. 2000. A case for using Plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American forests. Conservation Biology 15:558-569.

Wemple, B.C., J.A. Jones, and G.E. Grant. 1996. Channel network extension by logging roads in two basins, Western Cascades, Oregon. Water Resources Bulletin 32:1195–1207.

Westbrook, C.J., D.J. Cooper, and B.W. Baker. 2006. Beaver dams and overbank floods influence groundwater–surface water interactions of a Rocky Mountain riparian area. Water Resources Research 42:W06404.

Wetzel, R.G. 2003. Freshwater and wetland ecology; Challenges and future frontiers, *in* “Achieving Sustainable Freshwater Systems: A Web of Connections”. Holland, M.M., E.R. Blood, and L.R. Shaffer (eds.). Island Press, Washington, DC. pp. 111-123.

Whigham, D. and T. Jordan. 2003. Isolated wetlands and water quality. Wetlands 23:541–549.

Whigham, D.F., R.R. Twilley, and I.C. Feller. 1999. Within-stand nutrient cycling in wetland ecosystems. Ecology 80:2137-2138.

Whigham, D.F., R.L. Simpson, R.E. Good, and F. Sickels. 1989. Decomposition and nutrient-metal dynamics of litter in freshwater tidal wetlands. p. 167–187. *In* R. R. Sharitz and J. W. Gibbons (eds.) “Freshwater Wetlands and Wildlife”. USDOE Office of Scientific and Technical Information, Oak Ridge, TN, USA. U. S. Department of Energy Symposium Series No. 61.

White, J.R. and K.R. Reddy. 1999. Influence of nitrate and phosphorus loading on denitrifying enzyme activity in Everglades wetland soils. Soil Science Society of America Journal 63:1945–1954.

Wiggins G.B., R.J. Mackay, and I.M. Smith. 1980. Evolutionary and ecological strategies of animals in annual temporary pools. *Archiv für Hydrobiologie Supplement* 58:97-206.

Wilhelm, G.S. and D. Ladd. 1988. Natural area assessment in the Chicago region. Transactions of the North American Wildlife and Natural Resources Conference 53:361-375.

Wilhelm, G.S. and L.A. Masters. 1995. Floristic quality assessment in the Chicago Region and application computer programs. Morton Arboretum, Lisle, Illinois, USA.

Willson, J.D. and M.E. Dorcas. 2003. Effects of habitat disturbance on stream salamanders: Implications for buffer zones and watershed management. Conservation Biology 17:763-771

Winter, T.C. 2007. The role of groundwater in generating streamflow in headwater areas and in maintinaing base flow. Journal of the American Water Resources Association 43:15-25.

WI DNR (Wisconsin Department of Natural Resources). Manure Management and Water Quality. 2006. 2 January 2007. Available: http://www.dnr.state.wi.us/org/water/wm/nps/ag/waterquality.htm.

Zembal, R. 2007. Chipping away at *Arundo*. Southwest Hydrology 6:24-25 & 33.

Appendix A

Headwater Wetland Site Maps and Photo Points

Figure A.1 Bachelor Coastal Plain Natural

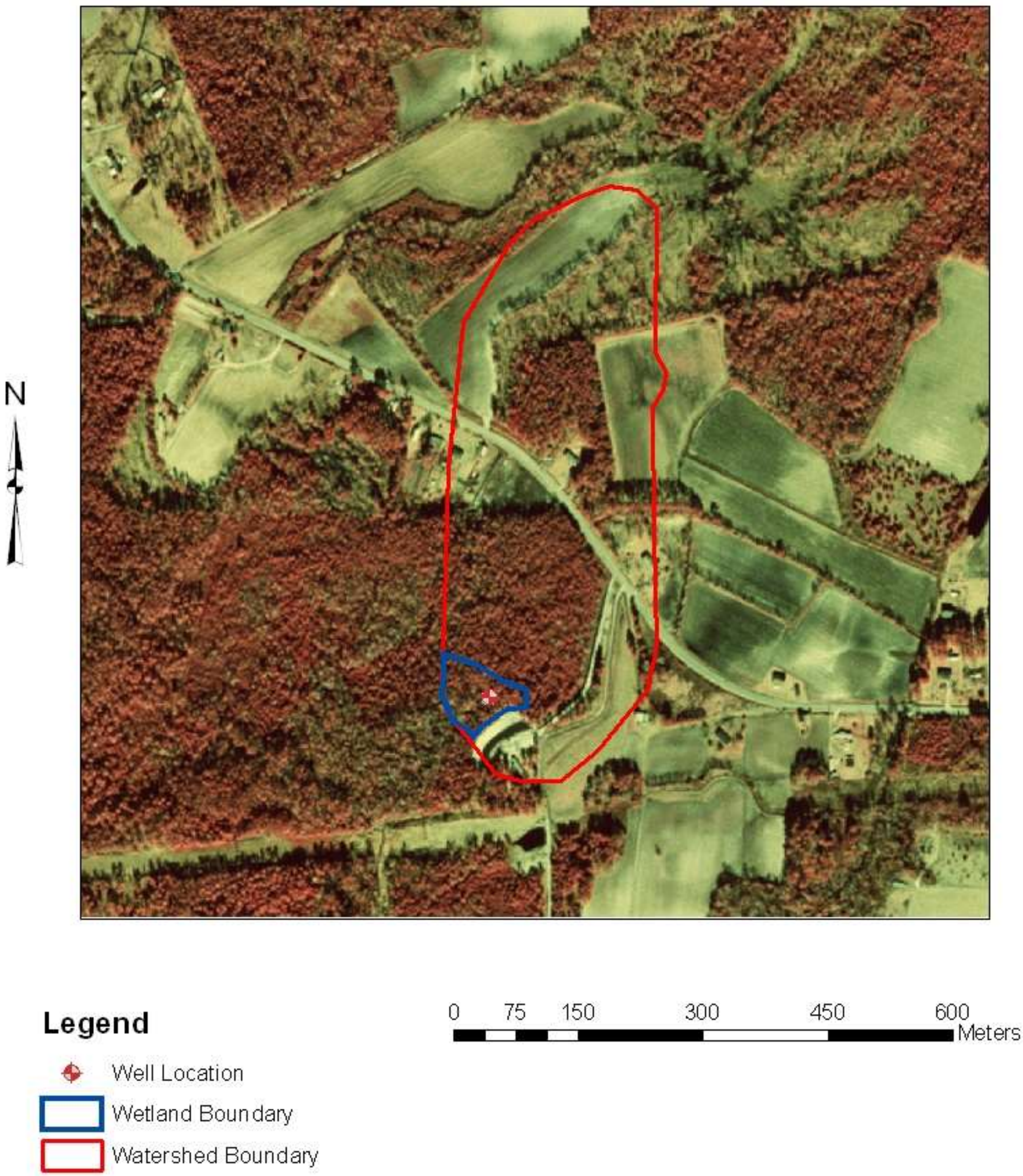


Figure A.2 Cox Coastal Plain Natural

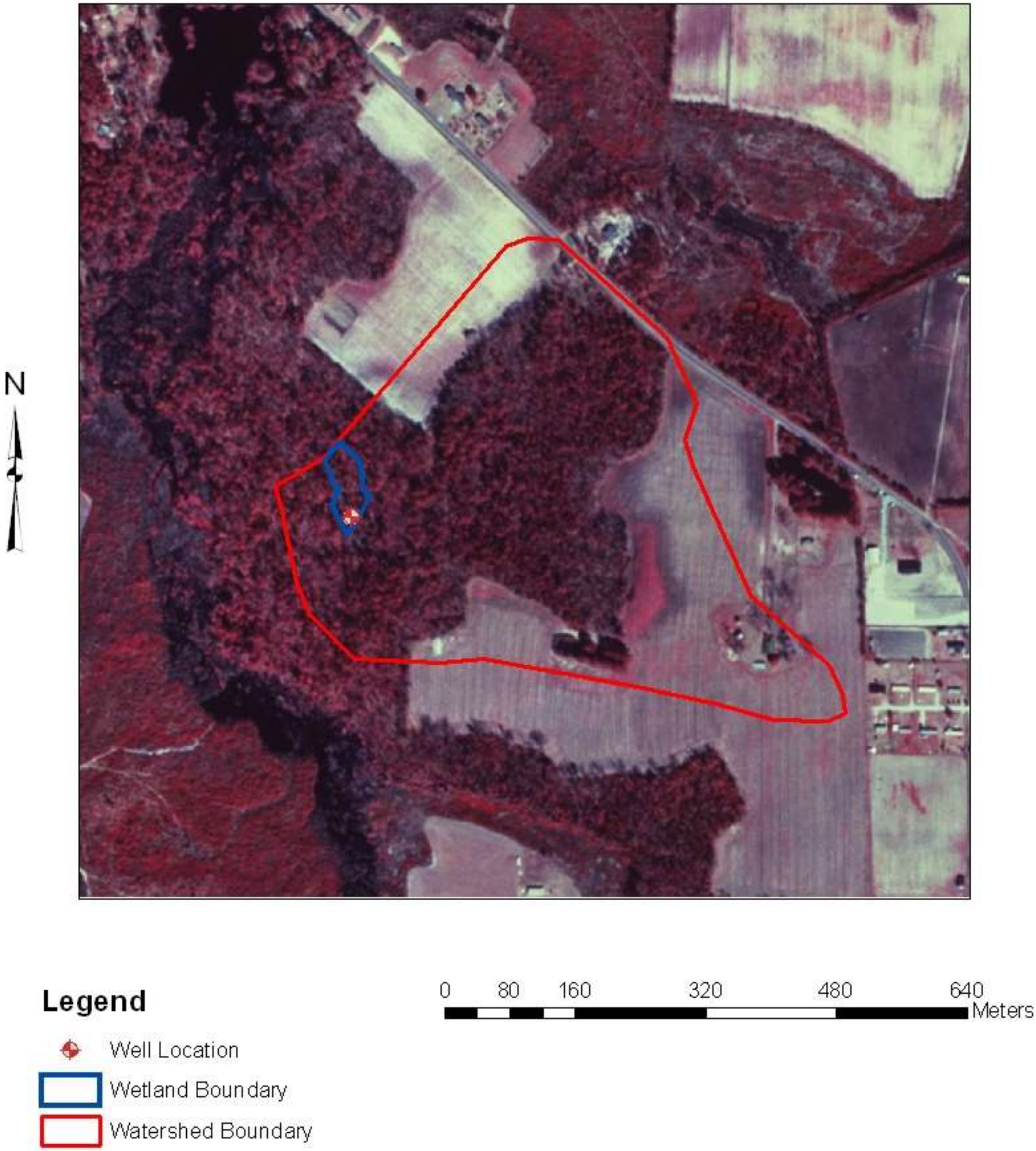


Figure A.3 PCS Coastal Plain Natural

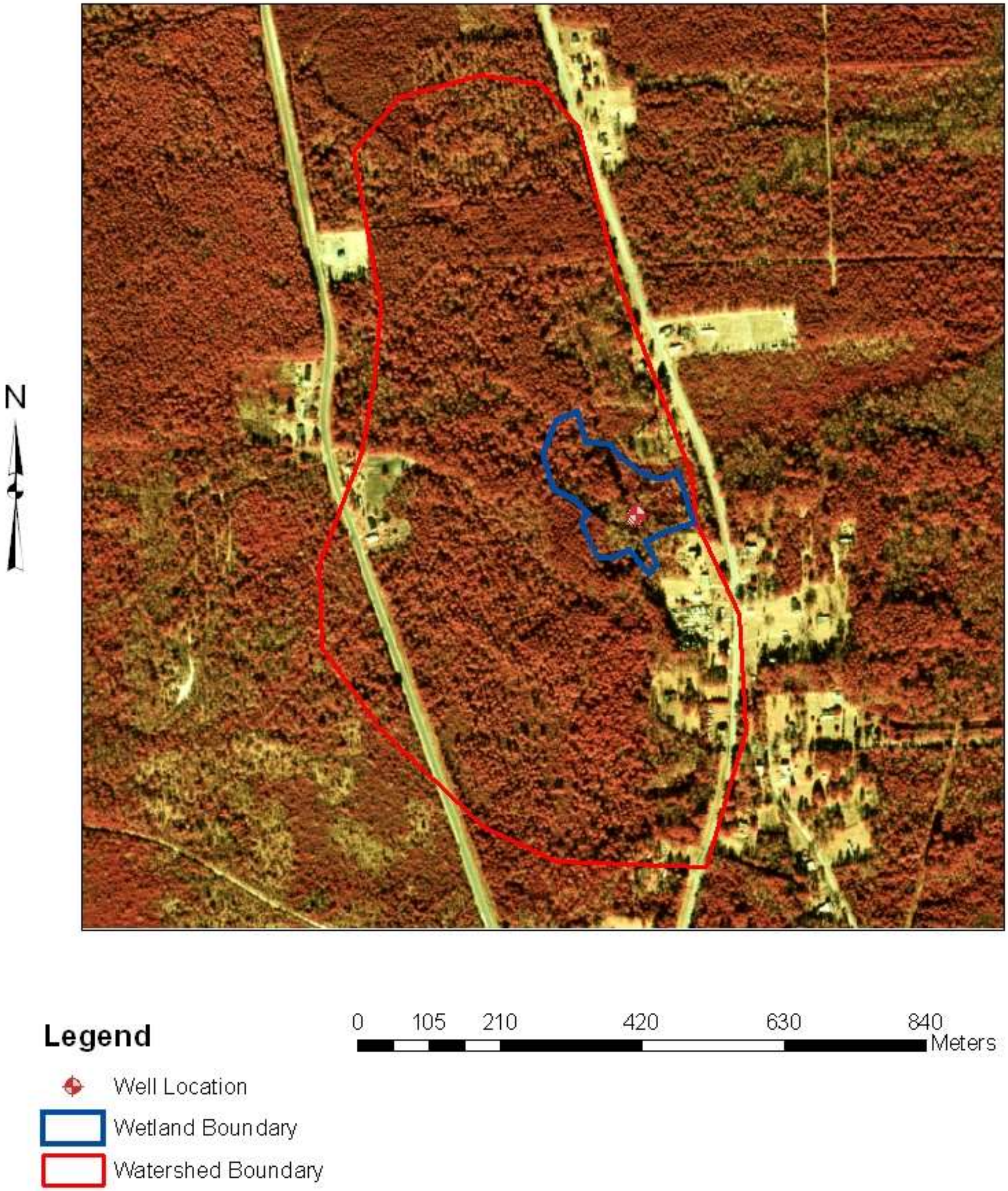


Figure A.4 Pete Harris Piedmont Natural

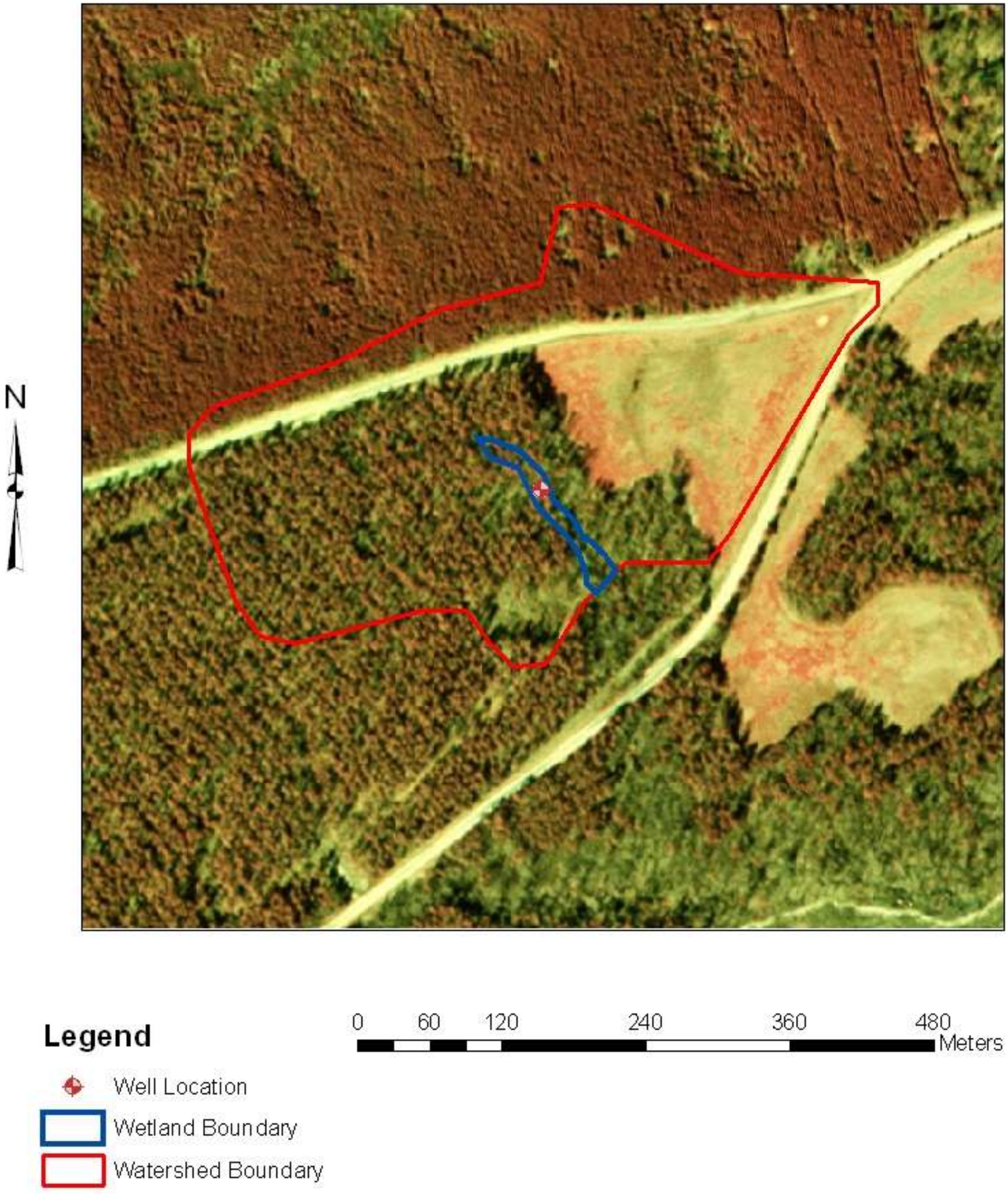


Figure A.5 Spring Garden Piedmont Natural

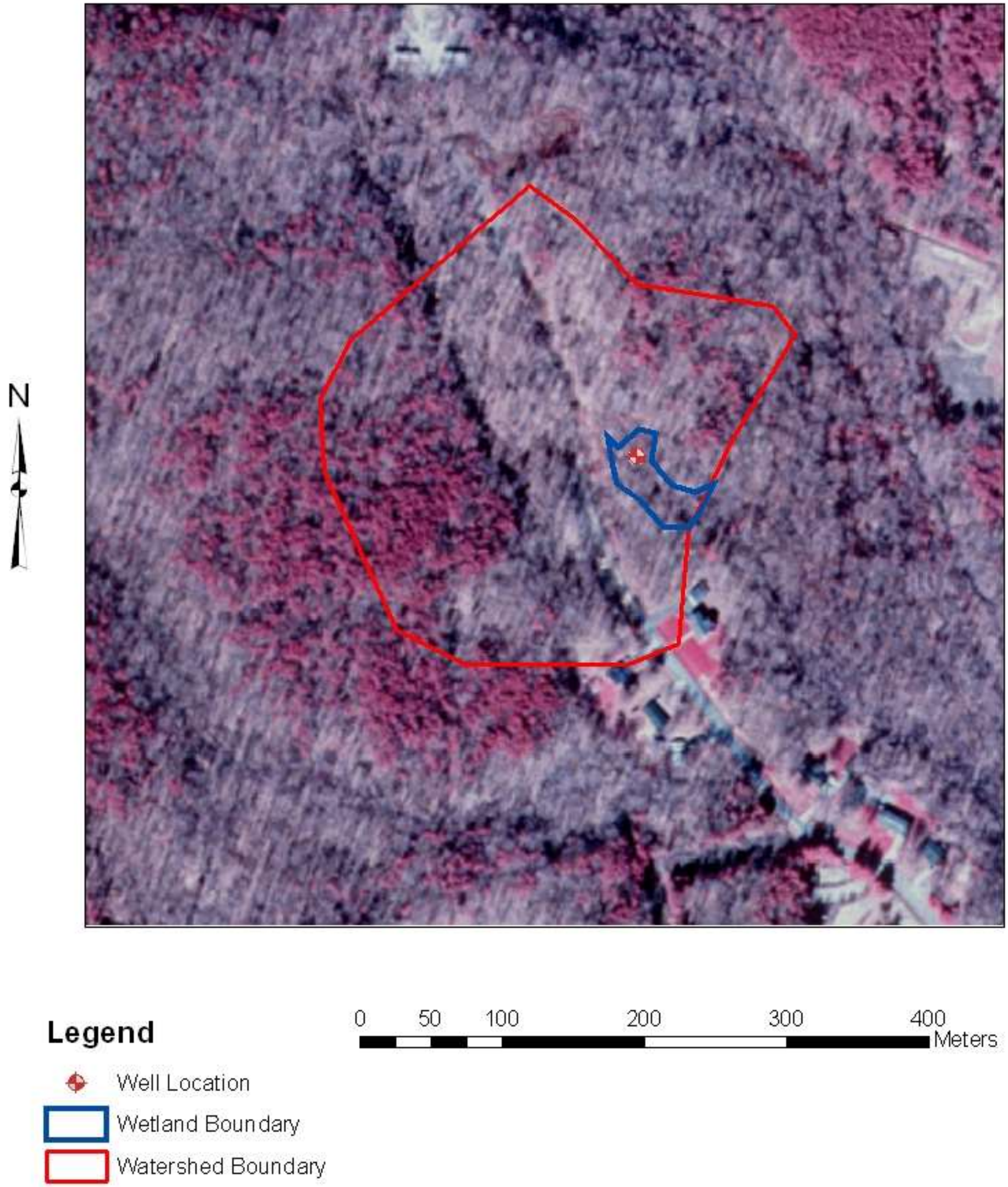


Figure A.6 Umstead Piedmont Natural

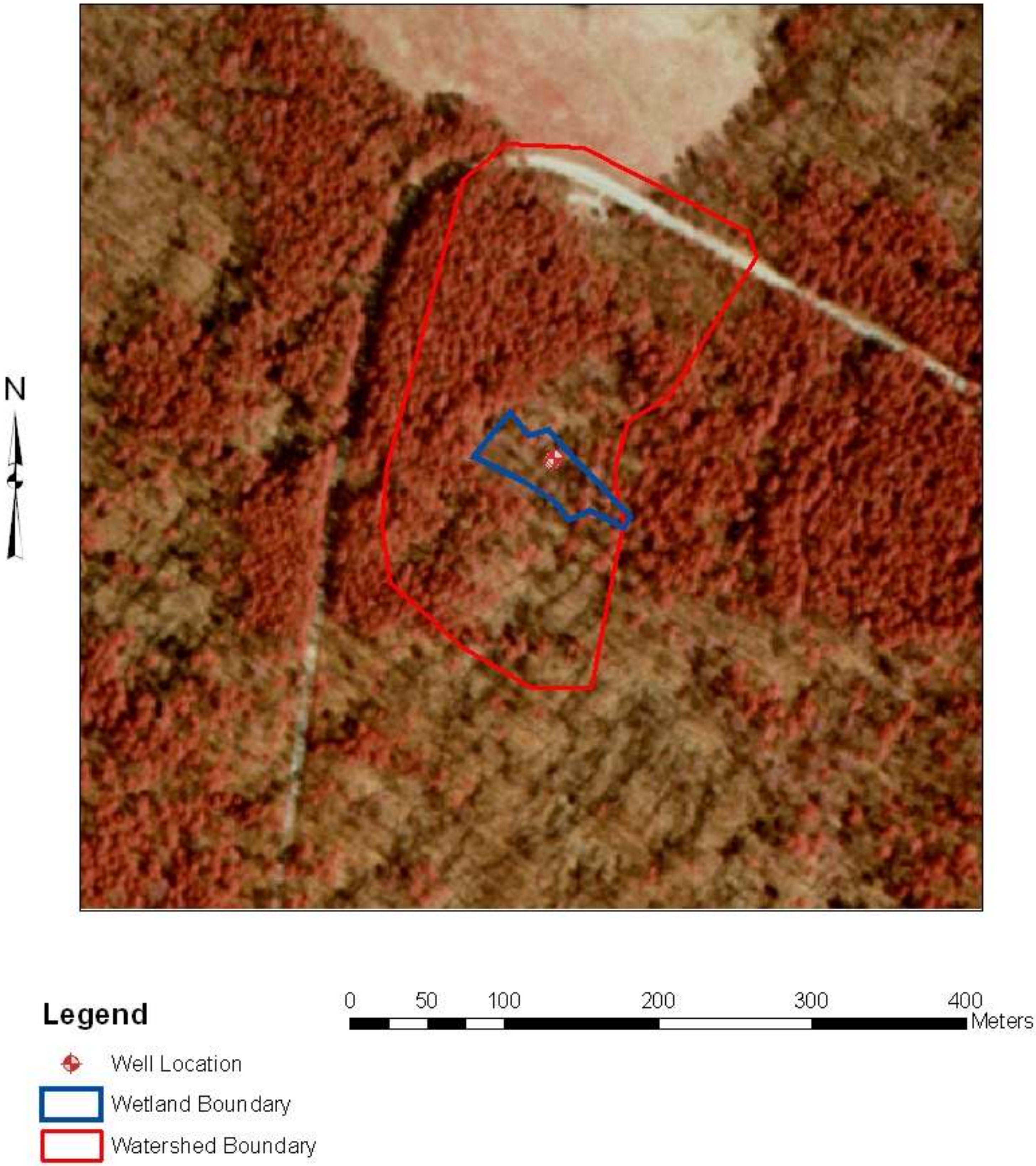


Figure A.7 East Fayetteville North and South Coastal Plain Rural

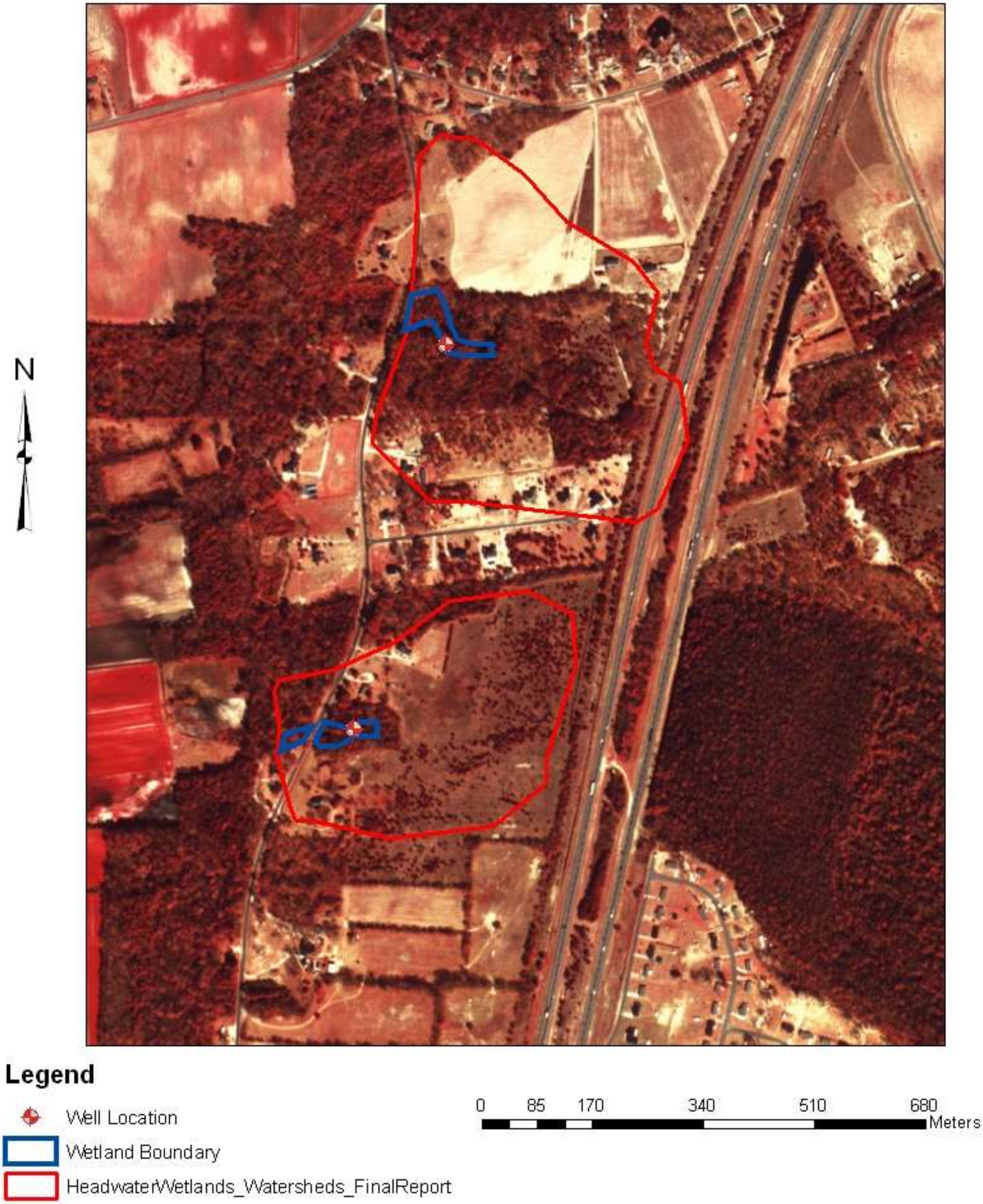


Figure A.8 Nahunta Coastal Plain Rural

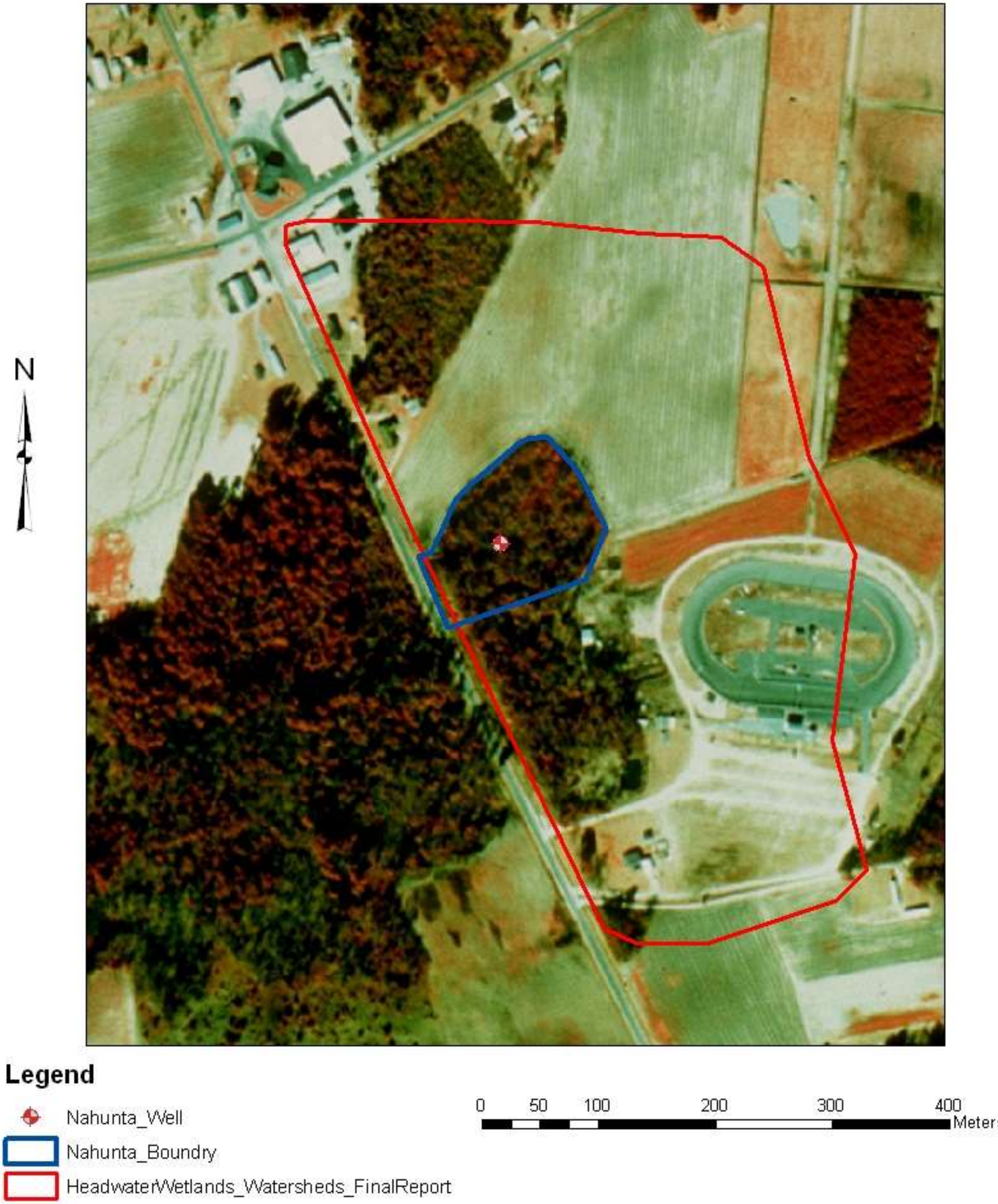


Figure A.9 Hog Farm Upper & Lower Coastal Plain Rural

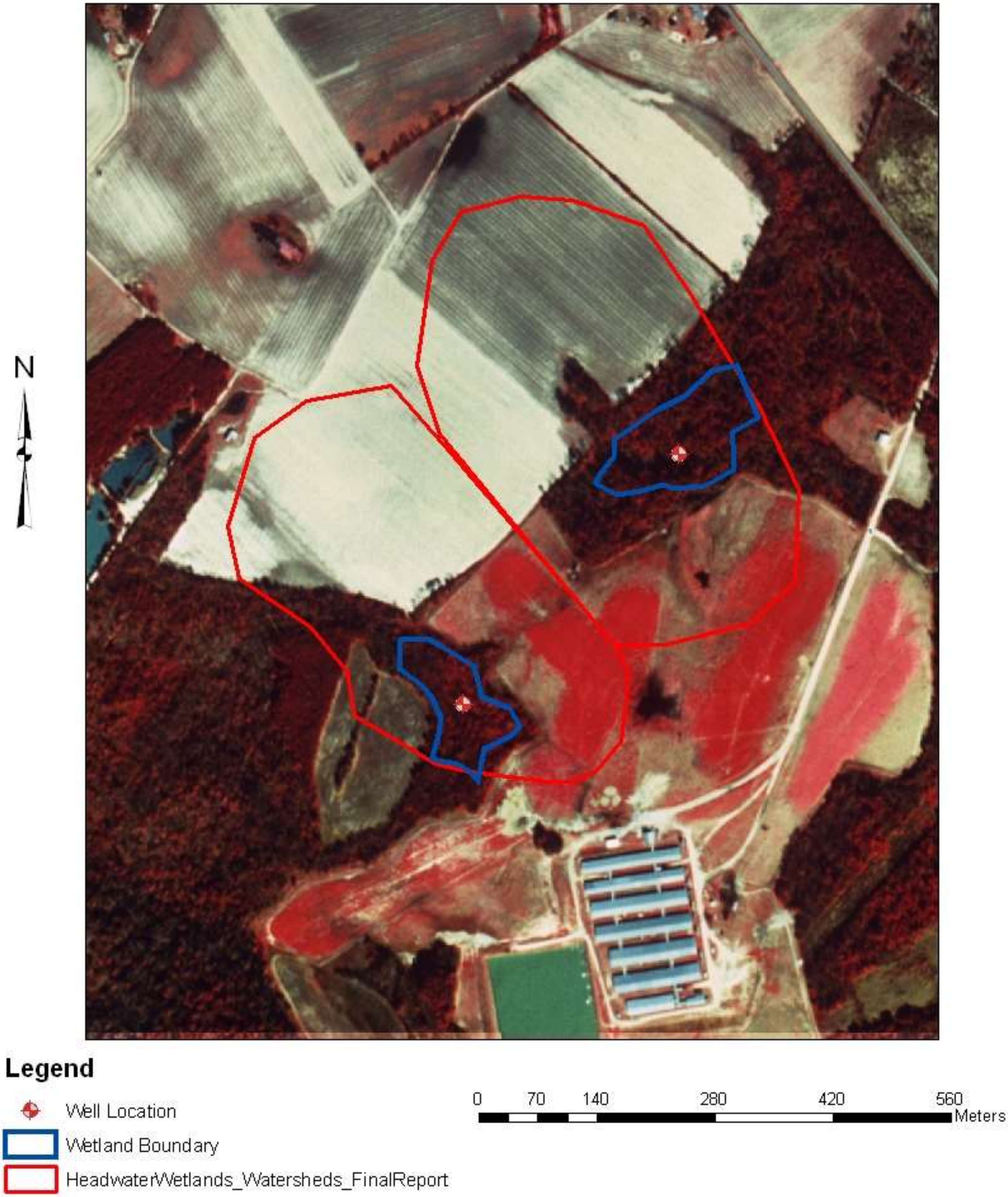


Figure A.10 Rough Rider Coastal Plain Rural

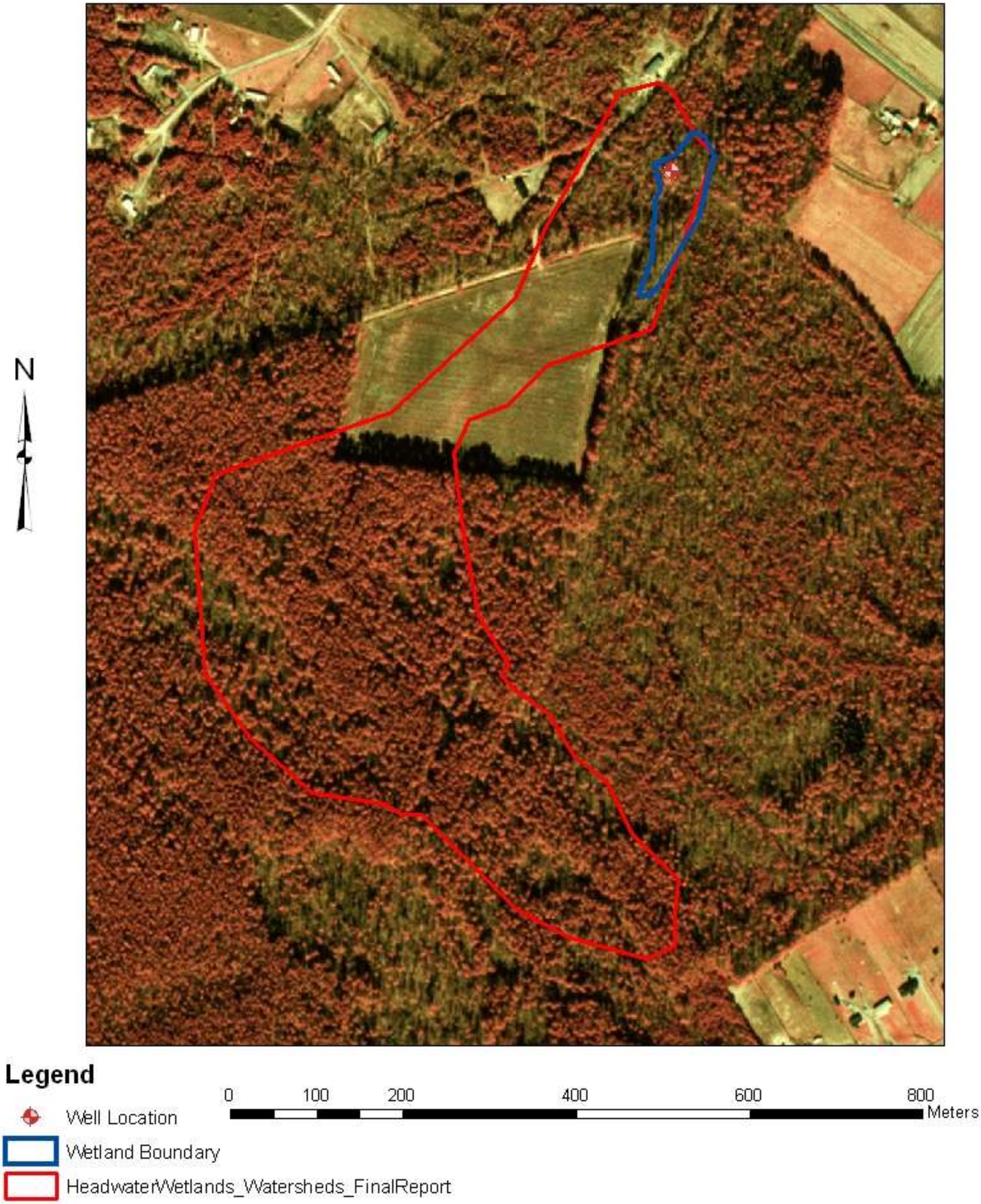


Figure A.11 Duke Forest Piedmont Natural

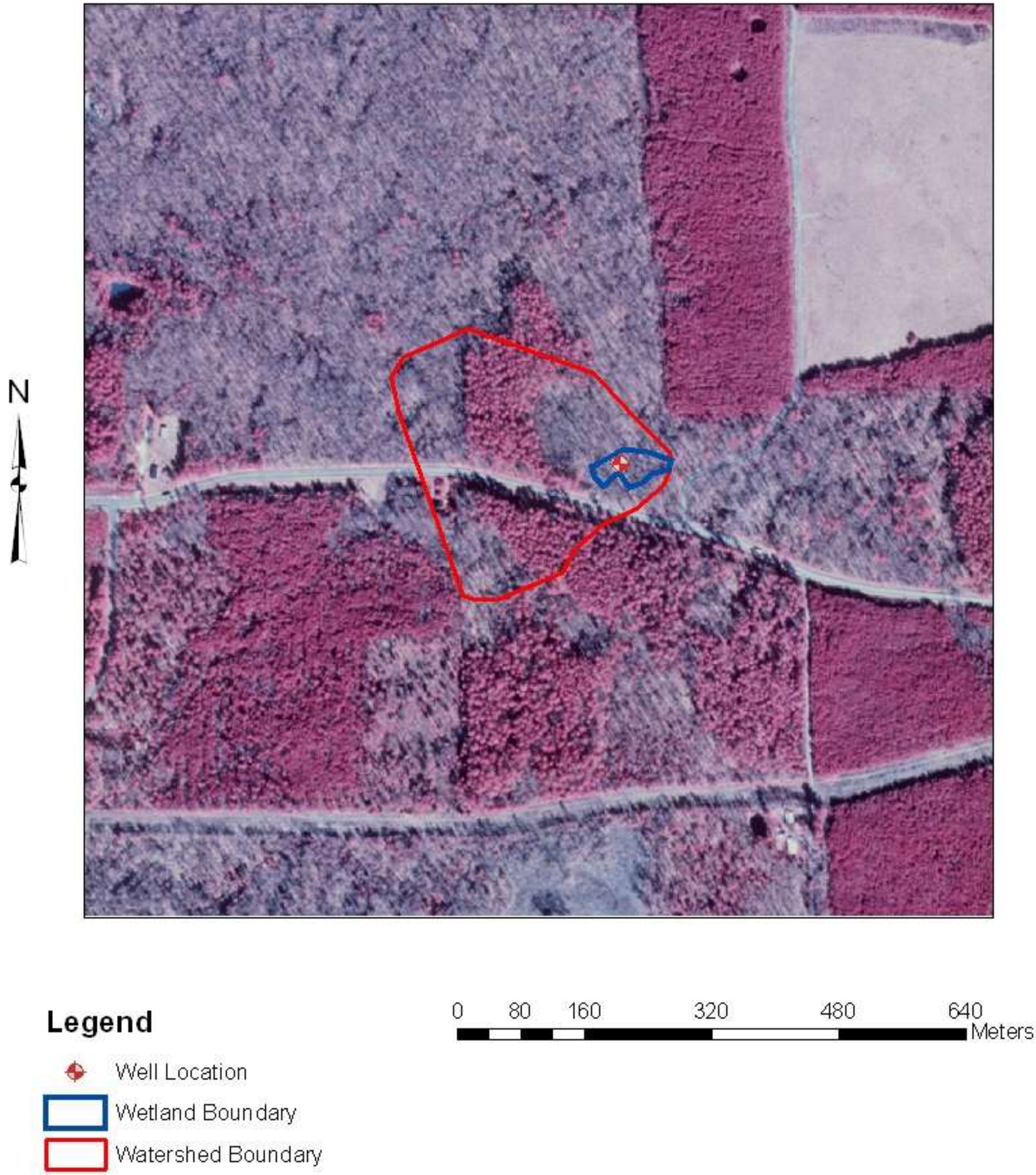


Figure A.12 Black Ankle Powerline & NonPowerline Piedmont Rural

Figure A.13 East of Mason Piedmont Rural

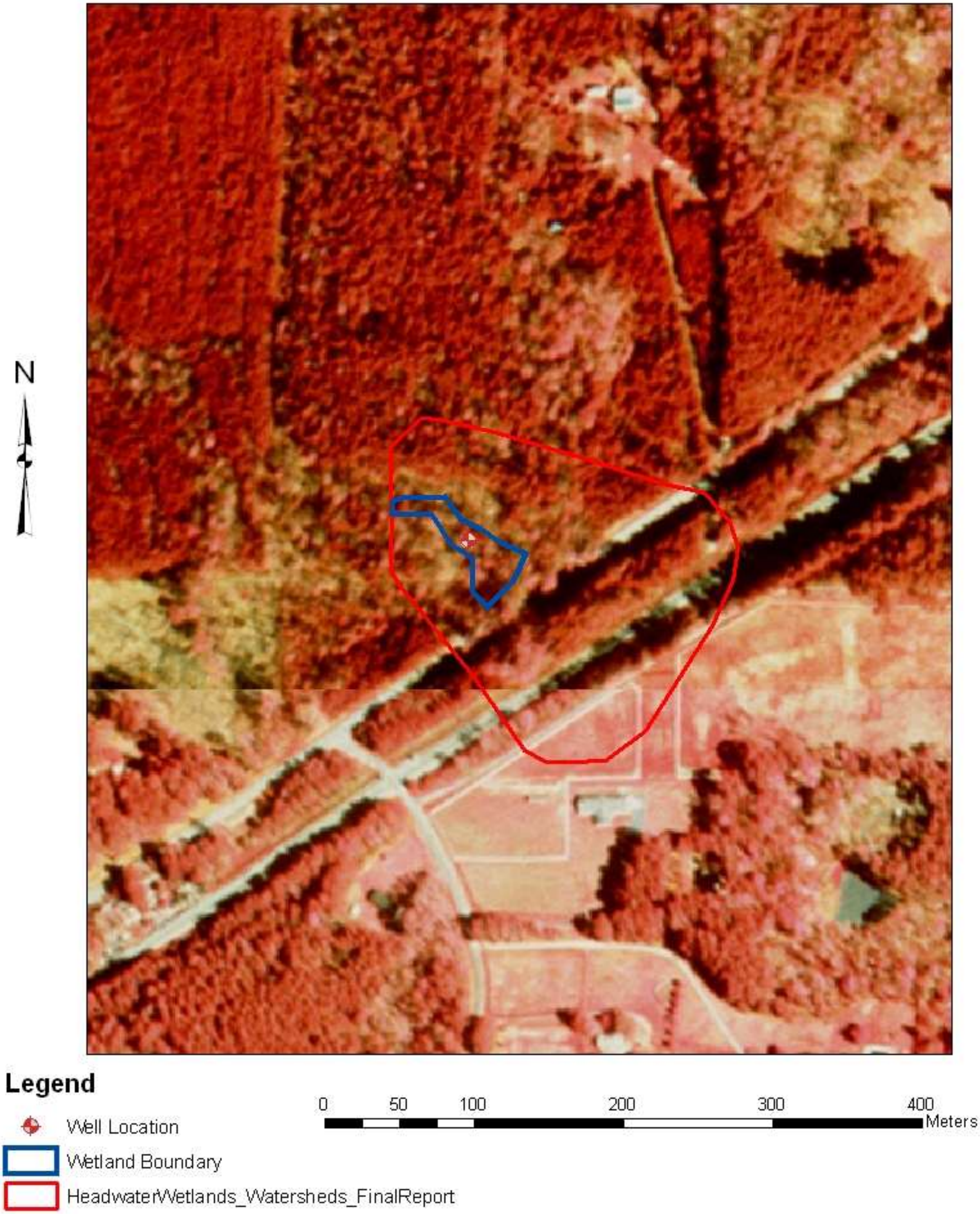


Figure A.14 Fire Tower Piedmont Rural

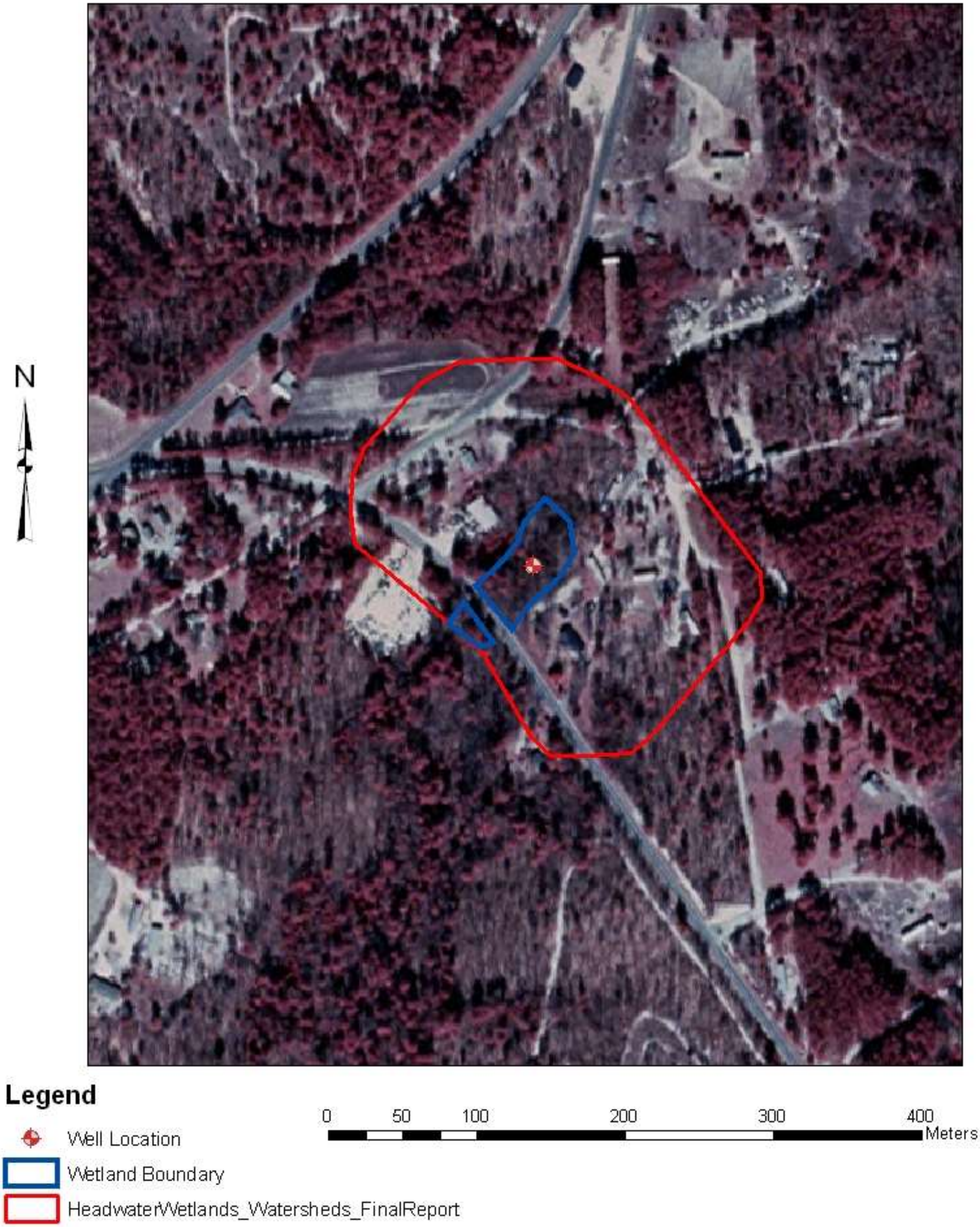


Figure A.15 Kelly Road Piedmont Rural

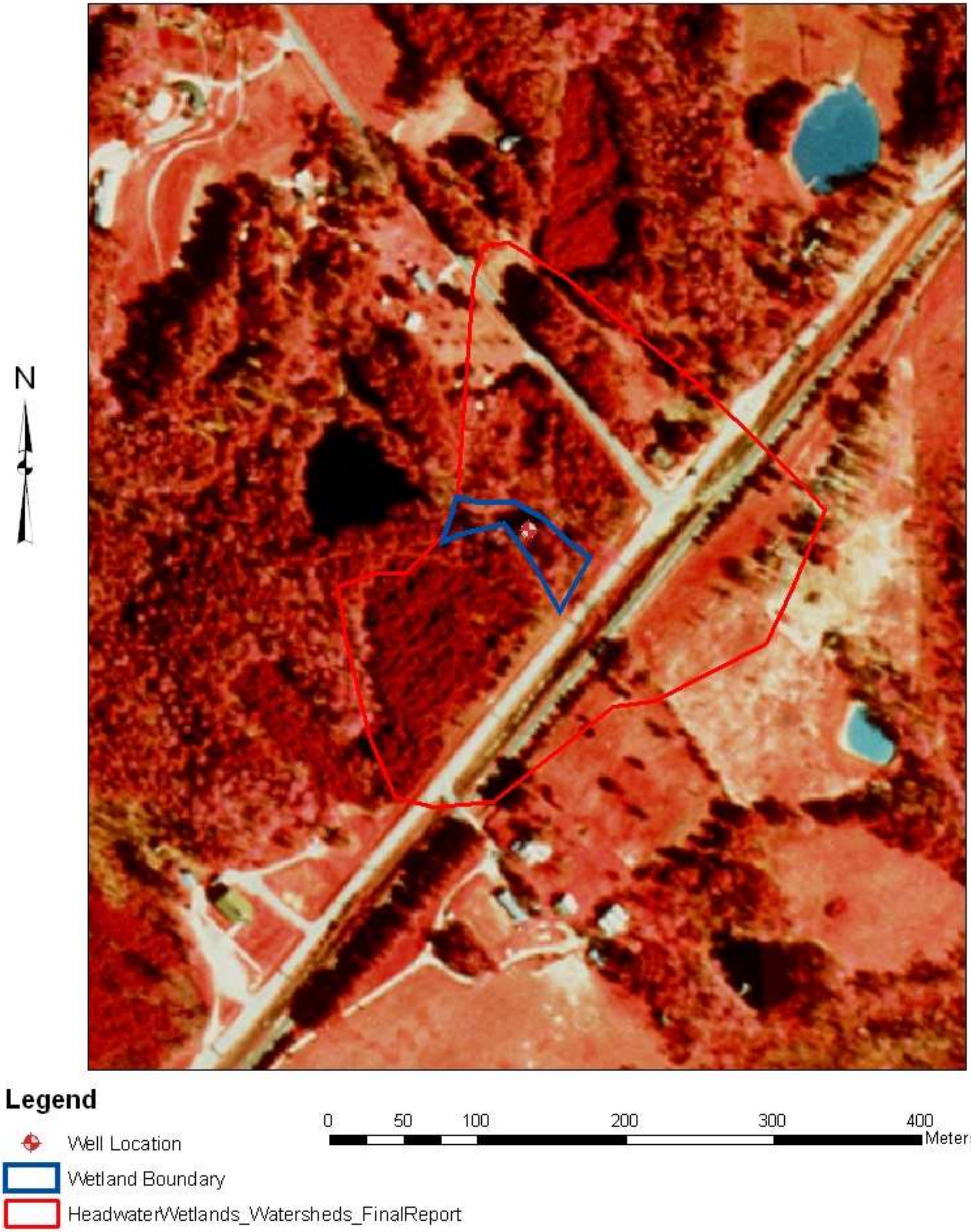


Figure A.16 Battle Park Coastal Plain Urban

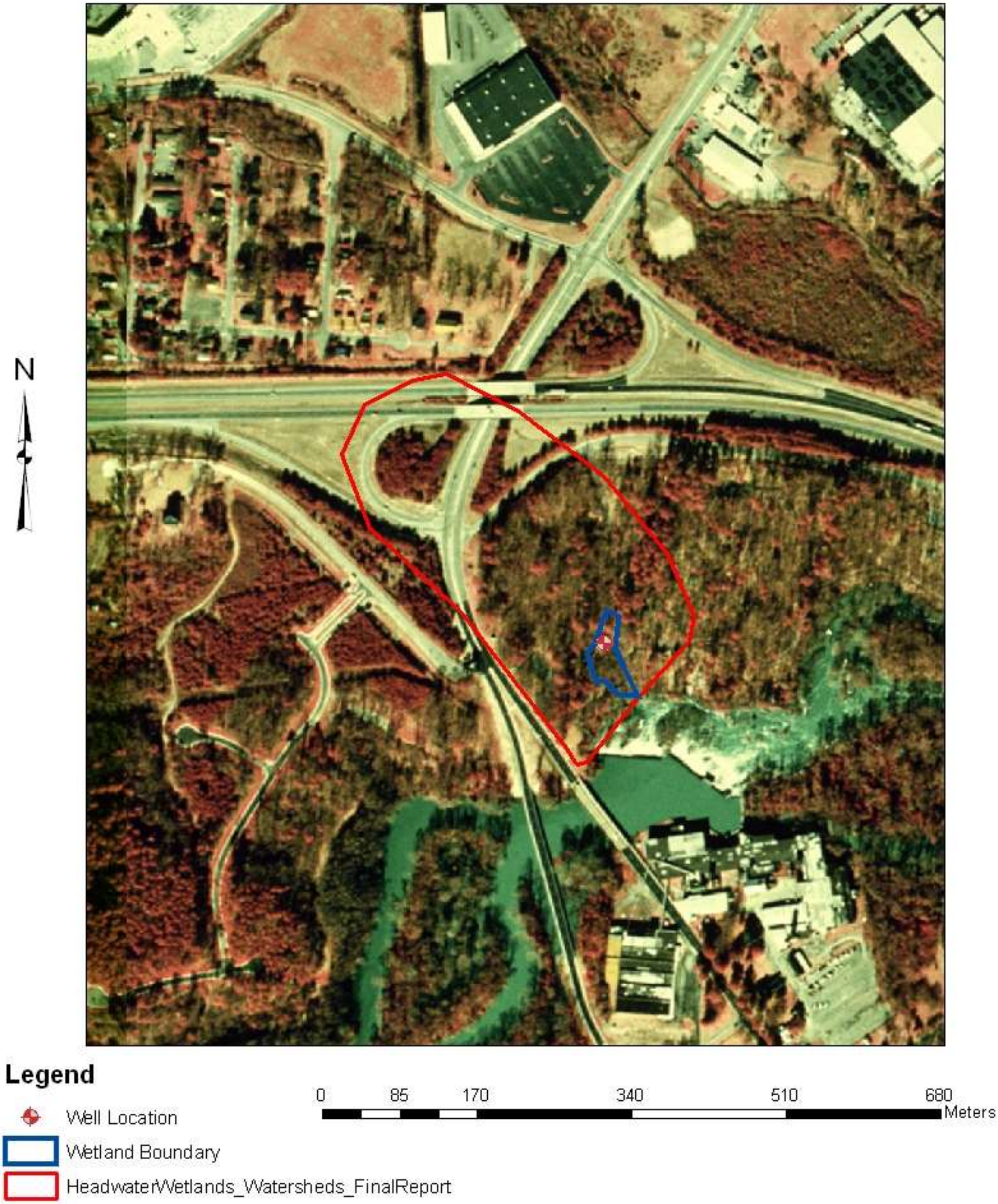


Figure A.17 Boddie Noell Coastal Plain Urban

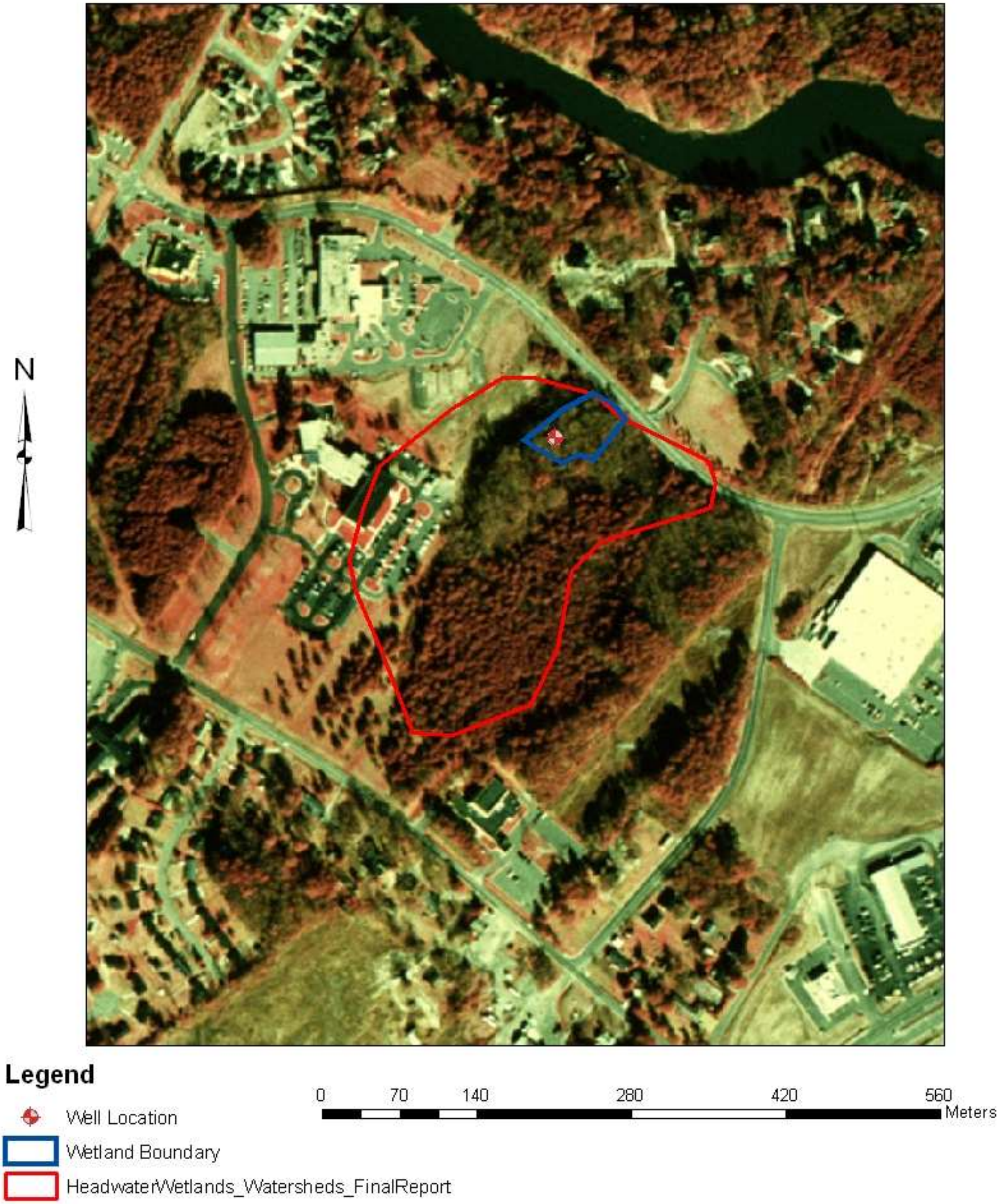


Figure A.18 Moonshine Piedmont Urban

Legend

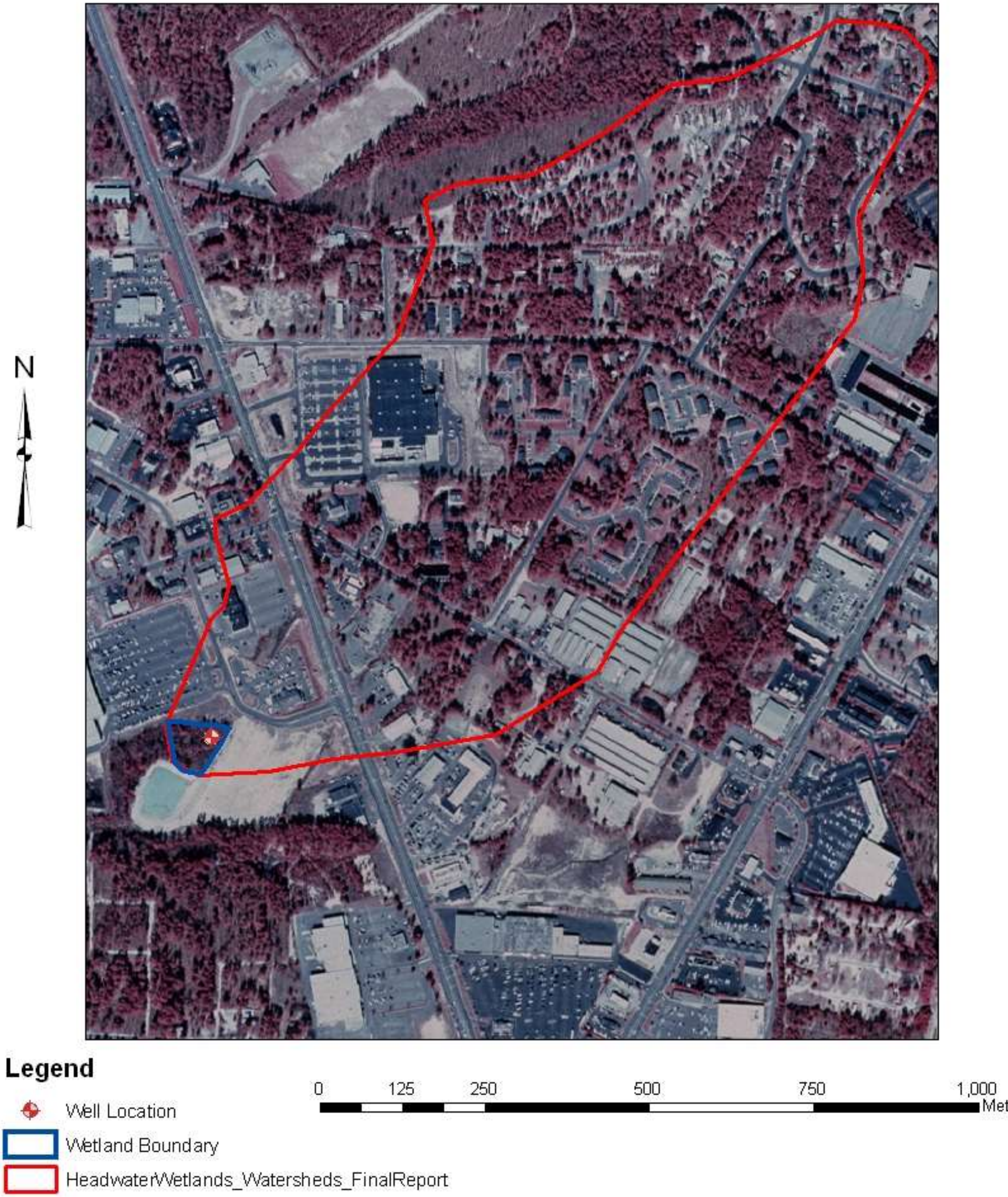
Well Location

Wetland Boundary

HeadwaterWetlands_Watersheds_FinalReport

Figure A.19 Troxler Piedmont Urban

Figure A.20 Walmart Piedmont Urban




Piedmont Spring Garden Photo Point at 240º


Piedmont Black Ankle Non-Powerline Photo Point at 120º


Piedmont Black Ankle Powerline Photo Point 360º


Piedmont Duke Forest Photo Point at 120º


Piedmont Walmart Photo Point 120º


Piedmont Fire Tower Photo Point 120º

Piedmont Troxler Site Photo

Piedmont Old US 1 Site Photo

Piedmont Umstead Photo Point 360º

Piedmont Pete Harris Photo Point 240º

Piedmont

Moonshine Site Photo

Piedmont Kelly Road Photo Point 240º


Coastal Plain PCS Photo Point 240º


Coastal Plain Bachelor Photo Point 240º


Coastal Plain Hog Farm Upper Photo Point 120º


Coastal Plain Battle Park Site Photo


Coastal Plain Boddie Noell Site Photo


Coastal Plain Cox Photo Point 240º

Coastal Plain E. Fayetteville North Photo Point 120º

Coastal Plain E. Fayetteville South Photo Point 360º

Coastal Plain Hog Farm Lower Photo Point 120º

Coastal Plain Nahunta Photo Point 240º

Coastal Plain Rough Rider Photo Point 120º

Appendix B

Headwater Wetland Monitoring Field Forms

Ohio Rapid Assessment Form - ORAM v. 5.0

DWQ Headwater Wetland Water Quality Monitoring Project Field Sheet
DWQ Water Quality Lab Form
Water Quality Sample Labels

DWQ Wetland Monitoring Project Well Depth Measurements taken by Hand
In-situ Vented Level Troll Well Monitoring Field Sheet

DWQ Headwater Wetland Monitoring Project Soils Diagram
DWQ Headwater Wetland Monitoring Project – Soil Field Data Sheet

DWQ Headwater Wetland Amphibian Wetland Monitoring Project Field Sheet
DWQ Headwater Wetland Monitoring Project- Amphibian Specimen List

DWQ Headwater Wetland Macroinvertebrate Sampling Field Sheet
DWQ Headwater Wetland Amphibian Monitoring Project-Data Sheet Macroinvertebrate Stations

DWQ Headwater Wetland Plot Layout and Slope Field Sheet
DWQ Wetland Plant Survey Species Cover Field Sheet
DWQ Wetland Woody Stem Survey Field Sheet

Site:	Rater(s):	Date:

Metric 1. Wetland Area (size).

max 6 pts. subtotal

Select one size class and assign score.

- [ ] >50 acres (>20.2ha) (6 pts)
- [ ] 25 to <50 acres (10.1 to <20.2ha) (5 pts)
- [ ] 10 to <25 acres (4 to <10.1ha) (4 pts)
- [ ] 3 to <10 acres (1.2 to <4ha) (3 pts)
- [ ] 0.3 to <3 acres (0.12 to <1.2ha) (2pts)
- [ ] 0.1 to <0.3 acres (0.04 to <0.12ha) (1 pt)
- [ ] <0.1 acres (0.04ha) (0 pts)

Metric 2. Upland buffers and surrounding land use.

max 14 pts. subtotal

2a. Calculate average buffer width. Select only one and assign score. Do not double check.

- [ ] WIDE. Buffers average 50m (164ft) or more around wetland perimeter (7)
- [ ] MEDIUM. Buffers average 25m to <50m (82 to <164ft) around wetland perimeter (4)
- [ ] NARROW. Buffers average 10m to <25m (32ft to <82ft) around wetland perimeter (1)
- [ ] VERY NARROW. Buffers average <10m (<32ft) around wetland perimeter (0)

2b. Intensity of surrounding land use. Select one or double check and average.

- [ ] VERY LOW. 2nd growth or older forest, prairie, savannah, wildlife area, etc. (7)
- [ ] LOW. Old field (>10 years), shrubland, young second growth forest. (5)
- [ ] MODERATELY HIGH. Residential, fenced pasture, park, conservation tillage, new fallow field. (3)
- [ ] HIGH. Urban, industrial, open pasture, row cropping, mining, construction. (1)

Metric 3. Hydrology.

max 30 pts. subtotal

3a. Sources of Water. Score all that apply.

- [ ] High pH groundwater (5)
- [ ] Other groundwater (3)
- [ ] Precipitation (1)
- [ ] Seasonal/Intermittent surface water (3)
- [ ] Perennial surface water (lake or stream) (5)

3b. Connectivity. Score all that apply.

- [ ] 100 year floodplain (1)
- [ ] Between stream/lake and other human use (1)
- [ ] Part of wetland/upland (e.g. forest), complex (1)
- [ ] Part of riparian or upland corridor (1)

3c. Maximum water depth. Select only one and assign score.

- [ ] >0.7 (27.6in) (3)
- [ ] 0.4 to 0.7m (15.7 to 27.6in) (2)
- [ ] <0.4m (<15.7in) (1)

3d. Duration inundation/saturation. Score one or dbl check.

- [ ] Semi- to permanently inundated/saturated (4)
- [ ] Regularly inundated/saturated (3)
- [ ] Seasonally inundated (2)
- [ ] Seasonally saturated in upper 30cm (12in) (1)

3e. Modifications to natural hydrologic regime. Score one or double check and average.

- [ ] None or none apparent (12)
- [ ] Recovered (7)
- [ ] Recovering (3)
- [ ] Recent or no recovery (1)

Check all disturbances observed

- [ ] ditch
- [ ] tile
- [ ] dike
- [ ] weir
- [ ] stormwater input
- [ ] point source (nonstormwater)
- [ ] filling/grading
- [ ] road bed/RR track
- [ ] dredging
- [ ] other________________

Metric 4. Habitat Alteration and Development.

max 20 pts. subtotal

4a. Substrate disturbance. Score one or double check and average.

- [ ] None or none apparent (4)
- [ ] Recovered (3)
- [ ] Recovering (2)
- [ ] Recent or no recovery (1)

4b. Habitat development. Select only one and assign score.

- [ ] Excellent (7)
- [ ] Very good (6)
- [ ] Good (5)
- [ ] Moderately good (4)
- [ ] Fair (3)
- [ ] Poor to fair (2)
- [ ] Poor (1)

4c. Habitat alteration. Score one or double check and average.

- [ ] None or none apparent (9)
- [ ] Recovered (6)
- [ ] Recovering (3)
- [ ] Recent or no recovery (1)

Check all disturbances observed

- [ ] mowing
- [ ] grazing
- [ ] clearcutting
- [ ] selective cutting
- [ ] woody debris removal
- [ ] toxic pollutants
- [ ] shrub/sapling removal
- [ ] herbaceous/aquatic bed removal
- [ ] sedimentation
- [ ] dredging
- [ ] farming
- [ ] nutrient enrichment

subtotal this page

Site:	Rater(s):	Date:

subtotal this page

Metric 5. Special Wetlands.

max 10 pts. subtotal

Check all that apply and score as indicated.

- ☐ Bog (10)
- ☐ Fen (10)
- ☐ Old growth forest (10)
- ☐ Mature forested wetland (5)
- ☐ Lake Erie coastal/tributary wetland-unrestricted hydrology (10)
- ☐ Lake Erie coastal/tributary wetland-restricted hydrology (5)
- ☐ Lake Plain Sand Prairies (Oak Openings) (10)
- ☐ Relict Wet Praires (10)
- ☐ Known occurrence state/federal threatened or endangered species (10)
- ☐ Significant migratory songbird/water fowl habitat or usage (10)
- ☐ Category 1 Wetland. See Question 1 Qualitative Rating (-10)

Metric 6. Plant communities, interspersion, microtopography.

max 20 pts. subtotal

6a. Wetland Vegetation Communities.
Score all present using 0 to 3 scale.

- ☐ Aquatic bed
- ☐ Emergent
- ☐ Shrub
- ☐ Forest
- ☐ Mudflats
- ☐ Open water
- ☐ Other______________

6b. horizontal (plan view) Interspersion.
Select only one.

- ☐ High (5)
- ☐ Moderately high(4)
- ☐ Moderate (3)
- ☐ Moderately low (2)
- ☐ Low (1)
- ☐ None (0)

6c. Coverage of invasive plants. Refer to Table 1 ORAM long form for list. Add or deduct points for coverage

- ☐ Extensive >75% cover (-5)
- ☐ Moderate 25-75% cover (-3)
- ☐ Sparse 5-25% cover (-1)
- ☐ Nearly absent <5% cover (0)
- ☐ Absent (1)

6d. Microtopography.
Score all present using 0 to 3 scale.

- ☐ Vegetated hummucks/tussucks
- ☐ Coarse woody debris >15cm (6in)
- ☐ Standing dead >25cm (10in) dbh
- ☐ Amphibian breeding pools

Vegetation Community Cover Scale

0	Absent or comprises <0.1ha (0.2471 acres) contiguous area
1	Present and either comprises small part of wetland's vegetation and is of moderate quality, or comprises a significant part but is of low quality
2	Present and either comprises significant part of wetland's vegetation and is of moderate quality or comprises a small part and is of high quality
3	Present and comprises significant part, or more, of wetland's vegetation and is of high quality

Narrative Description of Vegetation Quality

low	Low spp diversity and/or predominance of nonnative or disturbance tolerant native species
mod	Native spp are dominant component of the vegetation, although nonnative and/or disturbance tolerant native spp can also be present, and species diversity moderate to moderately high, but generallyw/o presence of rare threatened or endangered spp
high	A predominance of native species, with nonnative spp and/or disturbance tolerant native spp absent or virtually absent, and high spp diversity and often, but not always, the presence of rare, threatened, or endangered spp

Mudflat and Open Water Class Quality

0	Absent <0.1ha (0.247 acres)
1	Low 0.1 to <1ha (0.247 to 2.47 acres)
2	Moderate 1 to <4ha (2.47 to 9.88 acres)
3	High 4ha (9.88 acres) or more

Microtopography Cover Scale

0	Absent
1	Present very small amounts or if more common of marginal quality
2	Present in moderate amounts, but not of highest quality or in small amounts of highest quality
3	Present in moderate or greater amounts and of highest quality

GRAND TOTAL(max 100 pts)

Refer to the most recent ORAM Score Calibration Report for the scoring breakpoints between wetland categories at the following address: http://www.epa.state.oh.us/dsw/401/401.html

DWQ Headwater Wetland Water Quality Monitoring Project – Field Sheet

Site Name:________________________________ **Sampler's Initials:**______________________

Station Number: ___________________________ **County:**________________________________

Station Location: ___________________________ **Date:** __________________________________
(upstream-well, downstream) **(yy/mm/dd)**

Daily Lab Site Number: _________

Weather:

Air Temperature:____________________________________

Inches of Rain in last 48 hr:____________________________

Water Quality:

Time YSI / pH Parameters taken: ____________________ Chlorine Total ___________

Water Temperature:_____________________________ Chlorine Free ___________
(use YSI 85 meter)

DO:________________%_______________mg/L__________ Picture Number _________

Specific Conductivity: _________________________________ Camera Used ___________

PH: _______________ Temp with pH probe:_____________

Water Sampled:

Method: Direct Grab / Dug and Grab / Dug and Bailed / Bailed / Pumped

Comments on water quality / hydrology (e.g. water clarity or turbidity characteristics, raining at sampling time, numerous aquatic plants, presence of algae, presence of sphagnum moss or anything that might effect water quality on sampling day, metal or plastic shovel used, if sampled at new site:)____

Preservation Time: _______________ Sample Time: __________________

Sample type	**Preservative**	**Bottle Size**	**"X" if taken at this site**
Nutrients	H_2SO_4-Sulfuric Acid & ice	500 ml	
Metals (Pb, Cu, Zn, Ca,	HNO_3- Nitric Acid & ice	500 ml	
TOC	H_3PO_4- Phosphoric Acid & ice	200 ml	
DOC	H_3PO_4- Phosphoric Acid & ice	200 ml	
Turbidity	Ice	200 ml	
TSS	Ice	500 ml	
Fecal Coliform	Ice	250 ml	

DIVISION OF WATER QUALITY - LAB FORM

COUNTY :
RIVER BASIN : ____________
REPORT TO : ____________
SHIPPED BY : ____________
COLLECTOR(S) : ____________

PRIORITY
☐ AMBIENT ☐ QA
☐ COMPLIANCE ☐ CHAIN OF CUSTODY
☐ EMERGENCY

VisitID: ☐

W SAMPLE TYPE
☐ STREAM ☐ EFFLUENT
☐ LAKE ☐ INFLUENT
☐ ESTUARY

Lab Number : ____________
Date Received : ____________
Time Received : ____________
Received By : ____________

Data Released : ____________
Date Reported : ____________

Estimated BOD Range: Station Location: ____________

Seed: ____ Chlorinated: ____ Remarks: ____________

Station #	Date Begin (yy/mm/dd)	Date End (yy/mm/dd)	Time Begin	Time End	Depth - DM, DB, DBM	Value Type - A, H, L	Composite-T, S, B	Sample Type C G GNXX

BOD 310 mg/L	Chloride 940 mg/L	NH3 as N 610 mg/L	Li- Lithium 1132 ug/L
COD High 340 mg/L	Chl a: 70953 µg/L	TKN as N 625 mg/L	Mg- Magnesium 927 mg/L
COD Low 335 mg/L		NO2 plus NO3 as N 630 mg/L	Mn- Manganese 1055 µg/L
Coliform: MF Fecal 31616 #/100 mls		P: Total as P 665 mg/L	Na- Sodium 929 mg/L
Coliform: MF Total 31504 #/100 mls	Color: True 80 c.u.	PO4 as P 70507 mg/L	As- Arsenic:Total 1002 µg/L
Coliform: Tube Fecal 31615 #/100 mls	Color: (pH) 83 c.u.	P: Dissolved as P 666 mg/L	Se- Selenium 1147 µg/L
Coliform: Fecal Strep 31673 #/100 mls	Color: pH 7.6 82 c.u.	K- Potassium mg/L	Hg- Mercury 71900 µg/L
Residue: Total 500 mg/L	Cyanide 720 mg/L	Cd- Cadmium 1027 µg/L	Ba- Barium µg/L
Volatile 505 mg/L	Fluoride 951 mg/L	Cr- Chromium:Total 1034 µg/L	Organochlorine Pesticides
Fixed 510 mg/L	Formaldehyde 71880 mg/L	Cu- Copper 1042 µg/L	Organophosphorus Pesticides
Residue: Suspended 530 mg/L	Grease and Oils 556 mg/L	Ni- Nickel 1067 µg/L	
Volatile 535 mg/L	Hardness Total 900 mg/L	Pb- Lead 1051 µg/L	Acid Herbicides
Fixed 540 mg/L	Specific Cond. 95 µmhos/cm2	Zn- Zinc 1092 µg/L	
pH 403 units	MBAS 38260 mg/L	V- Vanadium µg/L	Base/Neutral&Acid Extractable Organics
Acidity to pH 4.5 436 mg/L	Phenols 32730 µg/L	Ag- Silver 1077 µg/L	TPH Diesel Range
Acidity to pH 8.3 435 mg/L	Sulfate 945 mg/L	Al- Aluminum 1105 µg/L	
Alkalinity to pH 8.3 415 mg/L	Sulfide 745 mg/L	Be- Beryllium 1012 µg/L	Purgeable Organics (VOA bottle req'd)
Alkalinity to pH 4.5 410 mg/L	Boron: Total 1022 µg/L	Ca- Calcium 916 mg/L	TPH Gasoline Range
TOC 680 mg/L	Tannin & Lignin 32240 µg/L	Co- Cobalt 1037 µg/L	TPH/BTEX Gasoline Range
Turbidity 82079 NTU	Hexavalent Chromium 1032 µg/L	Fe- Iron 1045 µg/L	Phytoplankton
Coliform Total Tube 31508 #/100 mls			

COMMENTS : ____________

LAB USE ONLY
Temperature on arrival (°C):

Sample Point % (2)	Conductance (94)	Water Temp-C (10)	D.O. (300)	pH (400)	8.3 Alkalinity (82244	4.5 Alkalinity (431)	4.5 Acidity (82243)	8.3 Acidity (82242)	Air Temp-C (20)
Secchi depth m	Salinity ppt (480)	Precipit-In/day (45)	Cloud Cover % (32)	Wind Dir-Deg (3	Strm Flow Sev (1351	Turbidity Severity (13	Wind Velocity-mph	Mean Strm Depth-ft (64)	Strm Width-ft (4)

W Body Bachelor Up
Station # 70501
Date ___/___/___
Collector R. Savage
Analysis Nutrients
Preservative H_2SO_4 + Ice

LAB #

W Body Bachelor Up
Station # 70501
Date ___/___/___
Collector R. Savage
Analysis Metals (Pb, Cu, Zn, Ca, Mg)
Preservative HNO_3 + Ice

LAB #

W Body Bachelor Up
Station # 70501
Date ___/___/___
Collector R. Savage
Analysis Fecal Coliform (___:___)
Preservative Ice

LAB #

W Body Bachelor Up
Station # 70501
Date ___/___/___
Collector R. Savage
Analysis TOC
Preservative H_3PO_4 + Ice

LAB #

W Body Bachelor Down
Station # 70502
Date ___/___/___
Collector R. Savage
Analysis Nutrients
Preservative H_2SO_4 + Ice

LAB #

W Body Bachelor Down
Station # 70502
Date ___/___/___
Collector R. Savage
Analysis Metals (Pb, Cu, Zn, Ca, Mg)
Preservative HNO_3 + Ice

LAB #

W Body Bachelor Down
Station # 70502
Date ___/___/___
Collector R. Savage
Analysis Fecal Coliform (___:___)
Preservative Ice

LAB #

W Body Bachelor Down
Station # 70502
Date ___/___/___
Collector R. Savage
Analysis TOC
Preservative H_3PO_4 + Ice

LAB #

W Body ________________
Station # ________________
Date ________________
Collector ________________
Analysis ________________
Preservative ________________

LAB #

W Body ________________
Station # ________________
Date ________________
Collector ________________
Analysis ________________
Preservative ________________

LAB #

DWQ Headwater Wetland Monitoring Project Well Depth Measurements taken by Hand

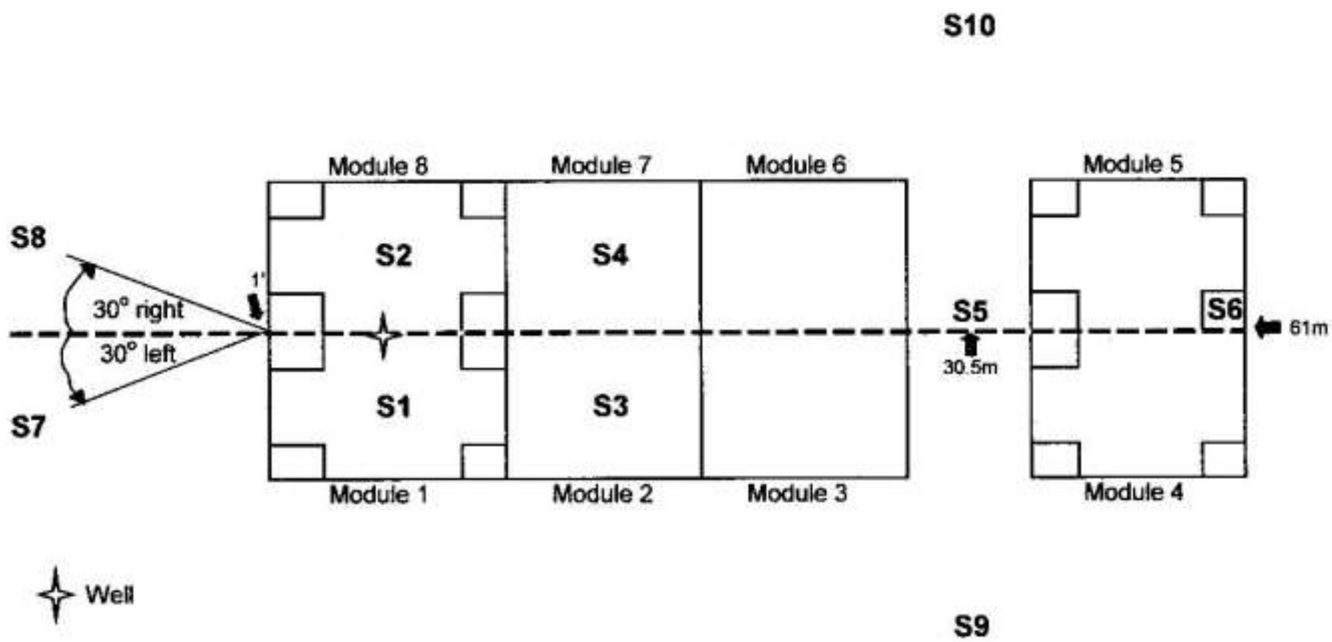
Page____ of____

Site	County	Date (yyyy/mm/dd)	Measuring Tape Drop	Wet	DTW	Height of well	Water above/below ground (+/-)	Comments	In Database ?

In-situ Vented Level Troll Well Monitoring Field Sheet

Site	County	Date (yyyy/mm/dd)	Depth of Probe Sensor in Well	DTW Measure by Hand	Depth Measure by Hand	In-Situ Electronic Depth Reading	Accuracy	Comments

Depth of Probe Sensor in well is measured from tope of well to Sensor
Depth of Measure by Hand=Depth of Prob Sensor-DTW
Accuracy = +/- (Depth Measurement by hand - In-Situ Depth Reading)


S10
Module 8
Module 7
Module 6
Module 5
S8
S2
S4
1'
30° right
S5
S6
61m
30° left
30.5m
S1
S3
S7
Module 1
Module 2
Module 3
Module 4
Well
S9

DWQ Headwater Wetland Monitoring Project - Soil Field Data Sheet

Site Name: ____________ Soil type from soil maps: ____________ Page # ____ OF ____ GPS Pts. (Y/N): ____

County: ____________ Soil type from field analysis: ____________ Soil PH: ____________

Sample # ____________ Observer initials: ____________ Date: ____________

Soil Depth (to 18 inches):	Matrix Color / Mottle Color (Munsell Moist):	Horizon	Mottle Abundance (%)	Texture	Comments	Photo #
1						
2						
3						
4						
5						

Sample # ____________ Soil type from soil maps: ____________ Soil PH: ____________

Soil type from field analysis: ____________ GPS Pts. (Y/N): ____________

Soil Depth (inches, 18 max):	Matrix Color / Mottle Color (Munsell Moist):	Horizon	Mottle Abundance (%)	Texture	Comments	Photo #
1						
2						
3						
4						
5						

DWQ Headwater Wetland Amphibian Wetland Monitoring Project Field Sheet

Site Name: ______________________ **County**: __________________ **Observers**: ____________________

Date: _______________________ **Time Start**: ________________ **Time Stop**: ________________

Weather:
Air Temperature: ___________________ Wind*:_____________________ Percent Cloud Cover:_________

Rain in last 48 hrs: light / medium / heavy Air Temperature Previous 2 days ______________________

Water Quality:
Time parameters taken:____________________ Water Temperature:____________________

Special Conductivity:_________________ Dissolved Oxygen:________________ pH:__________________

Comments on hydrology (saturation, inundation, depth of water, size and duration of pools etc)____________

Species	Life Stage (egg mass, larvae, juvenile, adult)	Number observed	Comments**	Specimen number (if collected)	Photo number

* Wind – Calm (<1 mph) smoke rises, light air 1-3 mph smoke drifts, light breeze (4-7mph) leaves rustle and can feel wind on face, gentle breeze (8-12 mph) twigs and leaves move around, moderate breeze (13-18 mph) moves thin branches, raises loose papers, fresh breeze (13-18 mph) moves thing branches, raises loose paper

** Comments- Include such things as microhabitat (under log, under leaves, in moss hammock, ephemeral pool, on vegetation, etc), if this is auditory observation than note in comments, how many individuals calling, malformations observed, behavior observed (e.g. guarding eggs, mating etc), questionable ID, photo taken and number)

DWQ Headwater Wetland Monitoring Project- Amphibian Specimen List

Specimen number	Species	Site Name	Date	Number observed	Photo taken Y/N	Habitat
DWQHW0105						
DWQHW0105						
DWQHW0205						
DWQHW0305						
DWQHW0405						
DWQHW0505						
DWQHW0605						
DWQHW0705						
DWQHW0805						
DWQHW0905						
DWQHW1005						
DWQHW1105						
DWQHW1205						
DWQHW1305						
DWQHW1405						
DWQHW1505						
DWQHW1605						
DWQHW1705						
DWQHW1805						
DWQHW1905						
DWQHW2005						
DWQHW2105						
DWQHW2205						
DWQHW2305						
DWQHW2405						
DWQHW2505						
DWQHW2605						
DWQHW2705						
DWQHW2805						
DWQHW2905						
DWQHW3005						
DWQHW3105						
DWQHW3205						

DWQ Headwater Wetland Amphibian Wetland Monitoring Project – Data Sheet
Macroinvertebrate Stations

Use same macroinvertebrate station ID as used on macroinvertebrate field sheet. WQ will be transferred off the macro field sheets to the Amphibian database at a later date.
For Specimen # - Use Site abbreviation followed by Amph06 _ # (e.g. Nah_Amph06_1, Nah_Amph06_2 etc) and put specimen # and date on label for glass vial. Use 10% formalin for preservation (wear gloves).
** Comments- Include such things as microhabitat (under log, under leaves, in moss hammock, detritus, algae, ephemeral pool, on vegetation, questionable ID, size, malformations, etc)

Site:		Date (yyyy/mm/dd):		Observers Initials:	Camera Used:	
Macroinvert Station ID	**Species**	**Life Stage** (egg mass, larvae, juvenile, adult)	**Number observed**	**Comments****	**Specimen number** (if collected)	**Photo number**

Site:		Date (yyyy/mm/dd):		Observers Initials:	Camera Used:	
Macroinvert Station ID	**Species**	**Life Stage** (egg mass, larvae, juvenile, adult)	**Number observed**	**Macroinvert Station ID**	**Species**	**Photo number**

Site:		Date (yyyy/mm/dd):		Observers Initials:	Camera Used:	
Macroinvert Station ID	**Species**	**Life Stage** (egg mass, larvae, juvenile, adult)	**Number observed**	**Macroinvert Station ID**	**Species**	**Photo number**

Site:		Date (yyyy/mm/dd):		Observers Initials:	Camera Used:	
Macroinvert Station ID	**Species**	**Life Stage** (egg mass, larvae, juvenile, adult)	**Number observed**	**Macroinvert Station ID**	**Species**	**Photo number**

DWQ Headwater Wetland Macroinvertebrate Sampling Field Sheet

Site: ______________________________ Sampler's Initials:_______________________
County: ___________________________ Start Date:_____________________________
(YYYY/MM/DD)

Macroinvertebrate Sweep and Funnel Field Data

ID Number (Site Abbrev _technique_#) *	Sampling Technique*	Date Start (yyyy/mm/dd)	Start Time	Date End (yyyy/mm/dd)	Time End (Fn only)	Total Hours Deployed (Fn only)	Comments

*Site Abbrev_Method_# Site Abbrev – see Methods usually first 3 letters, technique – **Sweep = SW**, **Funnel Trap = FN**, **Stove Pipe = SVP**, # (e.g. KelSW1, KelSW2, KelFN1, KelFN2, KelSVP1)
Make notes in comments if other technquique used – leaf pack, visual check of rocks or woody debris)

Sample Station Information

Water Chemistry (Date:_____________)

Station ID Number(s)	Air Temp	H_2O Temp	%DO	Mg of DO	Specific Condo	pH	Pic #	GPS Pt (y/n)	Comments* Camera Used________

*Comments- Include info on- smell, presence of fish, periphyton / filamentous Algae, Fe Oxidizing Bacteria

Station Description

Station ID Number(s)	Location (Up, Mid, Dn)	Flow Rate**	Pool / Stream	Stream width (w') / Pool Size (W'xL')	Depth of Sample location (in)	% Veg	%Shade	Substrate Texture***

** Flow Rate = No Flow, Slow, Med, Fast *** Substrate Texture = silt, sand, detritus, gravel (<2"), cobble (>2"), woody debris, sphagnum and aquatic plants include all

DWQ Headwater Wetland Plot Layout and Slope Field Sheet

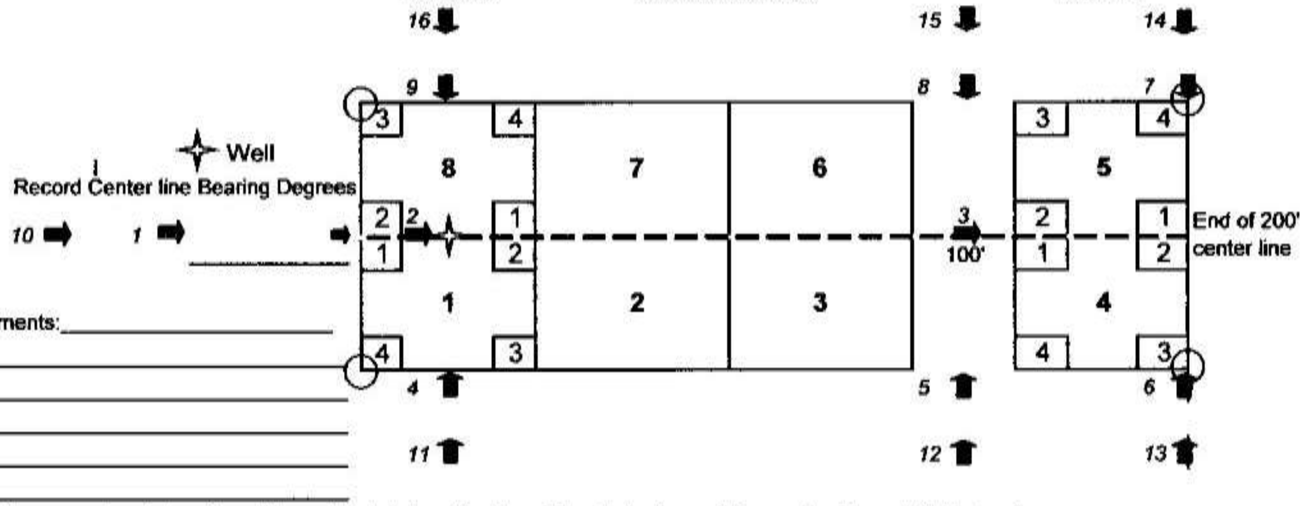
Site Name:________________

County:________________

Date:__________(yyyy/mm/dd)

Surveyors Initials:__________

Normal Plot Layout with Well Centered



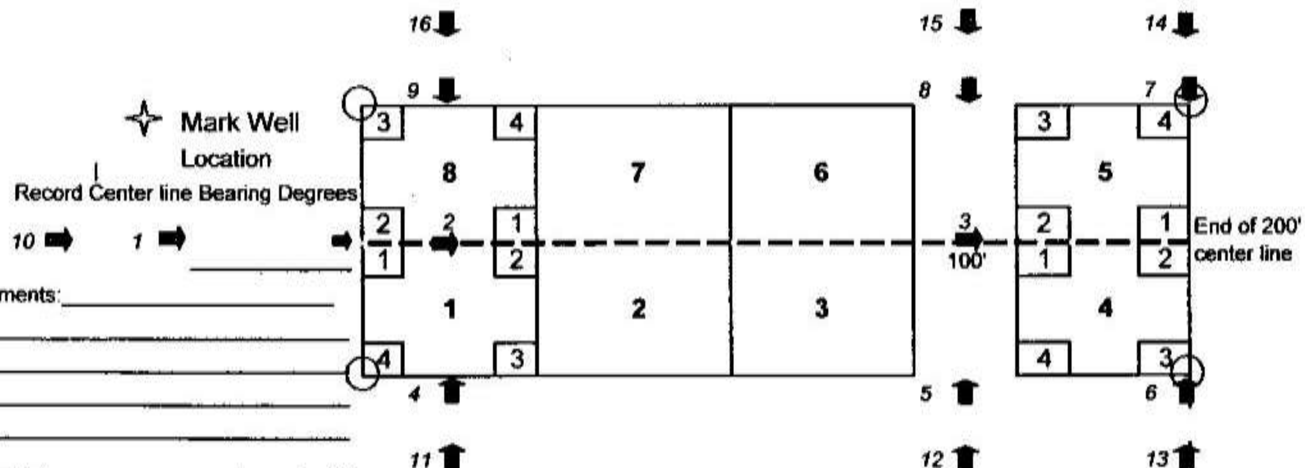
Comments:________________

Draw the approximate location of the wetland delineation line with a dashed pencil line on the Normal Plot Layout

Slope for a Plot ➡

				Distance of Slope
Slope *1*	______	Slope *9*	______	
Slope *2*	______	Slope *10*	______	______
Slope *3*	______	Slope *11*	______	______
Slope4	______	Slope *12*	______	______
Slope *5*	______	Slope *13*	______	______
Slope *6*	______	Slope *14*	______	______
Slope *7*	______	Slope *15*	______	______
Slope *8*	______	Slope *16*	______	______

Varied Plot Layout with Well Not Centered



Comments:________________

Mark well location with a " ✧ on the Varied Plot Layout and measure the distance of the well from the outer edges of the plot boundary (e.g. a well located in module 1 would be measured to the module boundary btw corners 1 and 4 and 3 and 4). Label the distances of the well to the Plot boundaries on the Varied Plot Layout. Draw the approximate location of the wetland delineation line with a dashed pencil line on the Varied Plot Layout.

◯ Gps point

Slope *1* - Read 10m from Slope *2* location (well for normal plot) along center line and shoot to slope *2* reading location.

Slope *2* - Read from well location (normal plot) or centerpoint btw modules *1* and *8* (varied plot) along center line and shoot to slope *3*.

Slope *3* - Read along center line and shoot to 200' centerline mark.

Slopes *4&9*, *5&8*, *6&7* - Read at edge of plot (10m from center line) at 90° to center line, shoot to slope *2*, *3*, and *4* respectively.

Slope *10* -Read at head of wetland along plot center line, shoot to slope *1*.

Slopes *8-16* - Read at edge of wetland at 90° angle to center line. Shoot slope *11* to *4*, slope *12* to *5*, slope *13* to *6*, slope *14* to *7*, slope *15* to *8* and slope *16* to *9*

DWQ Headwater Wetland Plant Survey Species Cover Field Sheet

Site Name:_______________ Date:________(yyyy/mm/dd)

County:__________________ Surveyors Initials:__________

Code	Plot Number	Collected	Module___			Module___			Module___			Module___			Res
	Stratum		H	S	C	H	S	C	H	S	C	H	S	C	Presence / Absence
	Statum % Cover														
	Corner Number		C#		% cov	C#		% cov	C#		% cov	C#		% cov	
Code	Species (Presence / Presence / % Cover)														

Stratum Height Classes --- H-Herb (0m-1m), S-Shrub 1m-6m), C-Canopy and Understory (>6m)

Stratum % Cover Classes--- 0-5%, 5-10%, 10-25%, 25-50%, 50-75%, 75-95%, 95-100% or Estimate % cover

Species % Cover Classes --- T=Trace (1-2 individuals), 0-1% ($1m^2$), 1-2% (1m x 2m), 2-5%(1m x 5m), 5-10% (1m x 10m), 10-25% ($5m^2$), 25-50% (5m x 10m), 50-75% ($8.7m^2$), 75-95% ($9.7m^2$), 95-100% ($10m^2$)

Presences Classes for Nested Corner Plots --- 5= 10cm x 10cm, 4= 32cm x 32 cm, 3= 1m x 1m, 4= 3.16m x 3.16m, 5= 10m x 10m, 0= overhanging

DWQ Headwater Wetland Woody Stem Survey Field Sheet

Site Name:_______________
County:_________________

Date:________(yyyy/mm/dd)
Surveyors Initials:_________

Code	Collected	Species	Module Number	Saplings / Vines		Trees							
				0-1 cm	1-2.5 cm	2.5-	5-	10-	15-	20-	25-	30-	≥35(write dbh)

Appendix C

Water Quality Disturbance Measurements

Table C.3.1 Water Quality Disturbance Measurement Table - Average Site and Relative Average Surface Water Quality Values

Site Name	Region	Ammonia	Calcium	Copper	DOC	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Fecal Coliform	Lead	Magnesium	NO2+NO3
Bachelor	Coastal Plain	0.03	1.23	2.14	18.6	37.79	3.44	4.33	10.86	0.82	0.02
Battle Park	Coastal Plain	0.1	8.67	13.88	33.8	32.98	3.4	490.6	24.6	2.3	0.02
Black Ankle Non-Powerline	Piedmont	0.15	1.3	4.8	2.93	38.6	3.78	533.78	19.44	0.67	0.02
Black Ankle Powerline	Piedmont	0.05	1.67	5.64	9.5	41.78	4.15	12	31.8	0.73	0.02
Boddie Noell	Coastal Plain	0.09	8.15	5.36	9.33	25.08	2.48	290	24.8	2.78	0.03
Cox	Coastal Plain	0.05	4.47	3.13	22.6	34.38	3.45	1631.38	16.63	1.77	0.03
Duke Forest	Piedmont	0.04	7.2	3.57	9.67	44.63	4.52	44	10	3.2	0.02
East Fayetteville North	Coastal Plain	0.05	2.6	2.12	7.37	14.74	1.4	1455.8	10	0.82	0.02
East Fayetteville South	Coastal Plain	0.04	5.17	8.47	11.8	18.58	1.5	2186.78	34.22	1.61	0.03
East of Mason	Piedmont	0.05	6.84	9.24	8.41	44.73	4.43	342.29	37.57	2.8	0.08
Fire Tower	Piedmont	0.03	1.72	3.14	3.4	32.76	3.14	518.86	10.14	0.88	0.17
Hog Farm Lower	Coastal Plain	0.11	6.14	2.94	12.12	22	2.8	708.6	10	3.6	0.81
Hog Farm Upper	Coastal Plain	0.03	15.18	2	5.84	56.42	5.46	804.69	10	11.18	19.77
Kelly Rd	Piedmont	0.05	2.75	2.91	4.22	40.2	3.89	82.57	11.14	1.37	0.02
Moonshine	Piedmont	0.06	3.1	3.03	16.4	35	3.09	257	10	1.1	0.02
Nahunta	Coastal Plain	0.14	10.32	2.68	16.92	24.33	2.5	439.56	10.13	7.83	0.64
PCS	Coastal Plain	0.05	2.32	8.93	22.25	12.78	1.25	925.71	21.5	0.56	0.06
Pete Harris	Piedmont	0.06	2.8	3.63	9.68	22.35	2.24	3783.17	19.33	1.48	0.02
Rough Rider	Coastal Plain	0.04	3.78	2.85	16	16.53	1.72	64.75	10.5	0.67	0.04
Spring Garden	Piedmont	0.02	4.73	2.74	4.26	56.45	5.72	85.2	12	1.63	0.02
Troxler	Piedmont	0.02	4.9	3.6	5.9	75.57	7.02	54	10	2.1	0.02
Umstead	Piedmont	0.09	6.62	5.7	16.86	47.58	4.31	253.86	11.57	2.52	0.02
Walmart	Piedmont	0.03	2.48	2	2.78	31.47	2.96	83.5	10	0.92	0.02

Table C.3.1 Water Quality Disturbance measurement Table - Average Site and Relative Average Surface Water Quality Values

Site Name	Region	Phosphorus	Specific Conductivity	TKN	TOC	TSS	Turbidity	Water Temp	Zinc	pH	Relative Ammonia
Bachelor	Coastal Plain	0.1	71.99	1.31	29.57	187.4	1.55	15.55	12.43	3.73	2.15
Battle Park	Coastal Plain	0.65	95.7	1.96	42	115.6	24	15.56	68.8	6.14	7.45
Black Ankle Non-Powerline	Piedmont	0.24	29.88	0.71	10.21	38.43	10.4	16.76	20.44	5.26	10.98
Black Ankle Powerline	Piedmont	0.19	47.17	1.97	38.18	643	71	16.58	25	5.34	3.58
Boddie Noell	Coastal Plain	0.63	81.13	1.67	36.04	510.6	160	14.6	69.6	5.17	6.3
Cox	Coastal Plain	0.38	70.71	2.68	67.43	27.71	27.5	16.33	18.38	4.76	3.79
Duke Forest	Piedmont	0.09	87.17	0.85	12.43	41.67	29	15.92	10.33	6.36	3.1
East Fayetteville North	Coastal Plain	0.15	55.42	0.87	17.6	69.55	82.5	17.47	11.7	4.77	3.44
East Fayetteville South	Coastal Plain	0.47	47.48	6.78	49.56	174	110	17.2	25	4.51	2.71
East of Mason	Piedmont	0.17	88.81	1.14	19.9	267.86	67.5	16.09	50	5.05	3.27
Fire Tower	Piedmont	0.08	31.51	0.8	13.59	61.83	20	16.58	12.71	5.04	2.46
Hog Farm Lower	Coastal Plain	0.25	100.16	0.87	19.26	22.7	9.05	17.51	30.1	4.53	7.59
Hog Farm Upper	Coastal Plain	0.15	369.55	0.91	9.77	103.36	11.5	17.23	11.77	5.9	2.42
Kelly Rd	Piedmont	0.12	50.87	0.63	6.13	77.33	56	14.94	25.38	4.96	3.38
Moonshine	Piedmont	0.1	51.5	1.05	21.33	39.33	14	20.43	14.67	5.36	4.54
Nahunta	Coastal Plain	0.36	130.75	1.85	28.31	171.92	21	15.36	16.88	5.46	9.8
PCS	Coastal Plain	0.35	79.21	3.77	62.56	45.55	14	16.22	34.31	4.03	3.89
Pete Harris	Piedmont	0.47	79.68	1.08	23.58	241	600	15.83	17.83	5.28	4.54
Rough Rider	Coastal Plain	0.26	79.8	0.94	32.75	145.5	97.5	14.35	11.5	5.75	3.04
Spring Garden	Piedmont	0.07	40.25	0.29	22.24	179.96	4.6	15.95	18.4	5.95	1.43
Troxler	Piedmont	0.09	43.37	0.35	8.2	97	.	18.9	56	5.91	1.43
Umstead	Piedmont	0.1	84.56	0.99	24.57	116.57	28.5	20.7	15	5.98	6.55
Walmart	Piedmont	0.03	47.23	0.38	4.2	23	1.8	18.97	10.67	5.24	2.15

Table C.3.1 Water Quality Disturbance measurement Table - Average Site and Relative Average Surface Water Quality Values

Site Name	Region	Relative Calcium	Relative Copper	Relative DOC	Relative Dissolved Oxygen (%)	Relative Dissolved Oxygen (Mg)	Relative Fecal Coliform	Relative Lead	Relative Magnesium	Relative No2+NO3	Relative Phosphorous
Bachelor	Coastal Plain	1.08	2.05	6.87	4.68	4.37	0.03	2.89	1.53	0.09	1.8
Battle Park	Coastal Plain	7.59	13.28	12.49	4.09	4.33	3.26	6.54	4.31	0.09	11.8
Black Ankle Non-Powerline	Piedmont	1.14	4.59	1.08	4.78	4.81	3.55	5.17	1.25	0.09	4.39
Black Ankle Powerline	Piedmont	1.46	5.4	3.51	5.18	5.28	0.08	8.45	1.36	0.09	3.42
Boddie Noell	Coastal Plain	7.14	5.13	3.45	3.11	3.15	1.93	6.59	5.21	0.16	11.51
Cox	Coastal Plain	3.91	2.99	8.35	4.26	4.38	10.84	4.42	3.31	0.14	6.87
Duke Forest	Piedmont	6.31	3.41	3.57	5.53	5.74	0.29	2.66	6	0.09	1.64
East Fayetteville North	Coastal Plain	2.28	2.03	2.72	1.83	1.78	9.67	2.66	1.53	0.11	2.79
East Fayetteville South	Coastal Plain	4.53	8.1	4.36	2.3	1.9	14.53	9.1	3.03	0.13	8.52
East of Mason	Piedmont	5.99	8.85	3.11	5.54	5.63	2.27	9.99	5.25	0.35	3.15
Fire Tower	Piedmont	1.51	3.01	1.26	4.06	4	3.45	2.7	1.65	0.78	1.48
Hog Farm Lower	Coastal Plain	5.38	2.81	4.48	2.73	3.56	4.71	2.66	6.75	3.7	4.57
Hog Farm Upper	Coastal Plain	13.3	1.91	2.16	6.99	6.95	5.35	2.66	20.98	90.18	2.72
Kelly Rd	Piedmont	2.41	2.79	1.56	4.98	4.95	0.55	2.96	2.57	0.09	2.16
Moonshine	Piedmont	2.72	2.9	6.06	4.34	3.93	1.71	2.66	2.06	0.09	1.76
Nahunta	Coastal Plain	9.04	2.56	6.25	3.02	3.18	2.92	2.69	14.69	2.9	6.6
PCS	Coastal Plain	2.03	8.54	8.22	1.58	1.58	6.15	5.71	1.04	0.27	6.33
Pete Harris	Piedmont	2.45	3.48	3.58	2.77	2.84	25.13	5.14	2.77	0.09	8.47
Rough Rider	Coastal Plain	3.31	2.73	5.91	2.05	2.18	0.43	2.79	1.25	0.17	4.64
Spring Garden	Piedmont	4.14	2.62	1.57	7	7.27	0.57	3.19	3.05	0.09	1.27
Troxler	Piedmont	4.29	3.45	2.18	9.37	8.93	0.36	2.66	3.94	0.09	1.64
Umstead	Piedmont	5.8	5.45	6.23	5.9	5.48	1.69	3.08	4.73	0.09	1.87
Walmart	Piedmont	2.17	1.91	1.03	3.9	3.76	0.55	2.66	1.72	0.11	0.58

Table C.3.1 Water Quality Disturbance measurement Table - Average Site and Relative Average Surface Water Quality Values

Site Name	Region	Relative Specific Conductivity	Relative TKN	Relative TOC	Relative TSS	Relative Turbidity	Relative WaterTemp	Relative Zinc	Relative pH	Relative Nutrients	Relative Metals
Bachelor	Coastal Plain	3.86	3.88	4.93	5.51	0.11	4.04	2.12	3.09	7.91	9.67
Battle Park	Coastal Plain	5.13	5.78	7.01	3.4	1.64	4.04	11.72	5.1	25.13	43.45
Black Ankle Non-Powerline	Piedmont	1.6	2.09	1.7	1.13	0.71	4.35	3.48	4.36	17.55	15.63
Black Ankle Powerline	Piedmont	2.53	5.81	6.37	18.91	4.86	4.31	4.26	4.44	12.91	20.94
Boddie Noell	Coastal Plain	4.35	4.94	6.01	15.01	10.95	3.79	11.86	4.29	22.91	35.93
Cox	Coastal Plain	3.79	7.91	11.25	0.81	1.88	4.24	3.13	3.95	18.71	17.77
Duke Forest	Piedmont	4.68	2.5	2.07	1.23	1.98	4.13	1.76	5.28	7.34	20.14
East Fayetteville North	Coastal Plain	2.97	2.58	2.94	2.05	5.65	4.54	1.99	3.96	8.91	10.49
East Fayetteville South	Coastal Plain	2.55	20.04	8.27	5.12	7.53	4.47	4.26	3.74	31.39	29.01
East of Mason	Piedmont	4.76	3.38	3.32	7.88	4.62	4.18	8.52	4.2	10.16	38.6
Fire Tower	Piedmont	1.69	2.37	2.27	1.82	1.37	4.3	2.17	4.19	7.08	11.03
Hog Farm Lower	Coastal Plain	5.37	2.56	3.21	0.67	0.62	4.55	5.13	3.76	18.42	22.73
Hog Farm Upper	Coastal Plain	19.83	2.7	1.63	3.04	0.79	4.48	2.01	4.9	98.02	40.86
Kelly Rd	Piedmont	2.73	1.86	1.02	2.27	3.83	3.88	4.32	4.12	7.49	15.05
Moonshine	Piedmont	2.76	3.1	3.56	1.16	0.96	5.31	2.5	4.45	9.49	12.84
Nahunta	Coastal Plain	7.01	5.47	4.72	5.06	1.44	3.99	2.88	4.53	24.77	31.86
PCS	Coastal Plain	4.25	11.16	10.44	1.34	0.96	4.21	5.85	3.35	21.65	23.18
Pete Harris	Piedmont	4.28	3.19	3.93	7.09	41.06	4.11	3.04	4.39	16.29	16.87
Rough Rider	Coastal Plain	4.28	2.76	5.46	4.28	6.67	3.73	1.96	4.77	10.62	12.04
Spring Garden	Piedmont	2.16	0.85	3.71	5.29	0.31	4.14	3.14	4.94	3.65	16.14
Troxler	Piedmont	2.33	1.03	1.37	2.85	.	4.91	9.54	4.91	4.2	23.88
Umstead	Piedmont	4.54	2.91	4.1	3.43	1.95	5.38	2.56	4.96	11.43	21.61
Walmart	Piedmont	2.53	1.12	0.7	0.68	0.12	4.93	1.82	4.35	3.96	10.28

Table C.3.1 Water Quality Disturbance Measurement Table - Average Site and Relative Average Surface Water Quality Values

Site Name	Region	Relative Pb Cu Zn	Relative Nutrients Metals FC TSS Condo	Relative Nutrients Cu Pb Zn FC TSS Condo
Bachelor	Coastal Plain	7.05	26.98	24.37
Battle Park	Coastal Plain	31.54	80.37	68.46
Black Ankle Non-Powerline	Piedmont	13.25	39.47	37.08
Black Ankle Powerline	Piedmont	18.11	55.36	52.53
Boddie Noell	Coastal Plain	23.58	80.13	67.79
Cox	Coastal Plain	10.54	51.92	44.7
Duke Forest	Piedmont	7.83	33.67	21.36
East Fayetteville North	Coastal Plain	6.68	34.09	30.28
East Fayetteville South	Coastal Plain	21.46	82.6	75.04
East of Mason	Piedmont	27.35	63.67	52.42
Fire Tower	Piedmont	7.87	25.07	21.91
Hog Farm Lower	Coastal Plain	10.6	51.9	39.77
Hog Farm Upper	Coastal Plain	6.58	167.09	132.81
Kelly Rd	Piedmont	10.08	28.09	23.11
Moonshine	Piedmont	8.06	27.96	23.18
Nahunta	Coastal Plain	8.13	71.63	47.89
PCS	Coastal Plain	20.1	56.57	53.49
Pete Harris	Piedmont	11.65	69.66	64.44
Rough Rider	Coastal Plain	7.48	31.65	27.09
Spring Garden	Piedmont	8.95	27.8	20.61
Troxler	Piedmont	15.64	33.61	25.38
Umstead	Piedmont	11.09	42.69	32.16
Walmart	Piedmont	6.39	18	14.11

Table C.3.2 Water Quality Disturbance Measurement Table - Median Site Surface Water Quality Values

Site Name	Region	Ammonia	Calcium	Copper	DOC	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Fecal Colliform	Lead	Magnesium	NO2+NO3
Bachelor	Coastal Plain	0.02	1.1	2	17	23.5	2.15	2	10	0.64	0.02
Battle Park	Coastal Plain	0.13	9.7	19	25	11.2	1.2	190	26	1.9	0.02
Black Ankle Non-Powerline	Piedmont	0.02	0.84	2	2.8	30	3.32	36	10	0.34	0.02
Black Ankle Powerline	Piedmont	0.03	1.8	5.2	11	51.3	5.13	8	26	0.86	0.02
Boddie Noell	Coastal Plain	0.04	8.35	4.9	9.75	24	2.125	38	10	2.8	0.02
Cox	Coastal Plain	0.05	2.55	2	25	47.15	4.285	1164.5	10	1.3	0.02
Duke Forest	Piedmont	0.03	7.2	3.2	10	43	4.55	48	10	3.2	0.02
East Fayetteville North	Coastal Plain	0.03	2.5	2	5.85	15.25	1.455	1320	10	0.805	0.02
East Fayetteville South	Coastal Plain	0.03	4.6	3.1	12.5	17.6	1.5	830	10	1.4	0.02
East of Mason	Piedmont	0.02	5.9	4.3	8.3	42.4	4	220	13	2.5	0.02
Fire Tower	Piedmont	0.03	1.2	2	3.45	32.8	3.09	160	10	0.76	0.13
Hog Farm Lower	Coastal Plain	0.06	6.1	2.4	9.65	19.55	1.75	240	10	3.15	0.1
Hog Farm Upper	Coastal Plain	0.02	14	2	5.8	57.1	6	670	10	12	16
Kelly Rd	Piedmont	0.02	2.4	2.2	4.2	35	3.2	15	10	1.3	0.02
Moonshine	Piedmont	0.08	3.1	2.9	16	44.5	3.9	38	10	1.1	0.02
Nahunta	Coastal Plain	0.08	10	2	17.75	20.8	2.055	71.75	10	7.5	0.105
PCS	Coastal Plain	0.03	1.7	2.35	24	12.7	1.22	57	10	0.51	0.06
Pete Harris	Piedmont	0.035	2.8	2.3	10.5	23.25	2.23	183.5	10	1.5	0.02
Rough Rider	Coastal Plain	0.035	3.78	2.4	14	14.95	1.585	13	10	0.665	0.02
Spring Garden	Piedmont	0.02	4.65	2	4.2	54.9	5.54	73	10	1.6	0.02
Troxler	Piedmont	0.02	4.9	3.6	5.9	69.2	7.18	54	10	2.1	0.02
Umstead	Piedmont	0.03	5	4.6	15	52.35	5.295	87	10	1.9	0.02
Walmart	Piedmont	0.03	2.5	2	2.45	34.75	2.975	84	10	0.87	0.02

Table C.3.2 Water Quality Disturbance Measurement Table - Median Site Surface Water Quality Values

Site Name	Region	Phosphorus	Specific Conductivity	TKN	TOC	TSS	Turbidity	Water, Temp	Zinc	pH
Bachelor	Coastal Plain	0.05	74.5	0.88	29	37	1.55	14.45	12	3.72
Battle Park	Coastal Plain	0.57	92	2	26	79	24	16.9	28	5.97
Black Ankle Non-Powerline	Piedmont	0.04	27.8	0.25	3.95	33	10.4	16.2	11	5.18
Black Ankle Powerline	Piedmont	0.11	42.1	1.8	21	185	71	17.5	20	5.33
Boddie Noell	Coastal Plain	0.55	82.4	1.7	16	489	160	15.4	48	5.25
Cox	Coastal Plain	0.1	62.6	1.3	33	27	27.5	16.85	13	4.73
Duke Forest	Piedmont	0.09	77.2	0.82	14	50	29	18	10	6.355
East Fayetteville North	Coastal Plain	0.115	47.3	0.725	19	59.5	82.5	16.6	10.5	4.805
East Fayetteville South	Coastal Plain	0.23	52	2.2	36	120	110	16.6	19	4.42
East of Mason	Piedmont	0.19	82.4	0.66	13	85	67.5	15.3	41	4.75
Fire Tower	Piedmont	0.04	33	0.45	6.7	26	20	16.25	10	5.07
Hog Farm Lower	Coastal Plain	0.19	97.9	0.78	13	21	9.05	18.35	22.5	4.665
Hog Farm Upper	Coastal Plain	0.08	344.6	0.91	7.4	52	11.5	16.1	11	5.96
Kelly Rd	Piedmont	0.09	56.9	0.42	4.2	90	56	14.1	21.66667	4.93
Moonshine	Piedmont	0.1	47	0.96	21	49	14	20.4	15	5.45
Nahunta	Coastal Plain	0.185	115.25	1.85	26.25	50.5	21	16.45	14	5.44
PCS	Coastal Plain	0.12	75	0.79	33.75	24.5	14	15.7	30	3.69
Pete Harris	Piedmont	0.15	55.65	0.965	13	45	600	15.25	18	5.49
Rough Rider	Coastal Plain	0.22	48.1	0.975	23.5	140	97.5	13.95	11.5	5.745
Spring Garden	Piedmont	0.08	42.95	0.2	5.8	64	4.6	15.1	20	6
Troxler	Piedmont	0.09	36.4	0.35	8.2	97	.	19.8	56	5.8
Umstead	Piedmont	0.09	95.7	0.92	19	67	28.5	21.75	10	5.91
Walmart	Piedmont	0.02	43.5	0.27	3.85	15	1.8	18.1	10	5.25

Table C.3.3 Water Quality Disturbance Measurement Table - Relative Average Surface Water Quality Values by Region

Region	Site Name	Relative Ammonia	Relative Calcium	Relative Copper	Relative DOC	Relative Dissolved Oxygen	Relative Dissolved Oxygen (mg/L)	Relative Fecal Coliform	Relative Lead	Relative Magnesium	Relative NO2+NO3
Coastal Plain	Bachelor	4.09	1.81	3.93	10.53	12.78	11.7	0.05	5.93	2.41	0.09
	Battle Park	14.16	12.74	25.48	19.14	11.16	11.58	5.45	13.43	6.78	0.09
	Boddie Noell	11.99	11.98	9.84	5.28	8.49	8.43	3.22	13.53	8.18	0.16
	Cox	7.2	6.57	5.74	12.8	11.63	11.73	18.12	9.07	5.21	0.15
	East Fayetteville North	6.54	3.82	3.89	4.17	4.99	4.77	16.17	5.46	2.4	0.11
	East Fayetteville South	5.15	7.6	15.54	6.68	6.29	5.09	24.29	18.68	4.75	0.13
	Hog Farm Lower	14.44	9.02	5.4	6.86	7.44	9.53	7.87	5.46	10.61	3.78
	Hog Farm Upper	4.61	22.32	3.67	3.31	19.09	18.58	8.94	5.46	32.96	92.07
	Nahunta	18.64	15.17	4.91	9.58	8.23	8.52	4.88	5.53	23.09	2.96
	PCS	7.41	3.41	16.38	12.6	4.32	4.24	10.28	11.73	1.64	0.28
	Rough Rider	5.79	5.56	5.23	9.06	5.59	5.84	0.72	5.73	1.96	0.17
Piedmont	Black Ankle Non-Powerline	23.17	2.81	9.6	3.12	7.55	7.68	8.82	10.07	3.45	4.43
	Black Ankle Powerline	7.55	3.62	11.28	10.11	8.17	8.43	0.2	16.48	3.75	4.43
	Duke Forest	6.55	15.62	7.13	10.28	8.73	9.17	0.73	5.18	16.51	4.43
	East of Mason	6.91	14.84	18.48	8.95	8.75	9	5.66	19.47	14.45	17.1
	Fire Tower	5.18	3.73	6.28	3.62	6.41	6.38	8.58	5.26	4.55	37.68
	Kelly Rd	7.12	5.97	5.83	4.49	7.87	7.91	1.36	5.77	7.07	4.43
	Moonshine	9.57	6.72	6.07	17.45	6.85	6.27	4.25	5.18	5.68	4.43
	Pete Harris	9.57	6.07	7.26	10.3	4.37	4.54	62.53	10.02	7.61	4.43
	Spring Garden	3.02	10.25	5.48	4.53	11.04	11.61	1.41	6.22	8.38	4.43
	Troxler	3.02	10.63	7.2	6.28	14.78	14.26	0.89	5.18	10.83	4.43
	Umstead	13.81	14.36	11.4	17.93	9.31	8.75	4.2	6	13	4.43
	Walmart	4.53	5.38	4	2.95	6.16	6.01	1.38	5.18	4.73	5.32

Table C.3.3 Water Quality Disturbance Measurement Table - Relative Average Surface Water Quality Values by Region

Region	Site Name	Relative Phosphorous	Relative Specific Conductivity	Relative TKN	RelTOC	RelTSS	Relative Turbidity	Relative Water Temp	Relative Zinc	Relative pH	Relative Nutrients
Coastal Plain	Bachelor	2.63	6.09	5.56	7.49	11.91	0.28	8.77	4	6.8	12.37
	Battle Park	17.32	8.1	8.29	10.64	7.34	4.3	8.77	22.16	11.22	39.86
	Boddie Noell	16.89	6.86	7.08	9.13	32.44	28.64	8.23	22.42	9.44	36.12
	Cox	10.08	5.98	11.34	17.08	1.76	4.92	9.2	5.92	8.69	28.76
	East Fayetteville North	4.09	4.69	3.69	4.46	4.42	14.77	9.85	3.77	8.71	14.43
	East Fayetteville South	12.5	4.02	28.72	12.55	11.06	19.69	9.7	8.05	8.23	46.5
	Hog Farm Lower	6.71	8.47	3.67	4.88	1.44	1.62	9.87	9.7	8.28	28.59
	Hog Farm Upper	3.99	31.27	3.87	2.47	6.57	2.06	9.71	3.79	10.79	104.54
	Nahunta	9.69	11.06	7.84	7.17	10.92	3.76	8.66	5.44	9.97	39.13
	PCS	9.29	6.7	15.99	15.84	2.89	2.51	9.15	11.05	7.37	32.96
	Rough Rider	6.82	6.75	3.96	8.29	9.24	17.45	8.09	3.7	10.49	16.74
Piedmont	Black Ankle Non-Powerline	13.79	6.91	6.91	4.99	2.1	1.15	8.07	7.4	8	48.3
	Black Ankle Powerline	10.75	19.23	19.23	18.66	35.19	7.86	7.98	9.04	8.13	41.97
	Duke Forest	5.15	8.28	8.28	6.08	2.28	3.21	7.67	3.74	9.67	24.41
	East of Mason	9.88	11.19	11.19	9.73	14.66	7.48	7.75	18.09	7.69	45.08
	Fire Tower	4.66	7.84	7.84	6.64	3.38	2.22	7.98	4.6	7.67	55.36
	Kelly Rd	6.79	6.14	6.14	3	4.23	6.2	7.2	9.18	7.54	24.49
	Moonshine	5.53	10.27	10.27	10.43	2.15	1.55	9.84	5.31	8.15	29.8
	Pete Harris	26.59	10.56	10.56	11.53	13.19	66.46	7.63	6.45	8.04	51.16
	Spring Garden	4	2.8	2.8	10.87	9.85	0.51	7.68	6.66	9.05	14.26
	Troxler	5.15	3.42	3.42	4.01	5.31	.	9.1	20.26	9	16.02
	Umstead	5.88	9.64	9.64	12.01	6.38	3.16	9.97	5.43	9.1	33.77
	Walmart	1.83	3.7	3.7	2.05	1.26	0.2	9.14	3.86	7.97	15.38

Table C.3.3 Water Quality Disturbance Measurement Table - Relative Average Surface Water Quality Values by Region

Region	Site Name	Relative Metals	Relative Cu Pb Zn	Relative Nutrients Metals FC TSS Condo	Relative Nutrients Cu Pb Zn FC TSS Condo
Coastal Plain	Bachelor	18.08	13.86	48.5	44.28
	Battle Park	80.58	61.06	141.34	121.82
	Boddie Noell	65.95	45.79	144.6	124.44
	Cox	32.5	20.73	87.13	75.35
	East Fayetteville North	19.34	13.12	59.05	52.83
	East Fayetteville South	54.63	42.27	140.49	128.13
	Hog Farm Lower	40.18	20.55	86.56	66.93
	Hog Farm Upper	68.2	12.92	219.51	164.23
	Nahunta	54.13	15.87	120.13	81.87
	PCS	44.22	39.17	97.06	92.01
	Rough Rider	22.18	14.67	55.64	48.12
Piedmont	Black Ankle Non-Powerline	33.33	27.07	99.46	93.2
	Black Ankle Powerline	44.17	36.8	140.76	133.39
	Duke Forest	48.18	16.05	83.88	51.75
	East of Mason	85.32	56.03	161.91	132.63
	Fire Tower	24.42	16.14	99.58	91.3
	Kelly Rd	33.81	20.78	70.04	57.01
	Moonshine	28.95	16.55	75.42	63.02
	Pete Harris	37.42	23.73	174.86	161.17
	Spring Garden	36.98	18.35	65.31	46.68
	Troxler	54.1	32.64	79.75	58.29
	Umstead	50.18	22.82	104.17	76.81
	Walmart	23.14	13.04	44.86	34.75

Appendix D

Hydrology Standard Operation Procedure

In-Situ Non-Vented Level Troll Standard Operating Procedure for Downloading Field Data and Maintaining "In-situ Monitoring Well Database".

Equipment and Forms:

Computer backpack
Ultra light Dell Lap Top (**Set computer up for field - user, Wetlands, epapc**).
Spare Desicap desicant caps with dry desicant
Troll Com Adapter attached to Serial to USB adapter
Keys for wells locks
Re-bar
Bent piece of pin flagging/or bent wire (to pull In-situ instrument out of well if necessary)
Leather man
Well measuring tape in 10th of feet
Blue chalk
Small towel / wash cloth
Clipboard
Calculator
Pencil
Level
WD-40
2 sets of pliers
Tray
Replacement Dessicant
Umbrella
Headwater Wetlands Monitoring Project Well Depth Measurements taken by Hand Field Sheet
In-situ Vented Level Troll Set-up Sheet
In-situ Vented Troll Well Monitoring Field Sheet

In-situ Non-Vented Level Troll Standard Operating Procedure for Downloading Field Data

Definitions:

Headwater Wetlands Monitoring Project Well Depth Measurements taken by Hand – Field sheet used to record all monitoring well water level measurements that are taken by hand with a 10th foot measuring tape and recorded in **DTW**.

In-situ Vented Level Troll Set-up Sheet – Field sheet used to record information specific to the set up and installation of each sites In-situ Vented Level Troll 500 Transducer. The value for **Depth of Probe Sensor in Well** is obtained from this sheet.

In-situ Vented Troll Well Monitoring Field Sheet – The field sheet used to record field measurements taken by hand that are used to calculate the accuracy of the of the measurements recorded electronically by the In-situ Vented Level Troll Transducers. Measurements for **DTW Measure by hand**, **Depth of Probe Sensor in Well**, **In-Situ Electronic Depth Reading**, and **Accuracy** are recorded on this field sheet.

In-situ Monitoring Well Database- Database created in Excel that is used to store all data sets recorded on temperature, pressure and depth by the In-situ Level Trolls and all data recorded on the *In-situ Vented Troll Well Monitoring Field Sheet.*

DTW – stands for "Distance to Water" or the distance from the top of the well casing to water. Determined by chalking the tape, dropping it into the water a recorded amount and subtracting how wet the tape is from that recorded amount.

DTW Measure by hand – DTW taken by hand in field as described above.

Depth of Probe Sensor in Well – Distance the Probe sensor is from the top of the well casing. Determined during the In-situ vented troll set up procedure and listed on the "*In-situ Vented Level Troll Set-up Sheet"* (highlighted in yellow).

Depth Measure by Hand – This is a measurement of how deep under water the In-situ Level Troll sensor is located and is determined in the field by hand with known values. **Depth Measure by Hand** = **Depth of Probe Sensor in Well** – **DTW Measure by hand**

In-Situ Electronic Depth Reading - This is a measurement of how deep under water the In-situ Level Troll sensor is located and determined electronically by the In-situ Level Troll transducer.

Accuracy – Accuracy is a measurement of how accurate the In-situ Level Troll 500 depth readings are. This measurement is determined by subtracting the measurement for depth recorded by the Level troll (**In-situ Electronic Depth Reading**) from the actual (and <u>hopefully</u> correct) field measurement for depth (**Depth Measure by Hand**) [**Accuracy** = **Depth Measurement by Hand** – **In-situ Electronic Depth Reading**]. Note **Accuracy** readings should not be > +/- 0.05'.

Field Procedure

1. Unlock well cap and chalk measuring tape (10^{th} of feet measurement). **Do not move or attempt to pull out the In-situ rugged-cable connector as this will change the water level.**

2. Measure **DTW** with chalked tape. Take measurement at least twice and more times if necessary, as the chalk may come off the tape. If there is > 0.01' difference between the 2 measurements it is necessary to take another measurement. Be sure to take measurement at appropriate location marked with permanent marker on the top of the monitoring well casing.

3. Record **DTW** and other labeled information (site, county, date etc) on "*Headwater Wetlands Monitoring Project Well Depth Measurements taken by Hand*" field sheet. Note, the well height should be similar to what is listed on the "*In-situ Vented Level Troll Set-up*" sheet. This **DTW** value is also the **DTW Measure by hand** value to be used on the "*In-situ Vented Troll Well Monitoring Field Sheet*".

4. Record site, county, date, and the **DTW Measure by hand** under the appropriate column headings on the "*In-situ Vented Troll Well Monitoring Field Sheet*".

5. Continue filling out field information on the "*In-situ Vented Troll Monitoring Field Sheet*" by using the "*In-situ Level Troll Set-up*" sheet to look up the **Depth of Probe Sensor in Well** measurement for the site in question (these values are highlighted in yellow) and record under the appropriate column heading on the "*In-situ Vented Troll Well Monitoring Field Sheet*".

6. On the "*In-situ Vented Troll Monitoring Field Sheet"*, calculate the **Depth Measure by Hand** measurement and record under the appropriate column heading. **Depth of Measure by Hand** = **Depth of Sensor** – **DTW Measure by Hand**.

7. Remove the Desicap desicant cap from the rugged–cable connector and attach the Troll Com Adapter Cable. **Do not pull In-situ rugged-cable connector any farther out of monitoring well than is necessary to attach Troll Com Adapter.** It is difficult to get the rugged cable back into the monitoring well casing.

8. Attach the Serial to USB adapter (which is already connected to the Troll Com Adapter) to the lower serial port on the ultra-light Dell laptop computer. **Be sure the Troll Com Adapter and Serial to USB adapter are not lying in mud or water** (put on top of backpack).

9. Open the laptop PC and it will turn on by itself (it will be in hibernate mode avoiding having to log on). Then double click the Win-Situ icon to start the program. Be sure laptop is set up for field (i.e. logged on to user, Wetlands, EPAPC).

10. Once the program is up, click the "connect button" in the lower right of the Win-Situ window. When the connection to the Transducer is successful, the "command screen" will display giving the current reading by the Transducer: Pressure, Depth, and Temperature.

11. At this point, check to see that the PC time and the Transducer time are in sync. Look at the upper right of the Win-Situ window and if they are not, the times will be displayed in red. Click on the synchronize button and the times will sync and will no longer be red. Take note of the time difference between the computer clock and transducer clock that are >1 hour as this will be recorded later.

12. Now click on the Data Log tab, in the upper left of the Win-Situ window. At least one file should be displayed with a status of Active or Running. The file name will be the "Site Name log data yyyy-mm-dd" (**e.g. PCS log data 2006-04-12).**

13. Right mouse click on the active/running file and from the displayed menu, select **STOP logging** (or you can click the stop logging button if the file is selected). A message will appear asking to you to confirm the stop logging action, click check mark. Status should now say stopped.

14. Right mouse click on the active file, and from the displayed menu, select **Download Data**. A message appears asking to download all the data, click YES (or you can click the download button if the file is selected).

15. The Win-Situ program will download the date from the transducer. When it is complete, it will ask if you want to view the data, click YES.

16. The Win-Situ program will show the data window, be sure the window is opened in "Log Data" folder. Before viewing the data, select the file menu at the upper left of the Win-Situ window and select "**Export to Text**". This last step backs up the current data and puts it in a form that allows it to later be imported into Excel.

17. Scroll to the end of the downloaded file and review the last couple of readings for depth (taken within previous 2 hours). Be sure to scroll all the way to the right to view depth readings. The last couple readings for depth should be similar to the **Depth Measure by Hand** (within +/- 0.05'). The most recent measurement for depth (the last measurement listed in the file) recorded by the vented troll transducer in the last half hour is the **In-Situ Electronic Depth Reading**. **Verify that the last couple depth readings are similar**, if the last depth reading is a few inches lower than the previous reading than use the previous reading as the **In-Situ Electronic Depth Reading** (if the last reading is a few inches lower than the previous reading this is due to lifting of the probe when attaching the Troll Com Adapter).

18. Copy the **In-Situ Electronic Depth Reading** onto the "*In-situ Vented Troll Well Monitoring Field Sheet*" under the appropriate column.

19. Calculate **Accuracy** and record under the appropriate column on the "*In-situ Vented Troll Well Monitoring Field Sheet*". (**Accuracy** = **Depth Measure by Hand** – **In-Situ Electronic Depth Reading**).

20. Under comments, on the "*In-situ Vented Troll Well Monitoring Field Sheet*", record the name of the Win-situ file that was just downloaded. The name of the Win-situ file should be site name data log date created(yyyy-mm-dd) date downloaded(yyyy-mm-dd), time downloaded**.** For example, a file created on June 12, 2006 at PCS and downloaded on July 13, 2006 would be named PCS

Data Log 2006-06-12 2006-07-13 (don't include the time when copying the file name). Also, record in comments any > 1 hour time discrepancies between the In-situ vented troll clock and the computer clock (note - the computer clock should be set correctly but might not be, check this).

21. Select the Data Logging tab in the upper left of the Win-Situ program. If two files are displayed, delete the oldest file by right mouse clicking on the file and choosing "Delete" from the menu. Select YES to the confirmation message.

22. Select the "new log" button in the lower left of the Win-Situ window. A dialog box will appear. First, make sure the correct location is selected which is the site you are currently at.

23. Name the new file: "site name log data yyyy-mm-dd" (e.g. PCS log data 2006-04-12), use day the file is created for date.

24. Select the next buttons until you can specify the sampling interval; make sure it is set to 30 minutes.

25. Select the next buttons until you can specify the start/stop conditions. Select "Scheduled" start. Set start the time with at least a ***10*** minute delay to the next hour or half hour. Therefore if it is 9:45 am, set the time to 10:00 am, however if it is 9:5***3*** am set the time to 10:30 am so there is enough time to disconnect and put the rugged cable back in the appropriate place in the well before a depth reading is taken by the transducer. On the same menu as the Start and Stop conditions specify that the data should be "Wrapped".

26. Select the next buttons until you can specify the measurement mode. Make sure the "Depth of Probe" is selected.

27. The last screen is a summary of the selection you have made or were defaulted. Make sure that "fresh water" is one of the selected options. Check the entire screen and make sure all the selections are correct. If not, use the back button to go to the screen and make the needed corrections.

28. Click finish on that screen and then make sure you are at the data-logging window (otherwise select the data logging tab in the upper left of the Win-Situ window). The newly created file status should read "pending", make sure the scheduled start time (including am versus pm) is correct.

29. Select the Home Tab at the upper left of the Win-Situ window. The current reading of the Transducer should be displayed. Push cable connector and Troll Com back down into well. The current reading for depth should be the same as the **In-situ Electronic Depth Reading** just recorded.

30. Disconnect the Win-situ program from Troll Com Adapter by pressing the connect/disconnect button in the lower right of the Win-Situ window; close Win-situ.

31. Remove Troll Com Adapter and Serial to USB adapter from serial port and turn off computer.

32. Pull the cable connector and Troll Com adapter just far enough out of the well to be able to disconnect Troll Com Adapter and Serial to USB adapter from rugged cable connector.

33. Replace the Desicap desicant cap if desicant crystals are pink/purple with new Desicap desicant cap with dry blue crystals (this will probably be necessary every few months).

34. Use the re-bar to push rugged-cable coils, cable connecter and Desicap cap down, and rugged cable hanging apparatus down into the well casing. Be sure the rugged cable hanging apparatus is flush against the monitoring well wire cross hairs and don't let the rugged-cable connector and desicant cap slide below the monitoring well wire x-hairs (if this happens, use the bent piece of wire to pull it above the x-hairs). The following months **In-situ Electronic Depth Readings** will be inaccurate if the In-situ transducer is not hanging at the same depth it was prior to downloading the In-situ data.

File Management Procedure to be completed at the office

Back in Office

1. Sign on the laptop as "user", "Wetlands", and "epapc".

2. Start Excel and from the file menu, select "Open". Make sure "all file types" is selected in the dialog box. Navigate to the location of the exported text file: "C:\documents and settings\user\my documents\win-situ data\exported data".

3. There will be folders with the sites names and the exported monthly text data will be in each corresponding site's folder. Select the site folder (e.g. Pete Harris) that contains the exported text data for transferring. Refer to *the In-situ Vented Troll Well Monitoring Field Sheet* for the correct file name of the exported text file and open it into Excel. Be sure the file chosen has the correct start and stop dates (site name log data start date end date).

4. Excel will prompt the user to properly format the data. First, make sure the "fixed width" is selected. Select "next" and Excel now prompts you to specify the columns.

5. Scroll down until you get to the data columns. Use the mouse to specify the location of the columns by left clicking or dragging existing column break arrow, one after the date, time, elapsed time seconds, pressure, temperature, and depth, resulting in 6 columns. If a column is in the wrong place, it will need to be moved and further clicks will just add more columns. Move the column by selecting with the mouse and hold the right button down and drag the column to the correct place. Select the "next" button and lastly select the "finish" button.

6. The time stamp column now needs formatting. Scroll to the top of the file and select the second column (column B) with the mouse, then right mouse click. Select "format cells", and when the dialog box appears, make sure the "number" tab is selected and then select "time" in the list box. In the type list box, select the 24-hour format example (i.e. 13:30:55). Then click the ok button. This will change the appearance of the data in the time column.

7. From the Excel file menu, select "save as". When the dialog box come up, first navigate to the desktop and the folder named "In-situ Monthly data transfer folder". Make sure the file type selected is: "excel workbook" and save. Close file.

8. Repeat steps 2-7 until all the monthly In-situ data files that need transferring and formatting are saved into the "In-situ Monthly data transfer folder". All files should be in Excel.

9. Close Excel and logoff the laptop.

10. Hook the laptop to an Ethernet cable and log on to the network by selecting with your personal username (first_last), password, and DWQ.

11. Navigate to \EPA Wetlands Monitoring Rick & Ginny\Field Data Grant 1\Monthly Vented Level Troll Data. Create a new folder and name it with the month(s) and year the In-situ data was downloaded.

12. Move all monthly excel files from the "In-situ Monthly data transfer folder" on the desktop of the laptop to the newly created folder on the shared drive. The "In-situ monthly data transfer folder" should now be empty.

Moving Monthly In-situ data Excel File information to the In-situ Monitoring Well Database

1. Open the new monthly folder created under S:\ EPA Wetlands Monitoring Rick & Ginny\Field Data Grant 1\Hydrology\Monthly Vented Level Troll Data. Choose a site and open the appropriate monthly In-situ data excel file for that site.

2. Delete the column and associated data under "Se Elapsed Time Seconds". There should now only be 5 columns of data in the following order: date, time, pressure, temperature, and depth. Copy all data under "date", "time", "temperature", "pressure", and "depth" data field headings (do not copy the field column headings themselves). There may be some data not taken during the sampling month (i.e. data taken from March to April or March to August that has already been transferred to the <u>In-situ Monitoring Well Database</u>). Delete this data before transferring the monthly in-situ data to the <u>In-situ Monitoring Well Database</u>.

3. Open the <u>In-situ Monitoring Well Database</u> Excel file under S:\ EPA Wetlands Monitoring Rick & Ginny\Field Data Grant 1\Hydrology. Paste the monthly site data under the appropriate field headings for "date", "time", "pressure", "temperature", and "depth" starting with the first empty row in the database.

4. Enter the "Site Name" and "County" under the appropriate field headings in the first empty row, which should be the same row the first set of data for "date", "time", "pressure", "temperature", and "depth" was just pasted into. Use the same spelling for "Site Name" and "County" (put county in capital) listed at the upper most rows of the database and in Table 1 shown below. Copy "Site Name" and "County" and paste in **all appropriate rows** for that site's data set. Delete the last row of In-situ data if the depth 0.1' or lower than the previous few depth readings. This indicates the last depth reading was taken after the probe was pulled out of the well to download data.

5. Go to the last record for that data set that was just copied into the "<u>In-situ Monitoring Well Database</u>". Use data recorded on the "*In-situ Vented Level Troll Well Monitoring Field Sheet*" to complete **last row only** of that data set. In that last row of data, enter the **Depth of Probe Sensor in Well**, **DTW Measure by Hand**, **Depth Measure by Hand**, and **Accuracy** measurements for that specific site and time frame as recorded on "*In-situ Vented Level Troll Well Monitoring Field Sheet*". Be sure the correct data from the "*In-situ Vented Level Troll Well Monitoring Field Sheet*" is being entered into the database. The **site name**, **county**, and especially **date** and **In-situ Electronic Depth Reading** listed on the field sheet should be **exactly the same** as that listed in the database. Again, **only** that last row of data in the database should contain a record for **Depth of Probe Sensor in Well**, **DTW Measure by Hand**, **Depth Measure by Hand**, and **Accuracy.** Do not copy and paste into all other rows for that sites data.

6. Under comments in the <u>In-situ Monitoring Well Database</u>, enter the name of the monthly In-situ data excel file the data was just copied from. The name of the file entered into comments should be exactly the same as the file name listed on the "*In-situ Vented Level Troll Well Monitoring Field Sheet*". Also, under comments, in the database, record any time discrepancies between the In-situ vented troll clock and computer clock that were recorded on the "*In-situ Vented Level Troll Well Monitoring Field Sheet*" or any other information specific the data set for that site. It is also possible to make a direct correction to the time copied into the database. Lastly, copy the information entered into comments and paste in all appropriate rows for that data set.

7. Save “In-situ Monitoring Well data base”.

8. Go back to the monthly In-situ data Excel file under S:\ EPA Wetlands Monitoring Rick & Ginny\Field Data Grant 1\Hydrology\Monthly Vented Level Troll and close, **do not save changes**.

9. Once the monthly In-situ Excel file is closed **re-name it immediately**. Put a DL (for Download) followed by today’s date in front of the existing file name (e.g. A file named “PCS data log 2006-04-12 2006-05-30” would be changed to “DL yyyy-mm-dd PCS data log 2006-05-30”). This last data management step is very important as it enables at a quick glance to determine if the data from that monthly In-situ Excel file has been copied into the In-situ Monitoring Well Database.

Table 1. In-situ Monitoring Well Database “Site” and “County” nomenclature

Site	County
Black Ankle Non-Powerline	MONTGOMERY
Cox	COLUMBUS
Boddie Noell	NASH
Fire Tower	MOORE
Hog Farm Upper	SAMPSON
Kelly Rd	WAKE
Nahunta	WAYNE
PCS	BEAUFORT
Rough Rider	GATES
Spring Garden	ROCKINGHAM
Troxler	ALAMANCE
Walmart	MOORE

Table 1. <u>In-situ Monitoring Well Database</u> "Site" and "County" nomenclature (Grant 2)

Site Name	Abbrev	Wetland Type
Fairport	Frp	BLH
Gray	Gra	BLH
Hancock	Han	BLH
Kim-Brooks	KBr	BLH
Munn	Mun	BLH
Powers	Pow	BLH
Belton Creek	Blt	Sm Basin
Dargan	Dar	Sm Basin
Dean	Dea	Sm Basin
Eastwood	Eas	Sm Basin
Goldston	Gld	Sm Basin
Hart	Hrt	Sm Basin
Doe Creek	Doe	RSwF
Hewett Wildlife	Hew	RSwF
Lockwood	Lck	RSwF
Mercer Seawatch	Msea	RSwF
Rourk	Rrk	RSwF
Winding River Pond	WRP	RSwF
Winding River Townhouse	WRT	RSwF
Bluegreen Golf	Blu	Sm Basin
Martin-Amment	Mar	Sm Basin
Mill Creek	Mil	Sm Basin
Seawatch Bay	Sbay	Sm Basin
Seawatch Nautica	SNau	Sm Basin
Sikka	Sik	Sm Basin

Appendix E

Macroinvertebrate Identification QAQC and Analysis Results

Rhinthron Associates Inc.

Technical Approach
Sample Processing Procedures

Rhithron has a standard set of sample processing procedures for bioassessment studies. Samples are generally cycled through four steps: receiving, processing, taxonomic determinations, and data management.

Our internal Quality Systems procedures are designed to intensively evaluate and improve the performance of our team and the efficiency of standard laboratory procedures. These begin as soon as the samples are received and continue through all processing, analysis and reporting. Additionally, we can adopt project-specific Quality Systems procedures to meet each client's requirements. Our laboratory is adaptable and accustomed to conforming to several Quality Systems programs simultaneously.

Sample Handling and Management

Upon arrival at the laboratory, Rhithron staff evaluate the condition of the samples, check them for leakage and breakage, and "top them off" with preservative, if necessary. An internal inventory is compiled and compared with the sample submittal form and any discrepancies are reported to the client immediately. Rhithron assures adequate protection of samples for which we have accepted custody at all times.

Processing of Samples

At the time of sample inventory, the laboratory procedures that are to be used for each sample are confirmed and noted. Notations are made for sub-sampling ranges and procedures for varying sample types, taxonomic resolution required, and reporting options. We also note specific Quality Systems checks, in addition to Rhithron's standard QA systems, requested by the client. Technical and taxonomy supervisors ensure that project protocols are followed by all staff from beginning to end of a project.

Rhithron's technicians employ Caton subsampling devices, divided into 30 grids, each approximately 5 cm by 6 cm, for all sample handling. To obtain subsamples of a specified minimum of organisms (100, 300, 500, or >500), samples are poured out into the device, grids are randomly chosen, and substrate materials lifted out and picked until the specified number of organisms is collected. National and Meiji stereoscopes with 10x-30x magnification are used for all sample sorting. For the sake of project integrity, sample remnants, including sorted substrate and unsorted remainders, are retained and stored until completion of the project or as specified by the client. Identified organisms are archived for a minimum of one year following completion of a project.

Sorting efficiency quality systems (QA)

Sorting efficiency checks require an independent observer to re-examine some portion of the sorted detritus and to count the number of organisms that may have been missed in the first sorting of a sample. Rhithron's standard Quality System for evaluating the level of sorting efficiency is unique, since it requires a check of 100% of the samples from most projects.

This procedure guarantees quality sorting and provides feedback to the technical staff. Our standard sorting efficiency checks do not preclude the use of program-specific quality assurance procedures. In fact, when combined with other procedures, we are able to provide a uniquely high standard of data quality because our efficiency may be evaluated in several ways. We can implement any level of validation in addition to our routine evaluation to provide a very rigorous assurance of data quality. If desired, Rhithron will report sample sorting efficiency for each sample, for each project, or both.

Taxonomy

Taxonomic Resolution and Validation

Rhithron's taxonomists can provide determinations of invertebrate groups to the resolution levels specified in Table 1 below.

Table 1. Levels of taxonomic resolution for various aquatic invertebrate groups provided by Rhithron's biologists.

Group	Taxonomic resolution
Ephemeroptera	Species
Odonata	Genus / Species
Megaloptera	Genus / Species
Plecoptera	Genus / Species
Hemiptera	Genus
Neuroptera	Genus
Heteroptera	Genus
Trichoptera	Genus / Species
Lepidoptera	Genus
Coleoptera	Genus / Species
Diptera	Genus
Chironomidae	Genus/ Species Group/ Species
Amphipoda	Genus
Isopoda	Genus
Porifera	Genus/ Species
Nematoda	Phylum
Bryozoa	Genus/ Species
Mollusca	Genus/ Species
Hirudinea	Genus
Amphipoda	Genus
Decapoda	Genus / Species
Pelecypoda	Family / Genus
Gastropoda	Genus
Tricladida	Family / Genus
Hirudinea	Genus / Species
Nemata	Order
Nematomorpha	Order
Nemertea	Genus
Oligochaeta	Genus / Species
Hydrachnidia	Genus

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Chironomidae	Genus/ Species Group/ Species
Amphipoda	Genus
Isopoda	Genus
Porifera	Genus/ Species
Nematoda	Phylum
Bryozoa	Genus/ Species
Mollusca	Genus/ Species
Hirudinea	Genus
Amphipoda	Genus
Decapoda	Genus / Species
Pelecypoda	Family / Genus
Gastropoda	Genus
Tricladida	Family / Genus
Hirudinea	Genus / Species
Nemata	Order
Nematomorpha	Order
Nemertea	Genus
Oligochaeta	Genus / Species
Hydrachnidia	Genus

Internal Taxonomic Quality Assurance

Rhithron's standard operating procedure for taxonomic quality assurance requires that 10% of the samples in a project are subject to identification by a second taxonomist. All discrepancies are addressed; if consensus on a particular determination cannot be reached, external verification is sought. In addition, the results of both series of identifications are analyzed for appropriate levels of taxonomic determination

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Sorting efficiency checks require an independent observer to re-examine some portion of the sorted detritus and to count the number of organisms that may have been missed in the first sorting of a sample. Rhithron's standard Quality System for evaluating the level of sorting efficiency is unique, since it requires a check of 100% of the samples from most projects.

Table E

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Coastal Plain Signifcant Correlations						
ALL CP	% Colepotera	Soils(Cu, wet)	-0.6878	0.0279	.	.
ALL CP	% Colepotera	Soils(Zn, wet)	-0.8317	0.0029	.	.
ALL CP	% Colepotera	a ORAM (no outliers)	0.6378	0.0472	.	.
ALL CP	% Colepotera	a ORAM (w/ outliers)	0.6503	0.0418	.	.
ALL CP	% Crustraceae	RelMetals	-0.5515	0.0984	.	.
ALL CP	% Crustraceae	RelNutrientsCuPbZnFCTSSCondo	-0.5879	0.0739	.	.
ALL CP	% Crustraceae	RelNutrientsMetalsFCTSSCondo	-0.6364	0.0479	.	.
ALL CP	% Crustraceae	Soils(Zn, wet)	-0.5152	0.1276	.	.
ALL CP	% Dominance of Top 3 Taxa	50 M LDI	0.6364	0.0479	.	.
ALL CP	% Dominance of Top 3 Taxa	Rel Lead	0.5461	0.1025	.	.
ALL CP	% Dominance of Top 3 Taxa	RelCuPbZn	0.5515	0.0984	.	.
ALL CP	% Dominance of Top 3 Taxa	RelTSS	0.6242	0.0537	.	.
ALL CP	% Dominance of Top 3 Taxa	a Soils(H O pH)	-0.6121	0.06	.	.
ALL CP	% Predator	Rel Lead	-0.6688	0.0345	.	.
ALL CP	% Predator	RelDOC	-0.5758	0.0816	.	.
ALL CP	% Predator	RelTKN	-0.6727	0.033	.	.
ALL CP	% Predator	RelTOC	-0.5879	0.0739	.	.
ALL CP	% Predator	a RelpH	0.5879	0.0739	.	.
ALL CP	% Predator	a Soils(H O pH)	0.5152	0.1276	.	.
ALL CP	% Predator	a Soils(H O pH, wet)	0.6848	0.0289	.	.
ALL CP	% Tolerant	a RelpH	-0.5394	0.1076	.	.
ALL CP	% Tolerant	a Soils(H O pH, stream)	-0.5152	0.1276	.	.
ALL CP	%Chronomidae	RelFecal Coliform	0.6727	0.033	.	.
ALL CP	%Chronomidae	RelNutrients	0.5394	0.1076	.	.
ALL CP	%Chronomidae	RelNutrientsCuPbZnFCTSSCondo	0.5394	0.1076	.	.
ALL CP	%Chronomidae	Soils(Zn, stream)	0.5758	0.0816	.	.
ALL CP	%Chronomidae	Soils(Zn, wet)	0.5152	0.1276	.	.
ALL CP	%Coleoptera	RelMetals	-0.6065	0.063	.	.
ALL CP	%Coleoptera	RelNutrientsCuPbZnFCTSSCondo	-0.6503	0.0418	.	.
ALL CP	%Coleoptera	RelNutrientsMetalsFCTSSCondo	-0.6003	0.0665	.	.
ALL CP	%Coleoptera	RelZinc	-0.6941	0.026	.	.
ALL CP	%Decapoda	RelNutrientsCuPbZnFCTSSCondo	-0.5152	0.1276	.	.
ALL CP	%Decapoda	RelNutrientsMetalsFCTSSCondo	-0.6	0.0667	.	.
ALL CP	%Decapoda	RelPhosphorous	-0.6242	0.0537	.	.
ALL CP	%Diptera	RelMetals	0.6485	0.0425	.	.
ALL CP	%Diptera	RelNutrients	0.5394	0.1076	.	.
ALL CP	%Diptera	RelNutrientsCuPbZnFCTSSCondo	0.7333	0.0158	.	.
ALL CP	%Diptera	RelNutrientsMetalsFCTSSCondo	0.7333	0.0158	.	.
ALL CP	%Diptera	Soils(Zn, wet)	0.6485	0.0425	.	.
ALL CP	%Diptera	a ORAM (no outliers)	-0.5273	0.1173	.	.
ALL CP	%Diptera	a ORAM (w/ outliers)	-0.5879	0.0739	.	.
ALL CP	%Dytiscidae	RelWater Temp	-0.6142	0.0589	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
	%Dytiscidae	Soils(Cu, stream)	-0.7306	0.0164	.	.
ALL CP	%Dytiscidae	Soils(Cu, wet)	-0.8857	0.0006	.	.
ALL CP	%Dytiscidae	Soils(Zn, wet)	-0.7435	0.0137	.	.
ALL CP	%EOT	Rel Lead	-0.7003	0.0241	.	.
ALL CP	%EOT	RelCopper	-0.8081	0.0047	.	.
ALL CP	%EOT	RelCuPbZn	-0.7176	0.0195	.	.
ALL CP	%EOT	RelPhosphorous	-0.6142	0.0589	.	.
ALL CP	%EOT	RelTOC	-0.7952	0.006	.	.
ALL CP	%EOT	RelTurbidity	-0.5883	0.0736	.	.
ALL CP	%EPT	RelCopper	-0.493	0.1476	.	.
ALL CP	%EPT	RelTOC	-0.493	0.1476	.	.
ALL CP	%EPT	a RelpH	0.5882	0.0737	.	.
ALL CP	%EPT	a Soils(H O pH)	0.6833	0.0294	.	.
ALL CP	%EPT	a Soils(H O pH, stream)	0.5882	0.0737	.	.
ALL CP	%EPT	a Soils(H O pH, wet)	0.5882	0.0737	.	.
ALL CP	%Microcrustaceae	Soils(Cu, wet)	-0.4985	0.1425	.	.
ALL CP	%Microcrustaceae	Soils(Zn, wet)	-0.541	0.1063	.	.
ALL CP	%Mollusk	a RelDissolved Oxygen (mg/L)	0.519	0.1242	.	.
ALL CP	%Mollusk	a Soils(H O pH)	0.6628	0.0367	.	.
ALL CP	%Mollusk	a Soils(H O pH, stream)	0.519	0.1242	.	.
ALL CP	%Oligochaets	Soils(Zn, stream)	0.5289	0.116	.	.
ALL CP	%Orthocladiinae	RelCalcium	0.5957	0.0692	.	.
ALL CP	%Orthocladiinae	RelFecal Coliform	0.5775	0.0804	.	.
ALL CP	%Orthocladiinae	RelMagnesium	0.5471	0.1017	.	.
ALL CP	%Orthocladiinae	RelMetals	0.4924	0.1482	.	.
ALL CP	%Orthocladiinae	RelNutrients	0.6383	0.047	.	.
ALL CP	%Orthocladiinae	RelNutrientsCuPbZnFCTSSCondo	0.5471	0.1017	.	.
ALL CP	%Orthocladiinae	RelNutrientsMetalsFCTSSCondo	0.5046	0.1369	.	.
ALL CP	%Orthocladiinae	RelWater Temp	0.614	0.059	.	.
ALL CP	%Orthocladiinae	Soils(Zn, stream)	0.6505	0.0417	.	.
ALL CP	%Orthocladiinae	Watershed LDI	0.4924	0.1482	.	.
ALL CP	%POET	Rel Lead	-0.7003	0.0241	.	.
ALL CP	%POET	RelCopper	-0.8081	0.0047	.	.
ALL CP	%POET	RelCuPbZn	-0.7176	0.0195	.	.
ALL CP	%POET	RelPhosphorous	-0.6142	0.0589	.	.
ALL CP	%POET	RelTOC	-0.7952	0.006	.	.
ALL CP	%POET	RelTurbidity	-0.5883	0.0736	.	.
ALL CP	%Terrestrial	RelMagnesium	-0.5758	0.0816	.	.
ALL CP	%Terrestrial	RelNutrients	-0.4909	0.1497	.	.
ALL CP	%Terrestrial	a RelDissolved Oxygen (%)	-0.5273	0.1173	.	.
ALL CP	%Terrestrial	a RelDissolved Oxygen (mg/L)	-0.5394	0.1076	.	.
ALL CP	%Tricoptera	RelCopper	-0.493	0.1476	.	.
ALL CP	%Tricoptera	RelTOC	-0.493	0.1476	.	.
ALL CP	%Tricoptera	a RelpH	0.5882	0.0737	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
ALL CP	%Tricoptera	a Soils(H O pH)	0.6833	0.0294	.	.
ALL CP	%Tricoptera	a Soils(H O pH, stream)	0.5882	0.0737	.	.
ALL CP	%Tricoptera	a Soils(H O pH, wet)	0.5882	0.0737	.	.
ALL CP	%Trombidiformes	RelWater Temp	-0.5294	0.1155	.	.
ALL CP	Biotic Index	RelNO2+NO3	0.503	0.1383	.	.
ALL CP	Chironomidae Richness	RelTSS	-0.535	0.1111	.	.
ALL CP	EPT Richness	RelCopper	-0.5222	0.1215	.	.
ALL CP	EPT Richness	RelTOC	-0.5222	0.1215	.	.
ALL CP	EPT Richness	a RelpH	0.6093	0.0615	.	.
ALL CP	EPT Richness	a Soils(H O pH)	0.6963	0.0253	.	.
ALL CP	EPT Richness	a Soils(H O pH, stream)	0.6093	0.0615	.	.
ALL CP	EPT Richness	a Soils(H O pH, wet)	0.6093	0.0615	.	.
ALL CP	Evenness	50 M LDI	-0.6606	0.0376	.	.
ALL CP	Evenness	RelTSS	-0.6121	0.06	.	.
ALL CP	Family Richness	Rel Lead	-0.7385	0.0147	.	.
ALL CP	Family Richness	RelCopper	-0.6201	0.0558	.	.
ALL CP	Family Richness	RelCuPbZn	-0.5714	0.0844	.	.
ALL CP	Family Richness	RelTOC	-0.5228	0.121	.	.
ALL CP	Family Richness	a Soils(H O pH)	0.5532	0.0972	.	.
ALL CP	Genera Richness	Rel Lead	-0.6074	0.0625	.	.
ALL CP	Genera Richness	a RelDissolved Oxygen (mg/L)	0.5152	0.1276	.	.
ALL CP	Genera Richness	a Soils(H O pH)	0.7818	0.0075	.	.
ALL CP	Genera Richness	a Soils(H O pH, stream)	0.6121	0.06	.	.
ALL CP	Genera Richness	a Soils(H O pH, wet)	0.5758	0.0816	.	.
ALL CP	OET Richness	Rel Lead	-0.7633	0.0102	.	.
ALL CP	OET Richness	RelCopper	-0.7802	0.0078	.	.
ALL CP	OET Richness	RelCuPbZn	-0.6884	0.0277	.	.
ALL CP	OET Richness	RelPhosphorous	-0.5835	0.0766	.	.
ALL CP	OET Richness	RelTKN	-0.5048	0.1367	.	.
ALL CP	OET Richness	RelTOC	-0.8326	0.0028	.	.
ALL CP	OET Richness	RelTurbidity	-0.5835	0.0766	.	.
ALL CP	POET Richness	Rel Lead	-0.7633	0.0102	.	.
ALL CP	POET Richness	RelCopper	-0.7802	0.0078	.	.
ALL CP	POET Richness	RelCuPbZn	-0.6884	0.0277	.	.
ALL CP	POET Richness	RelPhosphorous	-0.5835	0.0766	.	.
ALL CP	POET Richness	RelTKN	-0.5048	0.1367	.	.
ALL CP	POET Richness	RelTOC	-0.8326	0.0028	.	.
ALL CP	POET Richness	RelTurbidity	-0.5835	0.0766	.	.
ALL CP	Predator Richness	Rel Lead	-0.642	0.0454	.	.
ALL CP	Predator Richness	RelCopper	-0.6585	0.0384	.	.
ALL CP	Predator Richness	RelCuPbZn	-0.6403	0.0461	.	.
ALL CP	Predator Richness	RelZinc	-0.7012	0.0239	.	.
ALL CP	Predator Richness	a Soils(H O pH)	0.7134	0.0205	.	.
ALL CP	Predator Richness	a Soils(H O pH, stream)	0.5061	0.1355	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
ALL CP	Predator Richness	a Soils(H O pH, wet)	0.5	0.1411	.	.
ALL CP	Simpson's Index of Diversity	50 M LDI	-0.6727	0.033	.	.
ALL CP	Simpson's Index of Diversity	RelCuPbZn	-0.5152	0.1276	.	.
ALL CP	Simpson's Index of Diversity	RelTSS	-0.5879	0.0739	.	.
ALL CP	Simpson's Index of Diversity	a Soils(H O pH)	0.503	0.1383	.	.
ALL CP	Site Abundance	a RelDissolved Oxygen (mg/L)	0.5152	0.1276	.	.
ALL CP	Site Abundance	a Soils(H O pH)	0.5758	0.0816	.	.
ALL CP	Species Richness	Rel Lead	-0.6074	0.0625	.	.
ALL CP	Species Richness	RelCopper	-0.503	0.1383	.	.
ALL CP	Species Richness	a RelDissolved Oxygen (mg/L)	0.5152	0.1276	.	.
ALL CP	Species Richness	a Soils(H O pH)	0.7576	0.0111	.	.
ALL CP	Species Richness	a Soils(H O pH, stream)	0.5758	0.0816	.	.
ALL CP	Species Richness	a Soils(H O pH, wet)	0.5758	0.0816	.	.
Sweep CP	% Dominance of Top 3 Taxa	RelTurbidity	0.4909	0.1497	.	.
Sweep CP	% Dominance of Top 3 Taxa	a Soils(H O pH)	-0.6485	0.0425	.	.
Sweep CP	% Dominance of Top 3 Taxa	a Soils(H O pH, stream)	-0.5273	0.1173	.	.
Sweep CP	% Predator	50 M LDI	-0.6606	0.0376	.	.
Sweep CP	% Predator	Rel Lead	-0.6442	0.0444	.	.
Sweep CP	% Predator	RelCopper	-0.6242	0.0537	.	.
Sweep CP	% Predator	RelCuPbZn	-0.7697	0.0092	.	.
Sweep CP	% Predator	RelPhosphorous	-0.7697	0.0092	.	.
Sweep CP	% Predator	RelTKN	-0.6121	0.06	.	.
Sweep CP	% Predator	RelTOC	-0.6727	0.033	.	.
Sweep CP	% Predator	RelZinc	-0.6	0.0667	.	.
Sweep CP	%Coleoptera	RelWater Temp	-0.5883	0.0736	.	.
Sweep CP	%Coleoptera	Soils(Cu, stream)	-0.7306	0.0164	.	.
Sweep CP	%Coleoptera	Soils(Cu, wet)	-0.8599	0.0014	.	.
Sweep CP	%Coleoptera	Soils(Zn, wet)	-0.7693	0.0093	.	.
Sweep CP	%Coleoptera	a ORAM (w/ outliers)	0.5107	0.1314	.	.
Sweep CP	%Decapoda	RelMetals	-0.5758	0.0816	.	.
Sweep CP	%Decapoda	RelNutrients	-0.5515	0.0984	.	.
Sweep CP	%Decapoda	RelNutrientsCuPbZnFCTSSCondo	-0.6606	0.0376	.	.
Sweep CP	%Decapoda	RelNutrientsMetalsFCTSSCondo	-0.697	0.0251	.	.
Sweep CP	%Diptera	RelMetals	0.697	0.0251	.	.
Sweep CP	%Diptera	RelNutrients	0.6606	0.0376	.	.
Sweep CP	%Diptera	RelNutrientsCuPbZnFCTSSCondo	0.7576	0.0111	.	.
Sweep CP	%Diptera	RelNutrientsMetalsFCTSSCondo	0.8061	0.0049	.	.
Sweep CP	%Diptera	Soils(Zn, wet)	0.5394	0.1076	.	.
Sweep CP	%Diptera	a ORAM (no outliers)	-0.5515	0.0984	.	.
Sweep CP	%Diptera	a ORAM (w/ outliers)	-0.5636	0.0897	.	.
Sweep CP	%Dytiscidae	Soils(Cu, stream)	-0.5599	0.0924	.	.
Sweep CP	%Dytiscidae	Soils(Cu, wet)	-0.7101	0.0214	.	.
Sweep CP	%Dytiscidae	Soils(Zn, wet)	-0.5121	0.1302	.	.
Sweep CP	%EOT	RelCopper	-0.5872	0.0743	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep CP	%EOT	RelCuPbZn	-0.5121	0.1302	.	.
Sweep CP	%EOT	RelFecal Coliform	-0.5053	0.1363	.	.
Sweep CP	%EOT	RelPhosphorous	-0.5735	0.083	.	.
Sweep CP	%EOT	RelTOC	-0.5531	0.0973	.	.
Sweep CP	%EOT	RelTurbidity	-0.7579	0.0111	.	.
Sweep CP	%EOT	a RelDissolved Oxygen (%)	0.6009	0.0662	.	.
Sweep CP	%EOT	a RelDissolved Oxygen (mg/L)	0.6077	0.0624	.	.
Sweep CP	%EPT	RelCopper	-0.493	0.1476	.	.
Sweep CP	%EPT	RelTOC	-0.493	0.1476	.	.
Sweep CP	%EPT	a RelpH	0.5882	0.0737	.	.
Sweep CP	%EPT	a Soils(H O pH)	0.6833	0.0294	.	.
Sweep CP	%EPT	a Soils(H O pH, stream)	0.5882	0.0737	.	.
Sweep CP	%EPT	a Soils(H O pH, wet)	0.5882	0.0737	.	.
Sweep CP	%Microcrustaceae	RelFecal Coliform	0.6442	0.0444	.	.
Sweep CP	%Microcrustaceae	RelSpecific Conductivity	-0.5215	0.1221	.	.
Sweep CP	%Microcrustaceae	Soils(Zn)	-0.6197	0.056	.	.
Sweep CP	%Mollusk	a RelDissolved Oxygen (mg/L)	0.5754	0.0818	.	.
Sweep CP	%Mollusk	a Soils(H O pH)	0.6142	0.0589	.	.
Sweep CP	%Mollusk	a Soils(H O pH, stream)	0.5237	0.1203	.	.
Sweep CP	%Mollusk	a Soils(H O pH, wet)	0.4978	0.1431	.	.
Sweep CP	%Oligochaets	Soils(Zn, stream)	0.6018	0.0656	.	.
Sweep CP	%Orthocladiinae	RelCalcium	0.4985	0.1425	.	.
Sweep CP	%Orthocladiinae	RelFecal Coliform	0.5897	0.0728	.	.
Sweep CP	%Orthocladiinae	RelNutrients	0.6991	0.0245	.	.
Sweep CP	%Orthocladiinae	RelNutrientsCuPbZnFCTSSCondo	0.5714	0.0844	.	.
Sweep CP	%Orthocladiinae	RelNutrientsMetalsFCTSSCondo	0.541	0.1063	.	.
Sweep CP	%Orthocladiinae	Soils(Zn, stream)	0.5775	0.0804	.	.
Sweep CP	%POET	RelCopper	-0.5872	0.0743	.	.
Sweep CP	%POET	RelCuPbZn	-0.5121	0.1302	.	.
Sweep CP	%POET	RelFecal Coliform	-0.5053	0.1363	.	.
Sweep CP	%POET	RelPhosphorous	-0.5735	0.083	.	.
Sweep CP	%POET	RelTOC	-0.5531	0.0973	.	.
Sweep CP	%POET	RelTurbidity	-0.7579	0.0111	.	.
Sweep CP	%POET	a RelDissolved Oxygen (%)	0.6009	0.0662	.	.
Sweep CP	%POET	a RelDissolved Oxygen (mg/L)	0.6077	0.0624	.	.
Sweep CP	%Terrestrial	RelFecal Coliform	-0.6121	0.06	.	.
Sweep CP	%Terrestrial	RelWater Temp	-0.6242	0.0537	.	.
Sweep CP	%Tricoptera	RelCopper	-0.493	0.1476	.	.
Sweep CP	%Tricoptera	RelTOC	-0.493	0.1476	.	.
Sweep CP	%Tricoptera	a RelpH	0.5882	0.0737	.	.
Sweep CP	%Tricoptera	a Soils(H O pH)	0.6833	0.0294	.	.
Sweep CP	%Tricoptera	a Soils(H O pH, stream)	0.5882	0.0737	.	.
Sweep CP	%Tricoptera	a Soils(H O pH, wet)	0.5882	0.0737	.	.
Sweep CP	%Trombidiformes	RelWater Temp	-0.5294	0.1155	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep CP	Biotic Index	RelDOC	0.4909	0.1497	.	.
Sweep CP	Chironomidae Richness	RelCuPbZn	-0.494	0.1467	.	.
Sweep CP	Chironomidae Richness	RelZinc	-0.6065	0.063	.	.
Sweep CP	Chironomidae Richness	a RelpH	0.594	0.0702	.	.
Sweep CP	Chironomidae Richness	a Soils(H O pH)	0.7879	0.0068	.	.
Sweep CP	Chironomidae Richness	a Soils(H O pH, stream)	0.6816	0.03	.	.
Sweep CP	Chironomidae Richness	a Soils(H O pH, wet)	0.6128	0.0596	.	.
Sweep CP	EPT Richness	RelCopper	-0.5222	0.1215	.	.
Sweep CP	EPT Richness	RelTOC	-0.5222	0.1215	.	.
Sweep CP	EPT Richness	a RelpH	0.6093	0.0615	.	.
Sweep CP	EPT Richness	a Soils(H O pH)	0.6963	0.0253	.	.
Sweep CP	EPT Richness	a Soils(H O pH, stream)	0.6093	0.0615	.	.
Sweep CP	EPT Richness	a Soils(H O pH, wet)	0.6093	0.0615	.	.
Sweep CP	Family Richness	a RelpH	0.4909	0.1497	.	.
Sweep CP	Family Richness	a Soils(H O pH)	0.7576	0.0111	.	.
Sweep CP	Family Richness	a Soils(H O pH, stream)	0.6485	0.0425	.	.
Sweep CP	Family Richness	a Soils(H O pH, wet)	0.5394	0.1076	.	.
Sweep CP	Genera Richness	a RelpH	0.5636	0.0897	.	.
Sweep CP	Genera Richness	a Soils(H O pH)	0.8182	0.0038	.	.
Sweep CP	Genera Richness	a Soils(H O pH, stream)	0.7212	0.0186	.	.
Sweep CP	Genera Richness	a Soils(H O pH, wet)	0.6121	0.06	.	.
Sweep CP	OET Richness	Rel Lead	-0.569	0.0861	.	.
Sweep CP	OET Richness	RelCopper	-0.5826	0.0772	.	.
Sweep CP	OET Richness	RelCuPbZn	-0.4935	0.1472	.	.
Sweep CP	OET Richness	RelTOC	-0.6374	0.0474	.	.
Sweep CP	OET Richness	RelTurbidity	-0.6717	0.0334	.	.
Sweep CP	OET Richness	a RelDissolved Oxygen (%)	0.5483	0.1008	.	.
Sweep CP	OET Richness	a RelDissolved Oxygen (mg/L)	0.6032	0.0649	.	.
Sweep CP	POET Richness	Rel Lead	-0.5851	0.0756	.	.
Sweep CP	POET Richness	RelCopper	-0.6055	0.0636	.	.
Sweep CP	POET Richness	RelCuPbZn	-0.523	0.1209	.	.
Sweep CP	POET Richness	RelPhosphorous	-0.4954	0.1454	.	.
Sweep CP	POET Richness	RelTOC	-0.6606	0.0376	.	.
Sweep CP	POET Richness	RelTurbidity	-0.6881	0.0278	.	.
Sweep CP	POET Richness	a RelDissolved Oxygen (%)	0.578	0.0801	.	.
Sweep CP	POET Richness	a RelDissolved Oxygen (mg/L)	0.6331	0.0495	.	.
Sweep CP	Predator Richness	RelZinc	-0.5915	0.0717	.	.
Sweep CP	Predator Richness	a RelpH	0.6525	0.0409	.	.
Sweep CP	Predator Richness	a Soils(H O pH)	0.872	0.001	.	.
Sweep CP	Predator Richness	a Soils(H O pH, stream)	0.7012	0.0239	.	.
Sweep CP	Predator Richness	a Soils(H O pH, wet)	0.6646	0.036	.	.
Sweep CP	Simpson's Index of Diversity	Soils(Cu)	-0.4909	0.1497	.	.
Sweep CP	Simpson's Index of Diversity	a Soils(H O pH)	0.4909	0.1497	.	.
Sweep CP	Site Abundance	Soils(Cu)	-0.4909	0.1497	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep CP	Site Abundance	a Soils(H O pH)	0.5636	0.0897	.	.
Sweep CP	Species Richness	a RelpH	0.4909	0.1497	.	.
Sweep CP	Species Richness	a Soils(H O pH)	0.7576	0.0111	.	.
Sweep CP	Species Richness	a Soils(H O pH, stream)	0.6485	0.0425	.	.
Sweep CP	Species Richness	a Soils(H O pH, wet)	0.5394	0.1076	.	.
Trans All CP	% Crustraceae	300 M LDI Trans	.	.	-0.5999	0.0667
Trans All CP	% Crustraceae	RelMetals trans	.	.	-0.4981	0.1429
Trans All CP	% Crustraceae	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5611	0.0915
Trans All CP	% Crustraceae	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5059	0.1358
Trans All CP	% Crustraceae	RelZinc trans	.	.	-0.5828	0.077
Trans All CP	% Crustraceae	a trans ORAM (no outliers)	.	.	0.4982	0.1428
Trans All CP	% Dominance of Top 3 Taxa	RelCuPbZn trans	.	.	0.4934	0.1473
Trans All CP	% Dominance of Top 3 Taxa	RelTSS trans	.	.	0.5724	0.0837
Trans All CP	% Dominance of Top 3 Taxa	RelZinc trans	.	.	0.5373	0.1092
Trans All CP	% Dominance of Top 3 Taxa	a trans soils mean ph	.	.	-0.5415	0.106
Trans All CP	% Dominance of Top 3 Taxa	a trans soils ph wet	.	.	-0.6091	0.0616
Trans All CP	% Predator	RelDOC trans	.	.	-0.5865	0.0747
Trans All CP	% Predator	RelTKN trans	.	.	-0.5577	0.0939
Trans All CP	% Predator	RelTOC trans	.	.	-0.5761	0.0814
Trans All CP	% Predator	a trans soils ph wet	.	.	0.5719	0.0841
Trans All CP	%Chronomidae	RelWater Temp trans	.	.	0.6256	0.0531
Trans All CP	%Coleoptera	Rel Lead trans	.	.	-0.5367	0.1097
Trans All CP	%Coleoptera	RelCuPbZn trans	.	.	-0.5864	0.0748
Trans All CP	%Coleoptera	RelFecal Coliform trans	.	.	-0.6112	0.0605
Trans All CP	%Coleoptera	RelMetals trans	.	.	-0.6384	0.047
Trans All CP	%Coleoptera	RelNutrients trans	.	.	-0.6068	0.0628
Trans All CP	%Coleoptera	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.7076	0.0221
Trans All CP	%Coleoptera	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.6419	0.0454
Trans All CP	%Coleoptera	RelWater Temp trans	.	.	-0.5555	0.0955
Trans All CP	%Coleoptera	RelZinc trans	.	.	-0.6024	0.0653
Trans All CP	%Coleoptera	a trans ORAM (no outliers)	.	.	0.6147	0.0586
Trans All CP	%Coleoptera	trans soils zn wet	.	.	-0.6469	0.0432
Trans All CP	%Decapoda	RelMetals trans	.	.	-0.5639	0.0895
Trans All CP	%Decapoda	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5565	0.0947
Trans All CP	%Decapoda	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5425	0.1052
Trans All CP	%Decapoda	RelPhosphorous trans	.	.	-0.6147	0.0586
Trans All CP	%Diptera	RelCalcium trans	.	.	0.518	0.1251
Trans All CP	%Diptera	RelCuPbZn trans	.	.	0.521	0.1225
Trans All CP	%Diptera	RelFecal Coliform trans	.	.	0.8125	0.0043
Trans All CP	%Diptera	RelMetals trans	.	.	0.6975	0.0249
Trans All CP	%Diptera	RelNutrients trans	.	.	0.6487	0.0424
Trans All CP	%Diptera	RelNutrientsCuPbZnFCTSSCondo trans	.	.	0.7616	0.0105
Trans All CP	%Diptera	RelNutrientsMetalsFCTSSCondo trans	.	.	0.7206	0.0187
Trans All CP	%Diptera	RelPhosphorous trans	.	.	0.5353	0.1108

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Trans All CP	%Diptera	RelZinc trans	.	.	0.5558	0.0953
Trans All CP	%Diptera	a trans ORAM (no outliers)	.	.	-0.5993	0.0671
Trans All CP	%Diptera	trans soils zn wet	.	.	0.6846	0.029
Trans All CP	%Dytiscidae	RelWater Temp trans	.	.	-0.5069	0.1348
Trans All CP	%Dytiscidae	trans soils zn stream	.	.	-0.5264	0.1181
Trans All CP	%Dytiscidae	trans soils zn wet	.	.	-0.7739	0.0086
Trans All CP	%EOT	Rel Lead trans	.	.	-0.7589	0.0109
Trans All CP	%EOT	RelCopper trans	.	.	-0.7338	0.0157
Trans All CP	%EOT	RelCuPbZn trans	.	.	-0.7089	0.0217
Trans All CP	%EOT	RelPhosphorous trans	.	.	-0.6597	0.0379
Trans All CP	%EOT	RelTKN trans	.	.	-0.5799	0.0789
Trans All CP	%EOT	RelTOC trans	.	.	-0.7767	0.0082
Trans All CP	%EOT	RelTurbidity trans	.	.	-0.5442	0.1039
Trans All CP	%EPT	RelTOC trans	.	.	-0.504	0.1375
Trans All CP	%EPT	a RelpH trans	.	.	0.5761	0.0814
Trans All CP	%EPT	a trans soils mean ph	.	.	0.6926	0.0264
Trans All CP	%EPT	a trans soils ph stream	.	.	0.6247	0.0535
Trans All CP	%EPT	a trans soils ph wet	.	.	0.6679	0.0348
Trans All CP	%Leech	RelSpecific Conductivity trans	.	.	0.5096	0.1325
Trans All CP	%Microcrustaceae	RelCopper trans	.	.	-0.5493	0.1
Trans All CP	%Microcrustaceae	RelCuPbZn trans	.	.	-0.6221	0.0548
Trans All CP	%Microcrustaceae	RelZinc trans	.	.	-0.7219	0.0184
Trans All CP	%Microcrustaceae	trans soils zn wet	.	.	-0.5191	0.1241
Trans All CP	%Mollusk	a trans soils mean ph	.	.	0.6157	0.0581
Trans All CP	%Mollusk	a trans soils ph stream	.	.	0.5088	0.1331
Trans All CP	%Mollusk	a trans soils ph wet	.	.	0.515	0.1277
Trans All CP	%Oligochaets	RelFecal Coliform trans	.	.	0.6225	0.0546
Trans All CP	%Oligochaets	trans soils zn stream	.	.	0.5065	0.1352
Trans All CP	%Orthocladiinae	RelFecal Coliform trans	.	.	0.7142	0.0203
Trans All CP	%Orthocladiinae	RelWater Temp trans	.	.	0.5891	0.0732
Trans All CP	%Orthocladiinae	trans soils zn stream	.	.	0.5701	0.0853
Trans All CP	%POET	Rel Lead trans	.	.	-0.7587	0.011
Trans All CP	%POET	RelCopper trans	.	.	-0.735	0.0154
Trans All CP	%POET	RelCuPbZn trans	.	.	-0.7101	0.0214
Trans All CP	%POET	RelPhosphorous trans	.	.	-0.6615	0.0372
Trans All CP	%POET	RelTKN trans	.	.	-0.5813	0.078
Trans All CP	%POET	RelTOC trans	.	.	-0.7828	0.0074
Trans All CP	%POET	RelTurbidity trans	.	.	-0.5442	0.1039
Trans All CP	%Terrestrial	RelTKN trans	.	.	-0.5122	0.1302
Trans All CP	%Tricoptera	RelTOC trans	.	.	-0.4929	0.1477
Trans All CP	%Tricoptera	a RelpH trans	.	.	0.572	0.0841
Trans All CP	%Tricoptera	a trans soils mean ph	.	.	0.6896	0.0274
Trans All CP	%Tricoptera	a trans soils ph stream	.	.	0.6165	0.0577
Trans All CP	%Tricoptera	a trans soils ph wet	.	.	0.6587	0.0383

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Trans All CP	Chironomidae Richness	300 M LDI Trans	.	.	-0.6123	0.0599
Trans All CP	Chironomidae Richness	RelTSS trans	.	.	-0.6782	0.0311
Trans All CP	Chironomidae Richness	RelZinc trans	.	.	-0.6466	0.0433
Trans All CP	EPT Richness	RelTOC trans	.	.	-0.5319	0.1135
Trans All CP	EPT Richness	a RelDissolved Oxygen (mg/L) trans	.	.	0.5072	0.1346
Trans All CP	EPT Richness	a RelDissolved Oxygen trans	.	.	0.5085	0.1334
Trans All CP	EPT Richness	a RelpH trans	.	.	0.5853	0.0755
Trans All CP	EPT Richness	a trans soils mean ph	.	.	0.6987	0.0246
Trans All CP	EPT Richness	a trans soils ph stream	.	.	0.6447	0.0442
Trans All CP	EPT Richness	a trans soils ph wet	.	.	0.6904	0.0271
Trans All CP	Evenness	300 M LDI Trans	.	.	-0.6838	0.0292
Trans All CP	Evenness	RelTSS trans	.	.	-0.6633	0.0365
Trans All CP	Evenness	RelZinc trans	.	.	-0.6445	0.0442
Trans All CP	Family Richness	Rel Lead trans	.	.	-0.7275	0.0171
Trans All CP	Family Richness	RelCopper trans	.	.	-0.7063	0.0224
Trans All CP	Family Richness	RelCuPbZn trans	.	.	-0.8047	0.005
Trans All CP	Family Richness	RelPhosphorous trans	.	.	-0.5193	0.1239
Trans All CP	Family Richness	RelZinc trans	.	.	-0.7699	0.0092
Trans All CP	Genera Richness	Rel Lead trans	.	.	-0.5884	0.0735
Trans All CP	Genera Richness	RelCopper trans	.	.	-0.5703	0.0852
Trans All CP	Genera Richness	RelCuPbZn trans	.	.	-0.6993	0.0244
Trans All CP	Genera Richness	RelTSS trans	.	.	-0.5276	0.117
Trans All CP	Genera Richness	RelZinc trans	.	.	-0.7413	0.0141
Trans All CP	OET Richness	Rel Lead trans	.	.	-0.7637	0.0101
Trans All CP	OET Richness	RelCopper trans	.	.	-0.7333	0.0158
Trans All CP	OET Richness	RelCuPbZn trans	.	.	-0.7038	0.0231
Trans All CP	OET Richness	RelPhosphorous trans	.	.	-0.6653	0.0358
Trans All CP	OET Richness	RelTKN trans	.	.	-0.5948	0.0697
Trans All CP	OET Richness	RelTOC trans	.	.	-0.7831	0.0074
Trans All CP	OET Richness	RelTurbidity trans	.	.	-0.5522	0.0979
Trans All CP	POET Richness	Rel Lead trans	.	.	-0.7633	0.0102
Trans All CP	POET Richness	RelCopper trans	.	.	-0.7358	0.0153
Trans All CP	POET Richness	RelCuPbZn trans	.	.	-0.7064	0.0224
Trans All CP	POET Richness	RelPhosphorous trans	.	.	-0.669	0.0344
Trans All CP	POET Richness	RelTKN trans	.	.	-0.5975	0.0681
Trans All CP	POET Richness	RelTOC trans	.	.	-0.7954	0.0059
Trans All CP	POET Richness	RelTurbidity trans	.	.	-0.5522	0.0979
Trans All CP	Predator Richness	Rel Lead trans	.	.	-0.6962	0.0253
Trans All CP	Predator Richness	RelCopper trans	.	.	-0.6379	0.0472
Trans All CP	Predator Richness	RelCuPbZn trans	.	.	-0.7918	0.0063
Trans All CP	Predator Richness	RelZinc trans	.	.	-0.8146	0.0041
Trans All CP	Simpson's Index of Diversity	300 M LDI Trans	.	.	-0.6638	0.0364
Trans All CP	Simpson's Index of Diversity	RelCuPbZn trans	.	.	-0.5295	0.1154
Trans All CP	Simpson's Index of Diversity	RelTSS trans	.	.	-0.6499	0.0419

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Trans All CP	Simpson's Index of Diversity	RelZinc trans	.	.	-0.7156	0.02
Trans All CP	Site Abundance	RelCopper trans	.	.	-0.5194	0.1239
Trans All CP	Site Abundance	RelCuPbZn trans	.	.	-0.5904	0.0723
Trans All CP	Site Abundance	RelZinc trans	.	.	-0.649	0.0423
Trans All CP	Site Abundance	a trans soils mean ph	.	.	0.4945	0.1463
Trans All CP	Species Richness	Rel Lead trans	.	.	-0.5583	0.0935
Trans All CP	Species Richness	RelCopper trans	.	.	-0.5511	0.0987
Trans All CP	Species Richness	RelCuPbZn trans	.	.	-0.677	0.0315
Trans All CP	Species Richness	RelTSS trans	.	.	-0.5074	0.1344
Trans All CP	Species Richness	RelZinc trans	.	.	-0.7272	0.0172
Trans All CP	Species Richness	a trans soils mean ph	.	.	0.5144	0.1282
Trans Sweep CP	% Crustraceae	300 M LDI Trans	.	.	-0.6141	0.0589
Trans Sweep CP	% Crustraceae	RelCalcium trans	.	.	-0.5314	0.1139
Trans Sweep CP	% Crustraceae	RelMetals trans	.	.	-0.5122	0.1301
Trans Sweep CP	% Crustraceae	RelNutrients trans	.	.	-0.5413	0.1061
Trans Sweep CP	% Crustraceae	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.6174	0.0572
Trans Sweep CP	% Crustraceae	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.6205	0.0556
Trans Sweep CP	% Crustraceae	RelSpecific Conductivity trans	.	.	-0.563	0.0902
Trans Sweep CP	% Dominance of Top 3 Taxa	RelZinc trans	.	.	0.5458	0.1027
Trans Sweep CP	% Dominance of Top 3 Taxa	a trans soils mean ph	.	.	-0.5178	0.1253
Trans Sweep CP	% Dominance of Top 3 Taxa	a trans soils ph stream	.	.	-0.5255	0.1188
Trans Sweep CP	% Dominance of Top 3 Taxa	a trans soils ph wet	.	.	-0.5849	0.0757
Trans Sweep CP	% Predator	Rel Lead trans	.	.	-0.6262	0.0528
Trans Sweep CP	% Predator	RelCopper trans	.	.	-0.5163	0.1266
Trans Sweep CP	% Predator	RelCuPbZn trans	.	.	-0.5946	0.0698
Trans Sweep CP	% Predator	RelDOC trans	.	.	-0.5398	0.1073
Trans Sweep CP	% Predator	RelPhosphorous trans	.	.	-0.6668	0.0352
Trans Sweep CP	% Predator	RelTKN trans	.	.	-0.6995	0.0244
Trans Sweep CP	% Predator	RelTOC trans	.	.	-0.7635	0.0102
Trans Sweep CP	% Predator	RelZinc trans	.	.	-0.504	0.1375
Trans Sweep CP	% Predator	a trans soils ph wet	.	.	0.531	0.1143
Trans Sweep CP	%Chronomidae	RelWater Temp trans	.	.	0.5446	0.1035
Trans Sweep CP	%Coleoptera	RelFecal Coliform trans	.	.	-0.5448	0.1034
Trans Sweep CP	%Coleoptera	RelWater Temp trans	.	.	-0.5283	0.1165
Trans Sweep CP	%Coleoptera	trans soils zn stream	.	.	-0.5306	0.1146
Trans Sweep CP	%Coleoptera	trans soils zn wet	.	.	-0.7835	0.0073
Trans Sweep CP	%Corixidae+Coleoptera	RelDOC trans	.	.	0.5482	0.1009
Trans Sweep CP	%Decapoda	RelMetals trans	.	.	-0.5331	0.1126
Trans Sweep CP	%Decapoda	RelNutrients trans	.	.	-0.5921	0.0713
Trans Sweep CP	%Decapoda	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.7012	0.0238
Trans Sweep CP	%Decapoda	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.6567	0.0391
Trans Sweep CP	%Diptera	RelMetals trans	.	.	0.6073	0.0626
Trans Sweep CP	%Diptera	RelNutrients trans	.	.	0.575	0.082
Trans Sweep CP	%Diptera	RelNutrientsCuPbZnFCTSSCondo trans	.	.	0.6925	0.0264

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Trans Sweep CP	%Diptera	RelNutrientsMetalsFCTSSCondo trans	.	.	0.6554	0.0397
Trans Sweep CP	%Diptera	trans soils zn wet	.	.	0.526	0.1183
Trans Sweep CP	%Dytiscidae	trans soils zn wet	.	.	-0.5047	0.1368
Trans Sweep CP	%EOT	Rel Lead trans	.	.	-0.6121	0.06
Trans Sweep CP	%EOT	RelCopper trans	.	.	-0.5692	0.0859
Trans Sweep CP	%EOT	RelCuPbZn trans	.	.	-0.5272	0.1174
Trans Sweep CP	%EOT	RelPhosphorous trans	.	.	-0.5262	0.1182
Trans Sweep CP	%EOT	RelTOC trans	.	.	-0.5812	0.0781
Trans Sweep CP	%EOT	RelTurbidity trans	.	.	-0.765	0.0099
Trans Sweep CP	%EOT	a RelDissolved Oxygen (mg/L) trans	.	.	0.661	0.0375
Trans Sweep CP	%EOT	a RelDissolved Oxygen trans	.	.	0.5998	0.0668
Trans Sweep CP	%EPT	RelTOC trans	.	.	-0.511	0.1311
Trans Sweep CP	%EPT	a RelpH trans	.	.	0.5785	0.0797
Trans Sweep CP	%EPT	a trans soils mean ph	.	.	0.6944	0.0259
Trans Sweep CP	%EPT	a trans soils ph stream	.	.	0.6298	0.051
Trans Sweep CP	%EPT	a trans soils ph wet	.	.	0.6737	0.0327
Trans Sweep CP	%Leech	RelSpecific Conductivity trans	.	.	0.5132	0.1292
Trans Sweep CP	%Leech	trans soils mean cu	.	.	0.5231	0.1207
Trans Sweep CP	%Microcrustaceae	RelFecal Coliform trans	.	.	0.5224	0.1214
Trans Sweep CP	%Microcrustaceae	a trans soils mean ph	.	.	0.5673	0.0872
Trans Sweep CP	%Microcrustaceae	trans soils mean cu	.	.	0.5673	0.0872
Trans Sweep CP	%Mollusk	a RelDissolved Oxygen (mg/L) trans	.	.	0.5089	0.1331
Trans Sweep CP	%Mollusk	a trans soils mean ph	.	.	0.5887	0.0734
Trans Sweep CP	%Mollusk	a trans soils ph stream	.	.	0.5503	0.0993
Trans Sweep CP	%Mollusk	a trans soils ph wet	.	.	0.4907	0.1499
Trans Sweep CP	%Oligochaets	RelFecal Coliform trans	.	.	0.623	0.0543
Trans Sweep CP	%Oligochaets	trans soils zn stream	.	.	0.5283	0.1165
Trans Sweep CP	%Orthocladiinae	RelFecal Coliform trans	.	.	0.6936	0.0261
Trans Sweep CP	%Orthocladiinae	RelWater Temp trans	.	.	0.5115	0.1308
Trans Sweep CP	%Orthocladiinae	trans soils mean cu	.	.	0.5003	0.1409
Trans Sweep CP	%Orthocladiinae	trans soils zn stream	.	.	0.5578	0.0938
Trans Sweep CP	%POET	Rel Lead trans	.	.	-0.6126	0.0597
Trans Sweep CP	%POET	RelCopper trans	.	.	-0.5709	0.0847
Trans Sweep CP	%POET	RelCuPbZn trans	.	.	-0.5291	0.1158
Trans Sweep CP	%POET	RelPhosphorous trans	.	.	-0.5284	0.1163
Trans Sweep CP	%POET	RelTOC trans	.	.	-0.5874	0.0742
Trans Sweep CP	%POET	RelTurbidity trans	.	.	-0.7638	0.0101
Trans Sweep CP	%POET	a RelDissolved Oxygen (mg/L) trans	.	.	0.6662	0.0355
Trans Sweep CP	%POET	a RelDissolved Oxygen trans	.	.	0.6058	0.0634
Trans Sweep CP	%Terrestrial	RelTKN trans	.	.	-0.5172	0.1258
Trans Sweep CP	%Tricoptera	RelTOC trans	.	.	-0.5014	0.1398
Trans Sweep CP	%Tricoptera	a RelpH trans	.	.	0.5751	0.082
Trans Sweep CP	%Tricoptera	a trans soils mean ph	.	.	0.692	0.0266
Trans Sweep CP	%Tricoptera	a trans soils ph stream	.	.	0.6228	0.0544

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Trans Sweep CP	%Tricoptera	a trans soils ph wet	.	.	0.6657	0.0356
Trans Sweep CP	Chironomidae Richness	RelZinc trans	.	.	-0.5356	0.1106
Trans Sweep CP	Chironomidae Richness	a RelpH trans	.	.	0.5848	0.0758
Trans Sweep CP	Chironomidae Richness	a trans soils mean ph	.	.	0.7311	0.0163
Trans Sweep CP	Chironomidae Richness	a trans soils ph stream	.	.	0.6528	0.0407
Trans Sweep CP	Chironomidae Richness	a trans soils ph wet	.	.	0.6619	0.0371
Trans Sweep CP	EPT Richness	Rel Lead trans	.	.	-0.6168	0.0575
Trans Sweep CP	EPT Richness	RelCopper trans	.	.	-0.5676	0.087
Trans Sweep CP	EPT Richness	RelCuPbZn trans	.	.	-0.5269	0.1176
Trans Sweep CP	EPT Richness	RelTOC trans	.	.	-0.6255	0.0531
Trans Sweep CP	EPT Richness	RelTurbidity trans	.	.	-0.7152	0.0201
Trans Sweep CP	EPT Richness	a RelDissolved Oxygen (mg/L) trans	.	.	0.6775	0.0313
Trans Sweep CP	EPT Richness	a RelDissolved Oxygen trans	.	.	0.611	0.0606
Trans Sweep CP	Evenness	300 M LDI Trans	.	.	-0.6602	0.0378
Trans Sweep CP	Evenness	50 M LDI Trans	.	.	-0.5393	0.1076
Trans Sweep CP	Evenness	RelCuPbZn trans	.	.	-0.5068	0.135
Trans Sweep CP	Evenness	RelZinc trans	.	.	-0.7497	0.0125
Trans Sweep CP	Evenness	a trans ORAM (no outliers)	.	.	0.5295	0.1155
Trans Sweep CP	Family Richness	RelZinc trans	.	.	-0.6163	0.0577
Trans Sweep CP	Family Richness	a trans soils mean ph	.	.	0.5898	0.0727
Trans Sweep CP	Family Richness	a trans soils ph stream	.	.	0.5455	0.1029
Trans Sweep CP	Family Richness	a trans soils ph wet	.	.	0.5516	0.0983
Trans Sweep CP	Genera Richness	RelZinc trans	.	.	-0.6035	0.0647
Trans Sweep CP	Genera Richness	a trans soils mean ph	.	.	0.6047	0.064
Trans Sweep CP	Genera Richness	a trans soils ph stream	.	.	0.5447	0.1035
Trans Sweep CP	Genera Richness	a trans soils ph wet	.	.	0.5551	0.0958
Trans Sweep CP	OET Richness	Rel Lead trans	.	.	-0.6169	0.0574
Trans Sweep CP	OET Richness	RelCopper trans	.	.	-0.5644	0.0892
Trans Sweep CP	OET Richness	RelCuPbZn trans	.	.	-0.5234	0.1206
Trans Sweep CP	OET Richness	RelTOC trans	.	.	-0.6124	0.0598
Trans Sweep CP	OET Richness	RelTurbidity trans	.	.	-0.7189	0.0191
Trans Sweep CP	OET Richness	a RelDissolved Oxygen (mg/L) trans	.	.	0.6665	0.0353
Trans Sweep CP	OET Richness	a RelDissolved Oxygen trans	.	.	0.5979	0.0679
Trans Sweep CP	POET Richness	Rel Lead trans	.	.	-0.6168	0.0575
Trans Sweep CP	POET Richness	RelCopper trans	.	.	-0.5676	0.087
Trans Sweep CP	POET Richness	RelCuPbZn trans	.	.	-0.5269	0.1176
Trans Sweep CP	POET Richness	RelTOC trans	.	.	-0.6255	0.0531
Trans Sweep CP	POET Richness	RelTurbidity trans	.	.	-0.7152	0.0201
Trans Sweep CP	POET Richness	a RelDissolved Oxygen (mg/L) trans	.	.	0.6775	0.0313
Trans Sweep CP	POET Richness	a RelDissolved Oxygen trans	.	.	0.611	0.0606
Trans Sweep CP	Predator Richness	RelCuPbZn trans	.	.	-0.5704	0.0851
Trans Sweep CP	Predator Richness	RelZinc trans	.	.	-0.7019	0.0237
Trans Sweep CP	Predator Richness	a trans soils mean ph	.	.	0.622	0.0548
Trans Sweep CP	Predator Richness	a trans soils ph stream	.	.	0.4991	0.142

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Trans Sweep CP	Predator Richness	a trans soils ph wet	.	.	0.5621	0.0908
Trans Sweep CP	Simpson's Index of Diversity	300 M LDI Trans	.	.	-0.6624	0.0369
Trans Sweep CP	Simpson's Index of Diversity	50 M LDI Trans	.	.	-0.5345	0.1115
Trans Sweep CP	Simpson's Index of Diversity	RelCuPbZn trans	.	.	-0.5176	0.1254
Trans Sweep CP	Simpson's Index of Diversity	RelZinc trans	.	.	-0.7514	0.0122
Trans Sweep CP	Simpson's Index of Diversity	a trans ORAM (no outliers)	.	.	0.4975	0.1434
Trans Sweep CP	Site Abundance	a trans soils mean ph	.	.	0.6052	0.0637
Trans Sweep CP	Site Abundance	a trans soils ph stream	.	.	0.5641	0.0894
Trans Sweep CP	Site Abundance	a trans soils ph wet	.	.	0.517	0.126
Trans Sweep CP	Species Richness	RelZinc trans	.	.	-0.6163	0.0577
Trans Sweep CP	Species Richness	a trans soils mean ph	.	.	0.5898	0.0727
Trans Sweep CP	Species Richness	a trans soils ph stream	.	.	0.5455	0.1029
Trans Sweep CP	Species Richness	a trans soils ph wet	.	.	0.5516	0.0983
Piedmont Significant Correlations						
Sample	Metric	Disturbance Measurement	Spearman ρ	Prob>|ρ|	Correlation	Signif Prob
All PD	% Colepotera	50 M LDI	-0.541	0.1063	.	.
All PD	% Colepotera	Soils(Cu, stream)	-0.5273	0.1173	.	.
All PD	% Colepotera	Soils(Cu, wet)	-0.6878	0.0279	.	.
All PD	% Colepotera	Soils(Zn, stream)	-0.5636	0.0897	.	.
All PD	% Colepotera	Soils(Zn, wet)	-0.8317	0.0029	.	.
All PD	% Colepotera	a ORAM (no outliers)	0.6378	0.0472	.	.
All PD	% Colepotera	a ORAM (w/ outliers)	0.6503	0.0418	.	.
All PD	% Crustraceae	50 M LDI	-0.4924	0.1482	.	.
All PD	% Crustraceae	Soils(Cu)	-0.503	0.1383	.	.
All PD	% Crustraceae	Soils(Cu, wet)	-0.503	0.1383	.	.
All PD	% Crustraceae	Soils(Zn, wet)	-0.5152	0.1276	.	.
All PD	% Dominance of Top 3 Taxa	50 M LDI	0.6364	0.0479	.	.
All PD	% Dominance of Top 3 Taxa	a Soils(H O pH)	-0.6121	0.06	.	.
All PD	% Predator	RelCalcium	-0.7939	0.0061	.	.
All PD	% Predator	RelDoc	-0.503	0.1383	.	.
All PD	% Predator	RelMagnesium	-0.8545	0.0016	.	.
All PD	% Predator	RelMetals	-0.5152	0.1276	.	.
All PD	% Predator	RelTurbidity	-0.5273	0.1173	.	.
All PD	% Predator	a Soils(H O pH)	0.5152	0.1276	.	.
All PD	% Predator	a Soils(H O pH, wet)	0.6848	0.0289	.	.
All PD	% Sensitive	RelAmmonia	-0.7066	0.0223	.	.
All PD	% Sensitive	RelWaterTemp	-0.5565	0.0948	.	.
All PD	% Sensitive	a Soils(H O pH)	0.5815	0.0778	.	.
All PD	% Sensitive	a Soils(H O pH, stream)	0.5128	0.1296	.	.
All PD	% Tolerant	RelAmmonia	0.5152	0.1276	.	.
All PD	% Tolerant	RelCopper	0.7212	0.0186	.	.
All PD	% Tolerant	RelCuPbZn	0.8303	0.0029	.	.
All PD	% Tolerant	RelDoc	0.5879	0.0739	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
All PD	% Tolerant	RelLead	0.6991	0.0245	.	.
All PD	% Tolerant	RelMetals	0.697	0.0251	.	.
All PD	% Tolerant	RelNutrientsCuPbZnFCTSSCondo	0.7939	0.0061	.	.
All PD	% Tolerant	RelNutrientsMetalsFCTSSCondo	0.7939	0.0061	.	.
All PD	% Tolerant	RelPhosphorous	0.7939	0.0061	.	.
All PD	% Tolerant	RelSpecific Conductivity	0.8424	0.0022	.	.
All PD	% Tolerant	RelTKN	0.8424	0.0022	.	.
All PD	% Tolerant	RelTOC	0.5152	0.1276	.	.
All PD	% Tolerant	RelTSS	0.6364	0.0479	.	.
All PD	% Tolerant	RelTurbidity	0.7333	0.0158	.	.
All PD	% Tolerant	RelZinc	0.5879	0.0739	.	.
All PD	% Tolerant	a Soils(H O pH)	-0.5273	0.1173	.	.
All PD	% Tolerant	a Soils(H O pH, stream)	-0.5152	0.1276	.	.
All PD	% Tolerant	a Soils(H O pH, stream)	-0.5758	0.0816	.	.
All PD	% Tolerant	a Soils(H O pH, wet)	-0.5394	0.1076	.	.
All PD	%Chronomidae	50 M LDI	0.5593	0.0928	.	.
All PD	%Chronomidae	Soils(Cu)	0.6364	0.0479	.	.
All PD	%Chronomidae	Soils(Cu, stream)	0.5758	0.0816	.	.
All PD	%Chronomidae	Soils(Cu, wet)	0.7576	0.0111	.	.
All PD	%Chronomidae	Soils(Zn, stream)	0.5758	0.0816	.	.
All PD	%Chronomidae	Soils(Zn, wet)	0.5152	0.1276	.	.
All PD	%Coleoptera	RelNO2+NO3	-0.5443	0.1038	.	.
All PD	%Coleoptera	a Dissolved Oxygen (mg/L) 2	0.4909	0.1497	.	.
All PD	%Coleoptera	a RelDissolved Oxygen (%)	0.5879	0.0739	.	.
All PD	%Coleoptera	a RelpH	0.5273	0.1173	.	.
All PD	%Corixidae	Soils(Cu)	0.5891	0.0731	.	.
All PD	%Corixidae	Soils(Cu, wet)	0.5593	0.0928	.	.
All PD	%Decapoda	50 M LDI	-0.5289	0.116	.	.
All PD	%Decapoda	Soils(Cu, stream)	-0.5152	0.1276	.	.
All PD	%Diptera	300 M LDI	0.5273	0.1173	.	.
All PD	%Diptera	Soils(Cu)	0.5879	0.0739	.	.
All PD	%Diptera	Soils(Cu, wet)	0.6606	0.0376	.	.
All PD	%Diptera	Soils(Zn, wet)	0.6485	0.0425	.	.
All PD	%Diptera	Watershed LDI	0.5152	0.1276	.	.
All PD	%Diptera	a ORAM (no outliers)	-0.5273	0.1173	.	.
All PD	%Diptera	a ORAM (w/ outliers)	-0.5879	0.0739	.	.
All PD	%Dytiscidae	50 M LDI	-0.5488	0.1004	.	.
All PD	%Dytiscidae	Soils(Cu, stream)	-0.7306	0.0164	.	.
All PD	%Dytiscidae	Soils(Cu, stream)	-0.5897	0.0728	.	.
All PD	%Dytiscidae	Soils(Cu, wet)	-0.8857	0.0006	.	.
All PD	%Dytiscidae	Soils(Zn, stream)	-0.535	0.1111	.	.
All PD	%Dytiscidae	Soils(Zn, wet)	-0.7435	0.0137	.	.
All PD	%EOT	RelAmmonia	-0.5253	0.119	.	.
All PD	%EOT	RelFecalColiform	-0.5878	0.0739	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
All PD	%EPT	RelAmmonia	-0.6659	0.0356	.	.
All PD	%EPT	RelFecalColiform	-0.6271	0.0523	.	.
All PD	%EPT	a Soils(H O pH)	0.6833	0.0294	.	.
All PD	%EPT	a Soils(H O pH, stream)	0.5882	0.0737	.	.
All PD	%EPT	a Soils(H O pH, wet)	0.5882	0.0737	.	.
All PD	%Hemiptera	50 M LDI	0.678	0.0312	.	.
All PD	%Hemiptera	Soils(Cu)	0.7579	0.0111	.	.
All PD	%Hemiptera	Soils(Cu, stream)	0.6145	0.0587	.	.
All PD	%Hemiptera	Soils(Cu, wet)	0.6282	0.0518	.	.
All PD	%Hemiptera	Soils(Zn, stream)	0.5394	0.1076	.	.
All PD	%Hemiptera	Watershed LDI	0.6418	0.0454	.	.
All PD	%Hemiptera	a RelpH	-0.6555	0.0396	.	.
All PD	%Leech	RelFecalColiform	0.5593	0.0928	.	.
All PD	%Microcrustaceae	300 M LDI	-0.5228	0.121	.	.
All PD	%Microcrustaceae	RelCalcium	0.6687	0.0345	.	.
All PD	%Microcrustaceae	RelDoc	0.5106	0.1315	.	.
All PD	%Microcrustaceae	RelMagnesium	0.7173	0.0195	.	.
All PD	%Microcrustaceae	Soils(Cu, wet)	-0.4985	0.1425	.	.
All PD	%Microcrustaceae	Soils(Cu, wet)	-0.6201	0.0558	.	.
All PD	%Microcrustaceae	Soils(Zn, wet)	-0.541	0.1063	.	.
All PD	%Mollusk	RelAmmonia	-0.7301	0.0165	.	.
All PD	%Mollusk	RelCuPbZn	-0.5338	0.112	.	.
All PD	%Mollusk	RelFecalColiform	-0.5338	0.112	.	.
All PD	%Mollusk	RelNutrientsCuPbZnFCTSSCondo	-0.5951	0.0695	.	.
All PD	%Mollusk	RelNutrientsMetalsFCTSSCondo	-0.497	0.1439	.	.
All PD	%Mollusk	RelPhosphorous	-0.7792	0.0079	.	.
All PD	%Mollusk	RelSpecific Conductivity	-0.5215	0.1221	.	.
All PD	%Mollusk	RelTKN	-0.5215	0.1221	.	.
All PD	%Mollusk	a Soils(H O pH)	0.6628	0.0367	.	.
All PD	%Mollusk	a Soils(H O pH)	0.5951	0.0695	.	.
All PD	%Mollusk	a Soils(H O pH, stream)	0.519	0.1242	.	.
All PD	%Mollusk	a Soils(H O pH, stream)	0.6565	0.0392	.	.
All PD	%Oligochaets	RelCuPbZn	0.5515	0.0984	.	.
All PD	%Oligochaets	RelLead	0.535	0.1111	.	.
All PD	%Oligochaets	RelMetals	0.7333	0.0158	.	.
All PD	%Oligochaets	RelTSS	0.6	0.0667	.	.
All PD	%Oligochaets	RelZinc	0.6	0.0667	.	.
All PD	%Oligochaets	Soils(Zn, stream)	0.5289	0.116	.	.
All PD	%Orthocladiinae	Soils(Cu)	0.503	0.1383	.	.
All PD	%Orthocladiinae	Soils(Cu, wet)	0.6606	0.0376	.	.
All PD	%Orthocladiinae	Soils(Zn, stream)	0.6505	0.0417	.	.
All PD	%Orthocladiinae	Watershed LDI	0.4924	0.1482	.	.
All PD	%POET	RelAmmonia	-0.5253	0.119	.	.
All PD	%POET	RelFecalColiform	-0.5878	0.0739	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
All PD	%Terrestrial	RelNutrientsMetalsFCTSSCondo	-0.4978	0.1431	.	.
All PD	%Terrestrial	RelSpecific Conductivity	-0.653	0.0407	.	.
All PD	%Terrestrial	RelTKN	-0.653	0.0407	.	.
All PD	%Terrestrial	RelTSS	-0.5107	0.1314	.	.
All PD	%Terrestrial	RelTurbidity	-0.6013	0.066	.	.
All PD	%Tricoptera	RelAmmonia	-0.6659	0.0356	.	.
All PD	%Tricoptera	RelFecalColiform	-0.6271	0.0523	.	.
All PD	%Tricoptera	a Soils(H O pH)	0.6833	0.0294	.	.
All PD	%Tricoptera	a Soils(H O pH, stream)	0.5882	0.0737	.	.
All PD	%Tricoptera	a Soils(H O pH, wet)	0.5882	0.0737	.	.
All PD	Biotic Index	RelCalcium	0.6606	0.0376	.	.
All PD	Biotic Index	RelDoc	0.5394	0.1076	.	.
All PD	Biotic Index	RelMagnesium	0.5515	0.0984	.	.
All PD	Chironomidae Richness	RelAmmonia	-0.7217	0.0184	.	.
All PD	Chironomidae Richness	RelCopper	-0.4954	0.1454	.	.
All PD	Chironomidae Richness	RelCuPbZn	-0.6789	0.0309	.	.
All PD	Chironomidae Richness	RelLead	-0.5123	0.1301	.	.
All PD	Chironomidae Richness	RelNutrientsCuPbZnFCTSSCondo	-0.5505	0.0992	.	.
All PD	Chironomidae Richness	RelPhosphorous	-0.7401	0.0144	.	.
All PD	Chironomidae Richness	RelSpecific Conductivity	-0.5505	0.0992	.	.
All PD	Chironomidae Richness	RelTKN	-0.5505	0.0992	.	.
All PD	Chironomidae Richness	a Soils(H O pH)	0.685	0.0288	.	.
All PD	Chironomidae Richness	a Soils(H O pH, stream)	0.7095	0.0216	.	.
All PD	Chironomidae Richness	a Soils(H O pH, wet)	0.526	0.1183	.	.
All PD	EPT Richness	RelAmmonia	-0.7356	0.0153	.	.
All PD	EPT Richness	RelCopper	-0.4948	0.146	.	.
All PD	EPT Richness	RelFecalColiform	-0.5534	0.097	.	.
All PD	EPT Richness	RelPhosphorous	-0.5013	0.1399	.	.
All PD	EPT Richness	a Soils(H O pH)	0.6963	0.0253	.	.
All PD	EPT Richness	a Soils(H O pH, stream)	0.6093	0.0615	.	.
All PD	EPT Richness	a Soils(H O pH, wet)	0.6093	0.0615	.	.
All PD	Evenness	50 M LDI	-0.6606	0.0376	.	.
All PD	Evenness	RelMagnesium	-0.6121	0.06	.	.
All PD	Family Richness	RelAmmonia	-0.5046	0.1369	.	.
All PD	Family Richness	RelFecalColiform	-0.5532	0.0972	.	.
All PD	Family Richness	RelNutrientsCuPbZnFCTSSCondo	-0.5046	0.1369	.	.
All PD	Family Richness	RelSpecific Conductivity	-0.5532	0.0972	.	.
All PD	Family Richness	RelTKN	-0.5532	0.0972	.	.
All PD	Family Richness	a Dissolved Oxygen (mg/L) 2	0.5957	0.0692	.	.
All PD	Family Richness	a RelDissolved Oxygen (%)	0.5714	0.0844	.	.
All PD	Family Richness	a Soils(H O pH)	0.5532	0.0972	.	.
All PD	Genera Richness	RelAmmonia	-0.7333	0.0158	.	.
All PD	Genera Richness	RelNutrientsCuPbZnFCTSSCondo	-0.5152	0.1276	.	.
All PD	Genera Richness	RelPhosphorous	-0.6121	0.06	.	.

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Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
All PD	Genera Richness	RelSpecific Conductivity	-0.5879	0.0739	.	.
All PD	Genera Richness	RelTKN	-0.5879	0.0739	.	.
All PD	Genera Richness	a Soils(H O pH)	0.7818	0.0075	.	.
All PD	Genera Richness	a Soils(H O pH)	0.5152	0.1276	.	.
All PD	Genera Richness	a Soils(H O pH, stream)	0.6121	0.06	.	.
All PD	Genera Richness	a Soils(H O pH, stream)	0.5515	0.0984	.	.
All PD	Genera Richness	a Soils(H O pH, wet)	0.5758	0.0816	.	.
All PD	OET Richness	RelAmmonia	-0.6801	0.0305	.	.
All PD	OET Richness	RelCopper	-0.5975	0.0681	.	.
All PD	OET Richness	RelFecalColiform	-0.6039	0.0645	.	.
All PD	OET Richness	RelNutrientsMetalsFCTSSCondo	-0.5276	0.1171	.	.
All PD	OET Richness	RelPhosphorous	-0.5276	0.1171	.	.
All PD	POET Richness	RelCopper	-0.6608	0.0375	.	.
All PD	POET Richness	RelCuPbZn	-0.5664	0.0878	.	.
All PD	POET Richness	RelDoc	-0.6042	0.0643	.	.
All PD	POET Richness	RelMetals	-0.6294	0.0512	.	.
All PD	POET Richness	RelNutrientsCuPbZnFCTSSCondo	-0.579	0.0794	.	.
All PD	POET Richness	RelNutrientsMetalsFCTSSCondo	-0.7049	0.0228	.	.
All PD	POET Richness	RelPhosphorous	-0.5098	0.1322	.	.
All PD	POET Richness	RelSpecific Conductivity	-0.793	0.0062	.	.
All PD	POET Richness	RelTKN	-0.793	0.0062	.	.
All PD	POET Richness	RelTOC	-0.5098	0.1322	.	.
All PD	POET Richness	RelTSS	-0.4972	0.1437	.	.
All PD	POET Richness	RelTurbidity	-0.6608	0.0375	.	.
All PD	Predator Richness	RelAmmonia	-0.4985	0.1425	.	.
All PD	Predator Richness	RelCopper	-0.4924	0.1482	.	.
All PD	Predator Richness	RelCuPbZn	-0.5957	0.0692	.	.
All PD	Predator Richness	RelNutrientsCuPbZnFCTSSCondo	-0.6383	0.047	.	.
All PD	Predator Richness	RelNutrientsMetalsFCTSSCondo	-0.6261	0.0528	.	.
All PD	Predator Richness	RelPhosphorous	-0.6626	0.0368	.	.
All PD	Predator Richness	RelSpecific Conductivity	-0.7356	0.0153	.	.
All PD	Predator Richness	RelTKN	-0.7356	0.0153	.	.
All PD	Predator Richness	RelTurbidity	-0.535	0.1111	.	.
All PD	Predator Richness	a Soils(H O pH)	0.7134	0.0205	.	.
All PD	Predator Richness	a Soils(H O pH, stream)	0.5061	0.1355	.	.
All PD	Predator Richness	a Soils(H O pH, wet)	0.5	0.1411	.	.
All PD	Sensitive :Tolerant	RelAmmonia	-0.7816	0.0076	.	.
All PD	Sensitive :Tolerant	RelCopper	-0.494	0.1467	.	.
All PD	Sensitive :Tolerant	RelCuPbZn	-0.494	0.1467	.	.
All PD	Sensitive :Tolerant	RelPhosphorous	-0.494	0.1467	.	.
All PD	Sensitive :Tolerant	a Soils(H O pH)	0.594	0.0702	.	.
All PD	Sensitive :Tolerant	a Soils(H O pH, stream)	0.5378	0.1089	.	.
All PD	Simpson's Index of Diversity	50 M LDI	-0.6727	0.033	.	.
All PD	Simpson's Index of Diversity	RelMagnesium	-0.5515	0.0984	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
All PD	Simpson's Index of Diversity	a Soils(H O pH)	0.503	0.1383	.	.
All PD	Site Abundance	RelAmmonia	-0.7576	0.0111	.	.
All PD	Site Abundance	RelCopper	-0.5758	0.0816	.	.
All PD	Site Abundance	RelCuPbZn	-0.503	0.1383	.	.
All PD	Site Abundance	RelNutrients	-0.5152	0.1276	.	.
All PD	Site Abundance	RelNutrientsCuPbZnFCTSSCondo	-0.6606	0.0376	.	.
All PD	Site Abundance	RelNutrientsMetalsFCTSSCondo	-0.5152	0.1276	.	.
All PD	Site Abundance	RelPhosphorous	-0.6242	0.0537	.	.
All PD	Site Abundance	RelSpecific Conductivity	-0.6242	0.0537	.	.
All PD	Site Abundance	RelTKN	-0.6242	0.0537	.	.
All PD	Site Abundance	a Soils(H O pH)	0.5758	0.0816	.	.
All PD	Site Abundance	a Soils(H O pH)	0.5152	0.1276	.	.
All PD	Site Abundance	a Soils(H O pH, stream)	0.5273	0.1173	.	.
All PD	Species Richness	RelAmmonia	-0.7333	0.0158	.	.
All PD	Species Richness	RelNutrientsCuPbZnFCTSSCondo	-0.5152	0.1276	.	.
All PD	Species Richness	RelPhosphorous	-0.6121	0.06	.	.
All PD	Species Richness	RelSpecific Conductivity	-0.5879	0.0739	.	.
All PD	Species Richness	RelTKN	-0.5879	0.0739	.	.
All PD	Species Richness	a Soils(H O pH)	0.7576	0.0111	.	.
All PD	Species Richness	a Soils(H O pH)	0.5152	0.1276	.	.
All PD	Species Richness	a Soils(H O pH, stream)	0.5758	0.0816	.	.
All PD	Species Richness	a Soils(H O pH, stream)	0.5515	0.0984	.	.
All PD	Species Richness	a Soils(H O pH, wet)	0.5758	0.0816	.	.
Sweep PD	% Crustraceae	50 M LDI	-0.5471	0.1017	.	.
Sweep PD	% Crustraceae	Soils(Cu, stream)	-0.5636	0.0897	.	.
Sweep PD	% Crustraceae	Soils(Zn)	-0.6848	0.0289	.	.
Sweep PD	% Crustraceae	Soils(Zn, stream)	-0.4909	0.1497	.	.
Sweep PD	% Crustraceae	Soils(Zn, wet)	-0.6727	0.033	.	.
Sweep PD	% Dominance of Top 3 Taxa	a Soils(H O pH)	-0.6485	0.0425	.	.
Sweep PD	% Dominance of Top 3 Taxa	a Soils(H O pH, stream)	-0.5273	0.1173	.	.
Sweep PD	% Predator	50 M LDI	-0.6606	0.0376	.	.
Sweep PD	% Predator	RelCalcium	-0.7939	0.0061	.	.
Sweep PD	% Predator	RelMagnesium	-0.8545	0.0016	.	.
Sweep PD	% Sensitive	RelAmmonia	-0.653	0.0407	.	.
Sweep PD	% Sensitive	a Soils(H O pH)	0.6013	0.066	.	.
Sweep PD	% Sensitive	a Soils(H O pH, stream)	0.5366	0.1098	.	.
Sweep PD	% Tolerant	RelCopper	0.503	0.1383	.	.
Sweep PD	% Tolerant	RelCuPbZn	0.6485	0.0425	.	.
Sweep PD	% Tolerant	RelDoc	0.5152	0.1276	.	.
Sweep PD	% Tolerant	RelMagnesium	0.503	0.1383	.	.
Sweep PD	% Tolerant	RelMetals	0.7091	0.0217	.	.
Sweep PD	% Tolerant	RelNutrientsMetalsFCTSSCondo	0.5394	0.1076	.	.
Sweep PD	% Tolerant	RelPhosphorous	0.6364	0.0479	.	.
Sweep PD	% Tolerant	RelSpecific Conductivity	0.4909	0.1497	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep PD	% Tolerant	RelTKN	0.4909	0.1497	.	.
Sweep PD	% Tolerant	RelTSS	0.5758	0.0816	.	.
Sweep PD	% Tolerant	RelTurbidity	0.7818	0.0075	.	.
Sweep PD	% Tolerant	RelZinc	0.7212	0.0186	.	.
Sweep PD	%Chronomidae	50 M LDI	0.614	0.059	.	.
Sweep PD	%Chronomidae	Soils(Cu)	0.6485	0.0425	.	.
Sweep PD	%Chronomidae	Soils(Cu, stream)	0.6364	0.0479	.	.
Sweep PD	%Chronomidae	Soils(Cu, wet)	0.7455	0.0133	.	.
Sweep PD	%Coleoptera	50 M LDI	-0.5046	0.1369	.	.
Sweep PD	%Coleoptera	RelpH	0.503	0.1383	.	.
Sweep PD	%Coleoptera	Soils(Cu, stream)	-0.7306	0.0164	.	.
Sweep PD	%Coleoptera	Soils(Cu, stream)	-0.4909	0.1497	.	.
Sweep PD	%Coleoptera	Soils(Cu, wet)	-0.8599	0.0014	.	.
Sweep PD	%Coleoptera	Soils(Zn, stream)	-0.5636	0.0897	.	.
Sweep PD	%Coleoptera	Soils(Zn, wet)	-0.7693	0.0093	.	.
Sweep PD	%Coleoptera	a ORAM (w/ outliers)	0.5107	0.1314	.	.
Sweep PD	%Decapoda	50 M LDI	-0.5836	0.0765	.	.
Sweep PD	%Decapoda	Soils(Cu, stream)	-0.5879	0.0739	.	.
Sweep PD	%Decapoda	Soils(Zn)	-0.503	0.1383	.	.
Sweep PD	%Diptera	300 M LDI	0.5273	0.1173	.	.
Sweep PD	%Diptera	Soils(Cu)	0.5879	0.0739	.	.
Sweep PD	%Diptera	Soils(Cu, wet)	0.6606	0.0376	.	.
Sweep PD	%Diptera	Soils(Zn, wet)	0.5394	0.1076	.	.
Sweep PD	%Diptera	Watershed LDI	0.5152	0.1276	.	.
Sweep PD	%Diptera	a ORAM (no outliers)	-0.5515	0.0984	.	.
Sweep PD	%Diptera	a ORAM (w/ outliers)	-0.5636	0.0897	.	.
Sweep PD	%Dytiscidae	50 M LDI	-0.5793	0.0793	.	.
Sweep PD	%Dytiscidae	Soils(Cu, stream)	-0.5599	0.0924	.	.
Sweep PD	%Dytiscidae	Soils(Cu, stream)	-0.614	0.059	.	.
Sweep PD	%Dytiscidae	Soils(Cu, wet)	-0.7101	0.0214	.	.
Sweep PD	%Dytiscidae	Soils(Zn, stream)	-0.5228	0.121	.	.
Sweep PD	%Dytiscidae	Soils(Zn, wet)	-0.5121	0.1302	.	.
Sweep PD	%EOT	RelAmmonia	-0.5253	0.119	.	.
Sweep PD	%EOT	RelCopper	-0.5315	0.1139	.	.
Sweep PD	%EOT	RelFecalColiform	-0.6378	0.0472	.	.
Sweep PD	%EOT	RelNutrients	-0.5378	0.1089	.	.
Sweep PD	%EPT	RelAmmonia	-0.6828	0.0296	.	.
Sweep PD	%EPT	RelPhosphorous	-0.4916	0.149	.	.
Sweep PD	%EPT	a Soils(H O pH)	0.6833	0.0294	.	.
Sweep PD	%EPT	a Soils(H O pH, stream)	0.5882	0.0737	.	.
Sweep PD	%EPT	a Soils(H O pH, wet)	0.5882	0.0737	.	.
Sweep PD	%Hemiptera	300 M LDI	0.5222	0.1215	.	.
Sweep PD	%Hemiptera	50 M LDI	0.5238	0.1202	.	.
Sweep PD	%Hemiptera	Soils(Zn)	0.5222	0.1215	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep PD	%Hemiptera	Soils(Zn, wet)	0.5222	0.1215	.	.
Sweep PD	%Hemiptera	Watershed LDI	0.5222	0.1215	.	.
Sweep PD	%Hemiptera	a ORAM (no outliers)	-0.5222	0.1215	.	.
Sweep PD	%Hemiptera	a ORAM (w/ outliers)	-0.5222	0.1215	.	.
Sweep PD	%Microcrustaceae	RelCalcium	0.7254	0.0176	.	.
Sweep PD	%Microcrustaceae	RelDoc	0.6941	0.026	.	.
Sweep PD	%Microcrustaceae	RelMagnesium	0.6816	0.03	.	.
Sweep PD	%Microcrustaceae	RelpH	0.6253	0.0532	.	.
Sweep PD	%Microcrustaceae	Soils(Cu)	-0.5128	0.1296	.	.
Sweep PD	%Microcrustaceae	Soils(Zn)	-0.6197	0.056	.	.
Sweep PD	%Microcrustaceae	Soils(Zn)	-0.494	0.1467	.	.
Sweep PD	%Microcrustaceae	Soils(Zn, wet)	-0.5753	0.0819	.	.
Sweep PD	%Microcrustaceae	a Soils(H O pH)	0.5315	0.1139	.	.
Sweep PD	%Microcrustaceae	a Soils(H O pH, stream)	0.519	0.1242	.	.
Sweep PD	%Microcrustaceae	a Soils(H O pH, wet)	0.594	0.0702	.	.
Sweep PD	%Mollusk	RelAmmonia	-0.6688	0.0345	.	.
Sweep PD	%Mollusk	RelCuPbZn	-0.5338	0.112	.	.
Sweep PD	%Mollusk	RelFecalColiform	-0.5583	0.0935	.	.
Sweep PD	%Mollusk	RelNutrients	-0.5583	0.0935	.	.
Sweep PD	%Mollusk	RelNutrientsCuPbZnFCTSSCondo	-0.681	0.0302	.	.
Sweep PD	%Mollusk	RelNutrientsMetalsFCTSSCondo	-0.5461	0.1025	.	.
Sweep PD	%Mollusk	RelPhosphorous	-0.7792	0.0079	.	.
Sweep PD	%Mollusk	RelSpecific Conductivity	-0.5951	0.0695	.	.
Sweep PD	%Mollusk	RelTKN	-0.5951	0.0695	.	.
Sweep PD	%Mollusk	a Soils(H O pH)	0.6142	0.0589	.	.
Sweep PD	%Mollusk	a Soils(H O pH)	0.6197	0.056	.	.
Sweep PD	%Mollusk	a Soils(H O pH, stream)	0.5237	0.1203	.	.
Sweep PD	%Mollusk	a Soils(H O pH, stream)	0.6933	0.0262	.	.
Sweep PD	%Mollusk	a Soils(H O pH, wet)	0.4978	0.1431	.	.
Sweep PD	%Mollusk	a Soils(H O pH, wet)	0.5461	0.1025	.	.
Sweep PD	%Oligochaets	RelCuPbZn	0.5879	0.0739	.	.
Sweep PD	%Oligochaets	RelLead	0.5106	0.1315	.	.
Sweep PD	%Oligochaets	RelMetals	0.6	0.0667	.	.
Sweep PD	%Oligochaets	RelZinc	0.697	0.0251	.	.
Sweep PD	%Oligochaets	Soils(Zn, stream)	0.6018	0.0656	.	.
Sweep PD	%Orthocladiinae	Soils(Cu)	0.4909	0.1497	.	.
Sweep PD	%Orthocladiinae	Soils(Cu, wet)	0.6364	0.0479	.	.
Sweep PD	%Orthocladiinae	Soils(Zn, stream)	0.5775	0.0804	.	.
Sweep PD	%POET	RelAmmonia	-0.5503	0.0993	.	.
Sweep PD	%POET	RelCopper	-0.5065	0.1352	.	.
Sweep PD	%POET	RelFecalColiform	-0.5628	0.0903	.	.
Sweep PD	%Terrestrial	RelNutrientsCuPbZnFCTSSCondo	-0.5294	0.1155	.	.
Sweep PD	%Tricoptera	RelAmmonia	-0.6145	0.0587	.	.
Sweep PD	%Tricoptera	a Soils(H O pH)	0.6833	0.0294	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep PD	%Tricoptera	a Soils(H O pH, stream)	0.5882	0.0737	.	.
Sweep PD	%Tricoptera	a Soils(H O pH, wet)	0.5882	0.0737	.	.
Sweep PD	Biotic Index	RelCalcium	0.7576	0.0111	.	.
Sweep PD	Biotic Index	RelMagnesium	0.7576	0.0111	.	.
Sweep PD	Chironomidae Richness	RelAmmonia	-0.531	0.1143	.	.
Sweep PD	Chironomidae Richness	RelPhosphorous	-0.531	0.1143	.	.
Sweep PD	Chironomidae Richness	RelZinc	-0.5248	0.1194	.	.
Sweep PD	Chironomidae Richness	a Soils(H O pH)	0.7879	0.0068	.	.
Sweep PD	Chironomidae Richness	a Soils(H O pH)	0.673	0.033	.	.
Sweep PD	Chironomidae Richness	a Soils(H O pH, stream)	0.6816	0.03	.	.
Sweep PD	Chironomidae Richness	a Soils(H O pH, stream)	0.6915	0.0268	.	.
Sweep PD	Chironomidae Richness	a Soils(H O pH, wet)	0.6128	0.0596	.	.
Sweep PD	Chironomidae Richness	a Soils(H O pH, wet)	0.531	0.1143	.	.
Sweep PD	EPT Richness	RelAmmonia	-0.706	0.0225	.	.
Sweep PD	EPT Richness	RelPhosphorous	-0.5278	0.1169	.	.
Sweep PD	EPT Richness	a Soils(H O pH)	0.6963	0.0253	.	.
Sweep PD	EPT Richness	a Soils(H O pH, stream)	0.6093	0.0615	.	.
Sweep PD	EPT Richness	a Soils(H O pH, wet)	0.6093	0.0615	.	.
Sweep PD	Evenness	RelMagnesium	-0.5152	0.1276	.	.
Sweep PD	Evenness	Soils(Zn)	-0.4909	0.1497	.	.
Sweep PD	Family Richness	RelAmmonia	-0.7781	0.008	.	.
Sweep PD	Family Richness	RelPhosphorous	-0.6505	0.0417	.	.
Sweep PD	Family Richness	a Soils(H O pH)	0.7576	0.0111	.	.
Sweep PD	Family Richness	a Soils(H O pH)	0.6018	0.0656	.	.
Sweep PD	Family Richness	a Soils(H O pH, stream)	0.6485	0.0425	.	.
Sweep PD	Family Richness	a Soils(H O pH, stream)	0.6322	0.0498	.	.
Sweep PD	Family Richness	a Soils(H O pH, wet)	0.5394	0.1076	.	.
Sweep PD	Genera Richness	RelAmmonia	-0.7781	0.008	.	.
Sweep PD	Genera Richness	RelPhosphorous	-0.6505	0.0417	.	.
Sweep PD	Genera Richness	a Soils(H O pH)	0.8182	0.0038	.	.
Sweep PD	Genera Richness	a Soils(H O pH)	0.6018	0.0656	.	.
Sweep PD	Genera Richness	a Soils(H O pH, stream)	0.7212	0.0186	.	.
Sweep PD	Genera Richness	a Soils(H O pH, stream)	0.6322	0.0498	.	.
Sweep PD	Genera Richness	a Soils(H O pH, wet)	0.6121	0.06	.	.
Sweep PD	OET Richness	RelAmmonia	-0.653	0.0407	.	.
Sweep PD	OET Richness	RelCopper	-0.5948	0.0697	.	.
Sweep PD	OET Richness	RelFecalColiform	-0.6788	0.0309	.	.
Sweep PD	OET Richness	RelNutrients	-0.5495	0.0999	.	.
Sweep PD	OET Richness	RelNutrientsMetalsFCTSSCondo	-0.5431	0.1048	.	.
Sweep PD	OET Richness	RelPhosphorous	-0.5431	0.1048	.	.
Sweep PD	POET Richness	RelAmmonia	-0.6928	0.0263	.	.
Sweep PD	POET Richness	RelCopper	-0.5594	0.0927	.	.
Sweep PD	POET Richness	RelFecalColiform	-0.5403	0.1069	.	.
Sweep PD	POET Richness	RelPhosphorous	-0.5784	0.0798	.	.

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep PD	Predator Richness	RelAmmonia	-0.6566	0.0392	.	.
Sweep PD	Predator Richness	RelCuPbZn	-0.519	0.1242	.	.
Sweep PD	Predator Richness	RelPhosphorous	-0.7441	0.0136	.	.
Sweep PD	Predator Richness	RelTurbidity	-0.5065	0.1352	.	.
Sweep PD	Predator Richness	a Soils(H O pH)	0.872	0.001	.	.
Sweep PD	Predator Richness	a Soils(H O pH, stream)	0.7012	0.0239	.	.
Sweep PD	Predator Richness	a Soils(H O pH, wet)	0.6646	0.036	.	.
Sweep PD	Sensitive :Tolerant	RelAmmonia	-0.7306	0.0164	.	.
Sweep PD	Sensitive :Tolerant	RelPhosphorous	-0.4978	0.1431	.	.
Sweep PD	Sensitive :Tolerant	a Soils(H O pH)	0.6142	0.0589	.	.
Sweep PD	Sensitive :Tolerant	a Soils(H O pH, stream)	0.5625	0.0905	.	.
Sweep PD	Simpson's Index of Diversity	RelCalcium	-0.5879	0.0739	.	.
Sweep PD	Simpson's Index of Diversity	RelMagnesium	-0.6242	0.0537	.	.
Sweep PD	Simpson's Index of Diversity	Soils(Cu)	-0.4909	0.1497	.	.
Sweep PD	Simpson's Index of Diversity	a Soils(H O pH)	0.4909	0.1497	.	.
Sweep PD	Site Abundance	RelAmmonia	-0.8303	0.0029	.	.
Sweep PD	Site Abundance	RelPhosphorous	-0.6	0.0667	.	.
Sweep PD	Site Abundance	Soils(Cu)	-0.4909	0.1497	.	.
Sweep PD	Site Abundance	a Soils(H O pH)	0.5636	0.0897	.	.
Sweep PD	Site Abundance	a Soils(H O pH)	0.503	0.1383	.	.
Sweep PD	Site Abundance	a Soils(H O pH, stream)	0.4909	0.1497	.	.
Sweep PD	Species Richness	RelAmmonia	-0.7781	0.008	.	.
Sweep PD	Species Richness	RelPhosphorous	-0.6505	0.0417	.	.
Sweep PD	Species Richness	a Soils(H O pH)	0.7576	0.0111	.	.
Sweep PD	Species Richness	a Soils(H O pH)	0.6018	0.0656	.	.
Sweep PD	Species Richness	a Soils(H O pH, stream)	0.6485	0.0425	.	.
Sweep PD	Species Richness	a Soils(H O pH, stream)	0.6322	0.0498	.	.
Sweep PD	Species Richness	a Soils(H O pH, wet)	0.5394	0.1076	.	.
ALL Trans PD	% Crustraceae	50 M LDI Trans	.	.	-0.7084	0.0219
ALL Trans PD	% Crustraceae	Watershed LDI Trans	.	.	-0.5253	0.119
ALL Trans PD	% Predator	RelCalcium trans	.	.	-0.6153	0.0583
ALL Trans PD	% Predator	RelMagnesium trans	.	.	-0.7602	0.0107
ALL Trans PD	% Predator	RelMetals trans	.	.	-0.5399	0.1072
ALL Trans PD	% Predator	RelTurbidity trans	.	.	-0.6512	0.0414
ALL Trans PD	% Predator	RelZinc trans	.	.	-0.515	0.1276
ALL Trans PD	% Sensitive	RelAmmonia trans	.	.	-0.7202	0.0188
ALL Trans PD	% Sensitive	RelSpecific Conductivity trans	.	.	-0.5079	0.1339
ALL Trans PD	% Sensitive	RelTKN trans	.	.	-0.5079	0.1339
ALL Trans PD	% Sensitive	a trans soils mean ph	.	.	0.5196	0.1237
ALL Trans PD	% Sensitive	a trans soils ph stream	.	.	0.5113	0.1309
ALL Trans PD	% Tolerant	RelCopper trans	.	.	0.7098	0.0215
ALL Trans PD	% Tolerant	RelCuPbZn trans	.	.	0.6994	0.0244
ALL Trans PD	% Tolerant	RelDoc trans	.	.	0.5733	0.0832
ALL Trans PD	% Tolerant	RelLead trans	.	.	0.5901	0.0725

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
ALL Trans PD	% Tolerant	RelMetals trans	.	.	0.6552	0.0397
ALL Trans PD	% Tolerant	RelNutrients trans	.	.	0.6673	0.035
ALL Trans PD	% Tolerant	RelNutrientsCuPbZnFCTSSCondo trans	.	.	0.8115	0.0044
ALL Trans PD	% Tolerant	RelNutrientsMetalsFCTSSCondo trans	.	.	0.8456	0.0021
ALL Trans PD	% Tolerant	RelPhosphorous trans	.	.	0.8208	0.0036
ALL Trans PD	% Tolerant	RelSpecific Conductivity trans	.	.	0.6529	0.0407
ALL Trans PD	% Tolerant	RelTKN trans	.	.	0.6529	0.0407
ALL Trans PD	% Tolerant	RelTOC trans	.	.	0.729	0.0168
ALL Trans PD	% Tolerant	RelTSS trans	.	.	0.6348	0.0486
ALL Trans PD	% Tolerant	RelTurbidity trans	.	.	0.766	0.0098
ALL Trans PD	% Tolerant	RelZinc trans	.	.	0.6466	0.0434
ALL Trans PD	% Tolerant	a trans soils ph stream	.	.	-0.5039	0.1376
ALL Trans PD	%Chronomidae	50 M LDI Trans	.	.	0.5874	0.0742
ALL Trans PD	%Chronomidae	Watershed LDI Trans	.	.	0.5559	0.0952
ALL Trans PD	%Coleoptera	50 M LDI Trans	.	.	-0.5745	0.0824
ALL Trans PD	%Coleoptera	RelFecalColiform trans	.	.	-0.5431	0.1048
ALL Trans PD	%Coleoptera	a Dissolved Oxygen (mg/L) 2 trans	.	.	0.5304	0.1147
ALL Trans PD	%Coleoptera	a RelDissolved Oxygen (%) trans	.	.	0.5712	0.0846
ALL Trans PD	%Coleoptera	trans soils mean cu	.	.	-0.4945	0.1462
ALL Trans PD	%Decapoda	50 M LDI Trans	.	.	-0.7839	0.0073
ALL Trans PD	%Decapoda	trans soils mean zn	.	.	-0.4989	0.1422
ALL Trans PD	%Decapoda	trans soils zn wet	.	.	-0.5304	0.1147
ALL Trans PD	%Dytiscidae	50 M LDI Trans	.	.	-0.5685	0.0864
ALL Trans PD	%Dytiscidae	a Dissolved Oxygen (mg/L) 2 trans	.	.	0.5818	0.0777
ALL Trans PD	%Dytiscidae	a RelDissolved Oxygen (%) trans	.	.	0.6236	0.054
ALL Trans PD	%Dytiscidae	trans soils mean cu	.	.	-0.6663	0.0354
ALL Trans PD	%EOT	RelAmmonia trans	.	.	-0.6336	0.0492
ALL Trans PD	%EOT	RelCopper trans	.	.	-0.5188	0.1244
ALL Trans PD	%EOT	RelFecalColiform trans	.	.	-0.6894	0.0274
ALL Trans PD	%EOT	RelPhosphorous trans	.	.	-0.5086	0.1333
ALL Trans PD	%EPT	RelAmmonia trans	.	.	-0.7214	0.0185
ALL Trans PD	%EPT	RelFecalColiform trans	.	.	-0.7008	0.024
ALL Trans PD	%Hemiptera	50 M LDI Trans	.	.	0.6078	0.0623
ALL Trans PD	%Hemiptera	Watershed LDI Trans	.	.	0.6148	0.0586
ALL Trans PD	%Hemiptera	a RelpH trans	.	.	-0.5157	0.1271
ALL Trans PD	%Hemiptera	trans soils mean zn	.	.	0.5106	0.1316
ALL Trans PD	%Hemiptera	trans soils zn stream	.	.	0.5367	0.1097
ALL Trans PD	%Leech	RelFecalColiform trans	.	.	0.4948	0.146
ALL Trans PD	%Leech	RelPhosphorous trans	.	.	0.5311	0.1141
ALL Trans PD	%Microcrustaceae	RelCalcium trans	.	.	0.6651	0.0359
ALL Trans PD	%Microcrustaceae	RelMagnesium trans	.	.	0.7013	0.0238
ALL Trans PD	%Microcrustaceae	a trans soils mean ph	.	.	0.5164	0.1265
ALL Trans PD	%Microcrustaceae	a trans soils ph stream	.	.	0.5024	0.1389
ALL Trans PD	%Microcrustaceae	trans soils mean cu	.	.	0.5164	0.1265

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
ALL Trans PD	%Mollusk	RelAmmonia trans	.	.	-0.7175	0.0195
ALL Trans PD	%Mollusk	RelFecalColiform trans	.	.	-0.5933	0.0706
ALL Trans PD	%Mollusk	RelNutrients trans	.	.	-0.5175	0.1255
ALL Trans PD	%Mollusk	RelPhosphorous trans	.	.	-0.6962	0.0253
ALL Trans PD	%Mollusk	a Dissolved Oxygen (mg/L) 2 trans	.	.	0.501	0.1402
ALL Trans PD	%Oligochaets	RelTSS trans	.	.	0.5124	0.13
ALL Trans PD	%POET	RelAmmonia trans	.	.	-0.645	0.044
ALL Trans PD	%POET	RelCopper trans	.	.	-0.5231	0.1208
ALL Trans PD	%POET	RelFecalColiform trans	.	.	-0.6684	0.0346
ALL Trans PD	%POET	RelPhosphorous trans	.	.	-0.5147	0.1279
ALL Trans PD	%Terrestrial	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5783	0.0799
ALL Trans PD	%Terrestrial	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5517	0.0983
ALL Trans PD	%Terrestrial	RelSpecific Conductivity trans	.	.	-0.6011	0.066
ALL Trans PD	%Terrestrial	RelTKN trans	.	.	-0.6011	0.066
ALL Trans PD	%Terrestrial	RelTOC trans	.	.	-0.4999	0.1412
ALL Trans PD	%Terrestrial	RelTurbidity trans	.	.	-0.5663	0.0879
ALL Trans PD	%Tricoptera	RelAmmonia trans	.	.	-0.6876	0.028
ALL Trans PD	%Tricoptera	RelFecalColiform trans	.	.	-0.7509	0.0123
ALL Trans PD	Biotic Index	RelCalcium trans	.	.	0.5592	0.0928
ALL Trans PD	Biotic Index	RelDoc trans	.	.	0.5485	0.1007
ALL Trans PD	Biotic Index	RelMagnesium trans	.	.	0.5178	0.1252
ALL Trans PD	Biotic Index	RelTOC trans	.	.	0.6099	0.0612
ALL Trans PD	Chironomidae Richness	RelAmmonia trans	.	.	-0.8046	0.005
ALL Trans PD	Chironomidae Richness	RelCopper trans	.	.	-0.5867	0.0746
ALL Trans PD	Chironomidae Richness	RelCuPbZn trans	.	.	-0.6039	0.0645
ALL Trans PD	Chironomidae Richness	RelLead trans	.	.	-0.5815	0.0778
ALL Trans PD	Chironomidae Richness	RelNutrients trans	.	.	-0.5112	0.131
ALL Trans PD	Chironomidae Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5731	0.0833
ALL Trans PD	Chironomidae Richness	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5431	0.1048
ALL Trans PD	Chironomidae Richness	RelPhosphorous trans	.	.	-0.7532	0.0119
ALL Trans PD	Chironomidae Richness	RelSpecific Conductivity trans	.	.	-0.6212	0.0553
ALL Trans PD	Chironomidae Richness	RelTKN trans	.	.	-0.6212	0.0553
ALL Trans PD	Chironomidae Richness	RelZinc trans	.	.	-0.4978	0.1431
ALL Trans PD	Chironomidae Richness	a trans soils mean ph	.	.	0.6506	0.0416
ALL Trans PD	Chironomidae Richness	a trans soils ph stream	.	.	0.717	0.0196
ALL Trans PD	Chironomidae Richness	a trans soils ph wet	.	.	0.5697	0.0855
ALL Trans PD	EPT Richness	RelAmmonia trans	.	.	-0.7565	0.0113
ALL Trans PD	EPT Richness	RelCopper trans	.	.	-0.5166	0.1263
ALL Trans PD	EPT Richness	RelDoc trans	.	.	-0.551	0.0988
ALL Trans PD	EPT Richness	RelFecalColiform trans	.	.	-0.6433	0.0448
ALL Trans PD	EPT Richness	RelPhosphorous trans	.	.	-0.5378	0.1089
ALL Trans PD	Evenness	trans soils mean zn	.	.	-0.512	0.1303
ALL Trans PD	Evenness	trans soils zn stream	.	.	-0.4952	0.1455
ALL Trans PD	Evenness	trans soils zn wet	.	.	-0.5017	0.1396

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
ALL Trans PD	Family Richness	RelAmmonia trans	.	.	-0.5789	0.0795
ALL Trans PD	Family Richness	RelFecalColiform trans	.	.	-0.5593	0.0928
ALL Trans PD	Family Richness	RelNutrients trans	.	.	-0.5397	0.1073
ALL Trans PD	Family Richness	RelPhosphorous trans	.	.	-0.5252	0.119
ALL Trans PD	Family Richness	a Dissolved Oxygen (mg/L) 2 trans	.	.	0.6508	0.0416
ALL Trans PD	Family Richness	a RelDissolved Oxygen (%) trans	.	.	0.627	0.0524
ALL Trans PD	Genera Richness	RelAmmonia trans	.	.	-0.7013	0.0238
ALL Trans PD	Genera Richness	RelNutrients trans	.	.	-0.5058	0.1358
ALL Trans PD	Genera Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5051	0.1365
ALL Trans PD	Genera Richness	RelPhosphorous trans	.	.	-0.6272	0.0523
ALL Trans PD	Genera Richness	RelSpecific Conductivity trans	.	.	-0.5725	0.0837
ALL Trans PD	Genera Richness	RelTKN trans	.	.	-0.5725	0.0837
ALL Trans PD	Genera Richness	a trans soils ph stream	.	.	0.5548	0.096
ALL Trans PD	OET Richness	RelAmmonia trans	.	.	-0.6972	0.025
ALL Trans PD	OET Richness	RelCopper trans	.	.	-0.6456	0.0438
ALL Trans PD	OET Richness	RelCuPbZn trans	.	.	-0.5208	0.1227
ALL Trans PD	OET Richness	RelFecalColiform trans	.	.	-0.642	0.0454
ALL Trans PD	OET Richness	RelMetals trans	.	.	-0.5584	0.0934
ALL Trans PD	OET Richness	RelNutrients trans	.	.	-0.5368	0.1097
ALL Trans PD	OET Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5586	0.0933
ALL Trans PD	OET Richness	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.6073	0.0626
ALL Trans PD	OET Richness	RelPhosphorous trans	.	.	-0.6117	0.0602
ALL Trans PD	POET Richness	RelCopper trans	.	.	-0.7214	0.0185
ALL Trans PD	POET Richness	RelCuPbZn trans	.	.	-0.6773	0.0314
ALL Trans PD	POET Richness	RelDoc trans	.	.	-0.6751	0.0322
ALL Trans PD	POET Richness	RelLead trans	.	.	-0.6694	0.0342
ALL Trans PD	POET Richness	RelMetals trans	.	.	-0.7207	0.0187
ALL Trans PD	POET Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.707	0.0222
ALL Trans PD	POET Richness	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.7733	0.0087
ALL Trans PD	POET Richness	RelPhosphorous trans	.	.	-0.5412	0.1062
ALL Trans PD	POET Richness	RelSpecific Conductivity trans	.	.	-0.7252	0.0176
ALL Trans PD	POET Richness	RelTKN trans	.	.	-0.7252	0.0176
ALL Trans PD	POET Richness	RelTOC trans	.	.	-0.596	0.069
ALL Trans PD	POET Richness	RelTSS trans	.	.	-0.7042	0.023
ALL Trans PD	POET Richness	RelTurbidity trans	.	.	-0.6874	0.028
ALL Trans PD	Predator Richness	RelDoc trans	.	.	-0.5494	0.1
ALL Trans PD	Predator Richness	RelFecalColiform trans	.	.	-0.5069	0.1348
ALL Trans PD	Predator Richness	RelLead trans	.	.	-0.5043	0.1372
ALL Trans PD	Predator Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5687	0.0863
ALL Trans PD	Predator Richness	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5951	0.0695
ALL Trans PD	Predator Richness	RelPhosphorous trans	.	.	-0.6231	0.0543
ALL Trans PD	Predator Richness	RelTurbidity trans	.	.	-0.628	0.0519
ALL Trans PD	Sensitive :Tolerant	RelAmmonia trans	.	.	-0.6609	0.0375
ALL Trans PD	Sensitive :Tolerant	RelCopper trans	.	.	-0.6008	0.0662

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
ALL Trans PD	Sensitive :Tolerant	RelCuPbZn trans	.	.	-0.5651	0.0887
ALL Trans PD	Sensitive :Tolerant	RelMetals trans	.	.	-0.5162	0.1266
ALL Trans PD	Sensitive :Tolerant	RelSpecific Conductivity trans	.	.	-0.5563	0.0949
ALL Trans PD	Sensitive :Tolerant	RelTKN trans	.	.	-0.5563	0.0949
ALL Trans PD	Sensitive :Tolerant	RelZinc trans	.	.	-0.5374	0.1091
ALL Trans PD	Sensitive :Tolerant	a trans soils mean ph	.	.	0.6834	0.0294
ALL Trans PD	Sensitive :Tolerant	a trans soils ph stream	.	.	0.6823	0.0297
ALL Trans PD	Sensitive :Tolerant	a trans soils ph wet	.	.	0.5706	0.085
ALL Trans PD	Site Abundance	RelAmmonia trans	.	.	-0.5723	0.0838
ALL Trans PD	Site Abundance	RelSpecific Conductivity trans	.	.	-0.5087	0.1332
ALL Trans PD	Site Abundance	RelTKN trans	.	.	-0.5087	0.1332
ALL Trans PD	Species Richness	RelAmmonia trans	.	.	-0.7142	0.0203
ALL Trans PD	Species Richness	RelNutrients trans	.	.	-0.5391	0.1079
ALL Trans PD	Species Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5543	0.0964
ALL Trans PD	Species Richness	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5062	0.1355
ALL Trans PD	Species Richness	RelPhosphorous trans	.	.	-0.6481	0.0427
ALL Trans PD	Species Richness	RelSpecific Conductivity trans	.	.	-0.6086	0.0619
ALL Trans PD	Species Richness	RelTKN trans	.	.	-0.6086	0.0619
ALL Trans PD	Species Richness	a trans soils ph stream	.	.	0.5457	0.1028
Sweep Trans PD	% Crustraceae	50 M LDI Trans	.	.	-0.796	0.0059
Sweep Trans PD	% Crustraceae	Watershed LDI Trans	.	.	-0.506	0.1357
Sweep Trans PD	% Crustraceae	trans soils mean zn	.	.	-0.561	0.0916
Sweep Trans PD	% Crustraceae	trans soils zn wet	.	.	-0.5834	0.0767
Sweep Trans PD	% Predator	RelCalcium trans	.	.	-0.5696	0.0857
Sweep Trans PD	% Predator	RelMagnesium trans	.	.	-0.7139	0.0204
Sweep Trans PD	% Predator	RelTurbidity trans	.	.	-0.6029	0.0651
Sweep Trans PD	% Predator	RelZinc trans	.	.	-0.4983	0.1427
Sweep Trans PD	% Sensitive	RelAmmonia trans	.	.	-0.671	0.0336
Sweep Trans PD	% Sensitive	a trans soils mean ph	.	.	0.5659	0.0882
Sweep Trans PD	% Sensitive	a trans soils ph stream	.	.	0.5383	0.1085
Sweep Trans PD	% Tolerant	RelCopper trans	.	.	0.6048	0.064
Sweep Trans PD	% Tolerant	RelCuPbZn trans	.	.	0.6218	0.0549
Sweep Trans PD	% Tolerant	RelDoc trans	.	.	0.548	0.101
Sweep Trans PD	% Tolerant	RelMetals trans	.	.	0.63	0.0509
Sweep Trans PD	% Tolerant	RelNutrientsCuPbZnFCTSSCondo trans	.	.	0.6096	0.0613
Sweep Trans PD	% Tolerant	RelNutrientsMetalsFCTSSCondo trans	.	.	0.6546	0.04
Sweep Trans PD	% Tolerant	RelPhosphorous trans	.	.	0.7477	0.0129
Sweep Trans PD	% Tolerant	RelSpecific Conductivity trans	.	.	0.5514	0.0985
Sweep Trans PD	% Tolerant	RelTKN trans	.	.	0.5514	0.0985
Sweep Trans PD	% Tolerant	RelTOC trans	.	.	0.5038	0.1376
Sweep Trans PD	% Tolerant	RelTSS trans	.	.	0.5444	0.1038
Sweep Trans PD	% Tolerant	RelTurbidity trans	.	.	0.7603	0.0107
Sweep Trans PD	% Tolerant	RelZinc trans	.	.	0.6705	0.0338
Sweep Trans PD	% Tolerant	a trans soils ph stream	.	.	-0.5031	0.1383

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep Trans PD	%Chronomidae	50 M LDI Trans	.	.	0.6315	0.0502
Sweep Trans PD	%Chronomidae	Watershed LDI Trans	.	.	0.5392	0.1077
Sweep Trans PD	%Coleoptera	RelFecalColiform trans	.	.	-0.6671	0.0351
Sweep Trans PD	%Coleoptera	RelTurbidity trans	.	.	-0.4942	0.1465
Sweep Trans PD	%Coleoptera	a Dissolved Oxygen (mg/L) 2 trans	.	.	0.6496	0.042
Sweep Trans PD	%Coleoptera	a RelDissolved Oxygen (%) trans	.	.	0.7139	0.0204
Sweep Trans PD	%Decapoda	50 M LDI Trans	.	.	-0.8163	0.004
Sweep Trans PD	%Decapoda	Watershed LDI Trans	.	.	-0.513	0.1295
Sweep Trans PD	%Decapoda	trans soils mean zn	.	.	-0.5392	0.1077
Sweep Trans PD	%Decapoda	trans soils zn wet	.	.	-0.572	0.0841
Sweep Trans PD	%Dytiscidae	50 M LDI Trans	.	.	-0.5563	0.0949
Sweep Trans PD	%Dytiscidae	a Dissolved Oxygen (mg/L) 2 trans	.	.	0.5521	0.098
Sweep Trans PD	%Dytiscidae	a RelDissolved Oxygen (%) trans	.	.	0.5898	0.0727
Sweep Trans PD	%Dytiscidae	trans soils mean cu	.	.	-0.6901	0.0272
Sweep Trans PD	%EOT	RelAmmonia trans	.	.	-0.6475	0.0429
Sweep Trans PD	%EOT	RelCopper trans	.	.	-0.539	0.1079
Sweep Trans PD	%EOT	RelFecalColiform trans	.	.	-0.7028	0.0234
Sweep Trans PD	%EOT	RelNutrients trans	.	.	-0.524	0.12
Sweep Trans PD	%EOT	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5137	0.1288
Sweep Trans PD	%EOT	RelPhosphorous trans	.	.	-0.5181	0.125
Sweep Trans PD	%EPT	RelAmmonia trans	.	.	-0.6965	0.0252
Sweep Trans PD	%EPT	RelFecalColiform trans	.	.	-0.5789	0.0795
Sweep Trans PD	%Hemiptera	300 M LDI Trans	.	.	0.7376	0.0149
Sweep Trans PD	%Hemiptera	50 M LDI Trans	.	.	0.8328	0.0028
Sweep Trans PD	%Hemiptera	Watershed LDI Trans	.	.	0.7024	0.0235
Sweep Trans PD	%Hemiptera	a trans ORAM (no outliers)	.	.	-0.5702	0.0852
Sweep Trans PD	%Hemiptera	trans soils mean zn	.	.	0.579	0.0794
Sweep Trans PD	%Hemiptera	trans soils zn wet	.	.	0.6817	0.0299
Sweep Trans PD	%Leech	trans soils mean cu	.	.	0.5678	0.0869
Sweep Trans PD	%Microcrustaceae	RelCalcium trans	.	.	0.7084	0.0218
Sweep Trans PD	%Microcrustaceae	RelDoc trans	.	.	0.5422	0.1054
Sweep Trans PD	%Microcrustaceae	RelMagnesium trans	.	.	0.6309	0.0505
Sweep Trans PD	%Microcrustaceae	a RelpH trans	.	.	0.5036	0.1378
Sweep Trans PD	%Microcrustaceae	a trans soils mean ph	.	.	0.6385	0.0469
Sweep Trans PD	%Microcrustaceae	a trans soils ph stream	.	.	0.5668	0.0876
Sweep Trans PD	%Microcrustaceae	trans soils mean cu	.	.	0.6385	0.0469
Sweep Trans PD	%Mollusk	RelAmmonia trans	.	.	-0.6749	0.0323
Sweep Trans PD	%Mollusk	RelFecalColiform trans	.	.	-0.573	0.0834
Sweep Trans PD	%Mollusk	RelNutrients trans	.	.	-0.5041	0.1374
Sweep Trans PD	%Mollusk	RelPhosphorous trans	.	.	-0.691	0.0269
Sweep Trans PD	%Mollusk	a Dissolved Oxygen (mg/L) 2 trans	.	.	0.5035	0.1379
Sweep Trans PD	%Mollusk	a RelDissolved Oxygen (%) trans	.	.	0.4985	0.1425
Sweep Trans PD	%Oligochaets	RelTSS trans	.	.	0.4928	0.1478
Sweep Trans PD	%POET	RelAmmonia trans	.	.	-0.6634	0.0365

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep Trans PD	%POET	RelCopper trans	.	.	-0.5455	0.1029
Sweep Trans PD	%POET	RelFecalColiform trans	.	.	-0.6714	0.0335
Sweep Trans PD	%POET	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5037	0.1377
Sweep Trans PD	%POET	RelPhosphorous trans	.	.	-0.5278	0.1169
Sweep Trans PD	%Terrestrial	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5619	0.091
Sweep Trans PD	%Terrestrial	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.5165	0.1264
Sweep Trans PD	%Terrestrial	RelPhosphorous trans	.	.	-0.4961	0.1447
Sweep Trans PD	%Terrestrial	RelTOC trans	.	.	-0.5626	0.0905
Sweep Trans PD	%Tricoptera	RelAmmonia trans	.	.	-0.6693	0.0343
Sweep Trans PD	%Tricoptera	RelFecalColiform trans	.	.	-0.6245	0.0536
Sweep Trans PD	Biotic Index	RelCalcium trans	.	.	0.6704	0.0339
Sweep Trans PD	Biotic Index	RelMagnesium trans	.	.	0.7334	0.0158
Sweep Trans PD	Chironomidae Richness	RelDoc trans	.	.	-0.5301	0.115
Sweep Trans PD	EPT Richness	RelAmmonia trans	.	.	-0.7088	0.0217
Sweep Trans PD	EPT Richness	RelCopper trans	.	.	-0.6425	0.0451
Sweep Trans PD	EPT Richness	RelCuPbZn trans	.	.	-0.5234	0.1205
Sweep Trans PD	EPT Richness	RelFecalColiform trans	.	.	-0.6385	0.0469
Sweep Trans PD	EPT Richness	RelMetals trans	.	.	-0.5584	0.0934
Sweep Trans PD	EPT Richness	RelNutrients trans	.	.	-0.5385	0.1083
Sweep Trans PD	EPT Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5554	0.0956
Sweep Trans PD	EPT Richness	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.6028	0.0651
Sweep Trans PD	EPT Richness	RelPhosphorous trans	.	.	-0.62	0.0559
Sweep Trans PD	Evenness	trans soils mean zn	.	.	-0.5595	0.0927
Sweep Trans PD	Evenness	trans soils zn wet	.	.	-0.6131	0.0594
Sweep Trans PD	Family Richness	RelAmmonia trans	.	.	-0.9088	0.0003
Sweep Trans PD	Family Richness	RelPhosphorous trans	.	.	-0.6128	0.0596
Sweep Trans PD	Family Richness	a trans soils mean ph	.	.	0.5948	0.0697
Sweep Trans PD	Family Richness	a trans soils ph stream	.	.	0.6669	0.0352
Sweep Trans PD	Genera Richness	RelAmmonia trans	.	.	-0.894	0.0005
Sweep Trans PD	Genera Richness	RelPhosphorous trans	.	.	-0.586	0.0751
Sweep Trans PD	Genera Richness	a trans soils mean ph	.	.	0.5855	0.0753
Sweep Trans PD	Genera Richness	a trans soils ph stream	.	.	0.6555	0.0396
Sweep Trans PD	OET Richness	RelAmmonia trans	.	.	-0.7007	0.024
Sweep Trans PD	OET Richness	RelCopper trans	.	.	-0.6422	0.0453
Sweep Trans PD	OET Richness	RelCuPbZn trans	.	.	-0.515	0.1277
Sweep Trans PD	OET Richness	RelFecalColiform trans	.	.	-0.6607	0.0376
Sweep Trans PD	OET Richness	RelMetals trans	.	.	-0.5478	0.1012
Sweep Trans PD	OET Richness	RelNutrients trans	.	.	-0.5625	0.0905
Sweep Trans PD	OET Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5665	0.0877
Sweep Trans PD	OET Richness	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.6126	0.0597
Sweep Trans PD	OET Richness	RelPhosphorous trans	.	.	-0.6175	0.0571
Sweep Trans PD	POET Richness	RelAmmonia trans	.	.	-0.7088	0.0217
Sweep Trans PD	POET Richness	RelCopper trans	.	.	-0.6425	0.0451
Sweep Trans PD	POET Richness	RelCuPbZn trans	.	.	-0.5234	0.1205

Appendix E Coastal Plain and Piedmont Significant Correlations for Macroinvertebrates All = All Data, Sweep = Sweep Samples Only, CP = Coastal Plain, PD = Piedmont, Trans = transformed data tested with Pearson' Correlation Coefficient and Pairwise Comparson's

Sample	Metric	Disturbance Measurement	Spearman ρ Correlation	Spearmans Prob>|ρ|	Pearson's Correlation	Pairwise comparisons Signif Prob
Sweep Trans PD	POET Richness	RelFecalColiform trans	.	.	-0.6385	0.0469
Sweep Trans PD	POET Richness	RelMetals trans	.	.	-0.5584	0.0934
Sweep Trans PD	POET Richness	RelNutrients trans	.	.	-0.5385	0.1083
Sweep Trans PD	POET Richness	RelNutrientsCuPbZnFCTSSCondo trans	.	.	-0.5554	0.0956
Sweep Trans PD	POET Richness	RelNutrientsMetalsFCTSSCondo trans	.	.	-0.6028	0.0651
Sweep Trans PD	POET Richness	RelPhosphorous trans	.	.	-0.62	0.0559
Sweep Trans PD	Predator Richness	RelAmmonia trans	.	.	-0.6425	0.0451
Sweep Trans PD	Predator Richness	RelFecalColiform trans	.	.	-0.5168	0.1261
Sweep Trans PD	Predator Richness	RelPhosphorous trans	.	.	-0.6844	0.029
Sweep Trans PD	Predator Richness	RelTurbidity trans	.	.	-0.5845	0.0759
Sweep Trans PD	Sensitive :Tolerant	RelAmmonia trans	.	.	-0.6604	0.0377
Sweep Trans PD	Sensitive :Tolerant	RelCopper trans	.	.	-0.6025	0.0653
Sweep Trans PD	Sensitive :Tolerant	RelCuPbZn trans	.	.	-0.5726	0.0836
Sweep Trans PD	Sensitive :Tolerant	RelDoc trans	.	.	-0.5014	0.1398
Sweep Trans PD	Sensitive :Tolerant	RelMetals trans	.	.	-0.5288	0.1161
Sweep Trans PD	Sensitive :Tolerant	RelSpecific Conductivity trans	.	.	-0.5523	0.0979
Sweep Trans PD	Sensitive :Tolerant	RelTKN trans	.	.	-0.5523	0.0979
Sweep Trans PD	Sensitive :Tolerant	RelZinc trans	.	.	-0.547	0.1018
Sweep Trans PD	Sensitive :Tolerant	a trans soils mean ph	.	.	0.6704	0.0339
Sweep Trans PD	Sensitive :Tolerant	a trans soils ph stream	.	.	0.6705	0.0338
Sweep Trans PD	Sensitive :Tolerant	a trans soils ph wet	.	.	0.5616	0.0911
Sweep Trans PD	Simpson's Index of Diversity	trans soils mean zn	.	.	-0.5024	0.1389
Sweep Trans PD	Simpson's Index of Diversity	trans soils zn wet	.	.	-0.5479	0.1011
Sweep Trans PD	Site Abundance	RelAmmonia trans	.	.	-0.8199	0.0037
Sweep Trans PD	Site Abundance	a trans soils ph stream	.	.	0.5033	0.1381
Sweep Trans PD	Species Richness	RelAmmonia trans	.	.	-0.9088	0.0003
Sweep Trans PD	Species Richness	RelPhosphorous trans	.	.	-0.6128	0.0596
Sweep Trans PD	Species Richness	a trans soils mean ph	.	.	0.5948	0.0697
Sweep Trans PD	Species Richness	a trans soils ph stream	.	.	0.6669	0.0352

Macroinvertebrate Multiple Regression Analysis Results

Coastal Plain – Disturbance General

1.) **Regression equation to predict ORAM without outliers**

ORAM = 99.179376-0.129885(Site Abundance)+ 0.9852465(Species Richness)+ 0.7440127(%Microcrustaceae) -0.708794(%Diptera) -0.647804(%Decapoda)

Rsq =0 .983 p=0.0013

Percent of Variance Accounted for by each Variable in Model:

Site Abundance	17%	p=0.0013
Species Richness	15%	p=0.0042
%Microcrustaceae	10%	p=0.0094
%Diptera	35%	p=0.0008
%Decapoda	21%	p=0.0017

2.) **Regression Equation to predict 50m LDI**

LDI_50m = 270.72654-173.3369(Simpson's Index of Diversity) -49.21813(EPT Richness)+ 17.720607(Biotic Index) -1.634921(% Tolerant)+ 106.85764(%Tricoptera)

Rsq =0 .968 p=0.0043

Percent of Variance Accounted for by each Variable in Model:

Simpson's Index of Diversity	19%	p=.0117
EPT Richness	7%	p=.0164
Biotic Index	7%	p=.0410
% Tolerant	48%	p=.0482
%Tricoptera	17%	p=.0025

3.) **Regression Equation to predict 300m LDI**

LDI 300m = 412.27448 + 25.912912 (OET Richness) -3.278049 (% Tolerant) – 2.005671 (% Microcrustaceae) -1.102924 (%Chronomidae)

Rsq = 0.994 p=0.0001

Percent of Variance Accounted for by each Variable in Model:

% Tolerant	65%	p=0.0001
OET Richness	18%	p=0.0001
% Microcrustaceae	9%	p=0.0001
%Chronomidae	7%	p=0.0006

4.) **Regression Equation to predict watershed LDI**

Watershed_LDI = 262.54681-194.3378(Simpson's Index of Diversity)+ 4.909616(Genera Richness) -1.219932(%Microcrustaceae)

Rsq = 0.959 p=0.0001

Percent of Variance Accounted for by each Variable in Model:

Simpson's Index of Diversity	60%	p=0.0001
Genera Richness	24%	p=0.0001
%Microcrustaceae	20%	p=0.0051

<u>Coastal Plain – Disturbance Soils</u>

5.) **Regression Equation to predict Soils pH**

Soils pH = 4.4966502-0.010187(% Tolerant)+ 0.3563166(%Hemiptera)+ 0.1761529(%Mollusk)

Rsq =0.96   p=0.0001

Percent of Variance Accounted for by each Variable in Model:

% Tolerant	58%	p=0.0034
%Hemiptera	23%	p=0.0004
%Mollusk	15%	p=0.0001

6.) **Regression Equation to predict Soils zinc levels**

Soils ZN = 4.8099518-6.377977(Evenness)+ 0.3731323(Biotic Index)+ 0.3043475(% Sensitive)

Rsq =0 .872   p=0.0043

Percent of Variance Accounted for by each Variable in Model:

Evenness	62%	p=0.0142
Biotic Index	11%	p=0.0433
% Sensitive	7%	p=0.0008

7.) **Regression Equation to predict Soils copper levels**

Soils CU = 0.736893-0.000424(Site Abundance)+ 0.1171743(POET Richness) - 0.279286(%Leech) -0.004775(%Chronomidae)

Rsq =0 .874   p=0.0043

Percent of Variance Accounted for by each Variable in Model:

Site Abundance	19%	p=0.0144
POET Richness	14%	p=0.0049
%Leech	44%	p=0.0010
%Chronomidae	12%	p=0.0309

8.) **Regression Equation to predict Soils pH from the downstream samples only**

Soils PH_Stream = 4.3988878-4.870031(Sensitive :Tolerant)+ 0.4262148(%Mollusk)

Rsq =0.713 p=0.0127

Percent of Variance Accounted for by each Variable in Model:

Sensitive Tolerant	20%	p=0.0618
%Mollusk	51%	p=0.0062

9.) **Regression Equation to predict Soils pH from the wetland samples only**

Soils pH Wet = 4.2343377-0.075291(Predator Richness)+ 0.514346(%Hemiptera)+ 0.3320336(%Mollusk)

Rsq = 0.923 p=0.001

Percent of Variance Accounted for by each Variable in Model:

Predator Richness	16%	p=0.0136
%Hemiptera	23%	p=0.0017
%Mollusk	53%	p=0.0003

10.) **Regression Equation to predict Soils Zinc levels from the stream samples only**

Soils ZN_Stream = 0.4572185+0.1450827(% Predator)+ 0.2189366(% Sensitive) – 0.93052(%Hemiptera)

Rsq = 0.909 p=0.0016

Percent of Variance Accounted for by each Variable in Model:

% Predator	18%	p=0.0050
% Sensitive	62%	p=0.0082
%Hemiptera	11%	p=0.0362

11.) **Regression Equation to predict Soils Zinc levels from the wetland samples only**

Soils ZN_Wet = 2.25760140.+2337053(% Sensitive) -0.046287(%Microcrustaceae) – 8.33224(% Colepotera)

Rsq = 0.913 p=0.0014

Percent of Variance Accounted for by each Variable in Model:

% Sensitive	40%	p=0.0017
%Microcrustaceae	34%	p=0.0020
% Colepotera	17%	p=0.0143

12.) **Regression Equation to predict Soils copper levels in stream sample only**

Soils CU_Stream =0.6072002-0.035888(Predator Richness)+ 0.4126272(%EPT)+ 0.3563769(%Hemiptera) -0.141344(%Dytiscidae)

Rsq =0.942 p=0.0027

Percent of Variance Accounted for by each Variable in Model:

Predator Richness	6%	p=0.0469
%EPT	18%	p=0.0072
%Hemiptera	29%	p=0.0024
%Dytiscidae	41%	p=0.0003

13.) **Regression Equation to predict Soils copper levels in wetland sample only**

Soils CU_Wet = -0.373625+0.0104502(% Dominance of Top 3 Taxa)+ 0.0509195(% Sensitive)+ 0.4156877(%Hemiptera) -0.151937(%Dytiscidae)

Rsq =0.959 p=0.0012

Percent of Variance Accounted for by each Variable in Model:

% Dominance of Top 3 Taxa	14%	p=0.0043
% Sensitive	10%	p=0.0037
%Hemiptera	20%	p=0.0007
%Dytiscidae	51%	p=0.0001

Coastal Plain – Disturbance Water Quality

14.) **Regression Equation to predict levels of relative nutrients**

Rel Nutrients = -0.678765+43.758807(%Leech)+ 0.4394038(%Diptera)+ 1.6949256(%Orthocladiinae) -366.1841(% Colepotera)

Rsq =0 .969 p=0.0006

Percent of Variance Accounted for by each Variable in Model:

%Leech	6%	p=0.0074
%Diptera	16%	p=0.0051
%Orthocladiinae	67%	p=0.0007
% Colepotera	7%	p=0.0186

15.) **Regression Equation to predict levels of relative metals**

Rel Metals = 19.708689+62.145478(Sensitive :Tolerant) -0.926467(%Oligochaets)+ 0.4774804(%Diptera)+ 0.7706454(%Orthocladiinae)

Rsq = 0.946 p=0.0022

Percent of Variance Accounted for by each Variable in Model:

Sensitive :Tolerant	12%	p=0.0309
%Oligochaets	13%	p=0.0142
%Diptera	44%	p=0.0013
%Orthocladiinae	26%	p=0.0170

16.) **Regression Equation to predict levels of relative levels of copper, zinc, and lead**

Rel CuPbZn = 48.194558-1.658801(Family Richness) -34.53216(%Leech)+ 0.4454163(%Orthocladiinae)+ 7.9220009

Rsq = 0.981 p=0.0002

Percent of Variance Accounted for by each Variable in Model

Family Richness	58%	p=0 .0001
%Leech	19%	p=0.0002
%Orthocladiinae	8%	p=0.0055
%Dytiscidae	13%	p=0.0007

17.) **Regression Equation to predict levels of relative pH**

Rel pH = 9.7715575+1.0705927(EPT Richness) -0.042449(% Tolerant)+ 1.1897936(%Hemiptera)

Rsq = .906 p=0.0018

Percent of Variance Accounted for by each Variable in Model:

EPT Richness	37%	p=0.0020
% Tolerant	33%	p=0.0056
%Hemiptera	15%	p=0.0023

Piedmont – Disturbance General

1.) **Regression Equation to predict ORAM disturbance without outliers**

ORAM = 49.131448+7.1666937(POET Richness) -4.32693(Predator Richness)+ 1.4741468(%Oligochaets)+ 0.4428189(%Diptera)

Rsq = 0.92 p=0.0059

Percent of Variance Accounted for by each Variable in Model

POET Richness	12%	p=0.0024
Predator Richness	26%	p=0.0049
%Oligochaets	38%	p=0.0015
%Diptera	16%	p=0.0267

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2.) **Regression Equation to predict 50m LDI**

LDI_50m = -114.6837+5.6601461(% Dominance of Top 3 Taxa) – 3.220687(%Tolerant)+ 5.0517224(%Chronomidae)

Rsq =0 .955 p=0.0002

Percent of Variance Accounted for by each Variable in Model

% Dominance of Top 3 Taxa	26%	p=0.0011
% Tolerant	57%	p=0.0075
%Chronomidae	12%	p=0.0006

3.) **Regression Equation to predict 300m LDI**

LDI_300m = 510.53529-40.87017(POET Richness)+ 41.309687(Biotic Index) – 7.311557(% Tolerant) -6.286723(%Oligochaets)

Rsq =0.961 p=0.001

Percent of Variance Accounted for by each Variable in Model

POET Richness	22%	p=0.0024
Biotic Index	6%	p=0.0390
% Tolerant	23%	p=0.0009
%Oligochaets	45%	p=0.0022

4.) **Regression Equation to predict watershed LDI**

LDI_Watershed = 967.37539-16.92829(Family Richness) -9.063873(% Tolerant) – 54.07238(%Terrestrial)

Rsq = 0.921 p=0.001

Percent of Variance Accounted for by each Variable in Model

Family Richness	35%	p=0.0013
% Tolerant	48%	p=0.0002
%Terrestrial	9%	p=0.0415

<u>Piedmont – Disturbance Soils</u>

5.) **Regression Equation to predict soils pH**

Soils_pH = 5.076375-0.000329(Site Abundance) -0.009911(% Predator) – 0.005199(% Crustraceae)+ 0.0097319(%Microcrustaceae)+ 0.0091859(%Mollusk)

Rsq =0 .933 p=0.0185

Percent of Variance Accounted for by each Variable in Model

Site Abundance	11%	p=0.0166
% Predator	14%	p=0.0449
% Crustraceae	10%	p=0.0851
%Microcrustaceae	16%	p=0.0356
%Mollusk	42%	p=0.0535

6.) Regression Equation to predict soils zinc level

Soils_ZN = 20.068034-24.12724(Simpson's Index of Diversity) + 0.1683005(Chironomidae Richness) + 0.0626826(% Predator)

Rsq = 0.821 p=0.0116

Percent of Variance Accounted for by each Variable in Model

Simpson's Index of Diversity	29%	p=0.0097
Chironomidae Richness	39%	p=0.0054
% Predator	14%	p=0.0771

7.) **Regression Equation to predict soils copper level**

Soils_CU = 1.4534378-0.235413(Biotic Index) + 0.0099185(%Decapoda)+ 0.0139295(%Chronomidae)

Rsq =0.963 p=0.0001

Percent of Variance Accounted for by each Variable in Model:

Biotic Index	11%	p=0.0004
%Decapoda	20%	p=0.0013
%Chronomidae	65%	p=0.0001

8.) **Regression Equation to predict soils pH stream sample only**

Soils PH_Stream = 5.453887-0.017668(% Predator) -0.009429(% Crustraceae) + 0.0069794(%Mollusk)

Rsq = 0.797 p=0.0169

Percent of Variance Accounted for by each Variable in Model:

% Predator	12%	0.0390
% Crustraceae	13%	0.0950
%Mollusk	54%	0.0322

9.) **Regression Equation to predict soils pH wetland sample only**

Soils PH_ Wet = 4.2343377-0.075291(Predator Richness)+ 0.514346(%Hemiptera)+ 0.3320336(%Mollusk)

Rsq =0 .923 p=0.001

Percent of Variance Accounted for by each Variable in Model:

Predator Richness	22%	p=0.0136
%Hemiptera	17%	p=0.0017
%Mollusk	53%	p=0.0003

10.) **Regression Equation to predict soils zinc stream sample only**

Soils ZN_Stream = 0.4572185+0.1450827(% Predator)+ 0.2189366(% Sensitive) – 0.93052(%Hemiptera)

Rsq = 0.909 p=0.0016

Percent of Variance Accounted for by each Variable in Model:

% Predator	18%	p=0.0050
% Sensitive	62%	p=0.0082
%Hemiptera	11%	p=0.0362

11.) **Regression Equation to predict soils zinc wetland sample only**

Soils ZN_Wet = 2.2576014+0.2337053(% Sensitive) -0.046287(%Microcrustaceae) – 8.33224(% Colepotera)

Rsq =0 .913 p=0.0014

Percent of Variance Accounted for by each Variable in Model

% Sensitive	40%	p=0.0017
%Microcrustaceae	34%	p=0.0020
% Colepotera	17%	p=0.0143

12.) **Regression Equation to predict soils copper stream sample only**

Soils CU_Stream =0.4824544+0.1505997(OET Richness) -0.405319(%Dytiscidae) +12.152903(% Colepotera)

Rsq =0 .868 p=0.0048

Percent of Variance Accounted for by each Variable in Model

OET Richness	19%	p=0.0081
%Dytiscidae	50%	p=0.0067
% Colepotera	18%	p=0.0155

13.) **Regression Equation to predict soils copper wetland sample only**

Soils CU_Wet = -0.548113+0.0122942(% Dominance of Top 3 Taxa)+ 0.0023945(Chironomidae Richness)+ 0.0558515(% Sensitive)+ 0.4460519(%Hemiptera) -0.153573(%Dytiscidae)

Rsq = 0.961 p=0.0063

Percent of Variance Accounted for by each Variable in Model

% Dominance of Top 3 Taxa	8%	p=0.0494
Chironomidae Richness	19%	p=0.6501
% Sensitive	7%	p=0.0193
%Hemiptera	20%	p=0.0069
%Dytiscidae	51%	p=0.0006

Piedmont – Disturbance Water Quality

14.) **Regression Equation to predict relative nutrient levels**

Rel Nutrients = 8.9304523+0.5064651(% Tolerant) +0.5539664(%Chronomidae) – 0.704052(%Mollusk)

Rsq =0 .926 p=0.0009

Percent of Variance Accounted for by each Variable in Model

% Tolerant	15%	p=0.0132
%Chronomidae	27%	p=0.0013
%Mollusk	50%	p=0.0061

15.) **Regression Equation to predict relative levels of metals**

Rel Metals = -405.4503+0.0733023(Site Abundance)+ 558.67276(Simpson's Index of Diversity) -13.13607(OET Richness) – 12.47724(Predator Richness)+ 2.1925262(Genera Richness)

Rsq = 0.939 p=0.0153

Percent of Variance Accounted for by each Variable in Model

Site Abundance	18%	p=0.0048
Simpson's Index of Diversity	19%	p=0.0039
OET Richness	13%	p=0.0074
Predator Richness	29%	p=0.0017
Genera Richness	15%	p=0.0066

16.) **Regression Equation to predict relative levels of copper, lead, and zinc**

Rel CuPbZn = -239.2771+0.0571027(Site Abundance) +354.16033(Simpson's Index of Diversity) -19.21104(OET Richness)+13.819083(EPT Richness) – 6.103286(Predator Richness)

Rsq =0.877 p=0.0583

Percent of Variance Accounted for by each Variable in Model

Site Abundance	22%	p=0.0132
Simpson's Index of Diversity	20%	p=0.0155
OET Richness	10%	p=0.0432
EPT Richness	8%	p=0.0600
Predator Richness	28%	p=0.0088

17.) **Regression Equation to predict relative pH**

Rel PH = 1.1307087+6.1000638(Evenness) +0.0183574(% Crustraceae) +0.0352938(%Oligochaets) +0.0479021(%Mollusk)

Rsq = 0.806 p=0.0497

Percent of Variance Accounted for by each Variable in Model

Evenness	12%	p=0.0294
% Crustraceae	23%	p=0.0599
%Oligochaets	24%	p=0.0132
%Mollusk	21%	p=0.0194

Appendix F

Headwater Wetland Plant Coefficient of Conservatism Values

Table F.1
Appendix F - Headwater Plant IBI Development Table

Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
ACERFLOR		Acer floridanum	Southern Sugar Maple	Aceraceae	5.5		FACU+	Tree	W	DI	Tree
ACERNEGU		Acer negundo	Box elder	Aceraceae	4	FACW	FACW	Tree	W	DI	Tree
ACERRUBR		Acer rubrum	Red maple	Aceraceae	3	FAC	FAC	Tree	W	DI	Tree
ACERSACC		Acer saccharum	Sugar maple	Aceraceae	5	FACU-	FACU	Tree	W	DI	Tree
AGRIPARV		Agrimonia parviflora	Small-flowered agrimony	Roseaceae	3	FAC	FAC	Forb	PE	DI	Shade
AGRIPUBE		Agrimonia pubescens	Agrimonia	Roseaceae	4	NG	FAC	Forb	PE	DI	Shade
AGRIROST		Agrimonia rostellata	Beaked groovebur	Roseaceae	4.5	FAC	FAC	Forb	PE	DI	Shade
AGROHYEM		Agrostis hyemalis	Winter bentgrass	Poaceae	4	FAC		Grass	PE	MONO	Advent
AGROSPP		Agrostis spp	Bentgrass	Poaceae	.	NG	x	Grass	PE	MONO	x
AGROSTOL		Agrostis stolonifera	Spreading bentgrass	Poaceae	5	FACW		Grass	PE	MONO	Advent
AILAALTI		Ailanthus altissima	Tree-of-heaven	Simaroubaceae	0	NI	FACU-	Tree	W	DI	Advent
ALBIJULI		Albizia julibrissin	Mimosa	Mimosaceae	0	NI	FACU-	Tree	W	DI	Advent
ALLISPP		Allium spp	Wild garlic	Liliaceae	.	NG	x	Forb	PE	MONO	x
ALNUSERR		Alnus serrulata	Tag alder	Betulaceae	5	FACW	OBL	Shrub	W	DI	Full
AMBRARTE		Ambrosia artemisiifolia	Annual ragweed	Asteraceae	1	FACU	FACU	Forb	AN	DI	Full
AMELARBO		Amelanchier arborea	Downy service-berry	Roseaceae	5.5	FACU	FACU	Sm tre	PE	DI	Shade
AMIAMUSC	Amianthium muscitoxicum	Amianthium muscaetoxicum	Fly Poison	Liliaceae	7	FAC	FACU	Forb	PE	MONO	Partial
AMPEARBO		Ampelopsis arborea	Peppervine	Vitaceae	4	FAC+	FACW	Vine	PE	DI	Shade
AMSOTABE		Amsonia tabernaemontana	Eastern slimpod	Apocynaceae	6.5	FACW		Forb	PE	DI	
ANDRSPP		Andropogon spp	Broomsedge	Poaceae	.	NG	x	Grass	PE	MONO	Full
ANDRVIRG		Andropogon virginicus	Broomsedge	Poaceae	2.5	FAC-	FAC-	Grass	PE	MONO	Full

Table F.1
Appendix F - Headwater Plant IBI Development Table

Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
ANTEPLAN		Antennaria plantaginifolia	Plantain-leaved pussy toes	Asteraceae	3.5	NG	UPL	Forb	PE	DI	Full
APIOAMER		Apios americana	American potato bean	Fabaceae	4	FACW	FACW	Vine	PE	DI	Partial
ARALSPIN		Aralia spinosa	Hercules club	Araliaceae	4.5	FAC	FAC-	Shrub	W	DI	Shade
ARISTRIP		Arisaema triphyllum	Jack-in-the-pulpit	Araceae	6.5	FACW-	FACW-	Forb	PE	MONO	Shade
ARONARBU		Aronia arbutifolia	Red chokeberry	Roseaceae	7.5	FACW	FACW	Shrub	W	DI	Partial
ARONMELA	Prunus virginiana	Aronia melanocarpa	Black chokeberry	Roseaceae	7	FAC	FAC	Shrub	W	DI	Partial
ARUNGIGA		Arundinaria gigantea	Switch cane	Poaceae	6.5	FACW	FACW	Grass	PE	MONO	Full
ASPLPLAT		Asplenium platyneuron	Bradley's spleenwort	Aspleniaceae	3.5	FACU	FACU	Fern	PE	SVP	Shade
ASTELATE	Symphyotrichum lateriflorum	Aster lateriflorus	Calico aster	Asteraceae	3.5	FAC	FAC	Forb	PE	DI	Shade
ASTEPUNI	Symphyotrichum puniceum	Aster puniceus	Swamp aster	Asteraceae	6.5	OBL	OBL	Forb	PE	DI	Full
ASTESPP		Aster spp	Aster species	Asteraceae	.	NG	x	Forb	PE	DI	x
ASTESPP		Asteraceae spp	Aster family	Asteraceae	.	NG	x	Forb	PE	DI	x
ASTEVIMI	Symphyotrichum lateriflorum	Aster vimineus	Small White Aster	Asteraceae	5	FAC	FAC	Forb	PE	DI	Advent
ATHYFILI		Athyrium filix-femina	Lady fern	Dryopteridaceae	5.5	FAC	FAC	Fern	PE	SVP	Shade
BACCHALI		Baccharis halimifolia	Silverling	Asteraceae	2	FAC	FAC	Shrub	W	DI	Full
BERCSCAN		Berchemia scandens	Rattan vine	Rhamnaceae	5	FACW	FACW	H-vine	PE	DI	Shade
BETUNIGR		Betula nigra	River birch	Betulaceae	5	FACW	FACW	Tree	W	DI	Tree
BIDEFRON		Bidens frondosa	Devil's Beggar Ticks	Asteraceae	1	FACW	FACW+	Forb	AN	DI	Full
BIDESPP		Bidens spp	Beggar ticks	Asteraceae	.	NG	x	Forb		DI	x
BIGNCAPR		Bignonia capreolata	Crossvine	Bignoniaceae	5.5	FAC	FAC+	Vine	W	DI	Shade
BOEHCYLI		Boehmeria cylindrica	False nettle	Urticaceae	4	FACW+	FACW+	Forb	PE	DI	Shade
BOTRDISS		Botrychium dissectum	Dissected	Ophioglossaceae	5	FAC	FAC	Fern	PE	SVP	Shade

Table F.1
Appendix F - Headwater Plant IBI Development Table

Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
			grape fern								
CALACINN	Calamagrostis coarctata	Calamagrostis cinnoides	Nuttall's small reed grass	Poaceae	6	FACU-	OBL	Grass	PE	MONO	Advent
CALLAMER		Callicarpa americana	Beautyberry	Verbenaceae	3.5	FACU-	FACU-	Shrub	W	DI	Shade
CAMPRADI		Campsis radicans	Trumpet creeper	Bignoniaceae	2	FAC	FAC+	Vine	W	DI	Full
CARDBULB		Cardamine bulbosa	Bulbous bittercress	Brassicaceae	7.5	OBL	OBL	Forb	PE	DI	Shade
CAREALAT		Carex alata	Broad-winged sedge	Cyperaceae	.			Sedge	PE	MONO	
CAREATLA		Carex atlantica	Prickly bog sedge	Cyperaceae	7	FACW		Sedge	PE	MONO	Full
CARECRIN		Carex crinita	Fringed sedge	Cyperaceae	5	FACW+	OBL	Sedge	PE	MONO	Shade
CAREDEBI		Carex debilis	White-edge sedge	Cyperaceae	7	FACW		Sedge	PE	MONO	Shade
CAREELLI		Carex elliottii	Elliott's sedge	Cyperaceae	8	OBL		Sedge	PE	MONO	
CAREFOLL		Carex folliculata		Cyperaceae	7			Sedge	PE	MONO	
CAREGLAU		Carex glaucescens	Southern waxy sedge	Cyperaceae	7	OBL	OBL	Sedge	PE	MONO	Shade
CAREGRAC		Carex gracilescens		Cyperaceae	4			Sedge	PE	MONO	Shade
CAREHOWE		Carex howei	Howe Sedge	Cyperaceae	7	OBL		Sedge	PE	MONO	
CAREINTU		Carex intumescens	Bladder sedge	Cyperaceae	5	FACW		Sedge	PE	MONO	Shade
CARELOUI		Carex louisianica	Louisiana sedge	Cyperaceae	8	OBL		Sedge	PE	MONO	Shade
CARELUPU		Carex lupulina	Hop sedge	Cyperaceae	4	OBL		Sedge	PE	MONO	Full
CARELUPUGR		Carex lupulinae group		Cyperaceae	4			Sedge	PE	MONO	
CARELURI		Carex lurida	Shallow sedge	Cyperaceae	3	OBL		Sedge	PE	MONO	Full
CAREOVAL		Carex section ovales		Cyperaceae	.			Sedge	PE	MONO	
CAREOXLY		Carex oxylepis	Sharp-scale sedge	Cyperaceae	7	FACW-		Sedge	PE	MONO	
CAREPRAS		Carex prasina	Drooping sedge	Cyperaceae	7	OBL		Sedge	PE	MONO	Shade
CARESPP		Carex spp	Sedge	Cyperaceae	.	NG	x	Sedge	PE	MONO	x

Table F.1
Appendix F - Headwater Plant IBI Development Table

Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
CARESTIPMA		Carex stipata var maxima		Cyperaceae	3			Sedge	PE	MONO	Partial
CARETYPH		Carex typhina	Cat-tail sedge	Cyperaceae	5	OBL		Sedge	PE	MONO	Shade
CAREVENU		Carex venusta	Sedge	Cyperaceae	7	FACW+	OBL	Sedge	PE	MONO	Shade
CARPCARO		Carpinus caroliniana	Ironwood	Betulaceae	5	FAC	FAC+	Sm tre	W	DI	Shade
CARYCORD		Carya cordiformis	Bitternut hickory	Juglandaceae	6.5	FAC	FAC	Tree	W	DI	Tree
CARYGLAB		Carya glabra	Pignut hickory	Juglandaceae	6	FACU	FACU	Tree	W	DI	Tree
CARYOVAT		Carya ovata	Shag-bark hickory	Juglandaceae	7	FACU	FACU	Tree	W	DI	Tree
CARYSPP		Carya spp	Hickory	Juglandaceae	.	NG	x	Tree	W	DI	Tree
CARYTOME	Carya alba	Carya tomentosa	Mockernut hickory	Juglandaceae	6	NG	FACU-	Tree	W	DI	Tree
CASSFASI	Cassia fasciculata	Cassia fasiculata	Partridge pea	Fabaceae	1.5	FACU	FACU	Forb	AN	DI	Partial
CATASPEC		Catalpa speciosa	Indian cigar tree	Bignoniaceae	0	FAC-	FACU	Tree	W	DI	Advent
CELTLAEV		Celtis laevigata	Hackberry	Ulmaceae	4.5	FACW	FACW	Tree	W	DI	Tree
CELTSPP		Celtis spp	Hackberry	Ulmaceae	.	NG	x	Tree	W	DI	Tree
CENTASIA		Centella asiatica	Asian coinleaf	Apiaceae	3.5	FACW	FACW+	Forb	PE	DI	Advent
CEPHOCCI		Cephalanthus occidentalis	Buttonbush	Rubiaceae	5.5	OBL	OBL	Shrub	W	DI	Full
CERCCANA		Cercis canadensis	Redbud	Caesalpiniaceae	5.5	FACU	FACU	Sm tre	W	DI	Shade
CHAMTHYO		Chamaecyparis thyoides	Atlantic white cedar	Cupressaeae	9	OBL	OBL	Tree	W	GYMN	Tree
CHASLAXU		Chasmanthium laxum	Spike chasmanthium	Poaceae	5	FACW-	FACW-	Grass	PE	MONO	Shade
CHIMMACU		Chimaphila maculata	Spotted wintergreen	Pyrolaceae	7	NG	UPL	Forb	PE	DI	Shade
CICUBULB		Cicuta bulbifera	Bulb bearing water hemlock	Apiaceae	5.5	NI	OBL	Forb	PE	DI	Full
CICUMACU		Cicuta maculata	Spotted water hemlock	Apiaceae	5.5	OBL	OBL	Forb	PE	DI	Full
CINNARUN		Cinna arundinacea	Stout wood reed grass	Poaceae	6	FACW		Grass	PE	MONO	Shade

Table F.1
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Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
CINNARUN	Cinna arundinacea	Cinna arundinaceae	Stout wood reed grass	Poaceae	5	FACW	FACW	Grass	PE	MONO	Shade
CLAYVIRG		Claytonia virginica	Narrow leaf spring beauty	Portulaceae	6	FACU-	FAC	Forb	PE	DI	Shade
CLEMVIRG		Clematis virginiana	Virgin's bower	Ranunculaceae	3.5	FAC+	FAC+	Forb	PE	DI	Partial
CLETALNI		Clethra alnifolia	Sweet pepperbush	Clethraceae	5.5	FACW	FACW+	Shrub	W	DI	Advent
COMMCOMM		Commelina communis	Asiatic dayflower	Commeliniaceae	0	FAC	FAC	Forb	AN	DI	Advent
COMMSPP		Commelina spp	Dayflower	Commeliniaceae	.	NG	x	Forb		DI	x
CONIMACU		Conium maculatum	Poison Hemlock	Apiaceae	0	FACW	OBL	Forb	BI	DI	Advent
CORNFLOR		Cornus florida	Flowering dogwood	Cornaceae	5	FACU	FACU	Sm tre	W	DI	Shade
CORYAMER		Corylus americana	American hazelnut	Betulaceae	5	FACU	FACU	Shrub	W	DI	Full
CRATMARS	Crataegus marshallii	Crateagus marshallii	Parsley hawthorn	Roseaceae	6.5	FAC	FACW	Sm tre	W	DI	Shade
CRATSPP	Crataegus spp	Crateagus spp	Hawthorn	Roseaceae	.	NG	x	Sm tre	W	DI	x
CYPEERYT		Cyperus erythrorhizos	Red-root flatsedge	Cyperaceae	3	OBL		Sedge	AN	MONO	Full
CYPEPSEU		Cyperus pseudovegetus	Marsh flatsedge	Cyperaceae	3	FACW		Sedge	PE	MONO	
CYPERUS		Cyperus spp	Flatsedge	Cyperaceae	.	NG	x	Sedge		MONO	x
CYPESPP		Cyperaceae spp	Sedge	Cyperaceae	.	NG	x	Sedge		MONO	x
CYPESTRI		Cyperus strigosus	Straw-color flatsedge	Cyperaceae	1	FACW		Sedge	PE	MONO	Full
CYRIRACE		Cyrilla racemiflora	Titi	Ericaceae	8	FACW	FACW+	Shrub	W	DI	Advent
DECOVERT		Decodon verticillatus	Hairy swamp loosestrife	Lythraceae	6.5	OBL	OBL	Forb	PE	DI	Full
DECUBARB		Decumaria barbara	Southeast decumaria	Hydrangaceae	6.5	FACW	FACW	Vine	PE	DI	Shade
DESMCANA		Desmodium canadense	Showy tick-	Fabaceae	.	FAC-	?	Forb	PE	DI	Full

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Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
			trefoil								
DESMPANI		Desmodium paniculatum	Panicled Tick-Treefoil	Fabaceae	4	FACU	FACU	Forb	PE	DI	Shade
DESMSPP		Desmodium spp	Tick-trefoil	Fabaceae	.	NG	x	Forb	PE	DI	x
DICHSPP		Dichanthelium spp	Witch grass	Poaceae	.	NG	x	Grass	PE	MONO	x
DIGICOGN		Digitaria (Leptoloma) cognata		Poaceae	2			Grass	PE	MONO	
DIGIISCH		Digitaria ischaemum	Smooth crabgrass	Poaceae	0	UPL		Grass	AN	MONO	Advent
DIGISPP		Digitaria spp	Crabgrass	Poaceae	.	NG	x	Grass	AN	MONO	x
DIOSVILL		Dioscorea villosa	Wild Yamroot	Dioscoreaceae	5.5	FAC	FAC	Vine	PE	DI	Partial
DIOSVIRG		Diospyros virginiana	Common persimmon	Ebenaceae	3.5	FAC	FAC	Sm tre	W	DI	Shade
DRYOCART		Dryopteris carthusiana	Spinulose wood fern	Dryopteridaceae	.	FAC+	?	Fern	PE	SVP	Shade
DRYOCRIS		Dryopteris cristata	Crested shield-fern	Dryopteridaceae	8	OBL	OBL	Fern	PE	SVP	Shade
DRYOLUDO		Dryopteris ludoviciana	Southern Wood Fern	Dryopteridaceae	7.5	FACW	FACW	Fern	PE	SVP	Shade
DRYOSPP		Dryopteris spp	Wood fern	Dryopteridaceae	.	NG	x	Fern	PE	SVP	Shade
DUCHINDI		Duchesnea indica	Indian strawberry	Roseaceae	0	NI	FACU	Forb	PE	DI	Advent
ECHICRUS		Echinochloa crus-galli	Barnyard grass	Poaceae	0	FACW-		Grass	AN	MONO	Advent
ELAEANGU		Elaeagnus angustifolia	Russian olive	Elaeagnaceae	0	FAC	FACU	Sm tre	W	DI	Advent
ELAEUMBE		Elaeagnus umbellata	Autumn olive	Elaeagnaceae	0	NG	FACU	Sm tre	W	DI	Advent
ELEOSPP		Eleocharis spp	Spikerush spp	Cyperaceae	.	NG	x	Sedge		MONO	x
ELEOTORT		Eleocharis tortillis	Twisted spikerush	Cyperaceae	7	FACW		Sedge	PE	MONO	
ELEPNUDA		Elephantopus nudatus	Smooth elephant foot	Asteraceae	3.5	FAC	FACU	Forb	PE	DI	Partial
ELEPSPP		Elephantopus spp	Elephant foot spp	Asteraceae	.	NG	x	Forb	PE	DI	x
ELEPTOME		Elephantopus tomentosus	Devil's Grandmother	Asteraceae	3.5			Forb	PE	DI	Full

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Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
ELYMVIRG		Elymus virginicus	Virginia wild-rye	Poaceae	5	FAC		Grass	PE	MONO	
EUONAMER		Euonymus americanus	Strawberry bush	Celastraceae	5	FAC-	FAC-	Shrub	W	DI	Partial
EUONFORT		Euonymus fortunei	Winter creeper	Celastraceae	0	NG	FAC+	Vine	W	DI	Advent
EUPACAPI		Eupatorium capillifolium	Small dog fennel	Asteraceae	2	FACU	FACU	Forb	PE	DI	Partial
EUPACOMP		Eupatorium compositifolium	Dog fennel	Asteraceae	2	FAC-	FACU	Forb	PE	DI	Partial
EUPADUBI	Eupatorium dubius	Eupatorium dubium	Coastal Joe-pye-weed	Asteraceae	5.5	FACW	OBL	Forb	PE	DI	Advent
EUPAFIST		Eupatorium fistulosum	Hollow-stemmed Joe-pye-weed	Asteraceae	5.5	FAC+	FACW	Forb	PE	DI	Partial
EUPAHYSS		Eupatorium hyssopifolium	Hyssop thoroughwort	Asteraceae	4	NG	UPL	Forb	PE	DI	Partial
EUPAPERF		Eupatorium perfoliatum	Common boneset	Asteraceae	4.5	FACW+	OBL	Forb	PE	DI	Full
EUPAROTU		Eupatorium rotundifolium	Round-leaved thoroughwort	Asteraceae	4	FAC	FAC	Forb	PE	DI	Shade
EUPASPP		Eupatorium spp	Dog fennel	Asteraceae	.	NG	x	Forb		DI	x
EURYDIVA		Eurybia divaricata	White wood aster	Asteraceae	5.5	NG	UPL	Forb	PE	DI	Shade
FABASPP		Fabaceae spp	Bean species	Fabaceae	.	NG	x	Forb		DI	x
FAGUGRAN		Fagus grandifolia	American beech	Fagaceae	7	FACU	FACU	Tree	W	DI	Tree
FOTHGARD		Fothergilla gardenii	Dwarf witch alder	Hamamelidaceae	7.5	FACW	OBL	Shrub	W	DI	Partial
FRAGSPP		Fragaria spp	Strawberry spp	Roseaceae	.	NG	x	Forb	PE	DI	Full
FRAXPENN		Fraxinus pennsylvanica	Green ash	Oleaceae	5	FACW	FACW	Tree	W	DI	Tree
GALIAPAR		Galium aparine	Catchweed bedstraw	Rubiaceae	2	FACW+	FACW+	Forb	AN	DI	Partial
GALICIRC		Galium circaezans	Wild licorice	Rubiaceae	4.5	FACU-	FACU-	Forb	PE	DI	Shade

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GALIOBTU		Galium obtusum	Blunt leaf bedstraw	Rubiaceae	5	FACW-	FACW-	Forb	PE	DI	Full
GALIPILO		Galium pilosum	Hairy bedstraw	Rubiaceae	5	NG	UPL	Forb	PE	DI	Shade
GALISPP		Galium spp	Bedstraw	Rubiaceae	.	NG	x	Forb		DI	x
GALITINC		Galium tinctorium	Stiff marsh bedstraw	Rubiaceae	4	FACW	FACW	Forb	PE	DI	Full
GAYLFRON		Gaylussacia frondosa	Dangleberry	Ericaceae	5.5	FAC	FAC	Shrub	W	DI	Advent
GELSSEMP		Gelsemium sempervirens	Yellow jessamine	Loganiaceae	4	FAC	FAC	Vine	PE	DI	Advent
GENTCRIN	Genianopsis crinita	Gentiana crinita	Fringed gentian	Gentianaceae	9	FACW+	FACW+	Forb	PE	DI	Full
GEUMCANA		Geum canadense	White avens	Roseaceae	5	FAC	FAC	Forb	PE	DI	Shade
GEUMSPP		Geum spp	Avens	Roseaceae	.	NG	x	Forb	PE	DI	Shade
GLECHEDE	Glechoma hederacea	Glechoma hederacea	Ground ivy	Lamiaceae	0	FACU	FAC	Forb	PE	DI	Advent
GLYCSTRI		Glyceria striata	Fowl manna grass	Poaceae	4.5	OBL	OBL	Grass	PE	MONO	Shade
GLYCSTRIST		Glyceria striata var striata	Fowl manna grass	Poaceae	4.5	OBL	OBL	Grass	PE	MONO	Shade
GOODPUBE		Goodyera pubescens	Rattlesnake orchid	Orchidaceae	7	UPL	UPL	Forb	PE	MONO	Shade
GORDLASI		Gordonia lasianthus	Loblolly bay	Theaceae	8.5	FACW	OBL	Sm tre	W	DI	Tree
HEDEHELI		Hedera helix	English ivy	Araliaceae	0	NI	FACU	Vine	W	DI	Advent
HERBSPP		Herb spp	Herb spp	N/A	.	NG	x	Forb			x
HERBSPP		Unknown herb species	Unknown herb species	Herb	.	NG	x	Forb			NA
HEXAARIF		Hexastylis arifolia	Wild ginger	Aristolochiaceae	7	FAC-	FACU	Forb	PE	DI	Shade
HEXASPP		Hexastylis spp	Wild ginger	Aristolochiaceae	.	NG	x	Forb	PE	DI	Shade
HEXAVIRG		Hexastylis virginica	Wild ginger	Aristolochiaceae	7	FACU	FACU	Forb	PE	DI	Shade
HYDRSPP		Hydrocotyle spp	Pennywort	Apiaceae	.	NG	x	Forb	PE	DI	x
HYPEHYPE		Hypericum hypericoides	St. Andrew's-cross	Clusiaceae	5	FAC	FAC	Shrub	W	DI	Full

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HYPESPP		Hypericum spp	St. John's wort	Clusiaceae	.	NG	x	Shrub		DI	x
ILEXAMEL		Ilex amelanchier	Sarvis holly	Aquifoliaceae	8	OBL	OBL	Shrub	W	DI	Partial
ILEXCASS		Ilex cassine	Dahoon holly	Aquifoliaceae	7	FACW	OBL	Sm tre	W	DI	Full
ILEXCORI	Ilex coriacea	Ilex coriaceae	Gallberry	Aquifoliaceae	7.5	FACW	OBL	Shrub	W	DI	Advent
ILEXDECI		Ilex decidua	Deciduous holly	Aquifoliaceae	6	FACW-	FACW-	Shrub	W	DI	Full
ILEXGLAB		Ilex glabra	Gallberry	Aquifoliaceae	6	FACW	OBL	Shrub	W	DI	Advent
ILEXMYRT		Ilex myrtifolia	Myrtle holly	Aquifoliaceae	7.5	FACW	OBL	Shrub	W	DI	Full
ILEXOPAC		Ilex opaca	American Holly	Aquifoliaceae	5	FAC-	FAC	Sm tre	W	DI	Shade
ILEXSPP		Ilex spp	Holly species	Aquifoliaceae	.	NG	x	Shrub	W	DI	x
ILEXVERT		Ilex verticillata	Winter berry	Aquifoliaceae	6.5	FACW	FACW	Shrub	W	DI	Shade
ILEXVOMI		Ilex vomitoria	Yaupon holly	Aquifoliaceae	7	FAC	FACU	Shrub	W	DI	
IMPACAPE		Impatiens capensis	Jewelweed	Balsaminaceae	4	FACW	FACW	Forb	AN	DI	Partial
IRISSPP		Iris spp	Iris	Iridaceae	.	NG	x	Forb	PE	MONO	x
ITEAVIRG		Itea virginica	Virginia willow	Grossulariaceae	7	FACW+	OBL	Shrub	W	DI	Advent
JUNCABOR		Juncus abortivus	Pinebarren rush	Juncaceae	4	OBL		Rush	PE	MONO	
JUNCACUM		Juncus acuminatus	Taper-tip rush	Juncaceae	3.5	OBL	OBL	Forb	PE	MONO	Full
JUNCCORI		Juncus coriaceus	Leathery Rush	Juncaceae	5	FACW		Rush	PE	MONO	
JUNCEFFU		Juncus effusus	Soft rush	Juncaceae	2.5	FACW+	OBL	Forb	PE	MONO	Full
JUNCEFFUSO		Juncus effusus ssp solutus	Soft rush	Juncaceae	3	FACW+		Rush	PE	MONO	Full
JUNCMARG		Juncus marginatus	Grassleaf rush	Juncaceae	3	FACW	FACW+	Forb	PE	MONO	Full
JUNCSCIR		Juncus scirpoides	Needle-pod rush	Juncaceae	4	FACW+	OBL	Grass	PE	MONO	Full
JUNCSPP		Juncus spp	Reed	Juncaceae	.	NG	x	Forb		MONO	x
JUNCTENU		Juncus tenuis	Slender rush	Juncaceae	2	FAC		Rush	PE	MONO	Partial
JUNIVIRG		Juniperus virginiana	Eastern red cedar	Cupressaceae	3.5	FACU-	FACU-	Tree	W	GYMN	Tree
KUHNEUPA	Brickellia eupatorioides	Kuhnia eupatorioides	False boneset	Asteraceae	6.5	NG	UPL	Forb	PE	DI	Full

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Appendix F - Headwater Plant IBI Development Table

Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
LACHANCE		Lachnocaulon anceps	Whitehead bogbutton	Eriocaulaceae	7	OBL	OBL	Forb	PE	MONO	Partial
LACHCARO	Lachnanthes caroliana	Lachnanthes caroliniana	Red Root	Haemodoraceae	4	OBL	OBL	Forb	PE	MONO	Partial
LAMISPP		Lamiaceae spp	Mint species	Lamiaceae	.	NG	x	Forb		DI	x
LEERVIRG		Leersia virginica	Whitegrass	Poaceae	5	FACW	OBL	Grass	PE	MONO	Shade
LEPEVIRG	Lepidium virginicum	Lepidium virginicum	Poor man's pepper grass	Brassicaceae	2	FACU	FACU	Forb	AN	DI	Full
LESPCUNE		Lespedeza cuneata	Chinese bushclover	Fabaceae	0	NI	FACU	Forb	PE	DI	Advent
LESPVIRG		Lespedeza virginica	Slender bushclover	Fabaceae	3	NG	FACU	Forb	PE	DI	Full
LEUCAXIL		Leucothoe axillaris	Coastal dog-hobble	Ericaceae	7	FACW	OBL	Shrub	W	DI	Shade
LEUCRACE		Leucothoe racemosa	Fetterbush	Ericaceae	7	FACW	OBL	Shrub	W	DI	Advent
LIGUJAPO	Not in USDA Database	Ligustrum japonica	Japanese privet	Oleaceae	0	NG	FACU	Shrub	W	DI	Advent
LIGUSINE		Ligustrum sinense	Chinese privet	Oleaceae	0	FAC	FACW-	Shrub	W	DI	Advent
LINDBENZ		Lindera benzoin	Northern spicebush	Lauraceae	6.5	FACW	FACW	Shrub	W	DI	Shade
LIQUSTYR		Liquidambar styraciflua	Sweet gum	Hamamelidaceae	3	FAC+	FAC+	Tree	W	DI	Tree
LIRISPP		Liriope spp	Turf Lily	Liliaceae	0	NG	FAC	Forb	PE	MONO	Advent
LIRITULI		Liriodendron tulipifera	Tulip tree	Magnoliaceae	4	FAC	FAC	Tree	W	DI	Tree
LOBEINFL		Lobelia inflata	Indian tobacco	Campanulaceae	2	FAC	FAC	Forb	AN	DI	Full
LONIJAPO		Lonicera japonica	Japanese honeysuckle	Caprifoliaceae	0	FAC-	FAC	Vine	W	DI	Advent
LUDWALTE		Ludwigia alternifolia	Bushy seedbox	Onagraceae	4	OBL	OBL	Forb	PE	DI	Full
LUDWPALU		Ludwigia palustris	Marsh seedbox	Onagraceae	4	OBL	OBL	Forb	AN	DI	Full
LUDWSPP		Ludwigia spp	Primrose	Onagraceae	.	NG	x	Forb		DI	Full
LYCOFLAB		Lycopodium flabelliforme	Fan clubmoss	Lycopodiaceae	4.5	NG	FACU-	Forb	PE	DI	Shade
LYCOOBSC		Lycopodium obscurum	Tree	Lycopodiaceae	5.5	FACU-	FACU-	Fern	PE	SVP	Shade

Table F.1
Appendix F - Headwater Plant IBI Development Table

Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
			clubmoss								
LYCOSPP		Lycopus spp	Bugleweed	Lamiaceae	.	NG	x	Forb	PE	DI	Advent
LYCOVIRG		Lycopus virginicus	Virginia bugleweed	Lamiaceae	4	OBL	OBL	Forb	PE	DI	Full
LYONLIGU		Lyonia ligustrina	Maleberry	Ericaceae	7	FACW	FACW	Shrub	W	DI	Advent
LYONLUCI		Lyonia lucida	Fetterbush	Ericaceae	7	FACW	OBL	Shrub	W	DI	Advent
MAGNGRAN		Magnolia grandiflora	Southern magnolia	Magnoliaceae	1	FAC+	FAC	Tree	W	DI	Tree
MAGNTRIP		Magnolia tripetala	Umbrella magnolia	Magnoliaceae	7.5	FAC	FAC	Tree	W	DI	Tree
MAGNVIRG		Magnolia virginiana	Sweetbay magnolia	Magnoliaceae	7	FACW+	OBL	Tree	W	DI	Tree
MEDEVIRG		Medeola virginiana	Indian cucumber root	Liliaceae	6.5	NG	FACU-	Forb	PE	MONO	Shade
MELIAZED		Melia azedarach	Chinaberry	Meliaceae	0	NG	FACU-	Tree	W	DI	Advent
MICRVIMI		Microstegium vimineum	Nepalese browntop	Poaceae	0	FAC+	FACW-	Grass	AN	MONO	Advent
MIKASCAN		Mikania scandens	Climbing hempweed	Asteraceae	3	FACW+	FACW+	Vine	PE	DI	Shade
MITCREPE		Mitchella repens	Partridgeberry	Rubiaceae	6	FACU+	FACU	Forb	PE	DI	Shade
MONOUNIF		Monotropa uniflora	Indian pipe	Monotropaceae	5.5	FACU-	UPL	Forb	PE	DI	Shade
MORURUBR		Morus rubra	Red mulberry	Moraceae	4	FAC	FAC	Tree	W	DI	Tree
MOSS		Moss	Moss	Bryophyte	.	NG	x	Moss	PE	NV	Shade
MYRICERI	Morella cerifera	Myrica cerifera	Wax mytle	Myricaceae	4	FAC+	FACW	Shrub	W	DI	Full
MYRIHETE	Morella caroliniensis	Myrica heterophylla	Black bayberry	Myricaceae	7	FACW	OBL	Shrub	W	DI	Partial
NANDDOME		Nandina domestica	Nandina	Poaceae	0	NG	FACU	Grass	W	MONO	Advent
NYMPODOR		Nymphaea odorata	Fragrant water lily	Nymphaceae	6.5	OBL	OBL	Forb	PE	DI	Full
NYSSBIFL		Nyssa biflora	Swamp tupelo	Cornaceae	7	OBL	OBL	Tree	W	DI	Tree
NYSSSYLV		Nyssa sylvatica	Black gum	Cornaceae	6	FAC	FAC	Tree	W	DI	Tree
OPUNHUMI		Opuntia humifusa	Prickly pear	Cataceae	8	NG	UPL	Shrub	W	DI	Full

Table F.1
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Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
ORCHLILL		Orchidaceae/Lilliaceae	Orchid or lily	Orchidaceae/ Liliaceae	.	NG	x	Forb	PE	MONO	x
OSMAAMER		Osmanthus americanus	Devil-wood	Oleaceae	8	FAC	FACU	Tree	PE	DI	Shade
OSMUCINN		Osmunda cinnamomea	Cinnamon fern	Osmundaceae	6.5	FACW+	OBL	Fern	PE	SVP	Partial
OSMUREGA		Osmunda regalis	Royal fern	Osmundaceae	7.5	OBL	OBL	Fern	PE	SVP	Shade
OSTRVIRG		Ostrya virginiana	American hornbeam	Betulaceae	6	FACU-	FACU-	Tree	W	DI	Tree
OXALSTRI		Oxalis stricta	Yellow wood sorrel	Oxalidaceae	2.5	FACU	UPL	Forb	PE	DI	Full
OXYDARBO		Oxydendrum arboreum	Sourwood	Ericaceae	5	NI	FACU	Tree	W	DI	Tree
OXYPRIGI		Oxypolis rigidior	Stiff cowbane	Apiaceae	6.5	OBL	OBL	Forb	PE	DI	Full
PANIAMAR		Panicum amarum	Bitter panic grass	Poaceae	5.5	FAC		Grass	PE	MONO	
PANIANCE		Panicum anceps	Beaked panic grass	Poaceae	4.5	FAC-	FAC	Grass	PE	MONO	Full
PANIANCERH		Panicum anceps var. rhizomatum	Beaked panic grass	Poaceae	5	FAC-		Grass	PE	MONO	Full
PANILAXI		Panicum (Dichanthelium) laxiflorum	Lax-flower witchgrass	Poaceae	6	FAC		Grass	PE	MONO	Shade
PANISPP		Panicum spp	Panicum spp	Poaceae	.	NG	x	Grass		MONO	Advent
PARTQUIN		Parthenocissus quinquefolia	Virginia creeper	Vitaceae	4	FAC	FAC	Vine	W	DI	Shade
PASSLUTE		Passiflora lutea	Yellow passion flower	Passifloriaceae	3.5	NG	UPL	Vine	PE	DI	Partial
PASSSPP		Passiflora spp	Passion flower	Passifloriaceae	.	NG	x	Vine	PE?	DI	Advent
PERSBORB		Persea borbonia	Redbay	Lauraceae	7	FACW	FACW	Sm tre	W	DI	Shade
PHASSINU	Phaseolus polystachios	Phaseolus sinuatus	Thicket bean	Fabaceae	.	NG	?	Forb	PE	DI	Partial
PHORSERO	Phoradendron leucarpum	Phoradendron serotinum	Mistle toe	Viscaceae	5.5	NG	FAC	Epi	W	DI	Full
PHRACOMM	Phragmites australis	Phragmites communis	Common reed	Poaceae	0	FACW	FACW	Grass	PE	MONO	Full

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Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
PHYLAURE		Phyllostachys aurea	Golden bamboo	Poaceae	0	NG	FACU	Grass	W	MONO	Advent
PHYTAMER		Phytolacca americana	Common Pokeweed	Phytolaccaceae	2	FACU+	FACU	Forb	PE	DI	Full
PILEPUMI		Pilea pumila	Clearweed	Urticaceae	4	FACW	FACW+	Forb	AN	DI	Partial
PINUECHI		Pinus echinata	Southern Yellow Pine	Pinaceae	6.5	NG	FACU-	Tree	W	GYMN	Tree
PINUPALU		Pinus palustris	Longleaf pine	Pinaceae	8	FACU+	FAC-	Tree	W	GYMN	Tree
PINUSERO		Pinus serotina	Pond pine	Pinaceae	8	FACW+	FACW+	Tree	W	GYMN	Tree
PINUTAED		Pinus taeda	Loblolly pine	Pinaceae	2	FAC	FAC	Tree	W	GYMN	Tree
PINUVIRG		Pinus virginiana	Virginia pine	Pinaceae	3.5	NG	UPL	Tree	W	GYMN	Tree
PLATCRIS		Platanthera cristata	Yellow crested orchid	Orchidaceae	8	OBL	OBL	Forb	PE	MONO	Full
PLATOCCI		Platanus occidentalis	Sycamore	Platanaceae	5	FACW-	FACW-	Tree	W	DI	Tree
PLUCCAMP		Pluchea camphorata	Salt marsh camphor-weed	Asteraceae	4.5	FACW		Forb	AN	DI	Partial
POACSPP		Poaceae spp	Grass	Poaceae	.	NG	x	Grass		MONO	x
PODOPELT		Podophyllum peltatum	May-apple	Berberidaceae	4.5	FACU	FACU	Forb	PE	MONO	Shade
POLYACRO		Polystichum acrostichoides	Christmas fern	Dryopteridaceae	4.5	FAC	FAC	Fern	PE	SVP	Shade
POLYCESP		Polygonum cespitosum	Cespitose knotweed	Polygonaceae	0	FACW-	FACW-	Forb	AN	DI	Advent
POLYEREC		Polygonum erectum	Erect knotweed	Polygonaceae	3	FACU	FACU	Forb	AN	DI	Full
POLYHYDR		Polygonum hydropiperoides	Swamp smartweed	Polygonaceae	3.5	OBL	OBL	Forb	PE	DI	Full
POLYLAPA		Polygonum lapathifolium	Willow-weed	Polygonaceae	3	FACW	FACW	Forb	AN	DI	Full
POLYPERS		Polygonum persicaria	Lady's thumb	Polygonaceae	0	FACW	FACW	Forb	AN	DI	Advent
POLYPOLY	Pleopeltis Polypodioides	Polypodium polypodioides	Resurrection fern	Polypodiaceae	7	NG	FAC	Fern	PE	SVP	Shade
POLYSPP		Polygonum spp	Smartweed	Polygonaceae	.	NG	x	Forb		DI	Advent
POPUDELT		Populus deltoides	Eastern cottonwood	Salicaceae	5	FAC+	FACW	Tree	W	DI	Tree

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Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
POTESIMP		Potentilla simplex	Old field cinquefoil	Roseaceae	3.5	FACU	FACU	Forb	PE	DI	Full
PRENALTI		Prenanthes altissima	Tall white lettuce	Asteraceae	4.5	UPL	FACU-	Forb	PE	DI	Shade
PROSPALU		Proserpinaca palustris	Marsh mermaid-weed	Haloragaceae	6	OBL	OBL	Forb	PE	DI	Full
PRUNCARO		Prunus caroliniana	Carolina laurel cherry	Roseaceae	4	NG	FACU	Sm tre	PE	DI	Tree
PRUNSERO		Prunus serotina	Black cherry	Roseaceae	4	FACU	FACU	Tree	W	DI	Tree
PSEUOBTU	Pseudognaphalium obtusifolium	Gnaphalium obtusifolium	Rabbit tobacco	Asteraceae	3.5	NG	UPL	Forb	BI	DI	Partial
PTERAQUI		Pteridium aquilinum	Bracken fern	Dennstaedtiaceae	3.5	FACU	FACU	Fern	PE	SVP	Partial
PUERMONT		Pueraria montana	Kudzu	Fabaceae	0	NG	UPL	Vine	W	DI	Advent
PYRUCALL		Pyrus calleryana	Bradford pear	Roseaceae	0	NG	UPL	Sm tre	W	DI	Advent
QUERALBA		Quercus alba	White oak	Fagaceae	6	FACU	FACU	Tree	W	DI	Tree
QUERFALC		Quercus falcata	Southern red oak	Fagaceae	5.5	FACU-	FACU-	Tree	W	DI	Tree
QUERLAUR		Quercus laurifolia	Laural oak	Fagaceae	7	FACW	FACW+	Tree	W	DI	Tree
QUERMARI		Quercus marilandica	Black Jack Oak	Fagaceae	6	NG	UPL	Tree	W	DI	Tree
QUERMICH		Quercus michauxii	Swamp chestnut oak	Fagaceae	7	FACW-	FACW	Tree	W	DI	Tree
QUERNIGR		Quercus nigra	Water oak	Fagaceae	4	FAC	FAC+	Tree	W	DI	Tree
QUERPAGO		Quercus pagoda	Cherry bark oak	Fagaceae	7	FAC+	FACW-	Tree	W	DI	Tree
QUERPHEL		Quercus phellos	Willow oak	Fagaceae	5	FACW-	FACW-	Tree	W	DI	Tree
QUERPRIN		Quercus prinus	Chestnut oak	Fagaceae	6.5	UPL	UPL	Tree	W	DI	Tree
QUERRUBR		Quercus rubra	Red oak	Fagaceae	6.5	FACU	FACU	Tree	W	DI	Tree
QUERSTEL		Quercus stellata	Post Oak	Fagaceae	6.5	FACU	FACU-	Tree	W	DI	Tree
QUERVELU		Quercus velutina	Black oak	Fagaceae	5.5	NG	FACU	Tree	W	DI	Tree
QUERVIRG		Quercus virginiana	Live oak	Fagaceae	7	FACU+	FACU+	Tree	W	DI	Tree
RANUHISP		Ranunculus hispidus	Bristly	Ranunculaceae	5.5	FAC	FAC+	Forb	PE	DI	Shade

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Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
			buttercup								
RHEXSPP		Rhexia spp	Meadow beauty	Melastomataceae	.	NG	x	Forb		DI	Full
RHODATLA		Rhododendron atlanticum	Coastal azalea	Ericaceae	6.5	FAC+	FAC+	Shrub	W	DI	Partial
RHODCANE		Rhododendron canescens	Piedmont azalea	Ericaceae	6.5	FACW-	FACW-	Shrub	W	DI	Shade
RHODNUDI	Rhododendron periclymenoides	Rhododendron nudiflorum	Pink azalea	Ericaceae	6.5	FAC	FAC	Shrub	PE	DI	Shade
RHODSPP		Rhododendron spp	Azalea	Ericaceae	.	NG	x	Shrub	W	DI	x
RHODVISC		Rhododendron viscosum	Swamp Azalea	Ericaceae	7.5	FACW+	FACW+	Shrub	W	DI	Advent
RHUSCOPA	Rhus copallinum	Rhus copallina	Winged sumac	Anacardiaceae	3.5	NI	UPL	Shrub	W	DI	Full
RHUSSPP		Rhus spp	Sumac	Anacardiaceae	.	NG	x	Shrub		DI	Full
RHUSVERN	Toxicodendron vernix	Rhus vernix	Poison sumac	Anacardiaceae	7.5	OBL	OBL	Shrub	W	DI	Full
RHYNCAPI		Rhynchospora capitellata	Brownish beakrush	Cyperaceae	8	OBL		Sedge	PE	MONO	Full
RHYNCEPHCE		Rhynchospora cephalantha var. cephalantha	Clustered beakrush	Cyperaceae	7	OBL		Sedge	PE	MONO	
RHYNCHAL		Rhynchospora chalarocephala	Loose-head beakrush	Cyperaceae	3	OBL	OBL	Grass	PE	MONO	Partial
RHYNCORNCO		Rhynchospora corniculata var. corniculata	Short-bristle beakrush	Cyperaceae	5	OBL		Sedge	PE	MONO	
RHYNGLOM		Rhynchospora glomerata	Clustered beakrush	Cyperaceae	4	OBL	OBL	Sedge	PE	MONO	Partial
RHYNGRAC		Rhynchospora gracilenta	Slender beakrush	Cyperaceae	8	OBL		Sedge	PE	MONO	
RHYNINEX		Rhynchospora inexpansa	Nodding beakrush	Cyperaceae	2	FACW		Sedge	PE	MONO	
RHYNMILI		Rhynchospora miliacea	Millet beakrush	Cyperaceae	9	OBL		Sedge	PE	MONO	

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RHYNMILI	Rhychospora milacea	Rhynchospora miliacea	Millet beakrush	Cyperaceae	9	OBL	OBL	Grass	PE	MONO	Shade
RHYNMIXT		Rhynchospora mixta	Mingled beakrush	Cyperaceae	9	OBL		Sedge	PE	MONO	
RHYNOLIG		Rhynchospora oligantha	Few-flower beakrush	Cyperaceae	8	OBL	OBL	Grass	PE	MONO	Partial
RHYNSPP		Rhynchospora spp	Beakrush	Cyperaceae	.	NG	x	Grass	PE	MONO	Advent
ROSACARO		Rosa carolina	Carolina rose	Roseaceae	6.5	FACU	FACU	Shrub	W	DI	Full
ROSALAEV		Rosa laevigata	Cherokee rose	Roseaceae	0	NG	FACU	Vine	PE	DI	Advent
ROSAMULT		Rosa multiflora	Multiflora rose	Roseaceae	0	UPL	FACU+	Shrub	W	DI	Advent
ROSAPALU		Rosa palustris	Swamp rose	Roseaceae	6.5	OBL	OBL	Shrub	W	DI	Full
ROSASPP		Rosa spp	Rose	Roseaceae	.	NG	x	Shrub		DI	x
ROSESPP		Roseaceae spp	Rose spp	Roseaceae	.	NG	x	Shrub	W	DI	x
RUBUARGU		Rubus argutus	Highbush blackberry	Roseaceae	2	FACU+	FACU+	Shrub	W	DI	Full
RUBUFLAG		Rubus flagellaris	Prickly dewberry	Roseaceae	3	UPL	UPL	Shrub	W	DI	Full
RUBUHISP		Rubus hispidus	Bristly blackberry	Roseaceae	6	FACW	FACW	Forb	PE	DI	Partial
RUBUSPP		Rubus spp	Blackberry	Roseaceae	.	NG	x	Shrub	W	DI	Full
RUELCARO		Ruellia caroliniensis	Hairy ruellia	Acanthaceae	4.5	NG	FACU-	Forb	PE	DI	Full
SABAMINO		Sabal minor	Dwarf palmetto	Arecaceae	8	FACW	FACW	Shrub	PE	MONO	Shade
SAGILANC		Sagittaria lancifolia	Bull-tongue arrow-head	Alismataceae	7	FACW	OBL	Forb	PE	MONO	Full
SAGILATI		Sagittaria latifolia	Broad-leaf arrow-head	Alismataceae	4.5	OBL	OBL	Forb	PE	MONO	Full
SAGISPP		Sagittaria spp	Arrow-head	Alismataceae	.	OBL	OBL	Forb	PE	MONO	Full
SALINIGR		Salix nigra	Black willow	Salicaceae	3	OBL	OBL	Tree	W	DI	Tree
SAMBCANA	Sambucus nigra	Sambucus canadensis	American elder	Caprifoliaceae	4	FACW-	FACW	Shrub	W	DI	Full
SANICANA		Sanicula canadensis	Snakeroot	Apiaceae	4	FACU	FACU+	Forb	PE	DI	Shade

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SARRFLAV		Sarracenia flava	Yellow pitcher-plant	Sarraceniaceae	9	OBL	OBL	Forb	PE	DI	Partial
SASSALBI		Sassafras albidum	Sassafras	Lauraceae	3.5	FACU	FACU-	Tree	W	DI	Tree
SAURCERN		Saururus cernuus	Lizard's tail	Saururaceae	4.5	OBL	OBL	Forb	PE	MONO	Shade
SCIRCYPE		Scirpus cyperinus	Woolgrass	Cyperaceae	3	OBL	OBL	Sedge	PE	MONO	Full
SCIRSPP		Scirpus spp	Bulrush	Cyperaceae	.	OBL	OBL	Sedge		MONO	Full
SETASPP		Setaria spp	Fox tail	Poaceae	.	NG	x	Grass	AN	MONO	Advent
SIUMSUAV		Sium suave	Hemlock water parsnip	Apiaceae	5	OBL	OBL	Forb	PE	DI	Partial
SMILBONA		Smilax bona-nox	Saw greenbrier	Smilaceae	4	FAC	FAC	Vine	W	MONO	Advent
SMILGLAU		Smilax glauca	Cat greenbrier	Smilaceae	4.5	FAC	FAC	Vine	W	MONO	Shade
SMILLAUR		Smilax laurifolia	Laurel-leaf greenbrier	Smilaceae	5.5	FACW+	OBL	Vine	W	MONO	Advent
SMILRACE	Maianthemum racemosum	Smilacina racemosa	False Solomon seal	Liliaceae	6.5	FACU	FACU	Forb	PE	MONO	Shade
SMILROTU		Smilax rotundifolia	Common greenbrier	Smilaceae	4	FAC	FAC	Vine	W	MONO	Shade
SOLACARO		Solanum carolinense	Stinging Nettle	Solanaceae	2	FACU	FACU-	Forb	PE	DI	Advent
SOLIALTI		Solidago altissima	Tall goldenrod	Asteraceae	3.5	FACU+	FACU+	Forb	PE	DI	Full
SOLIELLI	Solidago latissimifolia	Solidago elliottii	Elliot's goldenrod	Asteraceae	7	FACU+	FACW	Forb	PE	DI	Full
SOLIPATU		Solidago patula	Rough-leaf golddenrod	Asteraceae	7.5	OBL	OBL	Forb	PE	DI	Full
SOLIRUGO		Solidago rugosa	Rough-stemmed goldenrod	Asteraceae	3	FAC	FAC+	Forb	PE	DI	Full
SOLISPP		Solidago spp	Goldenrod	Asteraceae	.	NG	x	Forb	PE	DI	Full
SPARAMER		Sparganium americanum	American bur-reed	Sparganiaceae	5.5	OBL	OBL	Forb	PE	MONO	Full
SPHASPP		Sphagnum spp	Sphagnum spp	Sphagnaceae	.	NG	OBL	Moss	PE	NV	Advent

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SPIRCERN		Spiranthes cernua	Nodding ladies'-tresses	Orchidaceae	8.5	FACW	OBL	Forb	PE	MONO	Full
SPIRPOLY		Spirodela polyrrhiza	Greater duckweed	Lemnaceae	4	OBL	OBL	Forb	AN	MONO	Full
SPIRSPP		Spiranthes spp	Ladies' tresses	Orchidaceae	.	NG	x	Forb	PE	MONO	Full
STELMEDI		Stellaria media	Common chickweed	Caryophyllaceaea	0	FACU	FACU	Forb	AN	DI	Full
STREROSE	Streptopus lanceolatus	Streptopus roseus	Rose twisted stalk	Liliaceae	9	FAC	FACU+	Forb	PE	MONO	Shade
SYMPELLI		Aster (Symphyotrichum) elliottii	Elliott's aster	Asteraceae	7.5	OBL		Forb	PE	DI	
SYMPPATE		Symphyotrichum patens	Late purple aster	Asteraceae	7	NG	UPL	Forb	PE	DI	Partial
SYMPTINC		Symplocos tinctoria	Horse sugar	Symplocaceae	6.5	FAC	FACU+	Shrub	W	DI	Shade
TAXOASCE		Taxodium ascendens	Pond cypress	Taxodiaceae	9	OBL	OBL	Tree	W	GYMN	Tree
TAXODIST		Taxodium distichum	Bald cypress	Taxodiaceae	8	OBL	OBL	Tree	W	GYMN	Tree
THALREVO		Thalictrum revolutum	Wax-leaf meadow-rue	Ranunculaceae	7	FAC+	FAC+	Forb	PE	DI	Full
THALTHAL		Thalictrum thalictroides	Rue anemone	Ranunculaceae	6.5	NG	FACU-	Forb	PE	DI	Shade
THELSPP		Thelypteris spp	Fern spp.	Thelypteridaceae	.	NG	x	Fern	PE	SVP	Shade
TIARCORD		Tiarella cordifolia	Foam flower	Saxifagaceae	6.5	FAC-	FAC-	Forb	PE	DI	Shade
TILICARO	Tilia caroliniana var caroliniana	Tilia caroliniana	American basswood	Tiliaceae	8.5	FACU	FACU	Tree	PE	DI	Tree
TILIHETE	Tilia caroliniana var heterophylla	Tilia heterophylla	White basswood	Tiliaceae	7.5	FACU	FACU	Tree	W	DI	Tree
TILLUSNE		Tillandsia usneoides	Spanish moss	Bromeliaceae	7	NG	FAC	Epi	PE	MONO	Shade
TIPUDISC		Tipularia discolor	Cranefly orchid	Orchidaceae	6.5	FACU	FACU-	Forb	PE	MONO	Shade
TOVAVIRG	Polygonum virginianum	Tovara virginiana	Jumpseed	Polygonaceae	5	FAC	FACW-	Forb	AN	DI	Shade
TOXIRADI		Toxicodendron radicans	Poison ivy	Anacardiaceae	2	FAC	FAC+	Vine	W	DI	Partial
TRACDIFF		Trachelospermum difforme	Climbing dogbane	Apocynaceae	4.5	FACW	FACW	Vine	PE	DI	Shade

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Species Code IBI Development	USDA Scientific Name	Scientific Name- Radford/Weakley	Common Name	Family	Ave C of C for Nc	NWI Reg 2 Ind	NC Wetland Ind	Form	Habit	Group	Shade
TRIAWALT		Triadenum walteri	Larger marsh St. John's wort	Clusiaceae	5.5	OBL	OBL	Forb	PE	DI	Partial
TRICDICH		Trichostema dichotomum	Blue curls	Lamiaceae	3	NG	UPL	Forb	AN	DI	Full
TYPHLATI		Typha latifolia	Broad-leaf cattail	Typhaceae	2	OBL	OBL	Forb	PE	MONO	Full
TYPHSPP		Typha spp	Cattail	Typhaceae	.	OBL	OBL	Forb	PE	MONO	Full
ULMUALAT		Ulmus alata	Winged elm	Ulmaceae	4	FACU+	FAC+	Tree	W	DI	Tree
ULMUAMER		Ulmus americana	American elm	Ulmaceae	5.5	FACW	FACW	Tree	W	DI	Tree
ULMURUBR		Ulmus rubra	Slippery elm	Ulmaceae	5.5	FAC	FAC	Tree	W	DI	Tree
ULMUSPP		Ulmus spp	Elm species	Ulmaceae	.	NG	x	Tree	W	DI	Tree
UNIOLATI	Chasmanthium latifolium	Uniola latifolia	River oats	Poaceae	4.5	FAC-	FAC+	Grass	PE	MONO	Shade
UTRISPP		Utricularia spp	Bladderwort	Lentibulariacea	.	OBL	OBL	Forb		DI	Full
UVULPERF		Uvularia perfoliata	Perfoliate bellwort	Liliaceae	6.5	FACU	FACU	Forb	PE	MONO	Shade
UVULSESS	Uvularia sessilifolia	Uvularia sessifolia	Sessile leaf bellwort	Liliaceae	7	FAC+	FAC+	Forb	PE	MONO	Shade
UVULSPP		Uvularia spp	Bellwort	Liliaceae	.	NG	x	Forb	PE	MONO	Shade
VACCARBO		Vaccinium arboreum	Sparkleberry	Ericaceae	6.5	FACU	FACU-	Shrub	W	DI	Partial
VACCCORY		Vaccinium corymbosum	Highbush blueberry	Ericaceae	6.5	FACW	FACW	Shrub	W	DI	Partial
VACCELLI		Vaccinium elliottii	Elliot blueberry	Ericaceae	7	FAC+	FAC+	Shrub	W	DI	Shade
VACCFUSC		Vaccinium fuscatum	Highbush blueberry	Ericaceae	6.5	FAC+	FACW	Shrub	W	DI	Shade
VACCMYRS		Vaccinium myrsinites	Shiny blueberry	Ericaceae	8	FACUP	FAC	Shrub	W	DI	Partial
VACCSTAM		Vaccinium stamineum	Deer berry	Ericaceae	5	FACU	FACU	Shrub	W	DI	Shade
VACCTENE		Vaccinium tenellum	Slender blueberry	Ericaceae	8	FACU-	FAC-	Shrub	W	DI	Partial
VERBALTE		Verbesina alternifolia	Wingstem	Asteraceae	3	FAC	FAC+	Forb	PE	DI	Partial
VERBURTI		Verbena urticifolia	White vervain	Verbenaceae	3	FAC+	FACU	Forb	PE	DI	Full

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VERNNOVE		Vernonia noveboracensis	New York ironweed	Asteraceae	5	FAC+	FAC+	Forb	PE	DI	Full
VERNSPP		Vernonia spp	Ironweed	Asteraceae	.	NG	x	Forb	PE	DI	Full
VIBUACER	Viburnum acerifolium	Viburnum acerifolium	Maple-leaved viburnum	Caprifoliaceae	6.5	FACU	FACU	Shrub	W	DI	Shade
VIBUDENT		Viburnum dentatum	Arrow-wood	Caprifoliaceae	5	FAC	FAC+	Shrub	W	DI	Full
VIBUNUDU		Viburnum nudum	Possum-haw	Caprifoliaceae	6	FACW+	OBL	Shrub	W	DI	Advent
VIBUPRUN		Viburnum prunifolium	Black-haw	Caprifoliaceae	6	FACU	FAC-	Shrub	W	DI	Shade
VIBURUFI		Viburnum rufidulum	Rusty blackhaw	Caprifoliaceae	7	FACU	FACU-	Shrub	W	DI	Partial
VIBUSPP		Viburnum spp	Viburnum	Caprifoliaceae	.	NG	x	Shrub	W	DI	Shade
VINCMAJO		Vinca major	Bigleaf periwinkle	Apocynaceae	0	NG	FAC	Vine	PE	DI	Advent
VINESPP		Unknown vine species	Unknown vine species	Vine	.	NG	x	Vine			NA
VIOLSPP		Viola spp	Violet	Violaceae	.	NG	x	Forb	PE	DI	Shade
VITIAEST		Vitis aestivalis	Summer grape	Vitaceae	5	FAC-	FAC	Vine	W	DI	Shade
VITIROTU		Vitis rotundifolia	Muscadine grape	Vitaceae	4.5	FAC	FAC-	Vine	W	DI	Advent
VITISPP		Vitis spp	Grape	Vitaceae	.	NG	x	Vine	W	DI	Advent
WISTFRUT		Wisteria frutescens	American wisteria	Fabaceae	6.5	FACW	FACW	Vine	W	DI	Shade
WISTSINE		Wisteria sinensis	Chinese wisteria	Fabaceae	0	NG	FACU	Vine	W	DI	Advent
WISTSPP	Wisteria spp	Wisteria species	Wisteria species	Fabaceae	.	NG	x	Vine	W	DI	Advent
WOODAREO		Woodwardia areolata	Netted chain fern	Blechnaceae	5	OBL	OBL	Fern	PE	SVP	Full
WOODSPP		Woody spp	Woody spp	Woody	.	NG	x	NI	W	NI	NA
WOODVIRG		Woodwardia virginiana	Virginia chain fern	Blechnaceae	8	OBL	OBL	Fern	PE	SVP	Full
XYRISPP		Xyris spp	Yellow-eyed grass	Xyridaceae	.	NG	x	Forb	PE	MONO	Full

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astesppa		Aster spp A	Aster species	Asteraceae	.			Forb		DI	
astesppb		Aster spp B	Aster species	Asteraceae	.			Forb		DI	
carasppa		Carex spp A	Sedge species	Cyperaceae	.			Sedge		MONO	
caresppa		Carex spp B	Sedge species	Cyperaceae	.			Sedge		MONO	
caresppc		Carex spp C	Sedge species	Cyperaceae	.			Sedge		MONO	
caresppd		Carex spp D	Sedge species	Cyperaceae	.			Sedge		MONO	
caresppe		Carex spp E	Sedge species	Cyperaceae	.			Sedge		MONO	
cypesppa		Cyperaceae spp A	Sedge species	Cyperaceae	.			Sedge		MONO	
cypesppb		Cyperaceae spp B	Sedge species	Cyperaceae	.			Sedge		MONO	
cypesppc		Cyperaceae spp C	Sedge species	Cyperaceae	.			Sedge		MONO	
cypesppd		Cyperaceae spp D	Sedge species	Cyperaceae	.			Sedge		MONO	
eupaspp		Eupatorium spp	Dog fennel	Asteraceae	.			Forb	PE	DI	
herbsppa		Herb spp A	Herb species		.			Forb			
herbsppb		Herb spp B	Herb species		.			Forb			
herbsppc		Herb spp C	Herb species		.			Forb			
herbsppd		Herb spp D	Herb species		.			Forb			
herbsppe		Herb spp E	Herb species		.			Forb			
herbsppf		Herb spp F	Herb species		.			Forb			
juncsppa		Junc spp A	Rush Secies	Juncaceae	.	OBL		Rush		MONO	
ludwsppa		Ludwidgia spp A	Seedbox species	Onagraceae	.	OBL		Forb	PE	DI	
ludwsppb		Ludwidgia spp B	Seedbox species	Onagraceae	.	OBL		Forb	PE	DI	
poacsppa		Poaceae spp A	Grass spp	Poaceae	.			Grass		MONO	

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poacsppb		Poaceaa spp B	Grass spp	Poaceae	.			Grass		MONO	
poacsppc		Poaceae spp C	Grass spp	Poaceae	.			Grass		MONO	
polysppa		Polygonum spp A	Smartweed	Polygonaceae	.			Forb		DI	
polysppb		Polygonum spp B	Smartweed	Polygonaceae	.			Forb		DI	
woodsppa		Woody spp A	Woody spp		.			Shrub	W	DI	

Table F.2 Normality Results based on Shapiro-Wilk W Goodness of Fit test for Plant Metrics

Plant Metric	W	Prob<W	Normal Distribution
Simpson's Diversity Index Metric	0.8233	0.0012	No
Simpson's Diversity Index Native Metric	0.8572	0.0046	No
Evenness Metric	0.8362	0.0020	No
Evenness Native sp Metric	0.8639	0.0060	No
Dominance Metric	0.9546	0.3886	Yes
Species Richness Metric	0.9635	0.5637	Yes
Vascular Plant Genera Metric	0.9539	0.3763	Yes
FQAI Metric	0.9755	0.8329	Yes
FQAI Cov Metric	0.8793	0.0117	No
Average C of C Metric	0.9734	0.7874	Yes
Percent Tolerant Metric	0.7566	0.0001	No
Percent Sensitive Metric	0.8185	0.0010	No
Invasive Cover Metric	0.6119	0.0000	No
Invasive Shrub Cover Metric	0.6460	0.0000	No
Invasive Grass Cover Metric	0.4846	0.0000	No
FAQWet Equation 3 Metric	0.9938	0.9999	Yes
FAQWet Cover Equation Metric	0.9899	0.9971	Yes
FAQWet equation 3 (mod 1 and mod 8)	0.9707	0.7275	Yes
FAQWet eqation 4 cov (mod 1 and mod 8)	0.9655	0.6084	Yes
Wetland Plant Richness Metric	0.9635	0.5637	Yes
Wetland Plant Cover Metric	0.9561	0.4146	Yes
Wetland Shrub Richness Metric	0.9635	0.5637	Yes
Wetland Shrub Cover Metric	0.8993	0.0288	No
Cryptogram Richness Metric	0.9635	0.5637	Yes
Cryptogram Cover Metric	0.9666	0.6329	Yes
Annual+Bi:Perrenial Metric	0.2878	0.0000	No
Bryphyte Cover Metric	0.7793	0.0002	No
Carex Richness Metric	0.9635	0.5637	Yes
Carex Cover Metric	0.7000	0.0000	No
Cyp, Poac, Junc Richness Metric	0.9635	0.5637	Yes
Cyp, Poac, Junc Cover Metric	0.8379	0.0021	No
Dicot Richness Metric	0.9635	0.5637	Yes
Dicot Cover Metric	0.8740	0.0093	No
Native Herb Richness Metric	0.9635	0.5637	Yes
Native Herb Cov Metric	0.8167	0.0009	No
Shade Metric	0.8453	0.0028	No
Sapling Density Metric (all stems)	0.9301	0.1232	Yes
Sapling Density Metric (tree&smtre stems)	0.7908	0.0004	No
Large Tree Density Metric (all Stems)	0.8371	0.0020	No
Large Tree Density Metric (tree&smtre stems)	0.7633	0.0001	No
Pole Timber Metric (all stems)	0.8590	0.0049	No
Pole Timber Density Metric with Tree Stems Only	0.8617	0.0055	No
Canopy IV Metric	0.9376	0.1769	Yes
Canopy IV Metric (canopy sp 4 density and dom only)	0.9723	0.7642	Yes
Ave Imp partial + shade Subcanopy Metric	0.9447	0.2471	Yes
Ave Imp partial + shade (shrub + sm tre sp only) Metric	0.9713	0.7412	Yes
Ave Importance Subcanopy Metric	0.9262	0.1022	Yes
Ave Importance Subcanopy (shrub sm tre only) Metric	0.9186	0.0710	Yes