Utilization of Natural Wetlands for Stormwater Assimilation

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Executive Summary

This study summarizes the results of four years of research assessing the impact of residential and commercial stormwater discharge on eight wetlands in the Piedmont and Coastal Plain of North Carolina. Parameters such as assimilative capacity, water chemistry, soils, vegetation, and other biota were measured to test for adverse impacts to wetlands and ability of these wetlands to retain and treat stormwater.

Results indicate that stormwater discharge to natural wetlands is feasible under certain circumstances and can provide benefits, such as hydrologic restoration of disturbed wetlands and reduction of some stormwater pollutants. Despite these benefits, adverse consequences were also observed. Channelization, sedimentation, and a shift in soil particle size were noted in several wetlands receiving stormwater discharge. Observed effects of stormwater discharge on wetland biota were minimal, though there was some evidence of flood-induced tree mortality.

Though stormwater discharge can help promote water quality in downstream waters, precautions need to be taken to minimize negative impacts to the wetlands associated with this practice. Pretreatment of stormwater and promotion of diffuse flow are necessary to reduce impacts to the wetland and to maximize stormwater assimilation. Proper site selection and adequate sizing of wetlands to be utilized for stormwater assimilation can prevent impacts to high quality wetlands and ensure adequate treatment of stormwater. Finally the Division of Water Quality should continue monitoring stormwater discharges to natural wetlands in order to further refine this practice and to safeguard against adverse impacts to North Carolina’s wetlands.

I. Introduction

Stormwater has received increasing attention as a major source of non-point source pollutants affecting North Carolina's waterways. The Division of Water Quality and locally delegated stormwater programs are tasked with mitigating the impact of runoff on the natural environment and accordingly require a number of practices to treat stormwater before it reaches water bodies. These agencies often recommend created wetlands as a means to treat stormwater, since wetlands have long been recognized as a sink and transformer of sediment, nutrients, and contaminants. In recent years, with expanding development and an abundance of wetlands in North Carolina, natural systems have increasingly been considered as a means to treat a variety of non-point sources.

The use of natural wetlands for stormwater treatment can be a beneficial practice, especially where space for land consuming treatment devices is not available or existing site conditions are prohibitive. In some cases, wetlands have been filled to make room for stormwater detention ponds, and in such instances it becomes necessary to ask whether stormwater assimilation in natural wetlands would be preferable. Also development can alter ground and surface water patterns that may cause wetlands to dry out. Under such circumstances, discharge of stormwater might actually help to maintain the wetland's natural hydrology.

Wetlands have been shown to be effective tools for filtering and trapping pollutants. Treatment of stormwater in wetlands can promote downstream water quality by settling out solids and adsorbed contaminants (Gersberg et al. 1984; Boto and Patrick 1979). Wetlands can provide a means of capture and transformation of nutrients through bacterial cycling and plant uptake (Chan et al. 1981; Lee 1975). Wetlands can also improve water quality by reducing peak flows and sustaining base flow over a longer duration, thus maintaining stable hydrology in downstream receiving waters (Daniels 1981).

Despite the advantages of using natural systems for stormwater treatment, a host of potential adverse consequences for the environment have been identified. Researchers have extensively examined the constituents of stormwater from different land uses and have studied the effects of stormwater on streams, rivers, and lakes. However wetlands are complex systems and the impacts of stormwater vary greatly based on the particular vegetation, soils, and hydrology of a wetland. Though wetlands do provide natural water storage and filtering functions, the levels of loadings associated with stormwater may exceed a wetland's assimilative capacity and thereby cause detrimental effects in the wetland.

When stormwater discharges exceed the assimilative capacity of a wetland, prolonged flooding can affect wetland vegetation and cause plant mortality (Azous and Cooke 2001; Stockdale1991). Flooding of woody plants may gradually reduce growth and be reflected in lower dry mass, leaf area, tree growth, and height of trees (Jones et al 1988). Hydrological alteration may also alter wetland plant diversity, which has been shown to be richer when exposed to periodic inundation as opposed to dry or semi-permanently flooded conditions (Conner et al. 1981; Barnes 1975). Though many wetland plants are capable of regenerating under a broad range of hydrological conditions, certain species germinate poorly when excessively inundated and may be especially affected by stormwater-induced flooding (Keddy and Ellis 1985).

Other potential impacts to wetlands are related to the constituents of stormwater. Problems may result from excess sedimentation, nutrient inputs, and contamination from metals adsorbed to suspended particles, as well as other chemical and biological sources of pollution. These disturbances may alter the water and sediment quality, affect the biotic components of the ecosystem, and eventually degrade the integrity of the wetland as a whole.

II. Study Objective

This study was designed to better understand the impacts of stormwater discharge on natural wetlands in North Carolina and to recommend methods for mitigating potentially adverse effects of this practice. The study included eight sites (along with reference sites in some cases) located in the Piedmont and Coastal Plain ecoregions of North Carolina. Wetlands representing a variety of different hydrogeomorphic and vegetation types were selected for study. Runoff to these sites was primarily residential in nature, though one site was being developed for commercial/office land use during the study.

Sites were identified through the NC Division of Water Quality's 401 Certification process and were in various stages of development. One site received stormwater before the study began, and a reference site with comparable hydrogeomorphic features was identified for comparison. Other sites had yet to receive stormwater discharges and were primarily used to derive baseline data on wetland function and to consider their potential to assimilate stormwater. In at least one case, some baseline data were obtained before stormwater was discharged to the wetland, allowing for pre and post-discharge comparisons at the same site.

The study was designed to focus on biotic and abiotic parameters in order to assess the impact of stormwater on the overall integrity of selected wetlands. Aspects of the watersheds draining to the wetlands and the volume of stormwater discharges were analyzed. The assimilative capacity of the wetlands was estimated in relation to these factors. Sedimentation rates and water chemistry parameters were measured as well. Assessment of the biotic components of the wetlands focused primarily on vegetation structure and composition, though invertebrates and amphibians were also monitored for signs of impact.

This report summarizes the methods used to study stormwater impacts to natural wetlands, an analysis of these impacts, and an assessment of the individual sites included within the study. Additionally, recommendations are provided with respect to how and under what circumstances stormwater can be effectively discharged into natural wetlands with minimal impact.

III. Methods

Site Selection

Candidate study sites were identified through the 401 Certification process by examining proposed stormwater outfalls of residential and commercial developments and the proximity of these devices to wetlands on a project site. In most sites direct stormwater outfalls to adjacent wetlands were identified. Wetland sites and project stormwater design were evaluated in order to assess suitability for the study. Permit applicants were contacted and permission was requested to include their project in the study. In a number of cases access was denied or sites were excluded from the study because of excessive impacts to the wetland from construction activities.

An attempt was made to select wetlands from all level III ecoregions of the state (areas of homogenous geology, climate, physiography, and vegetation (Woods et al. 1996)) and of various wetland types (Figure 1). Sites were not selected in the Blue Ridge ecoregion because of the paucity of wetlands and (in one case) the long travel required to visit sites. The wetland types selected were based on general hydrogeomorphic characteristics, such as hydrologic regime, topographic position, vegetation, and soils. In order to effectively assess stormwater impacts, reference sites were selected for a number of wetlands receiving stormwater discharge. Reference sites were chosen based on having conditions similar to the impacted site, i.e. landscape position, soils, hydrology, and vegetation where possible (Table 1).

In addition to collecting reference data from similar, non-impacted wetlands, baseline data were collected where possible before stormwater discharge was introduced. In one case (Carteret Co. site), it was possible to obtain some data before and after stormwater was directed into the wetlands. Several wetlands in the study were assessed for baseline conditions, however, they had yet to receive stormwater by the writing of this report. These sites are included to provide additional baseline and reference condition data and to estimate the future consequences of stormwater inputs.

Assimilative Capacity

The ability of each wetland to receive direct stormwater discharge and overland runoff from the surrounding landscape was analyzed to assess their hydrological assimilative capacity. The area of each wetland was calculated from aerial photo interpretation and review of submitted site plans. Maximum depth was estimated from the maximum water level observed during the study period. Since the 2003 growing season was extremely wet, it was assumed that the observed depths reflected the approximate wetland holding capacity. For sites that were not observed while inundated, maximum depth estimates were based on geomorphic features of the wetland such as slope, contour, and soil type. Maximum depth of the Guilford Co. 1 site was based on the predetermined height of the impoundment structure designed to eventually flood the wetland.

Table 1. General Features of Stormwater Wetland Sites in the Piedmont and Coastal Plain of North Carolina

Location Name	Site Name	Ecoregion	Stormwater Discharge?	NC WFAT Wetland Type ***	Geomorphic Wetland Type *	Hydrology	Predominant Soil Textures	Vegetation
Wake Co. Impact	Mountain Brook Subdivision	Piedmont	Present	Headwater Swamp	Riverine - headwater wetland	Flow through	Silty clay	Forested
Wake Co. Reference	Mountain Brook Subdivision	Piedmont	Absent	Headwater Swamp	Riverine - headwater wetland	Flow through	Silty, sandy clay	Forested
Gaston Co. **	Sundance Subdivision	Piedmont	Planned	Headwater Swamp	Riverine - headwater wetland	Flow through	Sandy clay	Forested/ emergent
Carteret Co. **	Newport Triangle	Mid-Atlantic Coastal Plain	Planned	Pocosin	Depressional - pocosin	Isolated	Peat	Forested
New Hanover Co. Impact	Tydalholme Subdivision	Mid-Atlantic Coastal Plain	Present	Other	Depressional - break in slope	Flow through	Muck and mucky sand	Forested/ emergent
Craven Co. Impact	MacDonald Downs	Mid-Atlantic Coastal Plain	Present	Swamp Forest – Nonriverine	Depressional - Carolina Bay	Flow through	Muck and sandy clay	Forested
Craven Co. Reference	Cool Springs Bay	Mid-Atlantic Coastal Plain	Absent	Swamp Forest – Nonriverine	Depressional - Carolina Bay	Isolated	Muck and mucky loam	Forested
Robeson Co. **	Comtech	Southeastern Coastal Plain	Planned	Freshwater Marsh – Non-tidal	Depressional - Carolina Bay	Isolated	Mucky sand	Scrub-shrub/ emergent
Guilford Co. 1 **	S. Buffalo Creek Floodplain	Piedmont	Planned	Bottomland Hardwood Forest	Riverine - bottomland floodplain	Flow through	NA	Forested
Guilford Co. 2 **	Deep River Pools	Piedmont	Uncertain	Ephemeral Wetland	Depressional - Vernal Pool	Isolated	Silty loam and sandy - silty clay	Forested

* Adapted from HGM settings as described in Brinson (1993)

** These sites will receive stormwater discharge once site build-out has occurred.

*** NC Wetland Functional Assessment Team (2004)

The drainage area of each site was derived from USGS 1:24,000 topographic maps and aerial photos. Overall land cover class and the hydrologic group of the predominant soil types in the drainage basin were estimated. In cases where construction was ongoing, future land use was estimated from site plans in order to predict future runoff volumes.

These attributes were then applied to the USDA SCS equation (USDA 1986) to calculate the runoff coefficient. Total depth of overland runoff was estimated using the equation:

$$\mathbf{R = (P / 0.2\ S)^2 / (P + 0.8\ S)} \text{ and where}$$

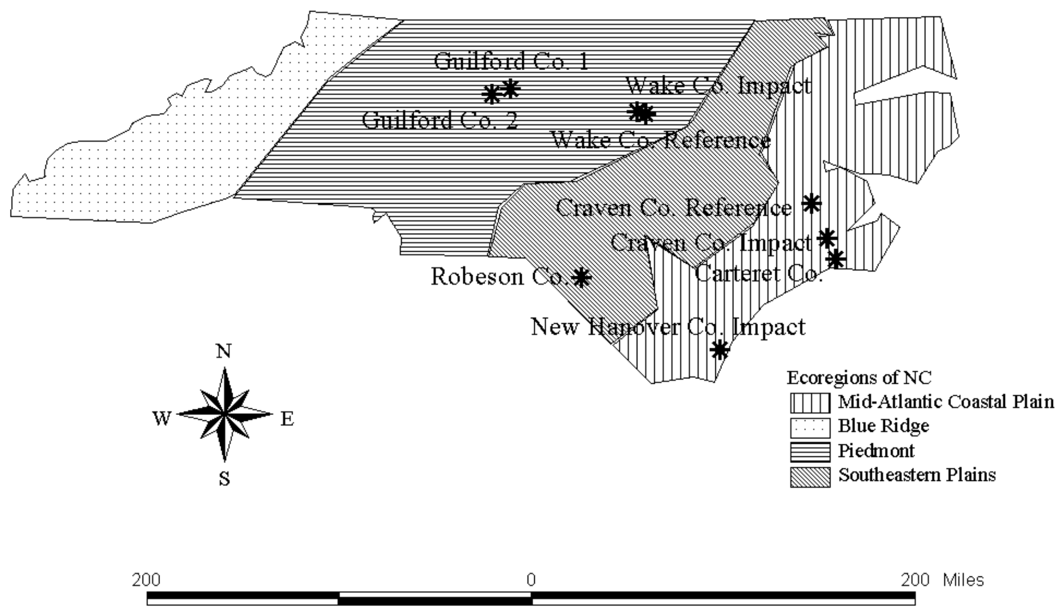
R = inches of runoff,

P = precipitation (calculations based on 1” rain event), and

S = 1000 / SCS Curve number – 10.

The depth of runoff was then multiplied by the acreage of the drainage area to calculate the total volume of runoff in acre/inches (Hunt 2000). The runoff volume was then compared to the holding capacity of the wetland to assess its ability to assimilate stormwater.

Figure 1. Location of Stormwater Wetland Sites in the Piedmont, Coastal Plain, and Southeastern Plains of North Carolina



Water Depth

Water depths were periodically measured when sites were visited for water quality and vegetation sampling. Depths were measured manually using a meter stick placed on the ground surface in a set location within the wetland. In sites where standing water was not present, groundwater was observed by installation of an auger hole and measurement of the water level beneath the ground surface.

Water Chemistry

Several water chemistry parameters (including TSS, nutrients, metals, and oil and grease) were explored to evaluate the water quality of sites receiving stormwater discharges, reference sites, and sites that had yet to receive stormwater discharges. Grab samples were collected at various times during the year from the sites and were processed according to standard NCDWQ laboratory methods (Table 2). For three sites, samples were taken at the head of the wetland near the stormwater discharge point and at the base near the outflow point from the wetland. This allowed water quality comparisons at these points and evaluation of the ability of the wetland to filter and reduce stormwater pollutant loadings. Data from Raleigh (City of Raleigh, NC 2000) and Greensboro, North Carolina (City of Greensboro, NC 2000) urban stormwater sampling stations were obtained to compare with pollutant loadings from the wetland sites. Mean pollutant concentrations were calculated from data collected from 1993 and 2000 at seven stations in both of these urban areas.

Soils

At each site soils were analyzed at several points along the path of stormwater discharge and flow through the wetland. Soil samples were taken from a depth of 2' using a soil auger. Samples were analyzed for texture, color using the Munsell Soil Color Chart (USDA 1994), and hydric soil features, such as presence and percentage of mottling and predominance of organic matter (qualitatively assessed). Sedimentation was also

Table 2. Collection and Preservation of Water Quality Samples for the NCDWQ Laboratory Section (NCDWQ, 2003)

Parameter	Minimum Required Volume	Container P-Plastic G-Glass	Preservation	Maximum Holding Time
Residue (TSS)	500 ml each	P (Disposable)	Cool, 4° C	7 days
Oil & Grease	2 liters (two 1 liter bottles)	G (Wide mouth quart jar, Teflon-lined cap)	Cool, 4° C, 1:1 H_2SO_4 to pH<2	28 days
NH_3 as N	500 ml x 1	P (Disposable)	Cool, 4° C, 25% H_2SO_4 to pH<2 0.008%$Na_2S_2O_3$	28 days
TKN as N	Combined with above	P (Disposable)	Cool, 4° C, 25% H_2SO_4 to pH<2 0.008%$Na_2S_2O_3$	28 days
$NO_3 + NO_2$ as N	Combined with above	P (Disposable)	Cool, 4° C, 25% H_2SO_4 to pH<2	28 days
P Total as P	Combined with above	P (Disposable)	Cool, 4° C, 25% H_2SO_4 to pH<2	28 days
Metals: Al, Cd, Cr, Cu, Fe, Pb, Zn	500 ml x 1	P (Disposable)	1+1 HNO_3 to pH<2	6 months

measured using two distinct techniques. Feldspar horizons were initially installed on the wetland soil surface (Kleiss1993). Because of the difficulty in installing these horizons under flooded conditions, sedimentation plates were installed during the latter half of the study. The plates consisted of a Plexiglas square 15-cm X 15-cm anchored to the wetland surface using a 10" lag bolt. These two methods yielded similar results, and data from the two methods were combined. Sediment accretion was measured to the 0.25-cm level and was expressed as mm / month.

Vegetation

Several vegetation parameters were measured using the sampling techniques of the NC Vegetation Survey (Peet et al.1998). Plot size varied from 100 – 300-m^2 depending on the vegetation structure and the ease of plot installation. Plot size tend to be smaller in denser vegetation where movement was constrained. Two plots were sampled in all but two wetlands where size constraints and restrictive vegetation prevented additional sampling. Plots were located in homogenous vegetation along the flow path in riverine wetlands and along one edge and in the center of depressional wetlands. General vegetation features, such as groundcover and percent cover of different vegetation strata (herbs, shrubs, understory, and canopy) were recorded for each plot. For three sites previously collected data were included in the analysis in order to provide species composition and tree basal area estimates.

In each plot all species present were recorded and the total number of species was calculated. Total cover of all woody and herbaceous plants was recorded for each plot. Cover was estimated using Daubenmire Cover classes (Bonham 1989). Cover classes were later converted to the median value for that class and the mean cover value for each species in the two plots per site was calculated.

The species and diameter at breast height (dbh) of all woody vegetation $\geq$ 3" dbh was recorded. Basal area of woody plants (ft^2 / acre) was calculated for each site based on the combined basal area of both sampling plots extrapolated to an area of one acre. Tree species were grouped by flood tolerance (least to most tolerant) and relative percentage of basal area per tolerance class was calculated (Hook 1984). The number of individual shrubs (woody plants < 3") and individual stems of vines was also recorded for each plot and extrapolated for an area of one acre.

Several methods were used to assess the vegetation of the sites and to compare reference and impacted wetlands. Total species richness was calculated for each site. Using the mean relative cover of all plant species present, the Shannon – Weinberg index of diversity was calculated as follows:

$$H' = -\sum p_i \ln p_i$$

where p_i is the relative cover of the $_i$ th species (Magrurran 1988). The total number and relative percent cover of native and exotic species was determined for each site. Additionally the wetland indicator status (USFWS 1996) of all plant species identified was determined and the relative cover of the major indicator status categories was calculated. Indices were compared across sites and between reference and impact wetlands.

Other Biotic Indicators

Aquatic invertebrate samples were collected for three sites that held sufficient standing water. Invertebrates were collected using a D-frame dip net. Approximately 20 sweeps of the net were conducted in each wetland in the water column, emergent vegetation, and in the substrate on the floor of the wetland. Invertebrates were field sorted and only organisms $\geq$ 500-μm were collected. All organisms were preserved in ethanol and identified to genus using a dissecting microscope.

Amphibians were sampled by dip netting aquatic larvae and calling surveys of breeding frogs. Calling surveys were conducted informally during site visits and presence of any calling species was recorded in the field. Larval dip netting was typically incidental during invertebrate sampling events. In one site (New Hanover Co.) it was possible to capture and identify adult frogs and their presence was recorded as well.

IV. Results

Assimilative capacity

The majority of wetland study sites were of adequate size to retain the volume of runoff generated by their drainage areas (Tables 3 and 4). One site was currently undersized for the runoff from its drainage area and two other sites to be developed were undersized for the predicted runoff from the built-out drainage area. The holding times for these wetlands were not calculated, because discharge was not measured or, in the case of

Table 3. Characteristics of Stormwater Wetland Drainage Areas

Site	Drainage Area (acres)	Soil Series	Hydrological Group	Present Land Use	CN *	Future Land Use	CN *	Present Runoff Volume (ac-in)	Future Runoff Volume (ac-in)
Wake Co. Impact	5.03	Cecil	B	1/4 ac lots	75			0.84	
Wake Co. Reference	10.32	Cecil	B	1/4 ac lots & woods	69			0.73	
Gaston Co.	17.11	Pacolet & Cecil	B	Woods	60	1/4 ac lots	75	0.07	2.85
Carteret Co.	17.76	Leon, Murville, & Baymead	A&D	Cleared area	79	Commercial	92	4.59	14.22
New Hanover Co. Impact	17.05	Kureb & Lynn Haven	A&D	1/4 ac lots	70			1.43	
Craven Co. Impact	12.77	Lenoir	D	1/4 ac lots	87			6.84	
Craven Co. Reference	119.5	Lenoir & Tarboro	A&D	Woods	70	Woods	70	10.02	10.02
Robeson Co.	35	Rains	D	Woods	79	Commercial & open space	95 & 89	9.05	29.71
Guilford Co. 1	8320	Enon-Urban & Mecklenburg-Urban	C	Commercial & business district	94			7793.00	
Guilford Co. 2	14.1	Cecil & Madison	B	Woods	60	1/4 ac lots	75	0.06	2.35

* CN = SCS Runoff Coefficient

Table 4. Hydrological Assimilative Capacity of Stormwater Wetlands

Site	Wetland Area (acres)	Estimated Depth (inches)	Wetland Volume (ac-in)	Present Runoff Volume (ac-in)	Future Runoff Volume (ac-in)
Wake Co. Impact *	0.75	1.00	0.75	0.84	
Wake Co. Reference	1.78	2.00	3.56	0.73	
Gaston Co.	1.55	1.50	2.33	0.07	2.85
Carteret Co.	8.64	4.00	34.56	4.59	14.22
New Hanover Co. Impact	21.40	6.00	128.40	1.43	
Craven Co. Impact	2.50	12.00	30.00	6.84	
Craven Co. Reference	1.80	12.00	21.60	10.02	10.02
Robeson Co. *	1.07	18.00	19.26	9.05	29.71
Guilford Co. 1 * †	21.00	12.00	252.00		7793.00
Guilford Co. 2	1.52	13.50	20.52	0.06	2.35

* Site not adequately sized to assimilate 1" rainfall event.
† Stormwater does not presently reach floodplain. Work is currently underway to restore floodwaters to floodplain by means of temporary controlled impoundment. Flooding is at this site will dissipate in 24 hours.

most of the depressional wetlands, there was no discharge from the site. Nevertheless, it appeared that wetlands with flow through hydrological patterns drained relatively quickly in comparison to the hydrologically isolated sites, which often retained water continuously through the last growing season.

Three wetlands were undersized in relation to the volume of runoff from their drainage basins (Table 4). The Wake Co. Impact site was ill suited for receiving stormwater, primarily because the site did not have sufficient depth to retain a large volume of runoff. Rills from the erosive stormwater flows were evident at this site. The Gaston Co. site, another flow through, riverine wetland, could also face potential erosion problems due to inadequate sizing. The Robeson Co. Impact site, a depressional wetland, was poorly sized for the predicted runoff to the wetland. If the drainage area builds out as predicted the wetland could be subjected to flooding. The Guilford Co. 1 site is an experimental site to be temporarily flooded by an automated, temporary dam on South Buffalo Creek. The impoundment is designed to flood the wetland area to a depth of 1 foot for no greater than 24 hours to prevent prolonged inundation. It is not clear whether this wetland will be undersized, and, accordingly, floodplain monitoring for this site was required in the 401 Certification in order to detect any deleterious effects.

In terms of the ability of the wetlands to retain stormwater, the riverine wetlands (Wake Co. and Gaston Co.) provided the least amount of retention. Wetlands in these sites contained braided channels and were clearly drained by perennial or intermittent stream channels at their base. Though the Craven Co. wetland had a constructed, outlet channel, flowing water was never observed in the outlet, and it was assumed that discharge from the wetland was minimal. This wetland site was depressional in nature and lacked any defined channels or flow paths. In general the depressional wetlands appeared to provide greater retention of stormwater than riverine wetlands.

Water Depth

Several factors confounded analysis of water depth data. The study period was characterized by extreme fluctuations in precipitation. The 2001 and 2002 growing seasons were extremely dry, whereas 2003 was an unusually wet year. Furthermore, accurate water level data were not collected on a consistent basis but rather were recorded when sites were visited for water quality and vegetation sampling. Nevertheless significant variation across sites and over seasons was observed (Table 5). The Carteret Co. site was consistently dry, while the nearby Craven Co. Impact site held water throughout the study period. Seasonal variation was noticeable at the Robeson Co. site, which was initially dry when visited in December 2002 but thereafter held water through July 2003.

Water Chemistry

Pollutant loadings in most wetland sites were much lower than mean concentrations found in urban stormwater (Appendix C). Mean urban stormwater concentrations of NO_2, NO_3, Cd, and Zn were higher than the maximum observed levels from any wetland

Table 5. Wetland Water Depths Recorded During Site Visits

Site	Location	Date	Depth (inches)	Change from previous (inches)	Soil Saturated?
Carteret Co.	Center	1/3/03	0	-	No
Carteret Co.	Center	5/9/03	0	0	No
Carteret Co.	Center	10/10/03	0	0	Yes
Craven Co. Impact	Center	1/3/03	24	-	Yes
Craven Co. Impact	Center	5/9/03	16	-8	Yes
Craven Co. Impact	Center	7/9/03	12	-4	Yes
Craven Co. Reference	Center	9/25/03	12	-	Yes
Craven Co. Reference	Center	10/7/03	24	+12	Yes
Gaston Co.	Head	12/3/02	0	-	Yes
Gaston Co.	Base	12/3/02	0	-	No
Gaston Co.	Head	2/11/03	0.5	+0.5	Yes
Gaston Co.	Base	2/11/03	0	0	No
Gaston Co.	Head	7/5/03	0	-.05	Yes
Gaston Co.	Base	7/5/03	1.5	+1.5	Yes
Guilford Co. 1	Center	12/28/02	2.5	-	Yes
Guilford Co. 2	Center	1/8/03	13	-	Yes
New Hanover Co. Impact	Center	4/24/03	12	-	Yes
New Hanover Co. Impact	Center	7/30/03	0	-12	Yes
Robeson Co.	Center	11/26/02	0	-	No
Robeson Co.	Center	3/12/03	18	+18	Yes
Robeson Co.	Center	4/24/03	18	0	Yes
Robeson Co.	Center	7/23/03	13	-5	Yes
Wake Co. Impact	Center	1/6/03	0	-	No
Wake Co. Impact	Center	3/15/03	0	0	No
Wake Co. Impact	Center	6/13/03	0	0	No
Wake Co. Reference	Center	1/15/03	1.5	-	Yes
Wake Co. Reference	Center	3/15/03	2	+0.5	Yes
Wake Co. Reference	Center	6/13/03	2	0	Yes

sample. In contrast, some sites such as the New Hanover Co. Impact site had higher concentrations of several pollutants than mean levels for urban stormwater, including oil and grease, TSS, TKN, Total P, and Pb. The Craven Co. Impact site also had a higher concentration of oil and grease than the mean for urban stormwater. The heightened levels in both of these two cases were observed at the head of the wetland where stormwater was discharged. The Wake Co. Impact site had levels of copper above the mean for urban stormwater and had the highest level of NO_2 of any wetland sampled (though still less than the mean for either Raleigh or Greensboro urban stormwater).

Grab samples collected from stormwater-impacted wetlands showed higher levels of pollutants than sites that did not receive discharge. Concentrations of some of the following constituents were twice as high or more in the impacted wetlands: TSS, oil and grease, TKN, NO_2 and NO_3, Total P, Al, and Pb (Table 6). Oil and grease concentrations were 30 times greater in impacted wetlands compared to reference wetlands. Levels of metals were typically low in most wetlands. For example, samples of Cd and Cr never yielded detectable levels. Al and Pb, however, were present in a number of sites and showed higher concentrations in stormwater-impacted wetlands than in reference/non-impacted wetlands. In contrast to the other parameters sampled, Zn concentrations were slightly higher in samples from reference wetlands. Levels of NH_3 and Cu did not vary greatly between impacted and reference/non-impacted wetlands.

Table 6. Comparison of Water Quality Parameters of Impacted and Non-impacted Wetlands

Water Quality Parameters		Site Type			
		Stormwater Impacted Wetlands	Number of Samples	Reference and Non-impacted Wetlands	Number of Samples
Mean Suspended Solids (mg/L) ± SE	Total	60.84 ± 23.08	6	27.5 ± 6.13	7
	Volatile	37.67 ± 15.62	6	7.7 ± 1.34	5
	Fixed	22 ± 7.19	6	3.2 ± 0.64	5
Grease & oil		59.84 ± 17.11	6	1.43 ± 0.29	7
Mean Nutrients (mg/L) ± SE	NH_3	0.04 ± 0.01	6	0.07 ± 0.02	7
	TKN	1.34 ± 0.32	6	0.69 ± 0.12	7
	NO_2	0.1 ± 0.06	6	0.03 ± 0.01	7
	Total P	0.22 ± 0.09	6	0.06 ± 0.01	7
Mean Metals (µg/L) ± SE	Cu	1.65 ± 0.65	6	1.16 ± 0.31	7
	Pb	1.84 ± 1.01	6	0 ± 0	7
	Zn	8.34 ± 2.25	6	10.15 ± 2.1	7
	Al	1566.67 ± 288.39	6	882.5 ± 139.67	7

* Samples collected between February and October of 2003.

Table 7. Percent Change of Pollutant Loadings in 3 North Carolina Wetlands*

Water Quality Parameter		Site		
		Craven Co. Impact	New Hanover Co. Impact	Gaston Co.
Mean Suspended Solids (mg/L) ± SE	Total	188%	-98%	-32%
	Volatile	100%	-97%	0%
	Fixed	1100%	-100%	0%
	Grease & oil	2400%	-42%	-100%
	NH3 *	71%	-67%	189%
Mean Nutrients (mg/L) ± SE	TKN	39%	-81%	180%
	NO2	0%	0%	-100%
	Total P	50%	-98%	200%
Mean Metals (µg/L) ± SE	Cu	0%	-100%	0%
	Pb	0%	-100%	0%
	Zn *	1100%	-100%	1400%
	Al *	140%	0%	184%

* Change calculated from head to the base of the wetland.

** N=3

Despite the increased concentrations of sediment, nutrients, and metals present in the stormwater impacted wetlands, reduction in pollutant loadings were noted in at least two wetlands (Table 7). Comparisons of grab samples from the head (near the outfall to the wetland) and base of wetlands (near the point of discharge from the wetland) were made for two stormwater- impacted and one non-impacted site. Though pollutant loadings increased from the head to the base of the Craven Co. Impact wetland, overall trends varied by site and by pollutant. Reductions in Total Suspended Solids and Grease and Oil were evident at the Gaston Co. and New Hanover Co. Impact site. The New Hanover Co. Impact site, in particular, showed marked reductions of unusually high pollutant levels from the head to the base of the wetland (Appendix C).

Soils

Most of the wetlands studied had well developed hydric soils based upon depth of organic matter, presence of a depleted matrix, and/or mottles or gleying (Table 8). In addition, wetland study sites in the Coastal Plain had a significant component of organic matter in their soils. The Carteret Co. site had a thick peat soil several feet deep. The New Hanover Co. site also had a peat layer of approximately 1.5 – 2' thick overlying gray, organic coated sands. Other Coastal Plain sites possessed soils with varying depths of organic matter underlain by a clay layer. Soils of Piedmont sites had lower organic content and were primarily sandy or silty clay. The soils of the Wake Co. Impact site lacked hydric characteristics, as they were high chroma in nature and did not possess any mottles.

Table 8. Soil Characteristics of Stormwater Wetland Sites

Site	Soil Series	Texture	Hue	Value/Chroma	Mottles	Organic / Mineral *
Wake Co. Impact	Cecil sandy loam 10-15% slopes	Silty clay	7.5 YR	4/3.5	No	Mineral
Wake Co. Reference	Chewacla	Silty, sandy clay	2.5 YR	4/1	Yes 20%	Mineral
Guilford Co. 2	Wehadkee	Silty, clay loam	10 YR	5/2	Yes 25%	Mineral
Gaston Co.	Chewacla	Sandy clay	10 YR	5/2	Yes 12.5%	Mineral
Robeson Co.	Rains	Mucky sand	10 YR	2/1	No	Mineral
Craven Co. Impact	Lenoir	Sandy, mucky loam and clay	-	-	No	Organic
Craven Co. Reference	Lenoir	Muck and sandy, mucky loam	-	-	No	Organic
Carteret Co.	Leon & Murville	Peat and muck	-	-	No	Organic
New Hanover Co. Impact	Lynn Haven & Dorovan	Muck and mucky sand	-	-	No	Organic

* Organic / Mineral represents a qualitative assessment of the predominant soil composition.

Table 9. Leaf Litter Depth and Sedimentation Rates of Stormwater Wetlands

Site	Date of Leaf Litter Sampling	Mean Depth of Leaf Litter (cm)	Mean Sedimentation Rate (mm/month)
Wake Co. Impact	1/16/03	7.5	3
Wake Co. Reference	1/15/03	7	3
Guilford Co. 2	1/8/03	7	6
Gaston Co.	2/11/03	0	25
Robeson Co. *	3/12/03	0	-
Craven Co. Impact	5/9/03	2.5	8
Craven Co. Reference *	9/25/03	-	-
Carteret Co. *	5/9/03	15	-
New Hanover Co. Impact *	7/30/03	0	-

* Sedimentation rates were not possible to monitor because of lack of water or inundation that prevented the installation of sediment markers.

Leaf litter was present in most wetlands, though depths varied site to site from 0 – 15-cm (Table 9). Litter depths were greatest in the Carteret Co. pocosin and least at the Gaston, Robeson, and New Hanover Co. sites. Differences in leaf litter depth were noticeable within sites due to scouring by stormwater flows. For example at the Wake Co. Impact site bare soil was evident in the stormwater flow path and leaf litter was absent. In general Piedmont riverine wetlands (Wake Co. Impact and Gaston Co.) had greater cover of exposed soil and were the only sites with a detectable cover area of gravel (Table 10).

Sediment accretion was difficult to monitor due to the variable hydrology of the sites. Installation and observation of sediment trapping devices was hampered by the presence of standing water. Though it was possible to monitor deposition on feldspar horizons under inundated conditions, these markers could not be installed in several wetlands where standing water was present. Where sediment observations were possible, accretion was high in wetlands with flow through hydrology patterns (Table 9). Some sedimentation was detected within one depressional wetland site. The greatest rate was observed in the Gaston Co. site, a site that also exhibited fairly high concentrations of suspended solids and had experienced clearing activities in adjacent uplands.

At the Wake Co. Impact site, scour was significant. Eroded areas were present along the entire stormwater flow path. The sediment that was deposited here was of a much coarser texture (sand and gravel) than the site's natural soil (sandy clay). The greatest sediment deposition observed in wetlands sites resulted from adjacent construction activities rather than stormwater discharge. Sedimentation from construction was appreciable at the Craven Co. Impact site as well as two additional Wake Co. sites that were initially considered for this study but not included. The Wake Co. sites were not selected for the study, because excessive sedimentation from upland construction activities practically buried the wetlands and precluded the collection of baseline data.

Vegetation

General vegetation features of reference and impacted wetlands differed in several respects (Table 10). Reference sites had greater mean canopy cover, greater cover of standing water, and less cover of leaf litter within vegetation plots. These differences appeared more to be more a function of site variation and were not likely influenced by the effects of stormwater discharge. In general, most of the forested sites were semi-mature with 30 to 40 foot tall canopies. The Craven Co. Reference site had distinctly more mature forest cover and contained individual pond cypress trees with 32" dbh. Other sites with distinctive vegetation structure included the Robeson Co. site, which was a primarily open water, scrub/shrub wetland, and the Carteret Co. pocosin site.

A total of 161 plant species was identified in all of the wetland sites (Appendix A). Mean species richness and diversity were greater in stormwater impacted sites than in reference /non-impacted sites, however this does not appear to be a function of stormwater discharge to the sites. Richness and diversity may be more closely related to the geomorphic type of the wetland, the hydrology, and the effects of long-term disturbance in a given site.

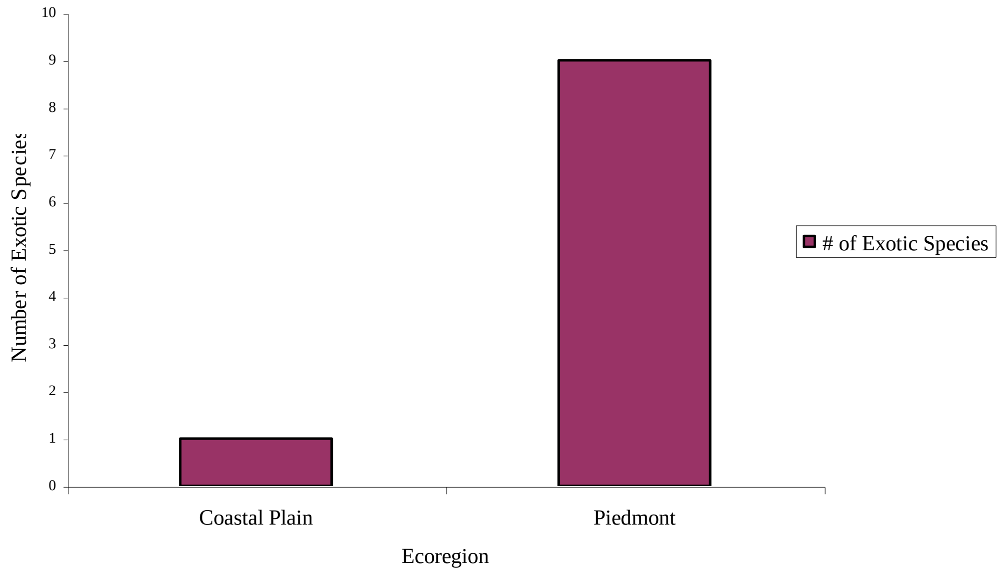
Table 10. General Vegetation Features of Stormwater Wetlands

	Site	Craven Co. Impact	Wake Co. Impact	New Hanover Impact	Craven Co. Reference	Robeson Co.	Wake Co. Reference	Gaston Co.	Carteret Co.	Guilford Co. 1	Guilford Co. 2
	Date Sampled	9-Jul-03	13-Jun-03	20-Jul-03	7-Oct-03	23-Jul-03	13-Jun-03	5-Jul-03	11-Oct-03	12-Jul-00	7-Jun-03
General Vegetation Features	**Vegetation structure**	Forested	Forested	Forested/ Emergent	Forested	Scrub-Shrub/ Emergent	Forested	Forested/ Emergent	Forested	Forested	Forested
	Total Species Richness	30	41	53	21	36	46	36	14	29	17
	Diversity (*H'*)	2.35	2.21	2.98	2.08	2.53	2.32	2.03	1.67	2.66	1.83
	Woody Basal Area (ft^2/ac)	87.17	2.3	18.4	123.45	9	10.18	21.75	7.55	115.18	55.35
	Vines/Acre	1265	350	275	42.5	292.5	250	325	475	-	92.5
	Shrubs/Acre	1022.5	750	1425	1227.5	700	475	1125	1050	-	507.5
	# of Exotics	0	8	1	0	0	3	3	0	3	2
Groundcover	**Bryophyte/Algae**	0%	0%	5%	1%	7%	1%	1%	0%	-	-
	Woody debris	18%	10%	13%	12%	2%	5%	11%	12%	-	-
	Gravel	0%	2%	0%	0%	0%	0%	0%	0%	-	63%
	Soil	0%	13%	1%	0%	0%	0%	18%	0%	-	-
	Leaf litter	49%	75%	75%	11%	7%	9%	61%	80%	-	-
	Open water	34%	0%	8%	77%	84%	85%	10%	8%	-	-
Vegetation Strata Cover	**Herb**	20%	33%	77%	9%	14%	80%	55%	50%	-	-
	Shrub	24%	15%	26%	23%	18%	4%	13%	75%	-	-
	Understory	30%	80%	23%	33%	12%	44%	48%	45%	-	-
	Canopy	30%	27%	20%	48%	0%	77%	0%	20%	-	-
	Exotics Cover	0%	3.90%	0.20%	0%	0%	1.20%	1.60%	0%	20.70%	37%
Relative Cover of Plant Indicator Status	**?**	0%	2%	0%	0%	2%	1%	0%	0%	16%	14%
	FACU, FACU+, UPL	0%	54%	3%	0%	0%	3%	1%	0%	2%	27%
	FAC, FAC-, FAC+	75%	43%	10%	22%	41%	69%	59%	22%	66%	49%
	FACW, FACW+	12%	2%	69%	34%	22%	11%	12%	73%	19%	13%
	OBL	13%	0%	21%	44%	36%	18%	30%	5%	0%	0%
Relative Basal Area of Flood Tolerant Classes	**Least**	0%	100%	0%	0%	0%	41%	0%	0%	2%	0%
	Moderate	90%	0%	61%	26%	57%	59%	100%	92%	88%	96%
	Most	7%	0%	37%	68%	43%	0%	0%	0%	0%	0%
	Weak	0%	0%	0%	0%	0%	0%	0%	0%	10%	4%
	?	4%	0%	3%	5%	0%	0%	0%	8%	0%	0%

For example the non-impacted Carteret Co. pocosin, which was the least rich or diverse of sites, remained dry during the study and was dominated by a low number of shrubs and vines with almost no herbaceous vegetation. Excessively flooded sites, such as Guilford Co. 2 and Craven Co. Reference, also exhibited low species richness. In contrast, the New Hanover Co. wetland was transitioning from a pocosin dominated wetland to a more open savanna type and contained plants of both these ecological types. This site also experienced a fluctuating hydrological pattern that supported a range of plants of various flooding tolerances. This was the case with other sites with variable hydrology including Robeson Co., Gaston Co., and Wake Co. Reference and Impact.

In terms of exotic species, Piedmont sites generally had a greater number and overall cover of non-native species (Figure 2). Three of the four Piedmont sites had three invasive species in common that were not present in the Coastal Plain sites, *Lonicera japonica*, *Ligustrum sinense*, and *Microstegium vimineum*. The Wake Co. Impact site was particularly plagued by exotics with approximately 20% of the plant species being non-native. Several ornamental plant species sampled in this site were clearly indicative of the stormwater impact from the residential neighborhood upslope. The only non-native species encountered at a Coastal Plain site was *Alteranthera philoxeroides*, which was present at the stormwater-impacted New Hanover Co. wetland.

Figure 2. Total Number of Exotic Species Encountered in Piedmont and Coastal Plain Wetland Sites



Cover of species of different wetland indicator classes differed between Piedmont and Coastal Plain sites (Figure 3). Piedmont wetlands had a greater percent cover of facultative upland and facultative plants, whereas Coastal Plain sites were dominated by obligate and facultative wet plant species. The Wake Co. impacted site in particular was dominated by upland and facultative upland species. Comparisons of impacted and reference sites indicated that reference sites had higher percent cover of wetland adapted species. The exception to this case was the New Hanover Co. Impact site, which was principally dominated by obligate and facultative wet plants.

Basal area of wetland sites varied considerably, though it was clearly greater in mature forested sites and quite low in immature and scrub/shrub wetlands (Table 10). Guilford Co. 1 and Craven Co. Reference site had the greatest basal areas primarily due to the density and maturity of trees. A slight decline in basal area at the Craven Co. Impact site was noticeable between sampling periods (Figure 4). This may be due to flooding at this site and mortality of *Pinus taeda*, a moderately flood tolerant species. Most sites included in the study were dominated by moderately flood tolerant tree species (Hook 1984), however, the Wake Co. Impact site was dominated by least tolerant species. Both Craven

Figure 3. Relative Cover of Wetland Indicator Status Categories

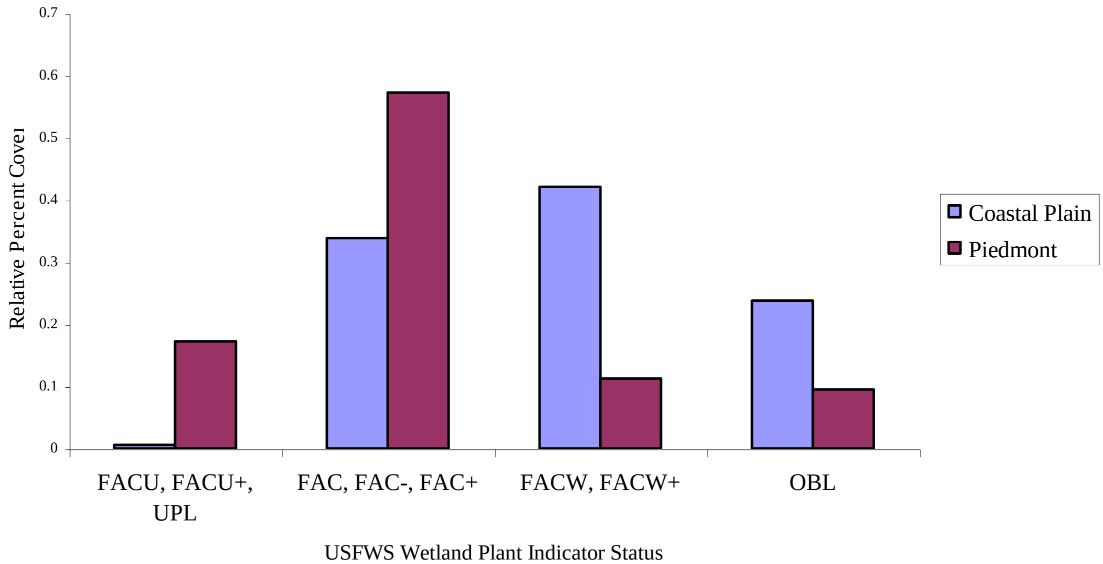
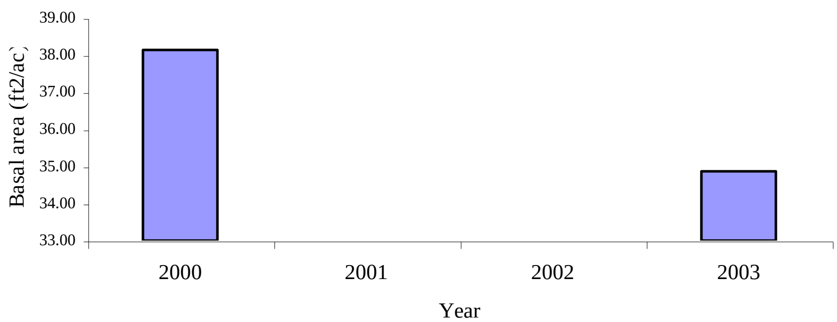


Figure 4. Basal Area of Woody Plants in Craven Co. Impact July 2000 and 2003



Co. Reference and the Robeson Co. site possessed a significant component of most tolerant woody species (Table 10).

Density of shrubs and vines appeared to vary across all sites, reflecting a diversity of natural conditions. The Wake Co. Impact site had a higher density of vines than its reference wetland, and the Craven Co. Impact site had greater density of both shrubs and vines, possibly indicating a tendency of this vegetation towards prolific growth in disturbed habitats (Table 10).

Rare plant species were identified at two of the sites in the study. State rare, *Peltandra sagitifolia*, was present in the New Hanover Co. stormwater-impacted site. Present but not captured in the vegetation survey at the Carteret Co. wetland were *Sarracenia purpurea* and *S. flava*. Though neither of these species is state or federally listed, they occur infrequently and are usually limited to undisturbed sites. This latter site was previously known to harbor *Lysimachia asperulifolia*, a federally threatened species, which was not found but may still be present at the site.

Other Biota

Amphibians were also present at most sites. Various species of frogs were observed either during dip net sampling or from calling surveys at all but one of the Coastal Plain sites visited, Carteret Co. The identified species include: *Pseudacris triseriata, P. crucifer, P. brimleyi, Hyla cinerea, Acris gryllus, Rana vigatipes,* and *R. sphenocephala*. At least two wetlands receiving stormwater, New Hanover and Carteret Co. Impact sites, had breeding populations of frogs as evidenced by abundant larva and calling male adults. One of the Piedmont sites, Guilford Co. 2, supported breeding populations of two salamander species, *Ambystoma maculata* and *A. opacum*.

It was not possible to collect aquatic invertebrates samples from all wetlands because of the short duration of standing water at some sites. Samples were obtained from Craven Co. Impact and Reference as well as the Robeson Co. site (Appendix C). Species richness of Craven Co. Impact and Reference did not differ greatly, though species composition did vary. Both Craven Co. sites were depauperate in comparison to the Robeson Co. site, which contained twice the number of species as the other two combined. The latter site also harbored fairy shrimp (*Eubranchipus* sp.), an unusual invertebrate that inhabits vernal pools and other ephemeral waters.

V. Discussion of Benefits and Impacts of Stormwater Discharge in Natural Wetlands

The results of this study suggest that stormwater discharges to natural wetlands are acceptable under certain circumstances. Though minor impacts were evident in some sites, these appeared to be of minimal detriment to most of the wetland ecosystems studied. It should be noted, however, that many of the potential impacts of stormwater discharge to natural wetlands are gradual in nature and that the limited time frame of this study did not allow for thorough examination of more long-term consequences of this practice. One site in particular (Wake Co. Impact) did manifest problems associated with stormwater discharge, though the impacts were in part due to the manner of stormwater discharge and the unsuitable characteristics of the site for stormwater treatment. Therefore long-term monitoring of these sites is clearly warranted in order to better understand the effect of stormwater on natural wetlands and to develop better guidelines.

This study identified two main benefits of stormwater discharges to natural wetlands: assimilation of stormwater and hydrological restoration of altered wetlands. The hydrological assimilative capacity of these wetlands is indicative of their ability to retain suspended solids, nutrients, and metals, and some of the stormwater-impacted sites were effective in this regard. The New Hanover Co. Impact site in particular was illustrative of this benefit, for despite high pollutant loadings in stormwater entering the site, the water quality at the base of the wetland was significantly improved. From the head to the base of the wetland, suspended solids were reduced 98%, Zn was reduced 58%, and oil and grease concentrations declined 42%.

An additional benefit of stormwater discharges to wetlands is the restoration of water levels in wetlands where hydrological connectivity to surface or ground water has been lost. Accordingly the pocosin-like Carteret Co. site is also well suited to function as a stormwater wetland. Due to road construction on three sides the wetland had become hydrologically isolated and was typically observed to be dry except on one occasion following a heavy rain event. This wetland was of sufficient size to receive twice the predicted amount of stormwater runoff after build-out and stormwater could potentially serve to restore adequate hydrology to the site. The wetland itself had no outlet, possessed well-developed organic soils, which could aid in adsorbing sediment, phosphorous, metals, and other contaminants.

Despite these benefits, however, several negative consequences were discernable from the study. A major concern for stormwater discharge to wetlands is the possibility of channelization and scouring below the discharge point (Morris et al. 1981; Brown 1985). A prime example of this problem was reflected in the Wake Co. impact site, where an end of pipe discharge had caused a channel to form through the receiving wetland. Scour and channelization in this case were the likely result of several factors: the untreated discharge of stormwater directly from a culvert, the gradient at which the discharge enters the wetland, and the inability of the wetland to absorb the runoff volume.

In comparison, the Wake Co. Reference site receives diffuse stormwater from a number of braided, intermittent channels that reduce the velocity of the runoff entering the site. The wetland is of adequate size to retain the discharge in hummocks, pools, and meandering braided channels, thus diminishing the potential for scour and formation of a single, heavily eroded channel. The two Coastal Plain wetlands, New Hanover and Craven Co. Impact, both receive stormwater only after it has been pre-treated to some extent in dry detention basins and grass swales respectively. These two wetlands were of adequate size to assimilate the runoff generated by their drainage areas. Furthermore the surrounding drainage areas had low gradients in relation to the wetlands and were primarily sandy soils that promote infiltration and reduce runoff. In neither of these two sites nor in the Wake Co. Reference site was there evidence of scour or erosion.

Sedimentation is another potential impact of stormwater discharge to wetlands. The Gaston Co. site exhibited the highest sedimentation rate, even though its drainage area had not yet been fully developed. Some of the sediment deposition may have resulted from clearing activities in the immediate upstream watershed. High sedimentation rates and additional future deposition could be problematic in this wetland, since it was undersized for its drainage area at predicted build-out conditions. In such cases, excessive sedimentation in the wetland or resuspension of previously deposited sediment during flooding could result, thus degrading already poor downstream water quality (Stockdale 1991). One mitigating factor for this site is the planned installation of a forebay at the head of the wetland that will hopefully act to capture sediment, reduce the velocity of, and disperse the flow of stormwater entering the wetland.

Another possible impact of sedimentation is a shift in substrate particle size in sites receiving stormwater discharges (USEPA 1993). Such changes in soil composition are related to lack of settling of solids before discharge and the hydraulic characteristics of the discharge itself (Strecker et al.1992). This effect was noted at the Wake Co. Impact site where stormwater was directly discharged from a culvert into the wetland at a steep gradient. Erosive riverine flows can also alter sediment composition by removing organic matter, which causes a gradual increase in the mineral component of the soil (Barnes 1978). Though the Wake Co. Impact site had a substantial amount of leaf litter, portions of the site scoured by stormwater had bare soil and substantial gravel deposits.

In addition to stormwater-driven sedimentation processes, deposition of sediments from adjacent construction also appeared potentially detrimental to the wetlands studied. Changes in particle size and sediment composition from construction-related sedimentation were observed in at least four wetlands visited for this study (Wake Co. Impact site, Craven Co. Impact site, and two other Wake Co. wetlands not studied due to excessive sedimentation). Smothering of herbaceous vegetation and alteration of site hydrology are possible negative impacts of this inadvertent sediment deposition .

Stormwater impacts to wetland vegetation are likely gradual in nature, and only minor impacts were detected in this study. The affects of stormwater on plants are primarily related to flooding and its physiological consequences, and are expressed in changes in wetland vegetation composition. Based on observations of water level fluctuation, it appeared that sites that were continuously dry or flooded were less species-rich than sites with varying hydrology such as Wake Co. Impact and Reference, Robeson Co., Gaston Co., and New Hanover Co. As pointed out above, the Carteret Co. site may benefit from additional hydrological inputs, however, other sites that may face excess flooding could be negatively impacted from the discharge. Due to the poor sizing of the Robeson Co. and Guilford Co. 1 site, excessive flooding may cause declines in the number of species able to survive in these sites. Though it was not possible to size the Guilford Co. 2 site, this wetland is already species-poor due to large areas of standing water and may face further declines with additional flooding.

Though many of the sites have at least moderately flood-tolerant woody plant species, abrupt hydrological changes may still cause die-offs of trees and shrubs. Even very tolerant species such as *Nyssa biflora* and *Taxodium distichum* may suffer mortality when flooding depth and/or duration increases suddenly (Hook 1984). Additional hydrological inputs in the form of stormwater could create such a spontaneous change in the flooding regime. Though only minor indications of tree mortality were observed at the Craven Co. Impact Site, further monitoring of stormwater wetlands over time is necessary to detect flooding-induced mortality. Flood induced mortality may prove problematic in Guilford Co. 1, Robeson Co., and the Craven Co. Impact site.

Disturbed wetland sites have been shown to be more susceptible to invasion by aggressive or exotic plant species (Cooke and Azous 2001). This was one of the most obvious biological impacts of stormwater flows into wetlands observed in the present study. In general, Piedmont sites were located in areas with a longer history of disturbance and accordingly contained a greater number of exotic species. Though certain exotic species were ubiquitous, the presence of ornamental plants directly down-slope of a discharge from a residential area (Wake Co. Impact) implicates stormwater as a disperser and source for introduced vegetation.

The least explored impact of this study is the possible consequence of stormwater on wetland fauna. At the same time that stormwater wetlands act as sinks for nutrients and contaminants, they harbor animal populations that are susceptible to the effects of contaminants. At least two sites (New Hanover and Craven Co. Impact) showed elevated concentrations of oil and grease that could be harmful to wetland fauna. Amphibians are of particular concern because of their permeable skin and aquatic breeding habit. Previous studies have linked increased urban development with declines in wetland amphibian abundance and diversity and also suggested that changes in flooding patterns may affect breeding activity of amphibians (Richter and Azous 2001). Though no obvious amphibian malformations were detected in this study, populations were not specifically monitored for such deformities nor were toxicological samples collected for testing. In order to explore this potential impact, more extensive monitoring is necessary.

VI. Recommendations for the Use of Natural Wetlands for Stormwater Assimilation

Having reviewed the advantages and disadvantages of stormwater treatment using natural wetlands, it is important to emphasize techniques that can promote the benefits of this practice while minimizing detriment to natural systems. Based on the observations made in this study and a review of relevant literature, guidelines are provided below that should be applied to stormwater discharge to wetlands to achieve these ends. Many of these recommendations were originally directed towards created wetlands, however, the same principles equally apply to natural systems.

Pretreatment and Bypass of Excess Discharge

Pre-treatment of stormwater before discharge to natural wetlands is of principal importance. Pre-treatment through created detention wetlands, dry detention basins, or grass swales can potentially reduce impacts associated with sediment deposition and erosion (Brown 1985). Reduction of sedimentation within the wetland itself can extend the functional lifespan of the system and its treatment capability (Stockdale 1991). Furthermore by capturing adsorbed pollutants in a forebay or sediment basin the risk of contaminating resident wetland fauna is minimized. Grass swales in particular have been shown to be highly effective in achieving pollutant removal (Canning 1985).

Diversion of excess stormwater flows can be an effective means to protect wetlands from flooding impacts. Limiting flooding levels has been recommended as a way to maintain the integrity and diversity of the wetland plant community and to ensure stable habitat for breeding amphibians (Azous et al. 2001 and Horner et al. 2001). Construction of a bypass device, such as a level spreader with an alternate conveyance for rain events greater than 1-inch, can capture the important first flush while diverting potentially damaging excess flows. Alternate conveyances can take the form of a grass swale or a riprap-lined channel (NCDWQ 2001).

Diffuse Flow

Promotion of diffuse flow of stormwater into a wetland can reduce the velocity of stormwater and provide for extended stormwater retention. The provision of diffuse flow evenly distributes flooding and a greater area of stormwater treatment can be achieved. Where diffuse flow is lacking and stormwater becomes concentrated, channelization, reduced residence time, and inadequate stormwater treatment can occur (Stockdale 1991). Use of a pretreatment device such as a detention basin with a broad-crested weir for discharge can promote diffuse flow and prevent erosion and short-circuiting in wetlands (Brown 1985). Grass swales and level spreaders can also effectively achieve diffuse flow.

Sizing and Residence Time

Adequate sizing of receiving wetlands is of particular importance. Wetlands that are too small to retain the runoff from a typical precipitation event will fail to properly treat stormwater and may experience negative effects of flooding. A properly sized wetland will retain stormwater long enough to allow for settling of particulates and contaminants (Hickok 1977). Residence time is a critical factor in determining the treatment ability of a wetland (Meyer 1985; Canning 1985). Other features such as topographic position and the geomorphology also influence residence time of stormwater in wetlands. Low elevation gradients between the drainage area and the wetland can reduce discharge velocity and extend retention of water. Longer residence times are more easily achieved in depressional wetlands and wetlands with isolated hydrological patterns. The above factors should be considered for proposed stormwater discharges into natural wetlands, and proper sizing of stormwater wetlands should be demonstrated by use of a methodology similar to the one in this study or other method incorporating the use of the USDA SCS equation (USDA 1986).

Vegetation and Soils

Dense vegetation is useful in extending residence time by reducing velocity of discharge through the wetland (Stockdale 1991). Plants can act to enhance uptake of nutrients either directly or by providing substrate for denitrifying bacteria (Hickok 1977). Vegetation is important for trapping sediment and preventing resuspension during flood events (Canning 1985). Deep organic soils are favorable for the treatment of stormwater because of their capacity to retain water and adsorb nutrients, metals, and other contaminants. Pocosin wetlands, characterized by deep organic soils and dense vegetation, are ideally suited to provide the above-mentioned functions. However, because they often sit perched on peat deposits, diffuse flow into these wetlands by means of adjacent grass swales is often necessary to ensure effective discharge into the wetland.

Selection of Stormwater Wetland Sites

Disturbed wetland sites should be preferentially selected for stormwater discharge (Stockdale 1991). These sites may include cutover wetlands, wetlands with degraded wildlife habitat, or sites that have lost hydrological connection to surrounding streams, lakes, or rivers. Sites that provide low habitat quality or that have been recently timbered are less likely to harbor sensitive species that may be affected by stormwater inputs. Wetlands that have lost hydrological connection are well suited for stormwater assimilation because they are less likely to act as a source for surface water contaminants and may benefit hydrologically from stormwater additions when their natural water sources have been diverted or altered.

Rare wetland types, wetlands of pristine natural quality, and sites that harbor rare, threatened, or endangered species should be protected from stormwater discharges. Sites that harbor sensitive species, e.g. amphibians that require specific dissolved oxygen levels or pH, should be avoided as well. Unfortunately, some of the sites included in this study fall into these categories and were still subjected to stormwater discharges. At least two of the sites that harbored rare or sensitive species also had been disturbed or altered to some degree. In such cases the benefits and consequences of discharging stormwater must be weighed carefully, especially when the species in question may face potential impacts. Before discharges are permitted, sites should be examined for presence of vulnerable or rare species. Where discharges into such sites are permitted protective measures should be taken and a monitoring plan should be established to ensure the viability of the species of concern.

Baseline and Ongoing Monitoring

Before discharge to natural wetlands occur, baseline biological data should be collected in order to determine the presence of any rare, vulnerable, or environmentally sensitive species. An analysis of plant and animal species should be conducted in order to determine their tolerance to habitat disturbance in the form of hydrological and/or chemical alteration. General wetland monitoring should take place before discharges take place in order to ascertain baseline conditions and to detect impacts as they are occurring. Baseline monitoring should encompass and improve on many of the parameters addressed in this study such as vegetation, fauna, hydrology, and soil composition and texture.

Furthermore on-going hydrological, chemical, and biological monitoring has been recommended as an essential requirement for discharge permitted in a natural wetland (Newton 1989). Monitoring requirements may depend on the circumstances of the discharge and the wetland to be impacted. For example, wetlands that are adequately sized in relation to their drainage area, have been previously impacted or degraded, and receive stormwater discharge after pre-treatment via diffuse flow should not require regular monitoring. Projects that do not conform to the above criteria or that propose discharges to sites with rare, vulnerable, or environmentally sensitive species or habitats should be required to provide a monitoring plan and to carry out monitoring on a regular basis. Any monitoring requirements and the ability of regulatory agencies to carry out compliance inspections should be explicitly stated in the permit approval that allows stormwater discharge to wetlands.

Appendix A. List of Plant Species Identified from 9 Wetland Sites from the Piedmont and Coastal Plain of North Carolina

Taxonomic Code	Plant species	Wetland Indicator Status	Native
ACBA	*Acer barbatum*	?	Y
ACCA	*Acnida canabinensis*	OBL	Y
ACNE	*Acer negundo*	FACW	Y
ACRU	*Acer rubrum*	FAC	Y
ALPH	*Alteranthera philoxeroides*	OBL	N
AMAR	*Amelanchier arborea*	FACU	Y
Andropogon sp.	*Andropogon* sp.	?	Y
ANGL	*Andropogon glaucopsis*	FACW+	Y
APAM	*Apios americana*	FACW	Y
ARAR	*Aronia arbutifolia*	FACW	Y
ARGI	*Arundinaria gigantea*	FACW	Y
ARME	*Aronia melanocarpa*	FAC	Y
ARTR	*Arisaema triphyllum*	FACW-	Y
ASPU	*Aster puniceus*	OBL	Y
ASTR	*Asimina triloba*	FAC	Y
ATAS	*Athyrium asplenoides*	FAC	Y
BENI	*Betula nigra*	FACW	Y
BOCY	*Boehmeria cylindrica*	FACW+	Y
BOVI	*Botrychium vriginiana*	FACU	Y
CAAL	*Carex alata*	OBL	Y
CACA	*Carpinus caroliniana*	FAC	Y
CACR	*Carex crinita*	FACW+	Y
CADE	*Carex debilis*	FACW	Y
CADI	*Carex digitalis*	FACU	Y
CAGL	*Carex glaucescens*	OBL	Y
CAIN	*Carex incomperta*	FACW	Y
CALU	*Carex lurida*	OBL	Y
CARA	*Campsis radicans*	FAC	Y
Carex sp.	*Carex* sp.	?	Y
CAST	*Carex striata*	OBL	Y
CATO	*Carya tomentosa*	UPL	Y
CATR	*Carex tribuloides*	FACW+	Y
CECA	*Cercis canadensis*	FACU	Y
CELA	*Celtis laevigata*	FACW	Y
CHLA	*Chasmathium latifolia*	FAC-	Y
CLAL	*Clethra alnifolia*	FACW	Y
Clematis sp.	*Clematis* sp.	?	?
COAM	*Cornus ammomum*	FACW+	Y
COCO	*Comelina communis*	FAC	N
COFL	*Cornus florida*	FACU	Y
CYRA	*Cyrilla racemosa*	FACW	Y
Dichanthelium sp.	*Dichanthelium* sp.	?	Y
DIDI	*Dichanthelium dichotomum*	FAC	Y
DIVI1	*Diospyros virginiana*	FAC	Y
DIVI2	*Dioscorea villosa*	FACW	Y
DUIN	*Duchesnia indica*	FACU	N
ELCA	*Elephantopus carolinensis*	FAC	Y
EUAM	*Eunonymus americana*	FAC-	Y
EUFI	*Eupatorium fistulosum*	FAC+	Y

Appendix A. List of Plant Species Identified from 9 Wetland Sites from the Piedmont and Coastal Plain of North Carolina (cont.)

Taxonomic Code	Plant species	Wetland Indicator Status	Native
EUPE	*Eupatorium perfoliatum*	FACW+	Y
EURA	*Eubotrys racemosa*	FACW	Y
FAGR	*Fagus grandifolia*	FACU	Y
FRPE	*Fraxinus pennsylvanica*	FACW	Y
Galium sp.	*Galium* sp.	?	Y
GESE	*Gelsemium sempervirens*	FAC	Y
GLST	*Glyceria striata*	OBL	Y
GOLA	*Gordonia lasianthus*	FACW	Y
Grass sp.	Grass sp.	?	?
HEHE	*Hedera helix*	?	N
Hexastylis sp.	*Hexastylis* sp.	?	Y
HYGA	*Hypericum galioides*	OBL	Y
ILCA	*Ilex cassine*	FACW	Y
ILCO	*Ilex coriacea*	FACW	Y
ILGL	*Ilex glabra*	FACW	Y
ILOP	*Ilex opaca*	FAC-	Y
IMCA	*Impatiens capensis*	FACW	Y
ITVI	*Itea virginiana*	FACW+	Y
JUEF	*Juncus effusus*	FACW+	Y
JUNI	*Juglans nigra*	FACU	Y
JUTR	*Juncus trigonocarpus*	OBL	Y
LEAX	*Leucothoe axillaris*	FACW	Y
LEOR	*Leersia oryzoides*	OBL	Y
LIBE	*Lindera benzoin*	FACW	Y
LISI	*Ligustrum sinense*	FAC	Y
LIST	*Liquidambar styraciflua*	FAC+	Y
LITU	*Liriodendron tulipifera*	FACW/FACU	Y
LOJA	*Lonicera japonica*	FAC-	N
LUPA	*Ludwigia palustris*	OBL	Y
LYLI	*Lyonia ligustrina*	FACW	Y
LYLU	*Lyonia lucida*	FACW	Y
LYVI	*Lycopus virginicus*	OBL	Y
MARA	*Maianthemum racemosum*	FACU	Y
MATR	*Magnolia tripetala*	FAC	Y
MAVI	*Magnolia virginiana*	FACW+	Y
MEMU	*Melica muticum*	UPL	Y
MIRE	*Mitchella repens*	FACU+	Y
MISC	*Mikania scandens*	FACW+	Y
MIVI	*Microstegium vimineum*	FAC+	N
MOCA	*Morella carolinensis*	FACW	Y
MOCE	*Morella cerifera*	FAC+	Y
NADO	*Nandina domestica*	UPL	N
NYBI	*Nyssa biflora*	OBL	Y
NYSY	*Nyssa sylvatica*	FAC	Y
Oenethera sp.	*Oenethera* sp.	?	N
ONSE	*Onoclea sensibilis*	FACW	Y
OSAM	*Osmanthus americana*	FAC	Y
OSCI	*Osmunda cinnamonea*	FACW+	Y
OSRE	*Osmunda regalis*	OBL	Y
Oxalis sp.	*Oxalis* sp.	?	?
OXAR	*Oxydendron arborea*	FACU	Y

Appendix A. List of Plant Species Identified from 9 Wetland Sites from the Piedmont and Coastal Plain of North Carolina (cont.)

Taxonomic Code	Plant species	Wetland Indicator Status	Native
PAQU	*Parthenocissus quinquefolia*	FAC	Y
PEPA	*Persea palustris*	FACW	Y
PESA	*Peltandra sagitifolia*	OBL	Y
PHAM	*Phytolacca americana*	FACU+	Y
PISE	*Pinus serotina*	FACW+	Y
PITA	*Pinus taeda*	FAC	Y
PLCA	*Pluchea camphorata*	FACW	Y
PLMA	*Plantago major*	FAC+	Y
PLOC	*Platanus occidentalis*	FACW-	Y
POAC	*Polystichum acrostichoides*	FAC	Y
POAN	*Poa annua*	FAC	N
POHE	*Populus heterophylla*	OBL	Y
Polygonum sp	*Polygonum* sp	?	?
POPU	*Polgonum punctatum*	FACW+	Y
POSA	*Polygonum sagittatum*	OBL	Y
PRPA	*Proserpinaca palustris*	OBL	Y
PRSE	*Prunus serotina*	FACU	Y
QUAL	*Quercus alba*	FACU	Y
QUNI	*Quercus nigra*	FAC	Y
QUPH	*Quercus phellos*	FACW	Y
QURU	*Quercus rubra*	FACU	Y
RHCE	*Rhnchospora cephalantha*	OBL	Y
RHCH	*Rhynchospora chalarocephala*	OBL	Y
RHFA	*Rhynchospora fasicularis*	FACW+	Y
RHMA	*Rhynchospora macrostachya*	OBL	Y
Rosa sp.	*Rosa* sp.	?	?
RUAR	*Rubus arguta*	FAC	Y
SACA 1	*Salix caroliniana*	OBL	Y
SACA 2	*Sanicula canadensis*	FACU	Y
SACA 3	*Sambucus canadensis*	FACW-	Y
SAGI	*Saccharum giganteum*	FACW	Y
SALA	*Sagitaria latifolia*	OBL	Y
SANI	*Salix nigra*	OBL	Y
SCCY	*Scirpus cyperinus*	OBL	Y
SMBO	*Smilax bona-nox*	FAC	Y
SMGL	*Smilax glauca*	FAC	Y
SMLA	*Smilax laurifolia*	FACW+	Y
SMRO	*Smilax rotundifolia*	FAC	Y
SMWA	*Smilax walterii*	OBL	Y
Solidago sp.	*Solidago* sp.	?	Y
SYTI	*Symplocos tinctoria*	FAC	Y
TAAS	*Taxodium ascendens*	OBL	Y
TORA	*Toxicodendron radicans*	FAC	Y
Trifolium sp.	*Trifolium* sp.	?	N
TYLA	*Typha latifolia*	OBL	Y
ULAM	*Ulmus americana*	FACW	Y
ULRU	*Ulmus rubra*	FAC	Y
Unknown seedling	Unidentified seedling	?	?
VACO	*Vaccinium corymbosum*	FACW	Y
VAFU	*Vaccinium fuscatum*	FAC+	Y
VENO	*Vernonia novaboracensis*	FAC+	Y

Appendix A. List of Plant Species Identified from 9 Wetland Sites from the Piedmont and Coastal Plain of North Carolina (cont.)

Taxonomic Code	Plant species	Wetland Indicator Status	Native
VICI	*Vitis cinerea*	FAC+	Y
VINU	*Viburnum nudum*	FACW+	Y
Viola sp.	*Viola* sp.	?	?
VIRE	*Viburnum recognitum*	FACW	Y
VIRO	*Vitis rotundifolia*	FAC	Y
Vitis sp.	*Vitis* sp.	?	Y
WIFR	*Wisteria fructescens*	FACW	Y
WOAR	*Woodwardia areolata*	OBL	Y
WOVI	*Woodwardia virginiana*	OBL	Y
XASI	*Xanthorhiza simplicissima*	FACW-	Y
XYFI	*Xyris fimbriata*	OBL	Y
ZEPU	*Zenobia pulvurenta*	OBL	Y

Appendix B. List of Invertebrates Collected from 3 Wetlands in the Coastal Plain of North Carolina

Order	Family	Genus	Craven Co. Impact	Craven Co. Reference	Robeson Co.
Ephemeroptera	Heptageniidae	?	1		
Ephemeroptera	Baetidae	*Centroptilum*			6
Diptera	Culicidae	*Culex*		1	
Diptera	Culicidae	*Aedes*			4
Diptera	Chironomidae	*Chironomus*	8	3	3
Diptera	Chaoboridae	*Chaoborus*			2
Diptera	Ceratopogonidae	*Palpomyia*			1
Coleoptera	Dysticidae	*Dystiscus*			9
Coleoptera	Dysticidae	*Coptotomus*			3
Coleoptera	Dysticidae	*Thermonectus*			3
Coleoptera	Dysticidae	*Hydaticus*			1
Coleoptera	Dysticidae	*Laccophilus*			18
Coleoptera	Hydrophilidae	*Tropisternus*	1		10
Coleoptera	Hydrophilidae	*Enochrus*			2
Coleoptera	Hydrophilidae	*Berosus*			2
Coleoptera	Haplidae	*Peltodytes*			1
Coleoptera	Noteridae	*Suphisellus*	3		
Coleoptera	Chrysomelidae	?			1
Odonata	Aeshnidae	*Boyeria*			3
Odonata	Aeshnidae	?			2
Odonata	Libellulidae	*Pachydiplax*	26	17	3
Odonata	Coenagrionidae	*Ischnura*			1
Odonata	Coenagrionidae	*Enallagma*	2		
Odonata	Lestidae	*Lestes*			1
Hemiptera	Belostomatidae	*Belostoma*		1	5
Hemiptera	Nepidae	*Ranatra*	1		
Hemiptera	Corixidae	*Sigara*	3	1	
Hemiptera	Notonectidae	*Notonecta*			4
Hemiptera	Mesoveliidae	*Mesovelia*		4	
Hemiptera	Gerridae	*Metrobates*			1
Decapoda	Cambaridae	*Procambarus*	3		2
Isopoda	Asellidae	*Caecidotea*		6	4
Amphipoda	Crangonyctidae	*Crangonyx*			4
Cladocera	Daphniidae	*Ceriodaphnia*			12
Copepoda	Cyclopidae	?			2
Acarina	Acaridae	?			2
Anostraca	Chirocephalidae	*Eubranchipus*			2
Oligochaete	Naidae	?		1	
Oligochaete	Tubificidae	?	1		
	Total Number of Species		10	8	30

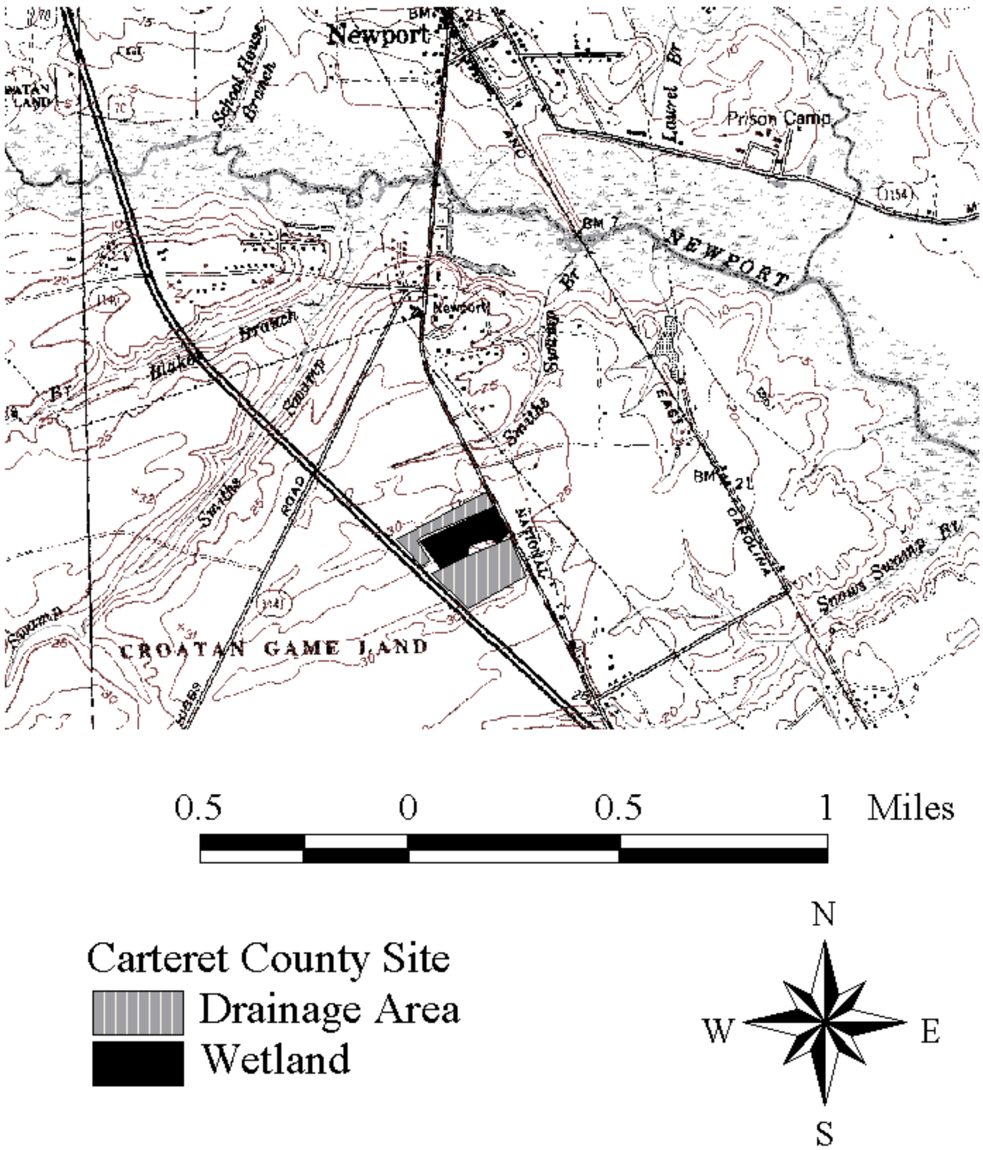
Appendix C. Water Quality Parameters for 5 Wetlands and Mean Urban Stormwater Concentrations for Raleigh and Greensboro, NC

Water Quality Parameters			Suspended Solids (mg/L)				Nutrients (mg/L)				Metals (µg/L)						
Site	Date	Sampling Location	Total	Volatile	Fixed	Grease & oil	NH3	TKN	NO2	Total P	Cd	Cr	Cu	Pb	Zn	Al	Fe
Wake Co. Impact	4-Feb	Center	18	6	12	6	0.07	0.49	0.6	0.1	2†	25†	7.1	10†	15	3000	-
Wake Co. Reference	4-Feb	Center	11	4	7	3	0.02	0.43	0.03	0.04	2†	25†	3.6	10†	10†	480	-
Robeson Co. Bay 1	25-Apr	Center	23	19	4	1†	0.02	1.5	.02†	0.11	2†	25†	2†	10†	23	-	-
Robeson Co. Bay 2	26-Apr	Center	12	7	5	3	0.02	1.3	.02†	0.09	2†	25†	2†	10†	12	-	-
New Hanover Co. Impact	25-Apr	Head	270	180	85	190	0.06	4.2	.02†	0.95	2†	25†	2.8	11	24	-	-
New Hanover Co. Impact	25-Apr	Base	6	6	5†	110	0.02	0.79	.02†	0.02	2†	25†	2†	10†	10†	-	-
Gaston Co.	12-Feb	Base	2.5	2.5	2.5†	1†	0.02†	.2†	0.11	0.02†	2†	25†	2.5	10†	10†	480	-
Gaston Co.	7-Jul	Head	82	-	-	2	0.09	0.3	0.06	0.03	2†	25†	2†	10†	10†	670	3600
Gaston Co.	7-Jul	Base	56	-	-	1†	0.26	0.84	.02†	0.09	2†	25†	2†	10†	14	1900	15000
Craven Co. Impact	12-May	Base	23	12	11	50	0.07	1.1	.02†	0.09	2†	25†	2†	10†	11	1200	-
Craven Co. Impact	12-May	Head	8	6	2.5†	2	.02†	0.79	.02†	0.06	2†	25†	2†	10†	10†	500	-
Craven Co. Impact	8-Oct	Center	40	16	24	1	.02†	0.63	.02†	0.05	2†	25†	2†	10†	10†	-	-
Craven Co. Reference	8-Oct	Center	6	6	2.5†	2	0.02	0.42	.02†	0.03	2†	25†	2	10†	22	-	-
Raleigh Stormwater Mean	*	Stormwater	217	-	-	46.77	1.09	3.54	1	0.84	-	-	-	-	-	-	-
Greensboro Stormwater Mean	*	Stormwater	171	-	-	-	-	-	1.25	-	2.11	9.8	3.8	3.5	27.4	-	-

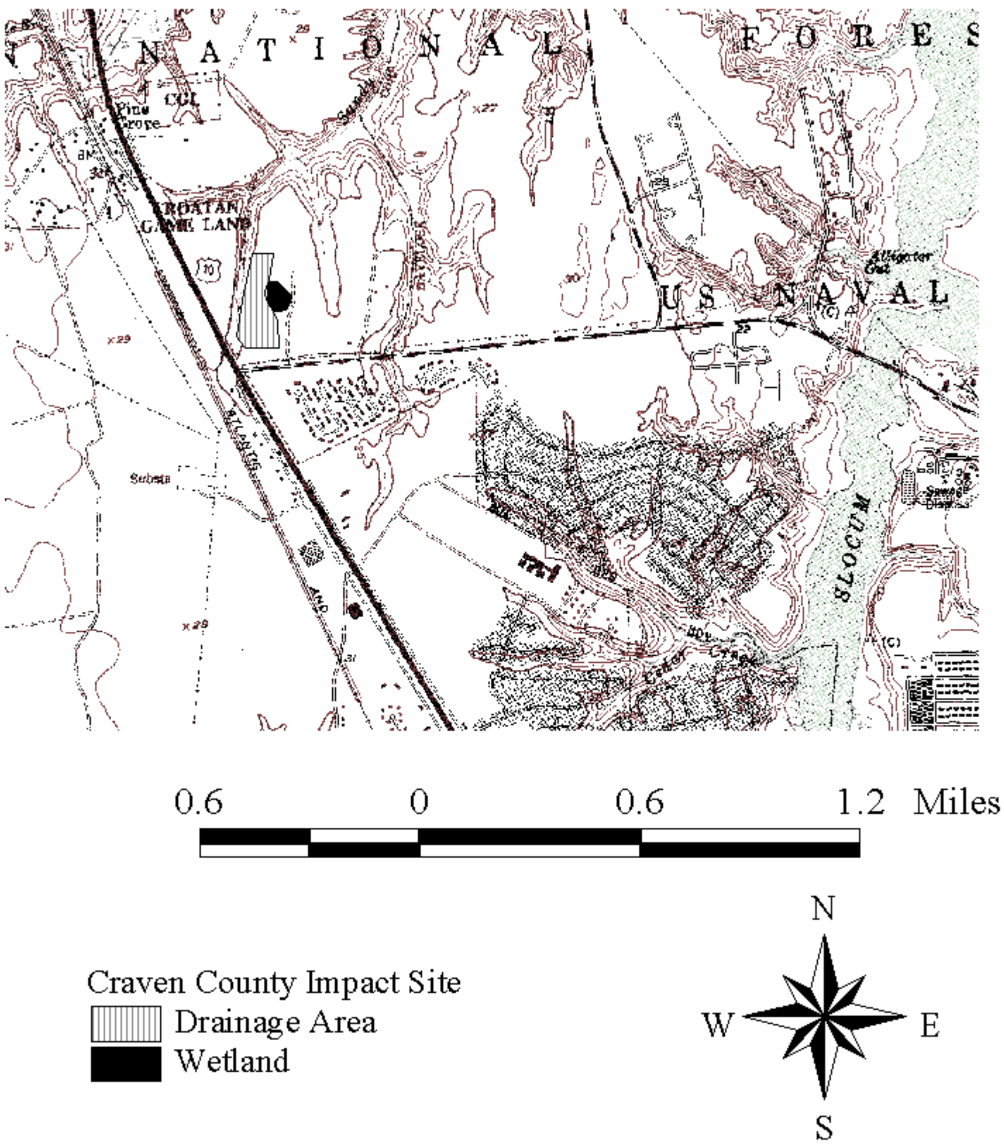
* Data collected from 1993 - 2000.

† Concentrations below detection threshold. Metals thresholds for urban stormwater were lower than for wetland sites.

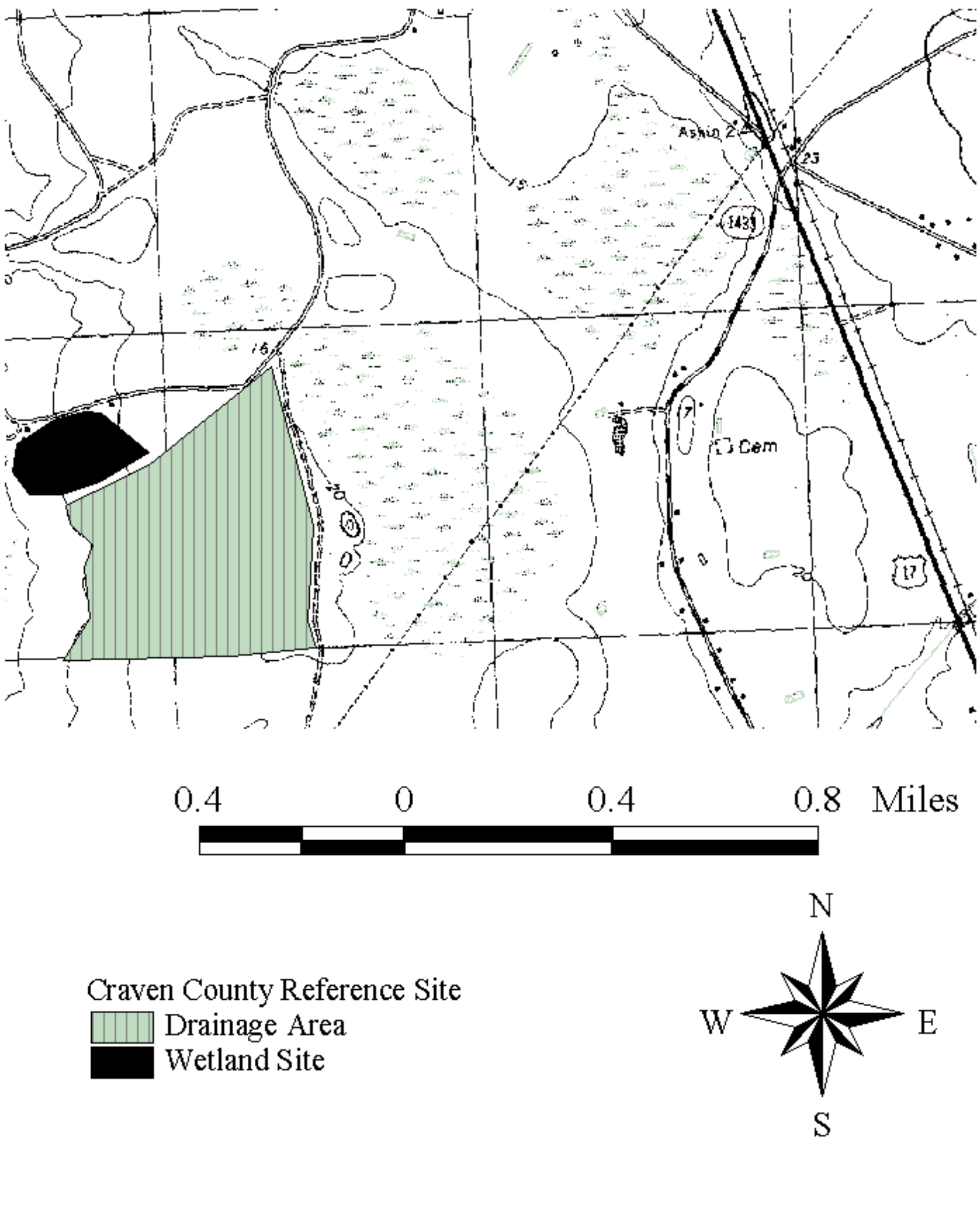
Appendix D.
Stormwater Wetland Sites
Carteret County Site



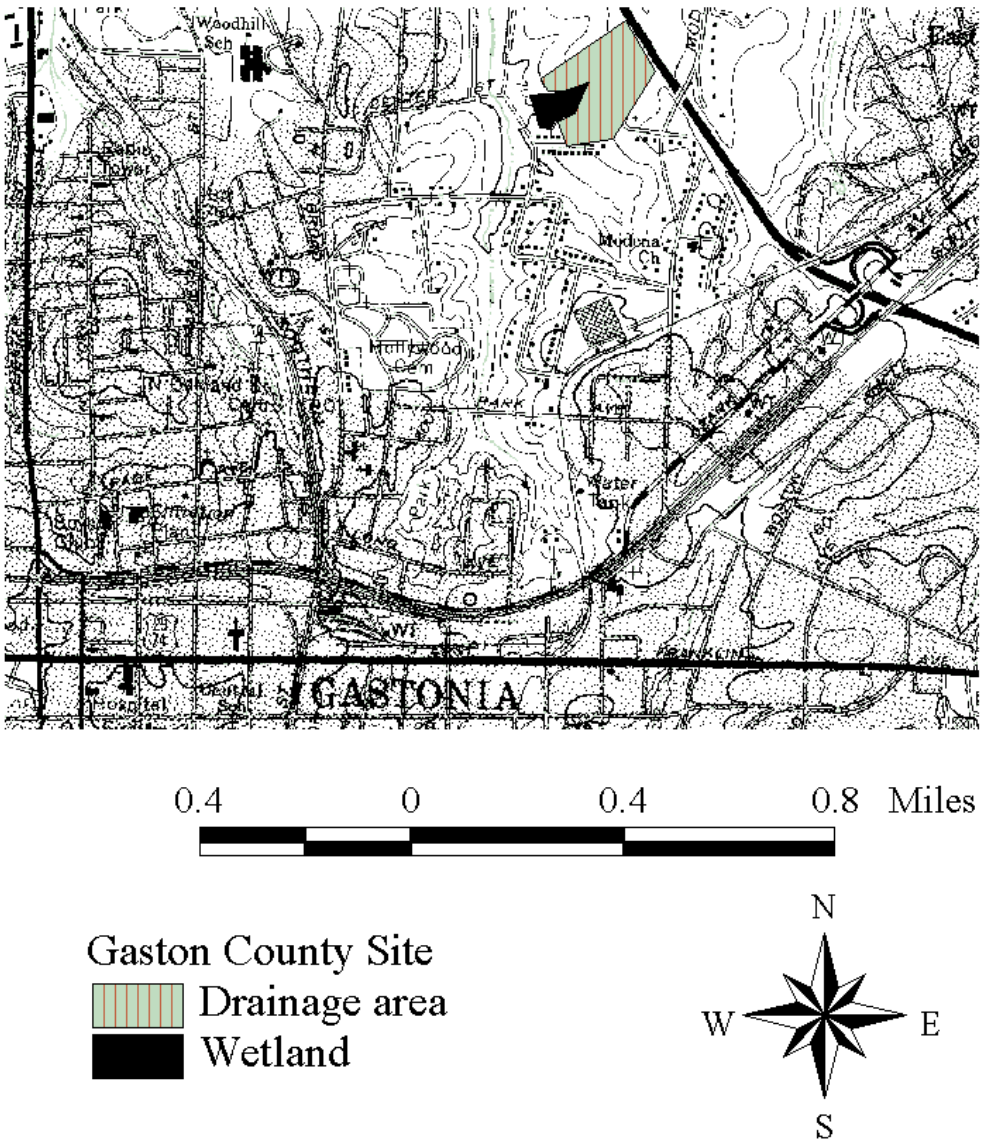
Craven County Impact Site



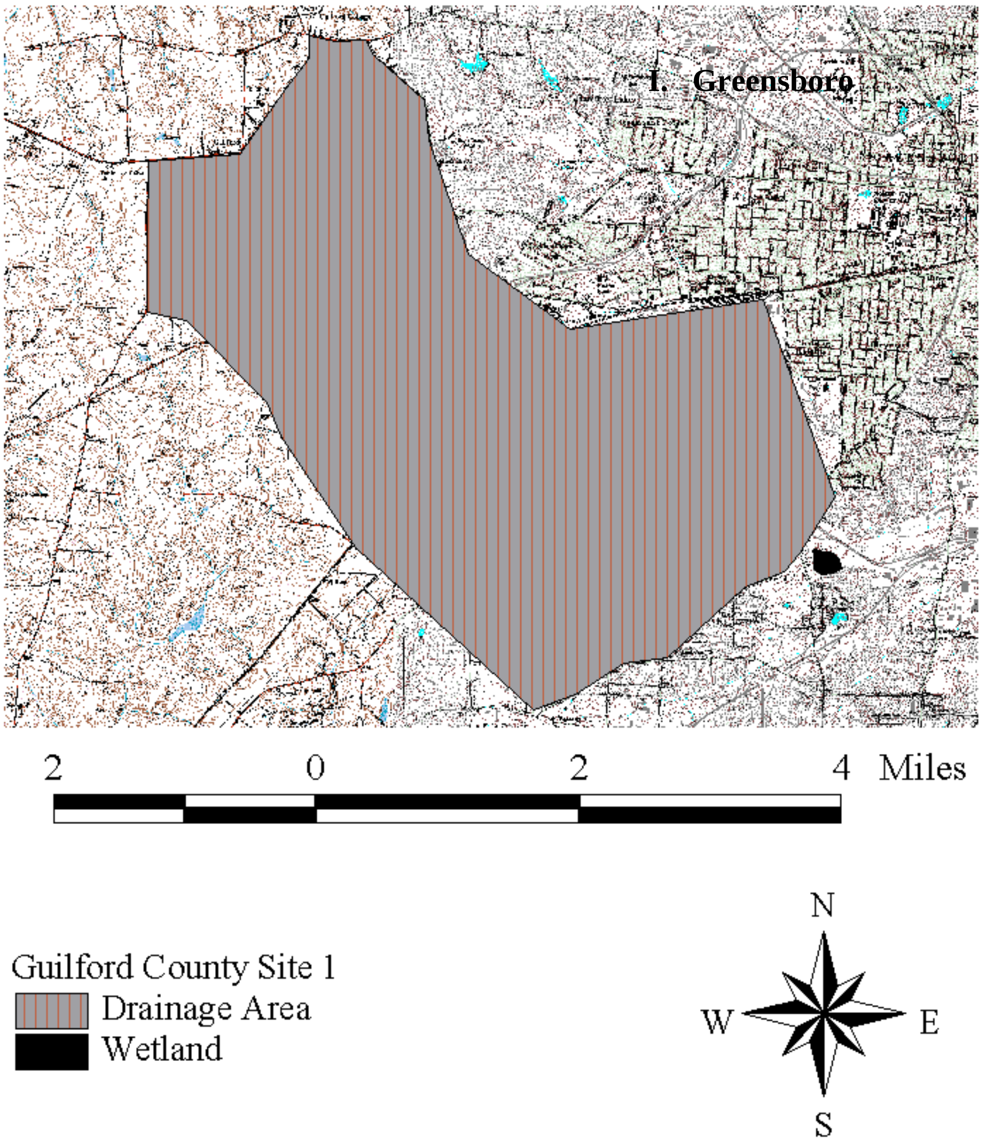
Craven County Reference Site



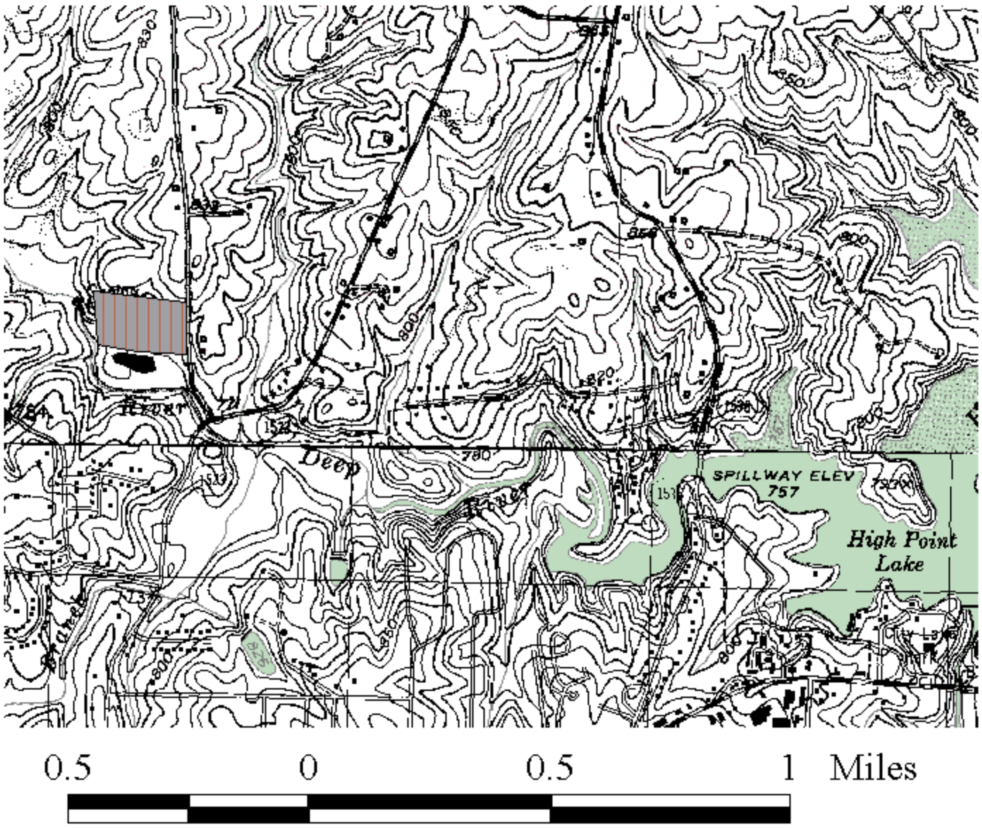
Gaston County Site



Guilford County Site 1



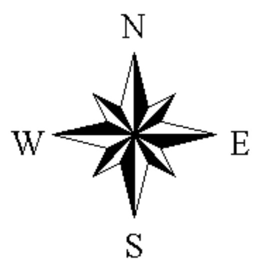
Guilford County Site 2



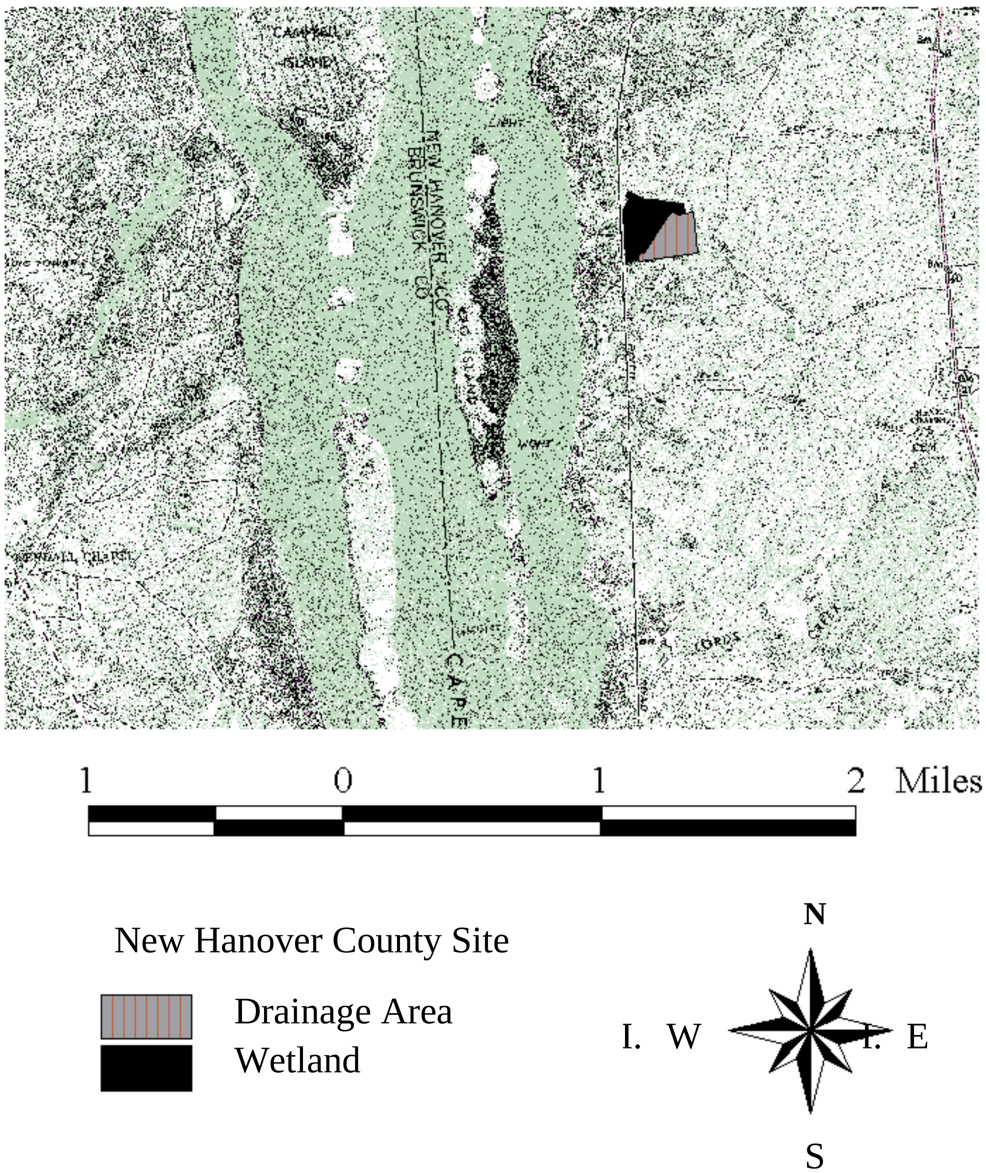
Guilford County Site 2

Drainage Area

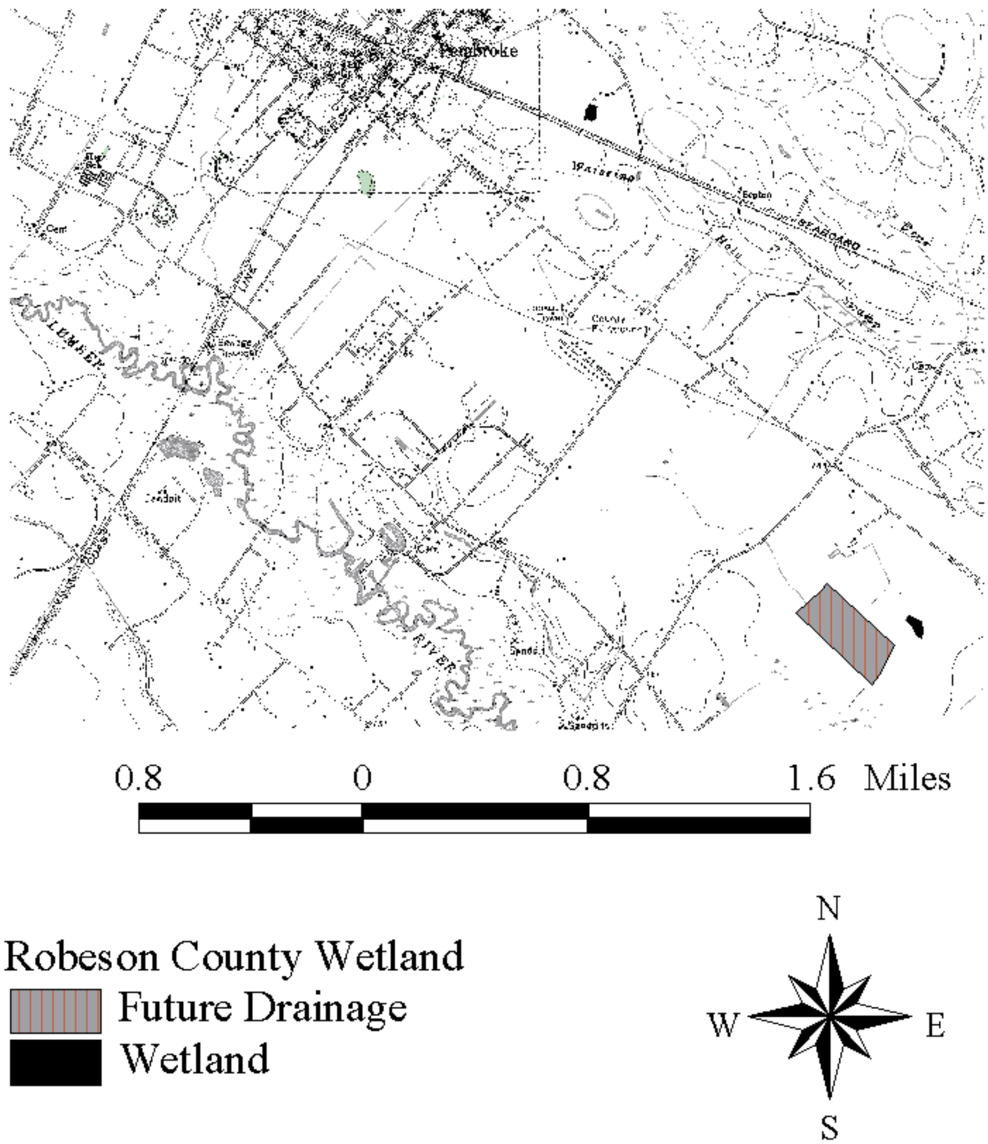
Wetland



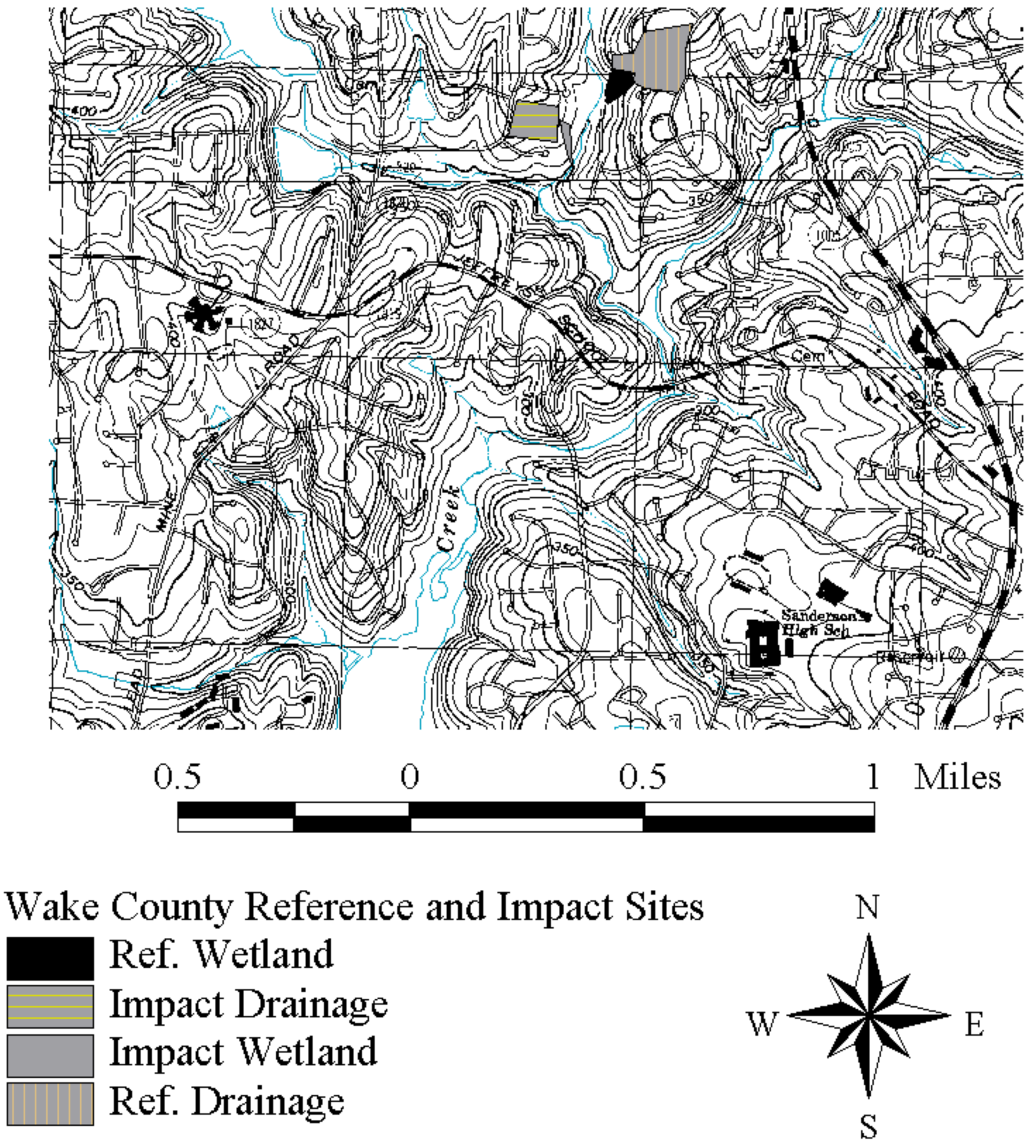
New Hanover County Site



Robeson County Site



Wake County Reference and Impact Site



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