ABSTRACT

LENHART, HAYES A. A North Carolina Field Study to Evaluate the Effect of a Coastal Stormwater Wetland on Water Quality and Quantity and Nitrogen Accumulation in Five Wetland Plants in Two Constructed Stormwater Wetlands. (Under the direction of W. F. Hunt.)

A stormwater wetland in River Bend, North Carolina, was instrumented to collect water quality samples and monitor water quantity between June 2007 and May 2008. Inflow and outflow water quality concentrations and loads were compared for total kjeldahl nitrogen (TKN), nitrate and nitrite (NO_{2-3}-N), ammonium (NH_4-N), total nitrogen (TN), total phosphorus (TP), ortho phosphorus (OP), and total suspended solids (TSS). Inflow and outflow runoff peaks and volumes were also examined.

A total of 24 and 11 storms for water quantity and water quality have been collected and statistically compared, respectively. The wetland reduced peak flow rates by 80% and runoff volumes by 54%. Both peak flow rates and runoff volumes were significantly ($p<0.05$) reduced. Mean concentration reductions of TKN, NO_{2-3}-N, NH_4-N, TN, TP, OP and TSS were -70%, 9%, -53%, -51%, 0%, 39% and -30%, respectively; while mean load reductions were 35%, 41%, 42%, 36%, 47%, 61% and 49%, respectively. There was no significant difference ($p>0.05$) between inflow and outflow concentrations for all but one of the previously mentioned pollutants. Inflow concentrations of OP were significantly greater ($p<0.05$) than outflow concentrations. There was no significant difference ($p<0.05$) between inflow and outflow loads for all but two of the previously mentioned pollutants. Inflow loads for OP and NH_{2-3}-N were significantly greater ($p<0.05$) than outflow loads. There was no

significant difference in pollutant loads ($p<0.05$) between the growing and non-growing seasons.

Mean influent and effluent concentrations were compared with background stream concentrations in the same watershed to better quantify wetland water quality. Mean influent and effluent concentrations from other wetland studies in North Carolina and those from River Bend were compared in order to determine how well the wetland is functioning with reference to other statewide wetlands.

Phosphorus deposition was also monitored by taking soil samples at specific locations in the wetland every 2 months for a year. It was found that there was a significantly greater ($p<0.05$) concentration of P in soils closer to the inlet of the wetland compared to P concentrations at the outlet. The P concentration profile from the wetland substrate did not appear to change substantially over time; therefore, no evidence of P migration along the wetland bottom existed. This suggested that the wetland had become saturated with P and was no longer effectively removing P.

Vegetation was harvested in two stormwater wetlands located in Smithfield and Pactolus, North Carolina, to evaluate the ability of five wetland plant species to sequester nitrogen. Biomass samples from harvested emergent vegetation for *Pontederia cordata* (Pickerelweed), *Saururus cernuus* (Lizard Tail), *Scirpus cyperinus* (Wool Grass), *Sagittaria latifolia* (Arrowhead) and *Schoenoplectus tabernaemontani* (Softstem Bulrush) were collected in September and October 2007 and analyzed for nutrient content on a % N of biomass basis. At the Pactolus wetland the *Pontederia cordata*, *Scirpus cyperinus* and *Schoenoplectus tabernaemontani* biomass retained significantly ($p<0.05$) more nitrogen than

Sagittaria latifolia and *Saururus cernuus*. At the Smithfield wetland, *Pontederia cordata* and *Sagittaria latifolia* biomass retained significantly more nitrogen than *Scirpus cyperinus* and *Saururus cernuus*.

A positive relationship was noticeable between the density of harvested biomass and nitrogen removal for two species, *Scirpus cyperinus* and *Sagittaria latifolia*. A model for estimating total nitrogen loading in Coastal Plain watersheds in North Carolina was used to determine that harvested vegetation from a wetland in the Tar-Pamlico River basin could potentially account for 21% of nitrogen entering the Pactolus wetland on an annual basis. The implementation of stormwater wetland harvesting as a maintenance activity appears to be a potentially important practice for nitrogen removal.

A North Carolina Field Study to Evaluate the Effect of a Coastal Plain Stormwater Wetland on Water Quality and Quantity and Nitrogen Accumulation in Five Wetland Plant Species in Two Constructed Stormwater Wetlands

by

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BIOGRAPHY

Hayes Austin Lenhart was born in Tucson, Arizona, on February 20, 1984. He is the son of James Herbert and Camilla Dillon Lenhart of Portland, Oregon, and an older brother to Marshall James Lenhart. James Lenhart is a professional engineer working at Contech Stormwater Solutions while Camilla Lenhart is a registered nurse working at a private practice. Even though Hayes was born in Tucson, AZ, he calls the state of Oregon his home as he grew up in the cities of Corvallis, Portland and Beaverton throughout his childhood. Hayes graduated from Beaverton High School in 2002 when he made his decision to attended Oregon State University and purse a degree in Civil Engineering. Upon graduation in 2006, Hayes, decided to pursue a master's degree in Biological and Agricultural Engineering from North Carolina State University in Raleigh, North Carolina under the direction of Dr. Bill Hunt. Upon graduation Hayes plans to work for a consulting firm designing stormwater treatment systems relating to sustainable design.

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These two chapters help address questions that are frequently asked when discussing stormwater wetlands in the research community. The most effective way of assessing stormwater treatment systems is a subject that has been explored in recent literature (Strecker et al. 2001, Urbonas 1995). Varying methods of data collection, analysis techniques and water quality parameters are just a few of the problems that exist with evaluating stormwater systems. Chapter 2 examines a stormwater wetland's ability to improve water quality using two evaluation techniques. The first technique was a standard assessment that compares influent and effluent concentrations and loads of total kjeldahl nitrogen (TKN), nitrate and nitrite ($NO_{2\text{-}3}$-N), ammonium (NH_4-N), total nitrogen (TN), total phosphorus (TP), ortho phosphorus (OP), and total suspended solids (TSS). The wetland was also assessed on its ability to mimic predevelopment hydrology by comparing the volume of influent and effluent stormwater runoff and peak flow reduction. The second technique was not considered a standard evaluation method. This process compared the effluent water quality to nearby in-stream background concentrations in an attempt to relate the wetland's influent and effluent water quality to existing natural systems. Additionally, the examined wetland's effluent concentrations were compared to those of other wetland studies in North Carolina. Consequently, this second chapter may help to show that stormwater treatment systems should not be strictly evaluated on concentration and load reductions; they may also need to be evaluated in the context of the surrounding environment.

The third chapter focuses on the potential benefit of harvesting plant biomass from a stormwater wetland to increase the removal of N from the system. The idea of harvesting biomass from wastewater wetlands has been discussed (Gersberg et al. 1986, Tanner 2001). These wastewater wetland studies, attempting to quantify the effect of harvesting on pollutant removal, have shown that plant harvesting could remove 6 to 16 percent of N from the system. This has typically been considered a minor amount, and the practice of harvesting vegetation from wastewater wetlands for N removal has been generally abandoned.

Consequently, wetland plant harvesting has not been recommended as a management strategy for N removal in *stormwater* treatment wetlands. As a result, there is still much debate about the potential significance of harvesting plant biomass from stormwater wetlands. Stormwater tends to carry lower concentrations of N than wastewater (Burchell II et al. 2007, House et al. 1994, Johnson 2006, Line et al. 2008). Therefore, harvesting of stormwater wetlands could prove to be a beneficial N removal strategy. Chapter 3 attempts to quantify the amount of harvestable N from plants native to the Southeast and Mid-Atlantic to determine if wetland plant harvesting could be a potential N management strategy in North Carolina. The methods used to quantify harvestable N involved the harvesting of two separate, well established stormwater wetlands in North Carolina. Comparisons were made between plant species to discern if certain species may sequester a greater amount of N than others. Based on this comparison, recommendations could be made for specific plant types if harvesting were to take place. The amount of potentially harvestable N was then compared to an estimated annual load of N from stormwater entering one of the wetlands.

In summary, both of these chapters deals with a particular aspect of stormwater wetlands that is debated in the stormwater community. Chapter two analyzes the effectiveness of a coastal plain stormwater wetland with a special focus on how the wetland's effluent concentrations relate to its surrounding environment, while chapter three attempts to help answer the question of whether or not harvesting plant biomass from stormwater wetlands should be considered a nitrogen management strategy.

CHAPTER 2

A NORTH CAROLINA FIELD STUDY TO EVALUATE THE EFFECT OF A STORMWATER WETLAND ON WATER QUALITY AND QUANTITIY

ABSTRACT

A stormwater wetland in River Bend, North Carolina, was instrumented to collect water quality samples and monitor water quantity between June 2007 and May 2008. The site was instrumented soon after the wetland's construction and monitoring began immediately after planting. During the study period the region underwent a severe drought, reducing the frequency of rain events to produce runoff and subsequently monitor. Inflow and outflow water quality concentrations and loads were compared for total kjeldahl nitrogen (TKN), nitrate and nitrite ($NO_{2\text{-}3}$-N), ammonium (NH_4-N), total nitrogen (TN), total phosphorus (TP), ortho phosphorus (OP), and total suspended solids (TSS). Inflow and outflow runoff peaks and volumes were also examined. A total of 24 and 11 storms for water quantity and water quality have been collected and statistically compared, respectively. The wetland reduced peak flow rates by 80% and runoff volumes by 54%. Both peak flow rates and runoff volumes were significantly ($p<0.05$) reduced. Mean concentration reductions of TKN, $NO_{2\text{-}3}$-N, NH_4-N, TN, TP, OP and TSS were -70%, 9%, -53%, -51%, 0%, 39% and -30%, respectively; while mean load reductions were 35%, 41%, 42%, 36%, 47%, 61% and 49%, respectively. There was no significant difference ($p>0.05$) between inflow and outflow concentrations for all but one of the previously mentioned pollutants. Inflow concentrations of OP were significantly greater ($p<0.05$) than outflow concentrations. There was no significant difference ($p<0.05$) between inflow and outflow loads for all but two of the

previously mentioned pollutants. Inflow loads for OP and NH_{2-3}-N were significantly greater ($p<0.05$) than outflow loads. There was no significant difference in pollutant loads ($p<0.05$) between the growing and non-growing seasons. However, upon examination of the data, it appears the differences between inflow and outflow loadings, particularly TKN and TP, are beginning to become more consistent and pronounced over time. Mean influent and effluent concentrations were compared with background stream concentrations in the same watershed to better quantify wetland water quality. Mean influent and effluent concentrations from other wetland studies in North Carolina and those from River Bend were compared in order to determine how well the wetland is functioning with reference to other statewide wetlands. Mean TKN, NH_4-N and TN influent concentrations at the River Bend wetland, 0.55, 0.05 and 0.73 mg/L respectively, were lower than the effluent concentrations from all the other wetlands examined. For all other nutrient species, NO_{2-3}-N, TP and OP, influent concentrations at River Bend, 0.18, 0.23, and 0.15 mg/L respectively, were lower than the effluent concentrations from at least one of the other wetland studies examined. In order to better understand the N process within this stormwater wetland, a comparison was made between N sources and sinks. N sources included stormwater runoff and preexisting N of the wetland soil. Sinks included outflow from the wetland and N plant uptake. From this comparison results from the water quality section were put into better context to help determine why this wetland was not reducing pollutant concentrations. On a mass basis the soil contained 91% of the TN in the system leading to the hypothesis that inflow concentrations of TN were irreducible. Phosphorus deposition was also monitored by taking soil samples at specific locations in the wetland every 2 months for a year. It was found that there was a significantly greater ($p<0.05$) concentration of P in soils closer to the inlet of the wetland compared to P concentrations at the outlet. The P concentration profile from the wetland substrate did not appear to change substantially over time; therefore, no evidence of P migration along the wetland bottom existed. This suggested that the wetland had become saturated with P and was no longer effectively removing P.

INTRODUCTION

Stormwater runoff has been identified as one of the largest sources of water pollution by the U.S. Environmental Protection Agency (USEPA). Stormwater has been shown to transport pesticides, oils, heavy metals, nutrients and a variety of other contaminants (Bannerman et al. 1993, Flint and Davis 2007, USEPA 1996). To reduce these negative effects, the Clean Water Act was amended in 1987 to require National Pollution Discharge Elimination System (NPDES) permits for stormwater. However, despite these amendments the EPA reported in 2000 that 45 percent of lakes and 50 percent of estuaries surveyed were impaired (USEPA 2002). In the Chesapeake Bay and North Carolina's Albemarle and Pamlico Sounds, excess nutrient loads, in part associated with urbanization, have negatively impacted fishery health (Abler et al. 2002, Stanley 1987). As a result a variety of stormwater Best Management Practices (BMPs) have been approved by the state of North Carolina to treat stormwater runoff (NCDWQ 2007). One such BMP is a constructed stormwater wetland.

To help reduce the impact of nutrients in the Neuse and Tar-Pamlico river basins the North Carolina Division of Water Quality recently created rules pertaining to nutrient loading in stormwater runoff commonly referred to as the Neuse Rules (NCDENR 2002) and Tar-Pamlico rules (NCDENR 2008). In the Neuse River Basin nitrogen loads from new developments must maintain their average nitrogen load at or below 3.6 lbs/acre/year. For the Tar-Pamlico river basin nitrogen loads from new developments cannot exceed 4 lbs/acre/yr. Due to the basin's high sensitivity to phosphorus, loading from new developments cannot exceed 0.4 lbs/acre/year. For both river basins peak flows from new developments must be at or below predevelopment conditions for the 1-year, 24 hour storm (NCDENR 2004).

Because of high water table levels in eastern North Carolina the two major BMPs favored in that region are stormwater wetlands and wet ponds. Currently, the North Carolina Department of Environmental and Natural Resources (NCDENR) assigns stormwater wetlands removal efficiencies of 85%, 40% and 35% for total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP), respectively (NCDWQ 2007). NCDENR assigns wet pond removal efficiencies of 85%, 25% and 40% for TSS, TN and TP, respectively. Due to their relatively high removal efficiency assigned to TN in the Neuse River Basin, stormwater wetlands have become popular in the coastal plain of NC.

In the past decade several constructed wetland studies have been conducted in North Carolina. Hathaway (2005) found a constructed wetland, located in Goldsboro, North Carolina, receiving groundwater contaminated by swine lagoon seepage to reduce TN and TP concentrations by 76% and 22%, respectively. This particular wetland did not receive stormwater from a surrounding watershed; however, it demonstrates the ability of constructed wetlands to significantly reduce TN and TP before groundwater makes its way to surface waters. Bass (2000) determined that an in-stream stormwater wetland in the North Carolina coastal plain reduced TN concentrations by 20%. The wetland received drainage from a 240 hectare (600 ac) watershed composed of urban and agricultural land uses. The wetland was designed to capture, treat and slowly release captured stormwater. However, Bass also found elevated TP concentrations at the outlet compared to inlet concentrations. Johnson (2006) monitored two wetlands in North Carolina and found the wetlands to meet or exceed the removal efficiencies for North Carolina. Johnson (2006) reported the wetland located in Charlotte, NC reduced TKN, TN, TP and TSS by 45%, 40%, 55% and 66%, respectively. This particular wetland was a flow through wetland, and therefore, did not reduce peak flows. Johnson reported another stormwater wetland located in Smithfield, NC, reduced TKN, TN, and TP by 54%, 80% and 73%, respectively. However, this wetland was designed to capture and slowly release the 2.54 cm (1 inch) water quality event. Line et al. (2008) monitored two wetlands located in the mountains and piedmont of NC. The UNC Asheville wetland reduced TKN, TN, TP and TSS mean concentrations by 39%, 42%, 52% and 83%, respectively. Peak flows and runoff volumes were also reduced by an average of 77% and 9%, respectively. The CMS Raleigh, NC, wetland located in the piedmont reduced TKN, TN, TP and TSS mean concentrations by 21%, 21%, 43% and 64%, respectively (Line et al. 2008). Peak flows and runoff volumes were also reduced by an average of 72% and 27%, respectively. Most of these wetlands have shown positive removal efficiencies for various pollutants. However, each research project had unique data collection methods, different calculation methods and varied comparative statistics. For example, in Johnson (2006) the wetland in Charlotte was monitored with ISCO automatic samplers to take flow weighted composite samples, while the wetland in Smithfield was monitored via grab samples. The particular way laboratories analyze samples varies from lab to lab so there will always be variability. However, there has been some research on ways to reduce this variability in an attempt to formulate better evaluation methods for stormwater BMPs (Strecker et al. 2001, Urbonas 1995).

The actual assessment of how stormwater BMPs perform is a topic of much discussion in the stormwater community. Strecker (2001) lists many of the inconsistencies associated with evaluating BMP performance including sample collection techniques, water quality constituents, tributary watershed information, efficiency estimation techniques and statistical validation of results. Currently all of the measures of effectiveness are based on the differences between concentration and loading from influent and effluent stormwater. However, Strecker (2001) eventually states that biological and downstream habitat assessment may need to be explored as an evaluation technique as well. Essentially putting stormwater BMPs in context of the environment they are in may be a better way of measuring how well BMPs are functioning than the currently used concentration and load basis.

Stormwater wetlands have proven to be an effective means of treating stormwater pollution, offering a more natural alternative that better fit certain landscapes. Wetlands are sized according to watershed area and are usually the most cost efficient BMP when land costs are low (Wossink and Hunt 2003). Wetlands are most effective at removing nitrates through plant uptake and denitrification (Ingersoll and Baker 1998). In an effort to increase nitrate removal levels in constructed wetlands Burchell et al. (2007) added organic matter into the wetland substrate. It was found by adding organic matter, the area required for an in stream wetland to treat drainage water was reduced (Burchell II et al. 2007). Wetlands can also remove phosphorus via sedimentation and adsorption (Kadlec 1999, Reddy et al. 1999). These two nutrients are the major pollutants of concern for this manuscript. The following is a brief introduction of nitrogen and phosphorus processes in wetlands relevant to this chapter.

Nitrogen

Nitrogen in both inorganic and organic forms are found in wetlands. Inorganic forms include ammonium (NH_4^+), nitrate and nitrite ($NO_{2\text{-}3}$-N), nitrous oxide (N_2O) and nitrogen gas (N_2). Organic N can be found in many compounds including amino acids and urea. Understanding the processes of how N changes and moves within the wetland system is essential to performing a N balance.

The main storage areas in a wetland for nitrogen are in the above ground plant biomass, rhizomes, roots and the wetland soil (Breen 1990, Kadlec and Knight 1995). In order to perform a nutrient balance, these storage areas must be separated and analyzed for N mass changes. Breen (1990) performed a N balance on a wastewater treatment wetland and attributed 5% N to the effluent water, 34% N to above ground plant biomass, 29% N to denitrification, 18% N to roots and the remaining 14 % to the rhizomes and the organic films on gravel and roots. Lund (1999) performed an N balance on a constructed pond system to treat wastewater to find 62% N was lost most likely to denitrification, but no effort was made to estimate the magnitude of plant uptake. Based on the results of the previously mentioned studies, some of the N loss was also likely due to plant uptake.

Denitrification is considered to be the major process behind N loss in wetlands (Bachand and Horne 1999, Reddy et al. 1989). Most treatment wetlands tend to receive nitrogen in the form of ammonium (NH_4^+) or organic nitrogen from influent water. This form of N will undergo conversion to NO_3^- through mineralization or nitrification (Ingersoll and Baker 1998). Once this occurs, NO_3^- can be denitrified to form N_2 or N_2O (Patrick and Reddy 1976).

Nitrification is an anaerobic two step process in which microbes convert NH_4^+ to NO_3^-. The first step is performed by *Nitrosomonas* bacteria to oxidize NH_4^+ to form NO_2^-. Then *Nitrobacter* bacteria oxidize NO_2^- to form NO_3^- (Reddy and Patrick 1984). Once nitrification has occurred denitrification can take place. Denitrification will occur when low oxygen levels causes bacteria to use NO_3^- instead of oxygen as an electron acceptor for respiration (Patrick and Reddy 1976). Typical groups of bacteria that facilitate denitrification are *Bacillus*, *Enterobacter*, *Micrococcus*, *Pseudomonas* and *Spirillum* (Kadlec and Knight 1995).

Nitrogen assimilation is the process by which vegetation sequesters nitrogen in its biomass. The two major forms of nitrogen used by plants are ammonium and nitrate. Most plants prefer ammonium for assimilation, however some can use nitrate (Melzer and Exler 1982). Aquatic macrophytes use nitrate-reductase and nitrite-reductase enzymes to change NO_2^- and NO_3^- to useable forms of N (Melzer and Exler 1982). The significance of plant uptake in wastewater treatment wetlands has been debated. Some researchers suggest that wetland vegetation can assimilate a majority of the N if conditions are favorable. A study performed on sub-surface flow (SSF) gravel wetlands found 70 to 85 percent of the nitrate loss could be attributed to plant uptake (Zhu and Sikora 1995). On the contrary, Tanner (2001) found only 6 to 11 percent of nitrogen removal could be attributed to plant uptake after three growing seasons. However, these studies focused on wastewater treatment wetlands, while an N balance for a stormwater wetland has not been explored in the literature. An investigation of N fate in a stormwater wetland is a focus of the research presented herein.

Phosphorus

Long term phosphorus removal is a particular concern in stormwater wetlands, as it has been shown that wastewater treatment wetlands eventually lose their ability to effectively remove P (Breen 1990), which can occur after only a couple of months (Kadlec 1995). Stein et al. (1998) showed initial wastewater wetland P removal of 40%, but eventually decreasing to almost zero after four months. Richardson et al. (1997) found P storage in wetlands is proportional to the P loading and eventually a wetland would reach a P loading threshold. Once this threshold is reached, effluent TP concentrations increase exponentially. Richardson et al. (1997) proposed once loading exceeds 1 g m^{-2} yr^{-1} all short-term removal mechanisms become P saturated, and P removal by plant uptake becomes unsubstantial. As a result Richardson et al. (1997) proposed a “One Gram Rule” for freshwater wetlands, stating that a 1 g m^{-2} yr^{-1} would result in a wetland reaching its assimilative capacity for P. Once this loading is reached the P removal is limited by long-term storage capacity controlled by peat and soil accretion. Loadings higher than this could lead an exponential rise in effluent TP concentrations

However, Kadlec (1999) argues that the one gram rule is an oversimplification. Depending on the individual wetland, complete treatment or zero removal of P can be provided. Kadlec (1999) writes wetlands will exhibit similar characteristics such as a decline in P concentration to a background concentration as a function of distance from the P source. The change from total P containment to non-containment occurs at different P loadings for each individual wetland.

Due to the fact watersheds in NC and elsewhere are sensitive to P, strategies to optimize P removal must be explored. There are three major mechanisms by which wetlands retain P.

The first mechanism is P sequestration by vegetation. Vegetation use P in their living tissue to promote biomass growth. McJannet (1995) found the range of P concentrations in 41 wetland plant species to vary between 0.13 to 1.07 percent of the biomass. However, P removal by wetland plant uptake is not considered to be a major P removal mechanism as it only acts as temporary storage. During senescence the beneficial uptake of P is lost as dead biomass and any P it may have sequestered during the growing season is released back into the wetland (Kröger et al. 2007).

The second major mechanism for P removal is assimilation by microorganisms. Just like plants, microorganisms such as bacteria, fungi, algae, and microinvertebrates utilize P for growth. A study performed by Richardson and Marshall (1986) found P uptake to occur on a time scale of hours, yet within 6 hours more than 90% was released back into the wetland. Microorganisms may have an initial role in P uptake, however, they do not provide any substantial long term treatment (Richardson and Marshall 1986).

The major P removal mechanism has been accredited to P accumulation on soil and peat sediments (Caraco et al. 1991, Kadlec 1999, Reddy et al. 1999, Richardson et al. 1996). Depending on wetland soil properties, P will be fixed or released to soil particles. In acid soils phosphorus is fixed by aluminum and iron, while in alkaline soils P is fixed by calcium and magnesium (Reddy and D'Angelo 1994).

The purpose of this study was to evaluate the ability of a stormwater wetland to remove nutrients from stormwater and to better understand P deposition within the wetland.

GOALS AND OBJECTIVES

The major goals of this research were as follows:

1. Evaluate the ability of a coastal plain stormwater wetland to effectively remove total kjeldahl nitrogen (TKN), nitrate and nitrite (NOx-N), ammonium (NH_4-N), total phosphorus (TP), ortho phosphorus (OP), and total suspended solids (TSS).
2. Determine if there are “start up” effects with regard to pollutant removal of a stormwater wetland. Does a stormwater wetland function differently immediately after it is constructed?
3. Evaluate the performance of a stormwater wetland compared to nearby in-stream concentrations of TKN, $NO_{2\text{-}3}$-N, NH_4-N, TP, OP and TSS.
4. Determine where phosphorus deposition occurs within a stormwater wetland.

SITE DESCRIPTION

The research site was a 0.14 hectare (0.34 acre) stormwater treatment wetland constructed in River Bend, NC, located in Craven County (Figure 1), and is the focus of the research presented herein (Table 1). The wetland was sized to capture runoff from the 3.3 cm (1.3 in) rainfall event and store approximately 122 m^3 (4300 ft^3) of water.

Figure 1. North Carolina counties map highlighting Craven County, where the research site is located.

Built in March 2007, the wetland treats stormwater from a 46.5 hectare (115 acre) watershed consisting of 0.2 ha (0.5 acre) residential lots, a small industrial area and a golf course (Table 2).

Table 1. River Bend wetland design parameters.

Wetland Location	River Bend, Craven County
Latitude and Longitude	N 35^{o} 4' 21.67", W 77^{o} 9' 2.17"
Wetland Area	0.14 ha (0.34 ac)
Watershed Area	46.5 ha (115 ac)
Watershed CN	60
Rainfall Event Captured	3.3 cm (1.3 in)
Ponding Depth	15.3 cm (6 in)
Capture Volume	122 m^3 (4300 ft^3)
Vegetation included on original planting plan	*Nyphaea odorata* (Water lily), *Nuphar luteum* (Spatterdock), *Pontederia cordata* (Pickerel weed), *Saururus cernuus* (Lizard tail), *Peltandra virginica* (Arrow arum), *Sagittaria lancifolia* (Duck potato), *Juncus effuses* (Common rush), *Scirpus cyperinus* (Wool grass), *Kosteletzkya virginica* (Marsh mallow), *Lobelia cardinalis* (Cardinal flower), *Lyonia lucida* (Pink fetterbush), *Clethera alnifolia* (Pepperbush), *Schoenoplectus tabernaemontani* (Softstem bulrush)

Table 2. Watershed Characteristics.

Land Use	Soil Hydrologic Group	Area (ha)	Area (ac)
0.2 ha (1/2 ac) residential	A	36.8	90.9
0.2 ha (1/2 ac) residential	B	3.2	7.8
0.2 ha (1/2 ac) residential	D	0.2	0.5
Town storage buildings	A	0.6	1.5
Town storage buildings	B	0.0	0.0
Town storage buildings	D	0.2	0.5
Golf course/grass field	A	4.6	11.4
Golf course/grass field	B	0.9	2.3
	Total	46.5	115.0

The watershed was delineated using ArcGIS software and existing LiDAR data supplied by the North Carolina Department of Transportation. Using a combination of an aerial photo and ArcGIS, land use types and their respective areas within the watershed were determined.

The hydraulic length of the watershed, estimated using ArcGIS, was 1250 m (4100 ft), with an average slope of 0.4%. The relative permeability of the watershed, as described by the Natural Resources Conservation Service (NRCS) curve number (CN) method, was calculated to be 54, indicating a moderately to very permeable watershed. To perform this calculation, runoff volumes from the 24 water quantity events were used to back calculate a CN using equations [1] and [2].

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad [1]$$

$$S = \frac{1000}{CN} - 10 \quad [2]$$

Where Q is the runoff (in), P is the precipitation (in), S is the potential maximum retention and CN is the curve number. The NRCS Web Soil Survey (WSS) reported five different soil series within the watershed: the Conetoe, Goldsboro, Masontown, Tarboro and Udorthents series. The primary series, Conetoe, present in 75 percent of the watershed, is a well drained loamy sand with slopes ranging from 0 to 10 percent, and an elevation range from 10 to 70 feet (NRCS 2002). As shown in Table 2 approximately 80% of the watershed land use consists of 0.2 ha (0.5 ac) residential lots underlain by a Conetoe or similar type sandy soil belonging to the A soil hydraulic group. This particular land use and soil type in this watershed should have a CN around 54 (Bedient and Huber 2002).

Based on historical averages from meteorological station number 316108, New Bern Craven Co Airport (N 35.067^{o}, W 77.05^{o}), which is 8.9 km (5.5 miles) west from the River Bend wetland, the average annual temperature is 16.8^{o}C (62.3^{o}F) ranging from a normal monthly minimum temperature of 1.1°C (33.9°F) in January to a normal monthly maximum of 31.3°C (88.3°F) in July. Average annual precipitation is 138.7 cm (54.6 in), ranging from a monthly mean of 8.6 cm (3.4 in) in April to 17.4 cm (6.84 in) in August (NCCO 2008). The growing season for Craven County begins March 18 and ends November 14 (Jurney 1934).

The River Bend wetland was first constructed in 1998. At that time the watershed was 30.4 ha (75 ac) consisting of 0.2 ha (0.5 ac) residential lots. The wetland was designed with a normal pool depth of (6 to 12 in), and was 0.07 ha (0.17 ac) in size. Between 1998 and 2006 the town of River Bend expanded the watershed by approximately 16.1 ha (40 ac). This occurred as a result of ditch digging beside roads along the perimeter of the original watershed that caused more land area to drain into the River Bend wetland. As a result the wetland was undersized (Figure 2). Because of its excessive depth the wetland often appeared more like a wet pond, as plants solely survived along the fringe.

Figure 2. River Bend wetland before being resized and reconstructed.

To remedy the situation, the wetland was resized in March 2007 to meet the standard design recommendations for a stormwater wetland, such as a shallow water normal pool depth from

2 to 4 inches (Hunt et al. 2007). At this time the wetland's surface area was expanded from 0.07 ha to 0.14 ha, and approximately 3200 plants of different species were planted in the wetland (Table 1). Soon afterward, a surprising late season freeze occurred in April which killed virtually all the plants in the wetland. As a result the wetland had to be replanted in June, with approximately 1000 plants of the same variety as the original planting plan. Figure 3 shows the River Bend wetland immediately after resizing and planting.

Figure 3. Pictured left the River Bend wetland post resizing and planting. Pictured right the River Bend wetland in July, 2008.

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MATERIALS AND METHODS

Water Quality

In June 2007 the inlet and outlet of the wetland were instrumented with flow monitoring equipment and samplers to collect water quality samples. A contracted rectangular weir was constructed at the inlet (Figures 4 and 5), and an ISCO model 6712 portable sampler and associated ISCO model 720 bubbler were installed to collect water quality samples and monitor runoff during storm events (Figure 6). Also at the inlet, an

ISCO model 673 tipping bucket rain gage was installed to monitor rainfall at the wetland. A compound weir consisting of a contracted v-notch and rectangular weir (Figures 5 and 7) was installed at the outlet with an ISCO model 6712 portable sampler and associated ISCO model 720 bubbler to collect water quality samples and monitor outflow during storm events (Figure 6). The ISCO flow monitoring equipment signaled the sampler to take 200 mL samples during storm events after a predefined volume of water had passed over the weir, resulting in a flow weighted composite sample for each event. Table 3 shows the automatic sampler settings. The automatic sampler settings were chosen to fully capture storm events between 0.64 cm (0.25 in) and 5.08 cm (2 in), meaning samples would be taken at intervals along the entire duration of the inflow period. The l0 L sampler jar would retain approximately 1000 mL of stormwater for the 0.64 cm storm and fill up completely for a 5.08 cm storm.

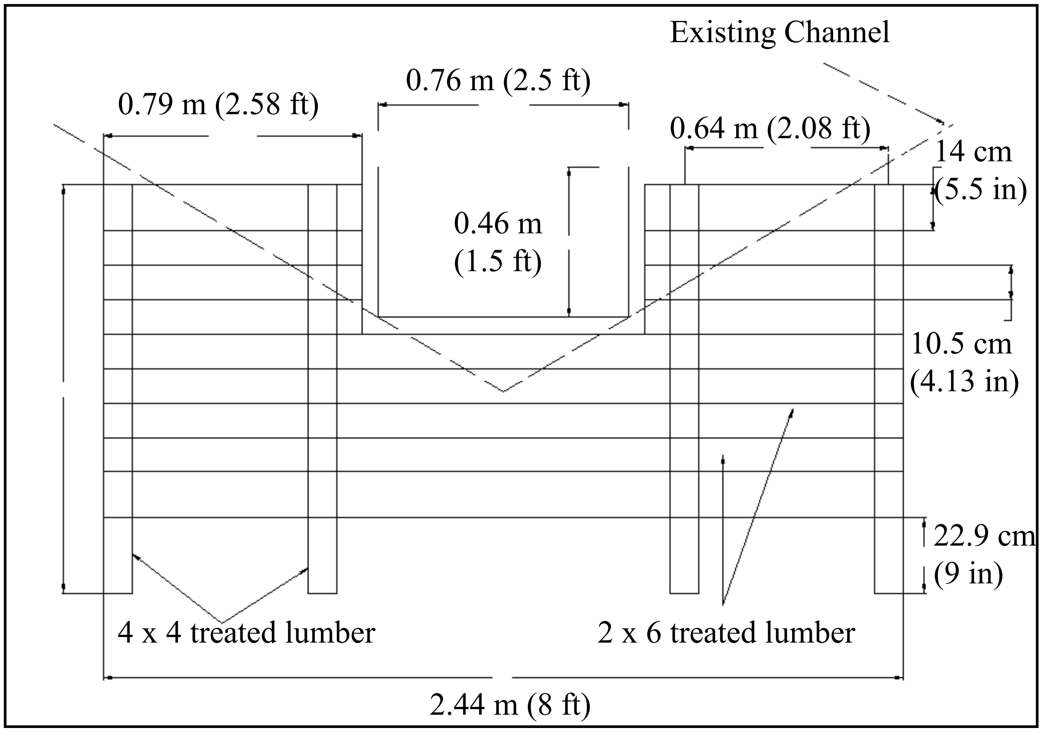

Figure 4. Inlet structural drawing.

Figure 5. From left: inflow and outflow weirs.

Figure 6. From left: inflow and outflow monitoring setup.

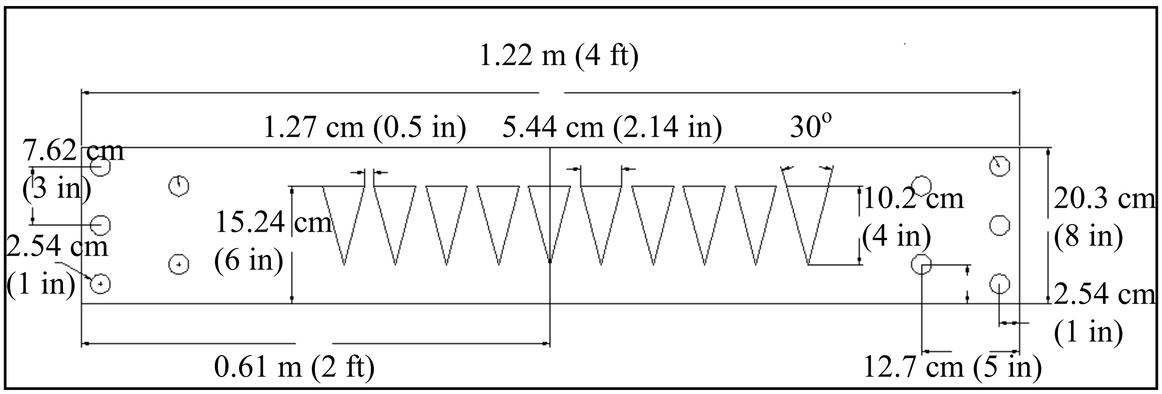

Figure 7. Outlet structural drawing.

Table 3. Automatic sampler settings for inlet and outlet.

Location	Sample Volume (mL)	Pacing (m^3)	Pacing (ft^3)
Inlet	200	6.5	230
Outlet	200	5.1	180

Starting in June 2007 and ending in May 2008 water quality samples were collected for storm events and analyzed for total kjeldahl nitrogen (TKN), nitrate and nitrite (NO_{2-3}-N), ammonium (NH_4-N), total phosphorus (TP), ortho phosphorus (OP), and total suspended solids (TSS). Samples were allowed to sit inside the sampling equipment for no more than two days. If a sample remained for longer it was discarded.

The collection of a sample for pollutant analysis involved three separate bottling techniques. First, the 10 L jar was shaken to re-suspend any settled solids. For TSS a 1 L plastic bottle was filled with sample water. For OP analysis 20 ml of sample water was drawn into a syringe and passed through a Whatman® Puradisc™ sterile and endotoxin free 0.45 µm PES filter media into a glass sample bottle. For $NO_{2\text{-}3}$-N, NH_4-N, TKN and TP analysis a pre-acidified 250 mL glass bottle with 0.25 ml of sulfuric acid was filled with sample water. Once sample collection was complete, the 10 L jar was emptied, rinsed with deionized water, and returned to its respective sampler unit. Collected sample bottles were placed on ice and delivered to the North Carolina State University Center for Applied Aquatic Ecology (CAAE) lab for analysis. The CAAE lab is located in Raleigh, NC, approximately 117 miles, or about two and a half hours by car from River Bend, NC. Table 4 describes the testing methods used for each pollutant by the CAAE laboratory.

Table 4. CAAE laboratory analysis methods.

Parameter	Method	Instrument
TKN	EPA[1] 351.1	QuAAtro (since Oct '07), TrAAcs 800 Continuous Flow Analyzer (prior to Oct '07)
$NO_{2\text{-}3}$-N	SM 18th[2] 4500-NO3-F	QuAAtro (since Oct '07), TrAAcs 800 Continuous Flow Analyzer (prior to Oct '07)
NH_4-N	SM 18th 4500-NH3-H	QuAAtro (since Oct '07), TrAAcs 800 Continuous Flow Analyzer (prior to Oct '07)
TP	SM 18th 4500-P-E	Lachat QuikChem 8000 FIA (Flow Injection Analysis)
Ortho P	SM 18th 4500-P-F	Lachat QuikChem 8000 FIA (Flow Injection Analysis)
TSS	SM 18th 2540 D	Vacuum filtered on glass fiber filters, Dried at 104 degrees C

[1] EPA – USEPA (1983)
[2] SM 18th – Standard Methods for the Examination of Water and Wastewater (1992)

As shown in Table 4 the instruments used to measure N species at the CAAE laboratory were changed in October of 2007. In conversing with the lab technician about this change, assurances were made that the change would not have affected the outcome of the analysis. Neither the chemical analysis techniques nor testing methodologies were different between the instruments. The change came because Seal Analytical bought out Bran+Luebbe (that made the Traacs instrument) and the Quaatro is their new and improved version of the Traacs, as the Traacs instrument is not made anymore.

Nitrogen sources and sinks

In order to better understand the most substantial source of N, four major N sources and sinks had to be quantified: inflow and outflow loadings, plant uptake and soil nutrients.

To quantify plant uptake, 25 randomly selected vegetative plots were harvested and analyzed for nutrients. This was performed by utilizing the AutoCAD® construction drawings for the wetland to establish a 0.25 m^2 grid system (Figure 8). Vertical and horizontal lines spaced 0.5 meters apart were oriented on top the construction drawing to establish this grid. Each complete 0.25 m^2 square that fell within the wetland was assigned a number beginning with one. The only areas excluded from sampling consisted of deep pools. These deep pools typically occupy 20 to 25 percent of the wetland area. During the second River Bend planting no deep pool species were included in the planting plan, resulting in deep pool exclusion from harvesting. There were a total of exactly 3000 complete 0.5 x 0.5 meter squares. A random number generator then selected 25 numbers from 1 to 3000. These 25 plots were those chosen for harvesting. Out of these 25 plots six were randomly selected, using a random number generator, for below ground harvesting.

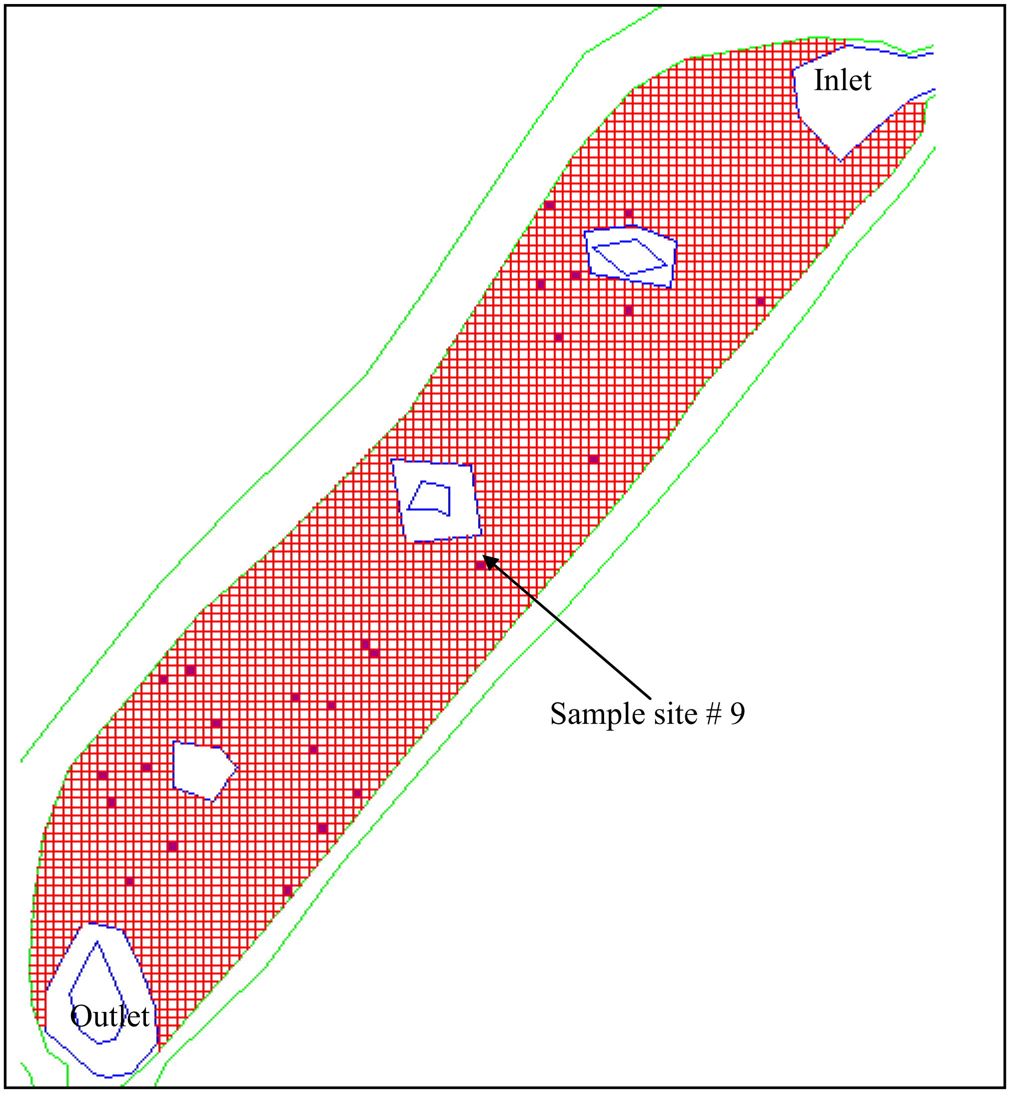

Figure 8. Locations of the 25 plant samples within the River Bend wetland.

Plant harvesting took place on October 1, 2007, just prior to senescence. The exact location of each square was located using a Sokkia Set 530R total station and Carlson Explorer data collector, and a 0.25 m^2 frame was placed on the ground at this location (Figure 9). The plant biomass within this frame was cut approximately 2.54 cm (1 in) above the soil to simulate plant harvesting. Above ground biomass was collected and kept separate for each square. Below ground biomass harvesting involved removing and bagging all of the roots associated with above ground biomass within the square. Any excess soil was washed from the root mass before being bagged. Below ground samples were stored and analyzed separately from their respective above ground specimens.

Figure 9. Picture of the 0.25 m^2 frame from a sample location at River Bend.

After harvesting was complete, all samples were rinsed and placed in an oven to dry at 80^{o}C (176^{o}F) for at least 24 hours in accordance with the N.C. Department of Agriculture (NCDA), Agronomics Division, lab protocol (Campbell 1992, Campbell and Plank 1992). All samples were then individually ground using a laboratory Wiley mill through a 20 mesh screen (1mm) and then weighed. Mineral nutrient analysis of the plant biomass was conducted by the NCDA, Agronomics Division, Raleigh, NC. TN was determined by oxygen combustion with an elemental analyzer (NA1500; CE Elantech Instruments, Milan, Italy).

Soil samples were also taken at the end of the study to estimate the TN concentration for the soil. Nine soil samples were taken from within the wetland. First the wetland was split into three approximately equal areas, X, Y, and Z (Figure 10). Next, 3 sample sites were randomly selected from within each area, for a total of nine samples. Soil sampling consisted of using a 5 cm (2 in) auger to remove the top 10 cm (4 in) of substrate at each location. Composite samples were then made for each area, X, Y and Z by combining the three samples from each respective area into one composite sample. Soil samples were put on ice and then delivered to TriTest labs in Raleigh, NC. Table 5 describes the methods used by TriTest labs to perform the N species analysis.

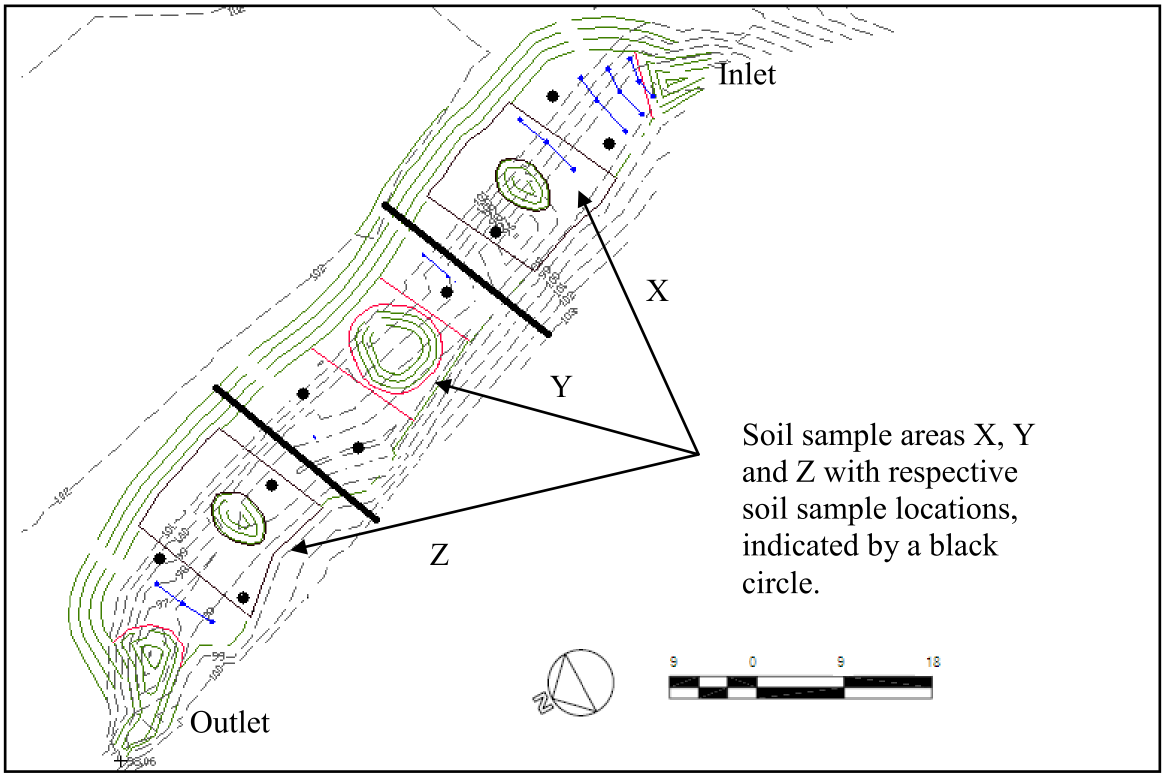

Figure 10. Soil sample areas and sample locations for N analysis (SI unit scale).

Table 5. TriTest laboratory analysis methods.

Test Performed	Method
TKN	EPA[1] 351.2
NO_{2-3}-N	EPA 353.2
TN	Calculated[2]
Percent Dry Weight	SM-18th[3] 2540B

[1] (USEPA 1983)
[2] Sum of TKN and NO_{2-3}-N
[3] (SM-18th 1992)

Phosphorus Deposition

Monitoring of phosphorus deposition consisted of taking soil samples at 21 locations within the wetland. Seven transects consisting of 3 sample sites in each transect were located perpendicular to the direction of flow. Most of the phosphorus deposition was expected to occur near the inlet forebay. Therefore, 4 transects were located near the entrance of the wetland, while 3 were spaced evenly through the remainder of the wetland. The seven transects were labeled A, B, C, D, E, F and G, respectively, beginning at the entrance and moving toward the exit (Figure 11). Sample locations were marked using pvc pipe hammered into the ground to insure consistent sampling (Figure 12).

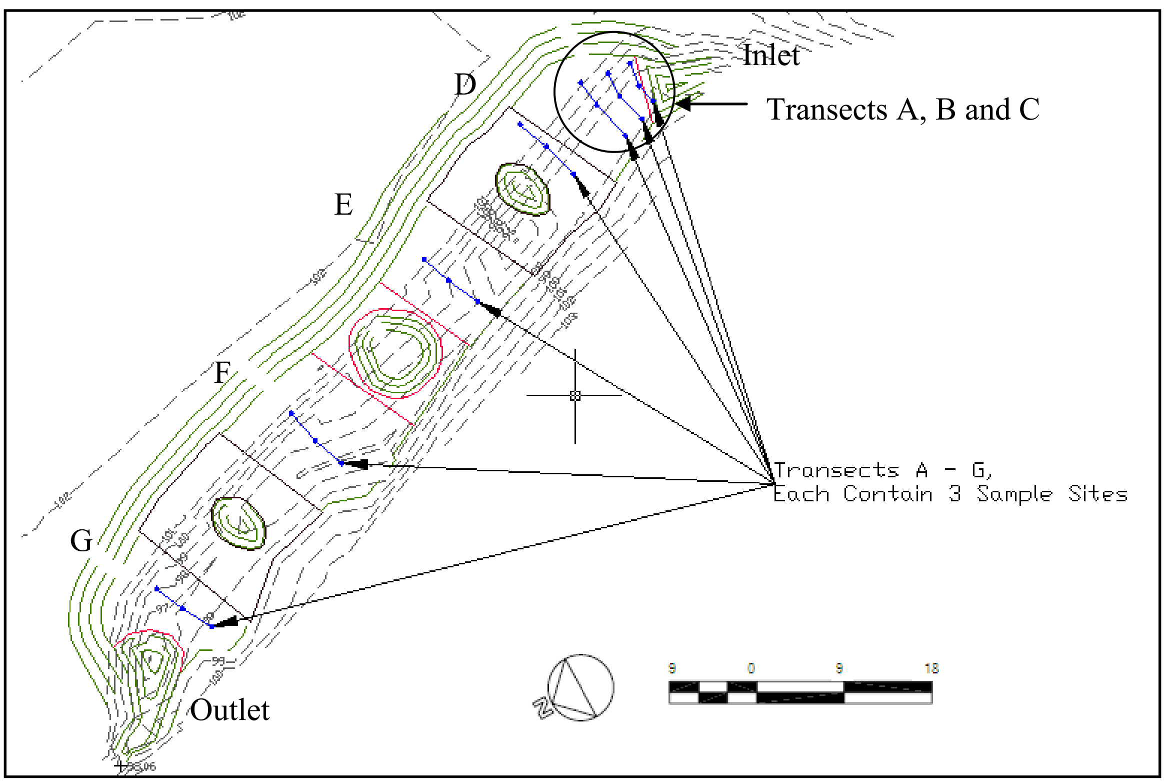

Figure 11. AutoCAD® drawing of soil sampling locations in the River Bend wetland (SI unit scale).

The sample sites were selected in this manner to better observe P frontal movement along the wetland bottom. Observations of P levels over time were also desired to determine how much P levels in soil were changing along the wetland with respect to time. By determining where in the wetland substrate P levels were at their highest, a potential maintenance strategy could be developed to replace P saturated soils with new soil. It was hypothesized that the area of highest P saturation would occur near the front of the wetland, which is the reason for the high concentrations of sampling sites near the wetland entrance.

Soil sampling, in accordance with the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) Agronomics Division sampling methodology, consisted of using a 5 cm (2 in) auger to remove the top 7.6 to 10 cm (3 - 4 in) of substrate at each location. Soil samples were taken every two months beginning in April 2007 for a year. Samples were delivered to the NCDA&CS Agronomics Division for analysis. Soil samples were analyzed for P by means of Mehlich-3 extractant using ICP on a volume basis (Mehlich 1984).

Figure 12. Soil sampling locations marked by PVC pipe.

RESULTS AND DISCUSSION

Water Quantity

Peak inflow and outflow rates from 24 rain events varied in size from 0.001 cms (0.04 cfs) to 0.22 cms (7.65 cfs). The wetland reduced outflow peaks by an average of 80%. Using the SAS System for Windows version 9.1®, a 1-way Analysis of Variance (ANOVA) table was used to determine whether the difference in peak flow between inflow and outflow was significant, which it was ($p<0.001$) (SAS 2008). The wetland reduced runoff volumes by an average of 54% (Table 6). Using the SAS System for Windows version 9.1®, a 1-way Analysis of Variance (ANOVA) table was used to determine that the difference in runoff volumes to be significant ($p<0.05$).

Four storms generated inflow but no outflow. The first two were an 18 mm (0.7 in) storm on September 15, 2007, and a 34 mm (1.3 in) storm on October 25, 2007, both during the severe North Carolina drought. The third was a 10 mm (0.4 in) rain event on December 21, 2007. The fourth was a 1.32 cm (0.52 in) rain event on December 30, 2007. A representative hydrograph from a 2.16 cm rain event on July 28, 2007, is shown in Figure 13. This hydrograph shows the wetland reduced the volume of runoff and peak flow by 57% and 88%, respectively. Outflow began approximately 15 minutes after inflow. Outflow persisted for approximately 12 hours after inflow had concluded. Inflow volumes varied between 4.7 m^3 (167 ft^3) and 5021 m^3 (177324 ft^3), while outflow volumes varied between 0 m^3 and 1427 m^3 (50410 ft^3).

The SAS System for Windows version 9.1® was used to develop a completely randomized split-block design (CRSPD) to determine if there was a difference between growing season and non-growing season runoff volumes and peak flows. Elements of the CRSPD were as follows: the whole plot unit was each event (runoff volume), the between plot factor was the season (spring/summer or fall/winter) and the within plot factor was the location (inflow or outflow). There was no significant difference ($p>0.05$) between growing and non-growing season runoff volumes. This was likely due to the drought conditions that impacted this site during the course of this study. Instead of runoff volumes depending on intensity and rainfall depths, they depended on antecedent moisture conditions. Table 6 summarizes the water quantity data collected from 24 storm events.

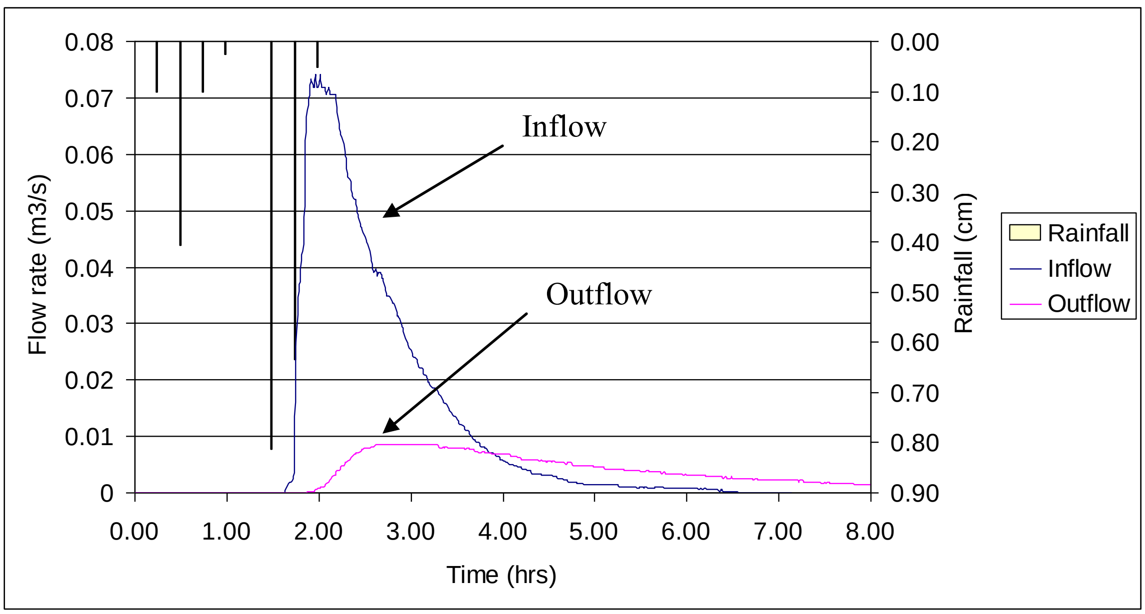

Figure 13. Hydrograph from the storm event on July 28, 2007, (2.16 cm rainfall).

Table 6. Rain events with respective runoff values, flow peaks and reductions.

#	Storm Date	Rainfall (cm)	Inflow (m^3)	Outflow (m^3)	Peak Inflow (cms)	Peak Outflow (cms)	Runoff Reduction (%)	Peak Flow Reduction (%)
1	7/7/07	3.73	615.7	547.3	0.10	0.04	11.1	65.8
2	7/10/07	1.96	309.8	178.6	0.05	0.01	42.3	82.7
3	7/11/07	1.80	596.5	587.5	0.06	0.02	1.5	64.9
4	7/13/07	2.51	1132.5	976.7	0.21	0.10	13.8	50.3
5	7/28/07	2.16	293.6	127.7	0.07	0.01	56.5	88.0
6	8/10/07	1.42	0.0	0.0	0.00	0.00	na	na
7	8/31/07	3.63	0.0	0.0	0.00	0.00	na	na
8	9/15/07	1.80	56.0	0.0	0.01	0.00	100.0	100.0
9	9/20/07	1.35	0.0	0.0	0.00	0.00	na	na
10	10/25/07	1.24	7.4	0.0	0.00	0.00	100.0	100.0
11	10/27/07	3.38	365.9	150.2	0.06	0.01	59.0	88.5
12	12/21/07	1.07	4.7	0.0	0.00	0.00	100.0	100.0
13	12/30/07	1.32	147.0	0.0	0.02	0.00	100.0	100.0
14	1/19/08	2.92	1240.2	1153.5	0.05	0.02	7.0	51.5
15	2/13/08	3.00	631.3	419.0	0.05	0.02	33.6	65.6
16	2/18/08	1.17	47.3	28.8	0.01	0.00	39.2	96.7
17	2/22/08	2.57	992.0	716.9	0.05	0.02	27.7	59.4
18	3/7/08	1.78	560.6	251.1	0.05	0.01	55.2	81.1
19	3/15/08	1.65	196.9	60.1	0.04	0.00	69.5	95.5
20	4/1/08	3.00	817.3	413.0	0.16	0.02	49.5	86.2
21	4/5/08	5.13	5021.3	1427.4	0.17	0.06	71.6	67.6
22	4/22/08	3.00	449.4	93.9	0.03	0.00	79.1	93.5
23	5/6/08	4.37	1169.5	528.8	0.22	0.06	54.8	70.8
24	5/11/08	1.83	504.8	160.5	0.05	0.01	68.2	82.6
						Mean	54.3	80.5

As mentioned previously, during the course of this study a severe drought occurred across North Carolina. Table 7 compares the monthly rainfall amounts for River Bend during the study and 1971 to 2000 normal monthly precipitation values from meteorological station number 316108, New Bern Craven Co Ap (N 35.067°, W 77.05°). The River Bend wetland is located approximately 8.9 km (5.5 miles) directly west of this station. River Bend rainfall values are based on ISCO automatic tipping bucket measurements unless values differed by more than 0.254 cm (0.10 in) when compared with manual rain gage. If the difference was greater than 0.254 cm, the values of the tipping bucket and manual gage were averaged.

Table 7. River Bend rainfall and NCCO normal monthly precipitation values.

	River Bend Rainfall*		Normal Monthly Precipitation*		Monthly Deficit	
Month	cm	in	cm	in	cm	in
Jul-07	14.22	5.60	16.46	6.48	2.24	0.88
Aug-07	9.50	3.74	17.37	6.84	7.87	3.10
Sep-07	4.93	1.94	13.84	5.45	8.92	3.51
Oct-07	7.70	3.03	8.61	3.39	0.91	0.36
Nov-07	0.94	0.37	8.20	3.23	7.26	2.86
Dec-07	5.97	2.35	9.75	3.84	3.78	1.49
Jan-08	5.87	2.31	12.12	4.77	6.25	2.46
Feb-08	7.90	3.11	9.65	3.80	1.75	0.69
Mar-08	6.10	2.40	11.40	4.49	5.31	2.09
Apr-08	12.47	4.91	8.64	3.40	-3.84	-1.51
May-08	6.20	2.44	10.64	4.19	4.45	1.75
TOTALS	81.79	32.20	126.70	49.88	44.91	17.68

*(NCCO 2008)

As shown in Table 7 River Bend had a total rainfall deficit of 44.91 cm (17.68 in) for this 11-month period. Of all 11 months only the month of April had more rain than normal.

Due to this drought, the volume of outflow did not seem to depend on storm size; however, it depended on the antecedent dry period. For example on August, 31, 2007, 3.6 cm (1.42 in) of rain generated no inflow. The one storm prior on August 10, 2007, had 1.42 cm (0.56 in) rainfall and produced no inflow. However, on October 27, 2007, a 3.4 cm (1.34 in) event occurred and produced 366 m^3 (12,922 cf) of inflow. The one storm prior on October 25, 2007, had 1.2 cm (0.49 in) of rain and generated 7.4 m^3 (261 cf) of inflow. The October 27th event generated a substantially larger amount of runoff than the similar rainfall event on August 31, 2007 because of high antecedent moisture conditions.

The relationship between the rainfall and runoff was also explored. Rainfall depths were divided into 3 categories: small, medium and large storms. Small storms were those with precipitation depths between 1.1 cm and 2.54 cm (0.42 in and 1 in). The 1.1 cm value was chosen as the lower cutoff rainfall depth as it was the smallest storm to generate runoff during this study, so any storm greater than 1.1 cm was considered to have the potential to produce runoff. The 2.54 cm value was chosen as the upper cutoff rainfall depth as it is considered the water quality storm event for much of the state of North Carolina (NCDENR 2007). Ten small storms produced between 1.1 cm and 2.54 cm of rainfall. Medium storms were considered those between 2.54 cm and 3.81 cm (1 in and 1.5 in). Eight medium storms occurred and were captured during the monitoring period. Large storms were those greater than 3.81 cm. Two large storms were measured during this study. Table 8 displays the averages calculated from storms that produced inflow. When examining these averages the expected positive correlation between rainfall and flow volumes appears (Figure 14). Mean runoff and peak flow percent reductions are also displayed. From Table 8 it can be inferred that more runoff and flow reduction, 64% and 89% respectively, occurs for small event storms; while for medium size storms there is less runoff and peak flow reduction, 38% and 73% respectively. For large storm events there is substantial runoff reduction (63%), most likely a result of the drought and the timing of the rainfall event, but there is less peak flow reduction (69%) compared to other storm sizes.

Table 8. Storm size and average runoff.

Storm Size (cm)	1.1 to 2.54	2.54 to 3.81	> 3.81
Mean inflow (m^3)	216	639	3095
Mean outflow (m^3)	115	437	978
Mean runoff reduction (%)	64	38	63
Mean peak flow reduction (%)	89	73	69

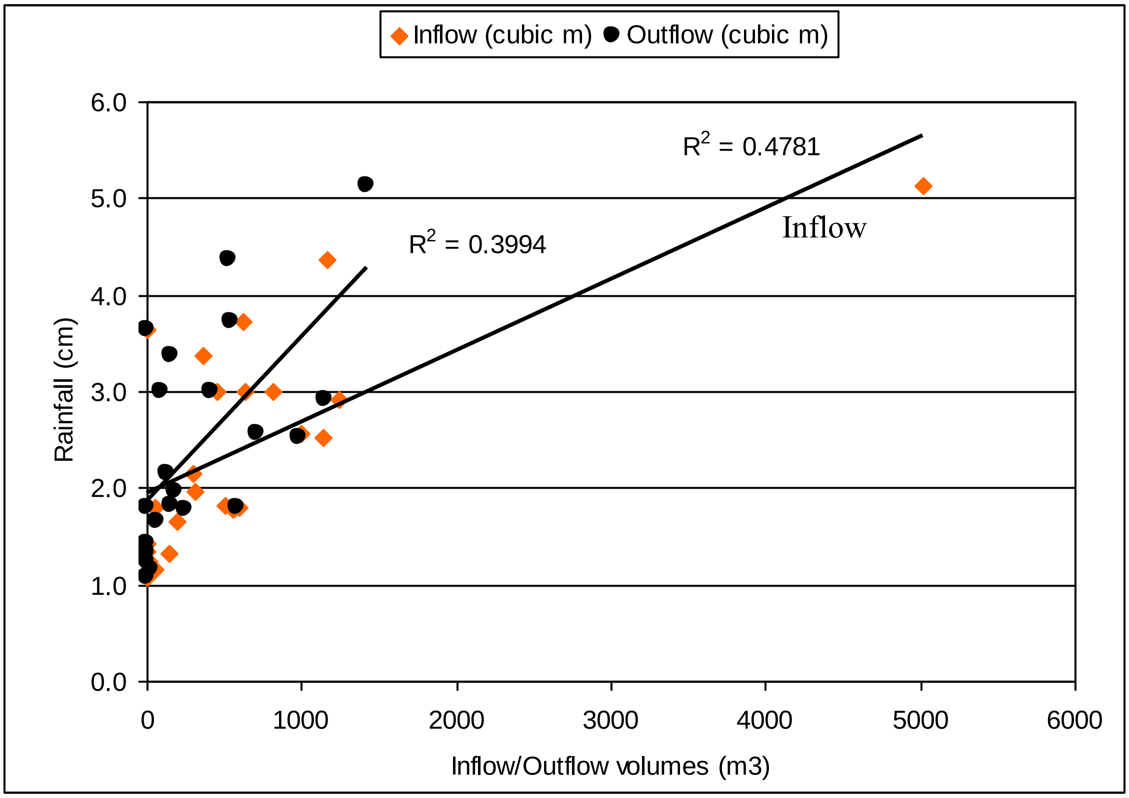

Figure 14. Rainfall vs. runoff volumes.

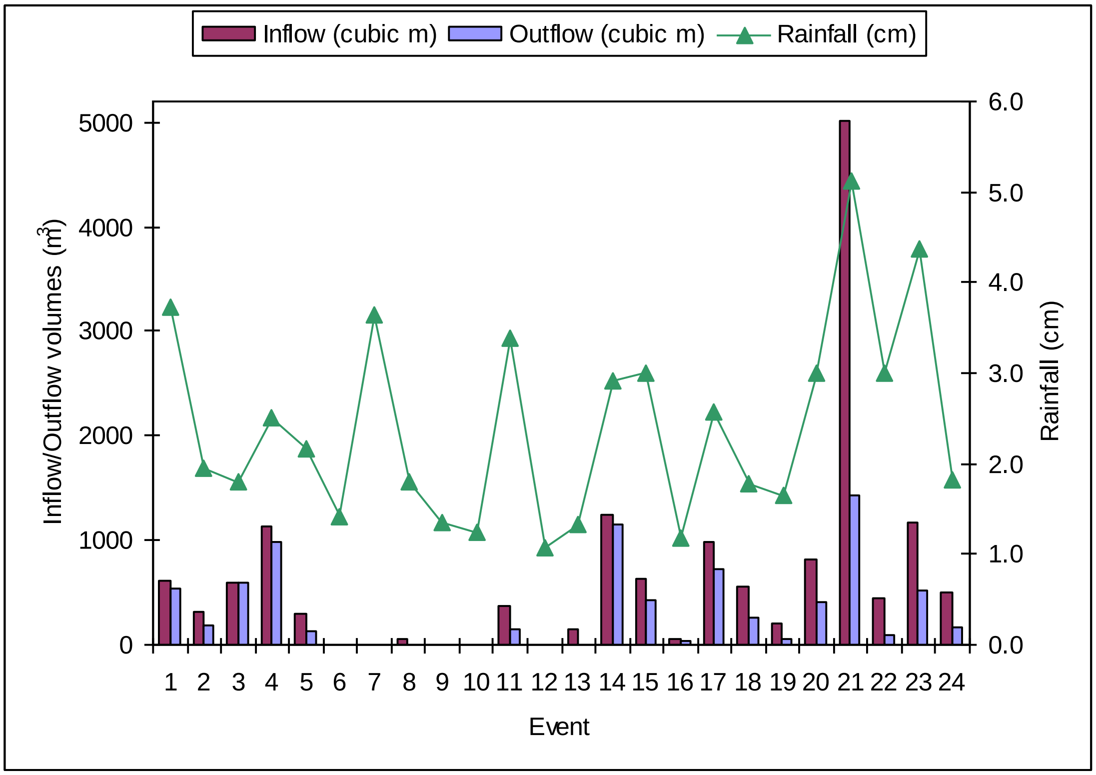

Figure 15. Rainfall compared with inflow and outflow volumes.

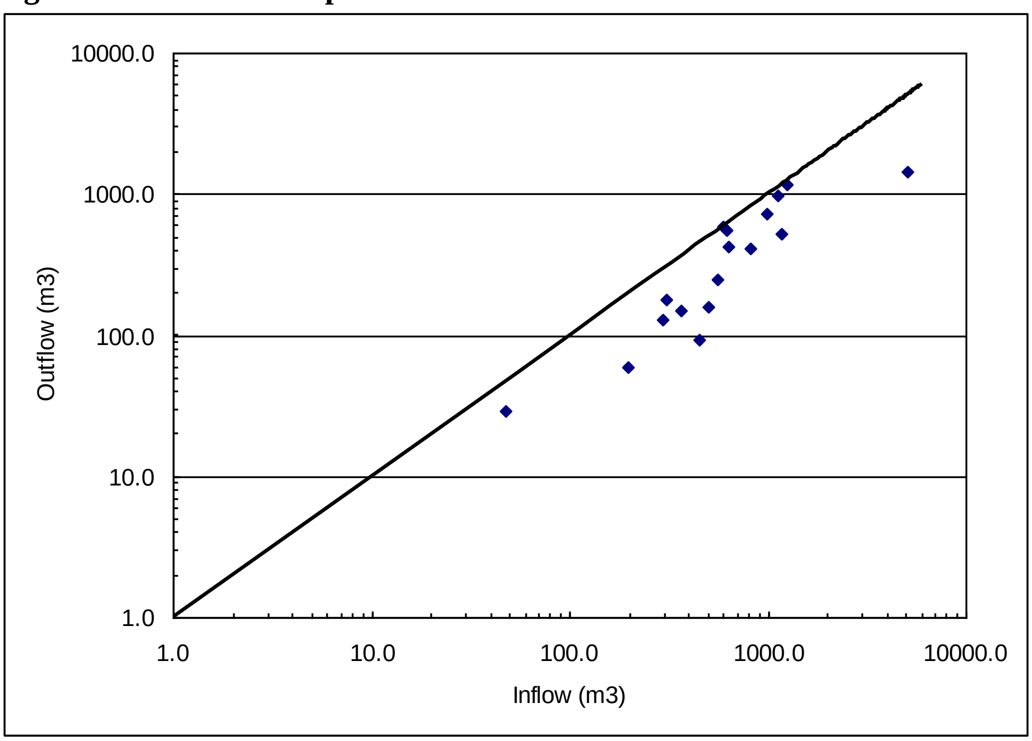

Figure 16. Log-Log inflow volumes vs. outflow volumes.

Based on Figures 15 and 16 there is a general positive relationship between rainfall and runoff. Yet the effects of the drought are evident in both these graphs. For example, events 7 and 11 had relatively high amounts of rainfall. However, their inflow and outflow volumes are minimal compared to events 3 and 4. As a result, the strength of the relationship between rainfall and runoff is not as strong as it may have been during a normal precipitation year, as evident from the weak R^2 values in Figure 14.

A graphical comparison was made between inflow and outflow volumes. Figure 16 shows the relationship between inflow and outflow volumes on a log-log scale. From the graph there appears to be a positive correlation between the inflow and outflow volumes. Based on this graph it is apparent that there is usually a reduction in outflow volumes compared to inflow volumes. All data points fall below the 1:1 line on the graph, demonstrating the ability of this wetland to substantially reduce runoff volumes. The wetland was able to permanently store portions of inflow in part due to the drought, and seepage and ET losses during the inter-event period.

To determine the relationship between storm intensity and runoff volume, small, medium and large storm 15 minute peak intensities were averaged. The average 15 minute peak intensity for small medium and large storms were 0.74 cm/hr (0.29 in/hr) 0.30 cm/hr (0.12 in/hr) and 0.30 cm/hr (0.12 in/hr) respectively. Small storms, on average, were more intense than large and medium storms. Smaller storms generated smaller amounts of rainfall but the rainfall fell in a much shorter period. Medium and large storms were not as intense but they tended to have much longer durations.

The largest event, 21, was further explored due to its extremely large inflow and outflow values. This storm on April 5, 2008, produced 5.13 cm (2.02 in) of rainfall over an 11-hour period, with a peak 15-minute intensity of 0.16 in/hr. The peak flow reached 0.17 cms (6.17 cfs). The hydrograph in Figure 17 shows the watershed delivering water to the wetland for approximately 29 hours. Approximately 3.5 times more water came into the wetland than exited (Table 6). The difference in volume was 3594 m^3, much larger than the capture volume for the River Bend wetland. Supposing the wetland had been dry the storage would be no larger than around 500 m^3. There are only two ways for water to be unaccounted for: by bypassing the outflow weir or by infiltration into the wetland bottom. Due to the drought the wetland was observed to be dry soon after storm events had produced runoff. However, there is such a large volume of water not accounted for that it would not all be lost to infiltration. There is a possibility that for a period of time water was overflowing the top of the outlet structure which would result in an unaccounted for volume of water. There was no noticeable malfunction with the ISCO automatic samplers after the storm event. In summary this storm generated some curious numbers and had a large influence on the outcome of water quality load reductions and should therefore be considered questionable.

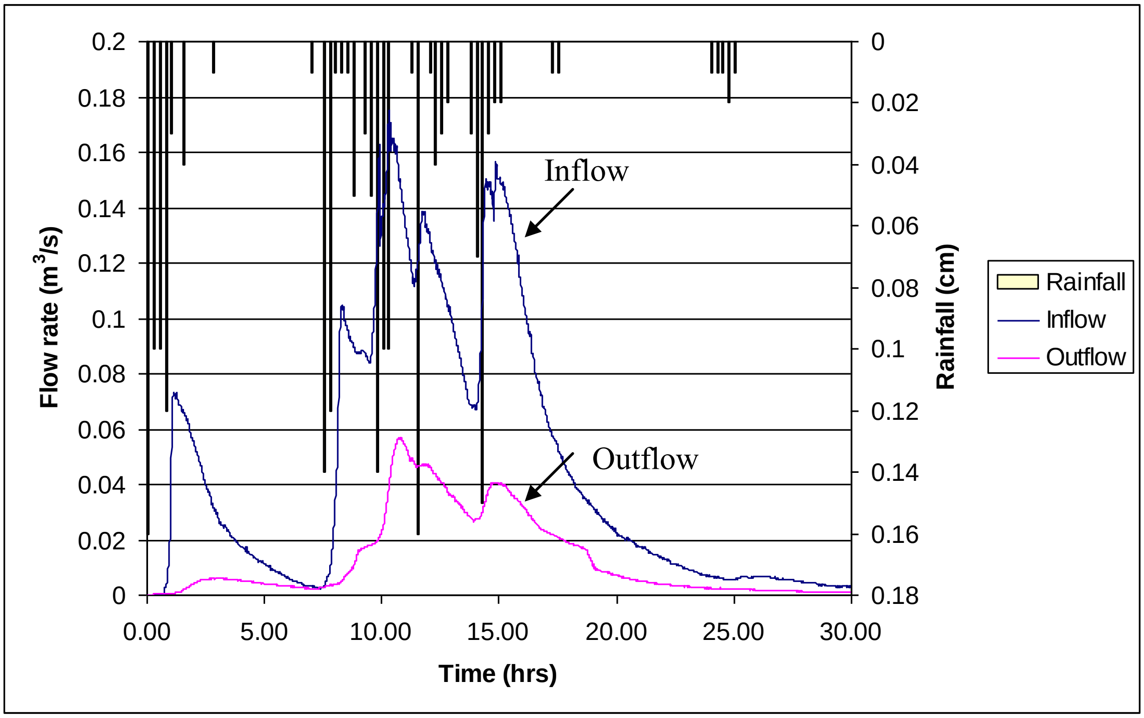

Figure 17. Hydrograph from the storm event on April 5, 2008 (event 21).

Storms not included in analysis

During the monitoring process three storms were collected, but discarded due to a series of unusual situations that necessitated their removal from statistical analysis and load calculations. The first issue was during an intense storm event on March 5, 2008, in which flow was traveling *into* the wetland from the outlet for a short period of time. The peak 15 minute rainfall intensity was 1.5 cm/hr (0.59 in/hr) with a total of 2.21 cm (0.87 in) of rainfall. This was the most intense storm recorded during the course of this study. It is reasonable to assume the intensity of this storm generated high volumes of runoff from an adjacent watershed. The outlet of this watershed was directing water near the stormwater wetland outlet. In addition to the intense rainfall, a large amount of debris was obstructing flow, pushing the flow path closer to the wetland outlet, resulting in a change of the hydraulic gradient. As a result water began to flow into the wetland from the outlet. Once this debris was manually removed during the event, the water began to flow as normal (away from the wetland) after less than a minute. If this situation occurred for any period of time the volume of water entering through the outlet would be accounted for twice by the ISCO sampler, once while the water was coming into the wetland from the outlet and again when the same volume was exiting. This was confirmed upon examination of the data, as the ISCO reported a greater outflow than inflow volume for this storm event which was likely due to this situation. Therefore, this storm was not included in any statistical analysis or load calculations. This situation was considered a one time incident, as all other storms consistently had greater inflow than outflow volumes.

Another issue was clogging of the outlet structure. This can be a common problem for stormwater wetlands that are not monitored daily, which greatly extends drawdown time. This problem noticeably affected outflow for the December 17, 2007, storm event. In this case the outflow volume was calculated to be greater than the inflow volume, because of elevated water levels caused by the clog. Debris such as leaves and plant litter blocked the multiple v-notch weirs resulting in inaccurate flow measurements. As a result this storm was not included in any statistical analysis or load calculations.

The final issue was a period of time when water was bypassing underneath the outflow weir. A scour had developed below the base of a structural portion of the weir and was repaired before the next storm event (Figure 18). Therefore, flow data for August 26, 2007, were not included in statistical analysis or load calculations. This problem did not appear to affect sampling of any previous storm events.

Figure 18. Scour hole resulting in water bypass of outflow weir.

Water Quality

A "traditional" way of examining the wetland's impact on water quality is first presented. Inflow and outflow concentrations and loads are discussed. Afterwards, there are discussions on two alternative means of assessing how well the wetland performed. For water quality analysis 11 storms were used to compare concentrations and loadings of TKN, $NO_{2\text{-}3}$-N, NH_4-N, TN, TP, OP and TSS. The storm on September 15, 2007, produced inflow but no outflow. However, this storm was used in the analysis and the wetland was considered to treat 100% of the pollutants it received from this storm. No water quality data collected between the dates of October 27, 2007, and January 19, 2008, could be used for concentration or load comparisons. The storm on December 16, 2007, did produce inflow and outflow, but as discussed earlier, the flow data were inaccurate and could not be used for comparisons. A storm on December 21, 2007, produced inflow, but not enough generate a large enough sample for analysis. The final storm between these two dates was on December

30, 2007, which produced inflow but no outflow. The inflow sample could not be analyzed properly due to holiday lab closure.

Using the SAS System for Windows version 9.1®, a 1-way Analysis of Variance (ANOVA) table was generated for each pollutant: TKN, NO_{2-3}-N, NH_4-N, TP, OP and TSS. This ANOVA table was used to determine if a significant difference existed between inflow and outflow concentrations and loads for each pollutant. The resulting ANOVA tables for TKN, NO_{2-3}-N, NH_4-N, TN, TP, OP and TSS showed no significant difference ($p>0.05$) between inflow and outflow concentrations for all but one of the previously mentioned pollutants. Inflow concentrations for OP were significantly greater ($p<0.05$) than outflow concentrations. ANOVA tables for all pollutants but OP and NH_{2-3}-N showed no significant difference ($p>0.05$) between loads as well. Inflow loads for OP and NH_{2-3}-N were significantly larger ($p<0.05$) than outflow loads. Pollutant loads during the growing season (March 14 to November 18) were not significantly ($p>0.05$) different than loads during the non-growing season. Load values proved to be normally distributed based on SAS residual plots, justifying the use of a 1-way ANOVA.

Based on mean pollutant concentrations the wetland is exporting or not reducing TKN, NH_4-N, TN (sum of TKN and NO_{2-3}-N), TP and TSS; however, concentrations of NO_{2-3}-N and Ortho P are being modestly reduced (Tables 9 and 10). Based on loading, the wetland is reducing all pollutant loads (Tables 11 and 12). This load reduction is a direct result of the significant reduction between inflow and outflow volumes. See Table 13 for concentration and load reduction means. The percent reductions on a concentration and load basis are based on the following metric:

$$\% \text{ Reduction} = (\text{Inflow}_x - \text{Outflow}_x)/(\text{Inflow}_x)*100 \quad [3]$$

where Inflow_x and Outflow_x are the respective concentrations or loads.

Table 9. Storm events with pollutant concentrations and reductions. A negative reduction reflects a concentration increase.

#	Storm Date	Inflow TKN (mg/L)	Outflow TKN (mg/L)	TKN % Reduction	Inflow NO_{2-3}-N (mg/L)	Outflow NO_{2-3}-N (mg/L)	NO_{2-3}-N % Reduction	Inflow NH_4-N (mg/L)	Outflow NH_4-N (mg/L)	NH_4-N % Reduction	Inflow TN (mg/L)	Outflow TN (mg/L)	TN % Reduction
1	7/7/07	0.62	0.99	-60	0.33	0.35	-6	0.03	0.11	-267	0.95	1.34	-41
2	7/10/07	0.60	1.18	-97	0.25	0.22	12	0.03	0.05	-67	0.85	1.40	-65
3	7/28/07	0.51	2.46	-382	0.37	0.55	-49	0.08	0.17	-113	0.88	3.01	-242
4	9/15/07	0.66	0.00	100	0.57	0.00	100	0.04	0.00	100	1.23	0.00	100
5	10/27/07	0.53	1.08	-104	0.06	0.25	-317	0.06	0.15	-150	0.59	1.33	-125
6	1/19/08	0.40	0.47	-18	0.08	0.08	0	0.04	0.06	-50	0.48	0.55	-15
7	2/22/08	0.44	0.49	-11	0.15	0.03	80	0.05	0.03	40	0.59	0.52	12
8	3/7/08	0.55	0.56	-2	0.02	0.02	0	0.18	0.07	61	0.57	0.58	-2
9	4/1/08	0.41	0.68	-66	0.01	0.01	0	0.04	0.06	-50	0.42	0.69	-64
10	4/5/08	0.56	0.69	-23	0.01	0.03	-200	0.06	0.07	-17	0.57	0.72	-26
11	5/11/08	0.59	0.87	-48	0.29	0.21	29	0.04	0.13	-233	0.88	1.08	-22

Table 10. Storm events with pollutant concentrations and reductions. A negative reduction reflects a concentration increase.

#	Storm Date	Inflow TP (mg/L)	Outflow TP (mg/L)	TP % Reduction	Inflow Ortho P (mg/L)	Outflow Ortho P (mg/L)	Ortho P % Reduction	Inflow TSS (mg/L)	Outflow TSS (mg/L)	TSS % Reduction
1	7/7/07	0.24	0.25	-4	0.14	0.09	36	52	89	-71
2	7/10/07	0.18	0.19	-6	0.10	0.03	70	20	33	-65
3	7/28/07	0.18	0.24	-33	0.11	0.08	27	27	45	-67
4	9/15/07	0.21	0.00	100	0.16	0.00	100	30	0	100
5	10/27/07	0.20	0.19	5	0.13	0.09	31	22	26	-18
6	1/19/08	0.27	0.24	11	0.25	0.19	24	15	11	27
7	2/22/08	0.20	0.15	25	0.15	0.08	47	8	11	-38
8	3/7/08	0.16	0.13	19	0.09	0.05	44	11	14	-27
9	4/1/08	0.14	0.15	-7	0.07	0.03	57	23	35	-52
10	4/5/08	0.15	0.19	-27	0.10	0.09	10	30	20	33
11	5/11/08	0.18	0.22	-19	0.12	0.09	29	28	43	-54

Table 11. Storm events with pollutant loads and reductions. A negative reduction reflects a load increase.

#	Storm Date	Inflow TKN (kg)	Outflow TKN (kg)	TKN % Reduction	Inflow NO_{2-3}-N (kg)	Outflow NO_{2-3}-N (kg)	NO_{2-3}-N % Reduction	Inflow NH_4-N (kg)	Outflow NH_4-N (kg)	NH_4-N % Reduction	Inflow TN (kg)	Outflow TN (kg)	TN % Reduction
1	7/7/07	0.38	0.54	-42	0.20	0.19	6	0.02	0.06	-226	0.59	0.74	-25
2	7/10/07	0.19	0.21	-13	0.08	0.04	49	0.01	0.01	4	0.26	0.25	5
3	7/28/07	0.15	0.32	-110	0.11	0.07	35	0.02	0.02	8	0.26	0.39	-49
4	9/15/07	0.04	0.00	100	0.03	0.00	100	0.00	0.00	100	0.07	0.00	100
5	10/27/07	0.19	0.16	16	0.02	0.04	-71	0.02	0.02	-3	0.22	0.20	7
6	1/19/08	0.50	0.54	-9	0.10	0.09	7	0.05	0.07	-40	0.60	0.64	-7
7	2/22/08	0.44	0.35	20	0.15	0.02	86	0.05	0.02	57	0.59	0.37	36
8	3/7/08	0.31	0.14	54	0.01	0.01	55	0.10	0.02	83	0.32	0.15	54
9	4/1/08	0.34	0.28	16	0.01	0.00	49	0.03	0.02	24	0.34	0.29	17
10	4/5/08	2.82	0.99	65	0.05	0.04	15	0.30	0.10	67	2.87	1.03	64
11	5/11/08	0.30	0.14	53	0.15	0.03	77	0.02	0.02	-6	0.45	0.17	61

Table 12. Storm events with pollutant loads and reductions. A negative reduction reflects a load increase.

#	Storm Date	Inflow TP (kg)	Outflow TP (kg)	TP % Reduction	Inflow Ortho P (kg)	Outflow Ortho P (kg)	Ortho P % Reduction	Inflow TSS (kg)	Outflow TSS (kg)	TSS % Reduction
1	7/7/07	0.15	0.14	7	0.09	0.05	43	32	49	-52
2	7/10/07	0.06	0.03	39	0.03	0.01	83	6	6	5
3	7/28/07	0.05	0.03	42	0.03	0.01	68	8	6	27
4	9/15/07	0.01	0.00	100	0.01	0.00	100	2	0	100
5	10/27/07	0.07	0.03	61	0.05	0.01	72	8	4	51
6	1/19/08	0.34	0.28	17	0.31	0.22	29	19	13	32
7	2/22/08	0.20	0.11	46	0.15	0.06	61	8	8	1
8	3/7/08	0.09	0.03	64	0.05	0.01	75	6	4	43
9	4/1/08	0.11	0.06	46	0.06	0.01	78	19	14	23
10	4/5/08	0.76	0.27	64	0.50	0.13	74	151	29	81
11	5/11/08	0.09	0.03	62	0.06	0.01	77	14	7	51

Table 13. Mean water quality concentrations, loads and reductions.

Pollutant	Mean Inflow Concentration (mg/L)	Mean Outflow Concentration (mg/L)	Mean Reduction (%)	Mean Inflow Load (kg)	Mean Outflow Load (kg)	Mean Reduction (%)
TKN	0.55	0.94	-70	0.51	0.33	34.9
NO_{2-3}-N	0.18	0.17	9	0.08	0.05	40.7
NH_4-N	0.05	0.08	-53	0.06	0.03	41.6
TN[1]	0.73	1.11	-51	0.60	0.38	35.7
TP	0.23	0.23	0	0.18	0.09	47.2
Ortho P	0.15	0.09	39	0.12	0.05	60.9
TSS	31.2	40.5	-30	24.8	12.6	49.2

[1] TN – Calculated by adding TKN and NO_{2-3}-N

Nitrogen

The three N species TKN, NH_4-N and TN were not reduced on a mean concentration basis (Table 13). All three show a concentration increase at the outlet of 70%, 53% and 51%, respectively. NO_{2-3}-N is the only N species being reduced on a concentration basis (9%). When N species loading is considered, TKN, NO_{2-3}-N, and NH_4-N were reduced, 35%, 41%, and 42%, respectively. The total inflow and outflow loads for TN these 11 storms were 6.56 kg and 4.22 kg, respectively, equating to a 36% reduction in total load.

Starting on January 19, 2008 (event 6), there appears to be a more consistent and substantial difference between inflow and outflow concentrations for TKN and TN (Figures 19 and 20). Influent concentrations for TKN during events 1-6 were consistently lower than their respective effluent concentrations. However, between October 27, 2007 (event 5) and event 6 outflow water quality concentrations uniformly reduced. Consequently, the outflow loads for TKN declined as the mean effluent load was 48% less than mean influent load after event 6, but was 30% higher before event 6. After event 6 the wetland appeared to more effectively reduce nitrogen species loads.

Concentrations for $NO_{2\text{-}3}$-N are consistently higher prior to event 6, as well (with the noticeable exception of event 11 on May 12), but after the 5th event both inflow and outflow concentrations greatly decline (Figure 21). Loading values decline as well; however, the data show the wetland was consistently reducing the outflow load except on event 5. Prior to event 6 the mean effluent load was 24% lower than the influent load (events 1-5). After and including event 6, the effluent load was 57% lower (events 6-11). NH_4-N values behave similarly to the other N species; however, the levels of NH_4-N are comparatively small, NH_4-N concentrations were typically 10% of those associated with TKN. From this it can be calculated that the source of N during the initial start up period was primarily organic N as TKN was the N species with the most substantial changes after January.

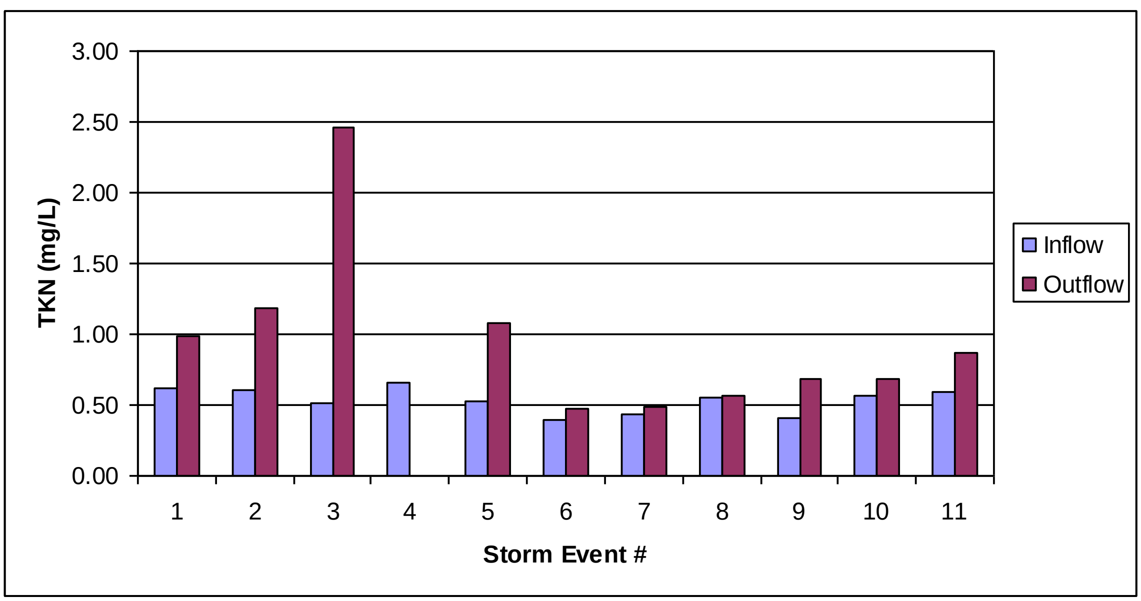

Figure 19. TKN concentrations by storm event. For event 4 only inflow was observed and measured.

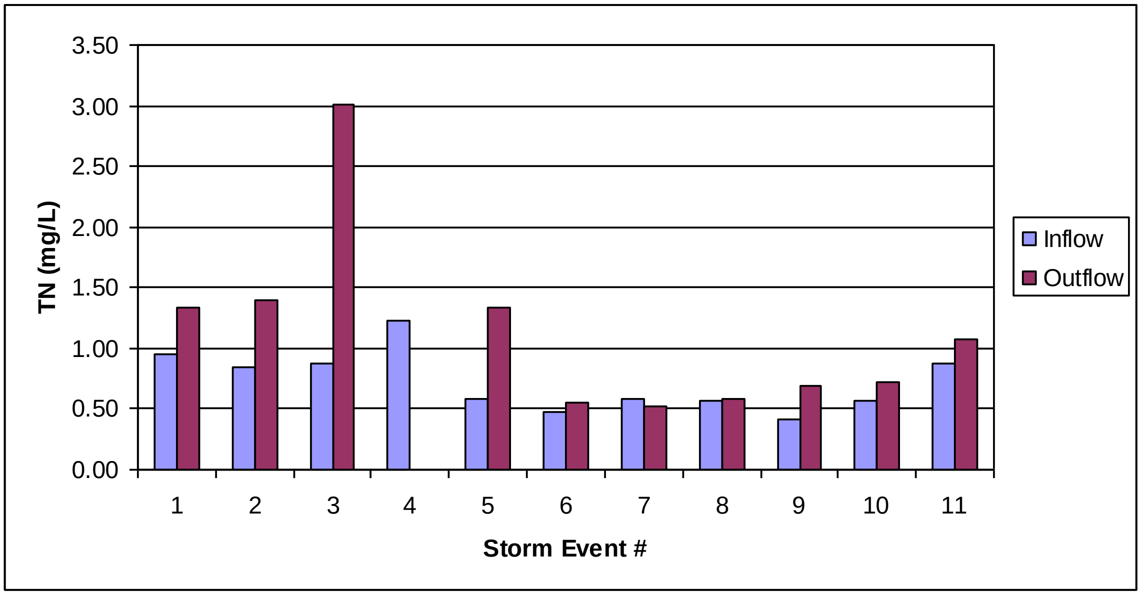

Figure 20. TN concentrations by storm event. For event 4 only inflow was observed and measured.

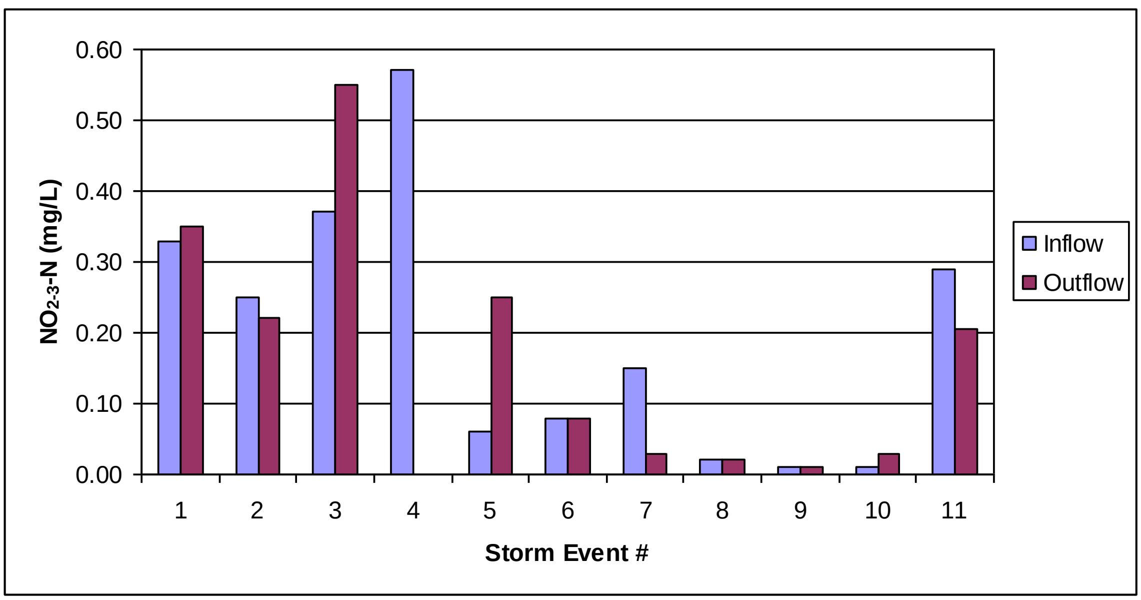

Figure 21. $NO_{2\text{-}3}$-N concentrations by storm event. For event 4 only inflow was observed and measured.

Phosphorus

On a mean concentration basis, TP does not differ between inflow and outflow, while OP was reduced by 39%. On a mean load basis TP and OP was reduced by 47% and 61%, respectively (Table 13). The total TP inflow and outflow loads for these 11 storms were 1.93 kg and 1.02 kg, respectively, equaling a 47% reduction in total loading.

Ortho P inflow concentrations were consistently higher than outflow concentrations throughout the study (Table 10). The difference in inflow and outflow load is even more pronounced. As stated earlier, OP is one of two pollutants the wetland significantly reduced ($p<0.05$). TP concentrations remained fairly consistent during monitoring. Inflow and outflow concentrations consistently remained in the 0.15 to 0.25 mg/L range. As shown in Table 13, the average inflow and outflow concentrations are the same. However, the differences between influent and effluent loads for TP show consistent treatment of TP. The reason for a positive load reduction in TP is likely due to sediment accumulation. Fixed mineral P is attached to soil particles that enter into the wetland system (Reddy et al. 1999). Sedimentation is occurring as shown by the 49% reduction in TSS (Table13). As a result, fixed mineral P is being retained within the wetland due to this process.

To relate these findings to those of Richardson et al. (1997), a TP loading rate was calculated. Approximately 2703 g of TP entered into the wetland during this year period. The surface area of the River Bend wetland is 1374 m^2, which yields a yearly loading rate of approximately 2 g m^{-2} yr^{-1}. Considering the drought, this might actually be a rather low estimate as a typical year would deliver more P contaminated stormwater. This is twice the rate at which Richardson et al. (1997) indicates the wetland should lose its short term P removal mechanisms. The River Bend wetland was first constructed in 1998 so it has been receiving this loading for 10 years. Soils may have reached P saturation many years ago, explaining the result of no net removal for TP concentrations.

TSS

On a mean concentration basis TSS outflow concentrations are 30% higher than inflow. Despite the increase in concentration from inlet to outlet, this wetland is retaining TSS on a mass basis. The total TSS inflow and outflow loads for these 11 storms were 273 kg and 139 kg, respectively, equaling a 49% reduction in total loading (Table 13).

Inlet and outlet TSS concentrations for this wetland were highest during the first storm event, but immediately decline and become more consistent in subsequent events (Figure 22). Outflow concentrations were consistently higher than those of inflow except for the three storm events, event 4 (when there was no outflow), event 6 and event 10. Inflow loads tended to be approximately equal or greater than outflow loads. One possible reason for this may be the maturity of the wetland. Due to the small number of plants in the wetland and their young age in the first months of the wetlands' maturation period, solids could have been resuspended from the bed of the wetland and into the water column much easier than a wetland with a well established plant community. Areas in which plants had yet to grow, resulted in less stabilized soil, therefore making the export of suspended solids much easier. Over time TSS concentrations appear to be falling below those of inflow, but it seems it will take more than a year for the plant community to better establish itself and substantially reduce concentrations.

A similar situation occurred in a study performed by Knowlton et al. (2002) in which a newly constructed wastewater wetland was releasing elevated TSS loadings due to erosion and disturbances by waterfowl. However, from 1994 (the time of construction) to 1998, the TSS removal efficiency increased to an average of 30% as the development of vegetative biomass became more mature.

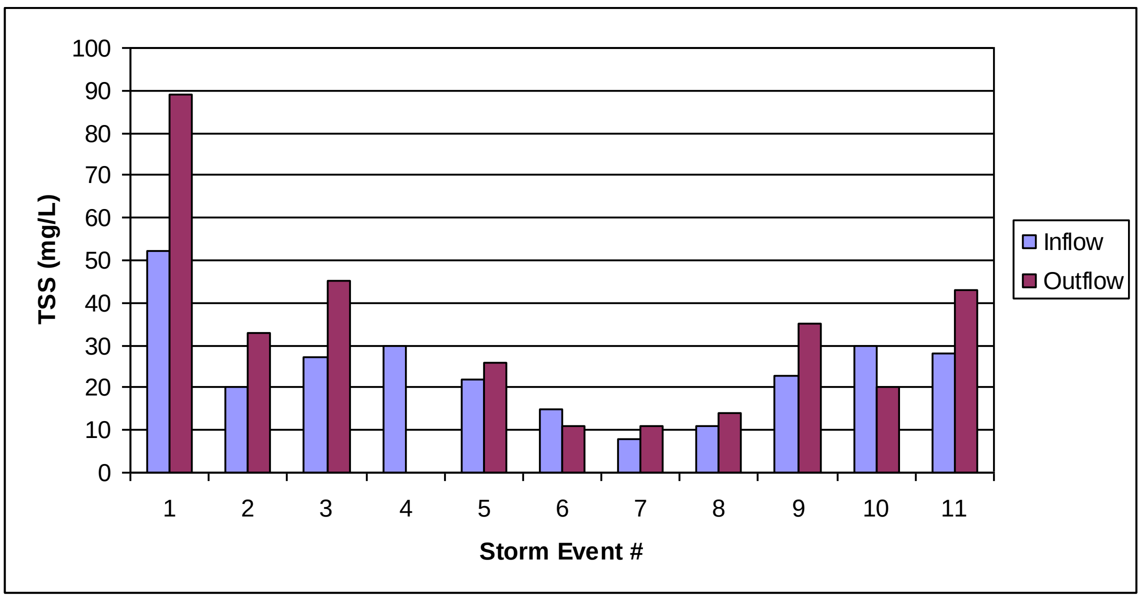

Figure 22. TSS concentrations by storm event. For event 4 only inflow was observed and measured.

Water quality data trends

Upon examination of the graphs, there are some general trends that merited further exploration. Loads from storm event 10 were noticeably larger than all of the other events as shown in Figures 17, 18, 19, and 20. This was the same storm, number 21, discussed earlier in the water quantity section. Due to the extremely high volume of inflow the loadings for this storm for all pollutants were high as well. Because load values were so high for this storm, loading values dominate mean percent reduction calculations. Due to this storm percent reduction values were elevated if this storm was not accurately monitored.

Despite event 10, there appears to be a “start up” effect based on N species concentrations. On average, outflow concentrations are greater than inflow concentrations. However, it is believed as the wetland matures outflow concentrations will begin to decrease. Between event 5 and event 6, there appeared to be a large change in concentrations for TKN and $NO_{2\text{-}3}$-N (Figures 19 and 21). Storms that occurred from the time of construction through event 5 had substantially higher outflow concentrations than inflow concentrations. Between events 1 and 5 there was a 96% increase in TKN, while between events 6 and 11 there was a 27% increase. Notice inflow TKN concentrations stayed within a fairly consistent range, from 0.4 to 0.6 mg/L throughout the study while outflow concentrations were initially high, between 0.99 mg/L and 2.46 mg/L, and rapidly decrease to concentrations similar to those of the inflow. This would suggest that there is an organic N source within the wetland, especially during the initial maturation of the wetland, which supports the hypothesis that the initially high TKN loadings could have been attributed to an algal bloom, that occurred during the months following reconstruction (Figure 23).

Figure 23. Algal bloom that occurred following construction of the River Bend wetland.

When concentrations of nitrogen and phosphorus are added to surface waters there becomes a potential for algal blooms (Mallin et al. 2004). Algae use nutrients and sunlight to grow and typically their biomass is composed of 2 to 9 percent N (Kadlec and Knight 1995). Directly after the construction there were no plants giving shade to the wetland, making conditions in the wetland susceptible to the formation of algae. During the months of July, August and September the algal bloom senesced due to an increase in shade and a respective decrease in sunlight as the plants became better established (Healy and Cawley 2002). The algae then decomposed within the wetland, resulting in the probable export of organic N out of the system. Storms prior to algal death could have flushed algae out of the wetland during high flow periods resulting in elevated outflow N concentrations.

Possible explanations for this apparent “start up effect” could include construction, the algal bloom, a relatively clean watershed or a combination of all three. Water quality comparisons have been made in the next section to help determine which of these explanations may be most reasonable.

There did not appear to be any substantial P source within the wetland, as inflow and outflow concentrations were very similar. One explanation was mentioned in the above phosphorus section; the wetland can no longer reduce P concentrations as a result of P saturation. Another possibility may be that the watershed produces runoff with relatively low P concentrations. The wetland could potentially be receiving irreducible concentrations of P and perhaps should not be expected to reduce already low P concentrations. To examine whether irreducible concentrations were entering the wetland, River Bend concentrations were compared with neighboring streams and previous stormwater wetland studies within North Carolina. This analysis is detailed in next sections.

Water Quality Comparisons: Neighboring streams and rivers

To better relate the water quality results from this wetland, the influent and effluent concentrations have been compared with water quality concentrations from three NCDENR stream and river monitoring sites in the same watershed as the River Bend wetland. Comparing these concentrations will help put the results of this study into context with natural or typical background pollutant concentrations in the area. In short, how did wetland influent and effluent water quality compare to these background concentrations.

The first stream monitoring location, station number J8690000 (N 35.06364, W 77.46107) (Figure 24), is stationed along the Trent River. It is located approximately 12.9 km (8 miles) W of the River Bend wetland. Between September 27, 2000, and August 24, 2005, 53 samples were analyzed for nutrient concentrations and 19 samples for TSS concentrations. This monitoring location has never experienced more than 10% of values exceeding water quality boundaries at or above the 95% statistical confidence level (NCDENR 2006). This particular area of the Trent River has been given a bioclassification (bioclass) of Moderate. Bioclass ratings range from Poor to Excellent. These ratings are given to monitoring locations based on the results of benthic sampling; the more intolerant Ephemeroptera, Plecoptera, and Trichoptera (EPT) insects present, the higher the bioclass.

The next stream monitoring location, station number J8730000 (N 35.00993, W 77.21891) (Figure 24), is also stationed along the Trent River. It is located approximately 9.7 km (6 miles) SW of the River Bend wetland. Between October 17, 2000, and August 30, 2005, 134 water samples were analyzed for nutrient concentrations and 0 for TSS concentrations. This monitoring location has never experienced more than 10% of values exceeding water quality boundaries at or above the 95% statistical confidence level (NCDENR 2006). This area has been given a Moderate bioclass as well.

The final stream monitoring location, station number J8770000 (N 35.07502, W 77.11627) (Figure 24), is again stationed along the Trent River. It is located approximately 3.2 km (2 miles) E of the River Bend wetland. Between September 20, 2000, and August 16, 2005, 58 water samples were analyzed for nutrient concentrations and 18 for TSS concentrations. This monitoring location has never experienced more than 10% of values exceeding water quality boundaries at or above the 95% statistical confidence level (NCDENR 2006). A bioclass for this area is not available. See Table 14 for the exact locations of these sampling locations.

Tables 15 and 16 compare the minimum, maximum and mean influent and effluent concentrations from River Bend with the 10th, 90th and 50th percentile concentrations from streams geographically close to the wetland and in the same Trent River watershed.

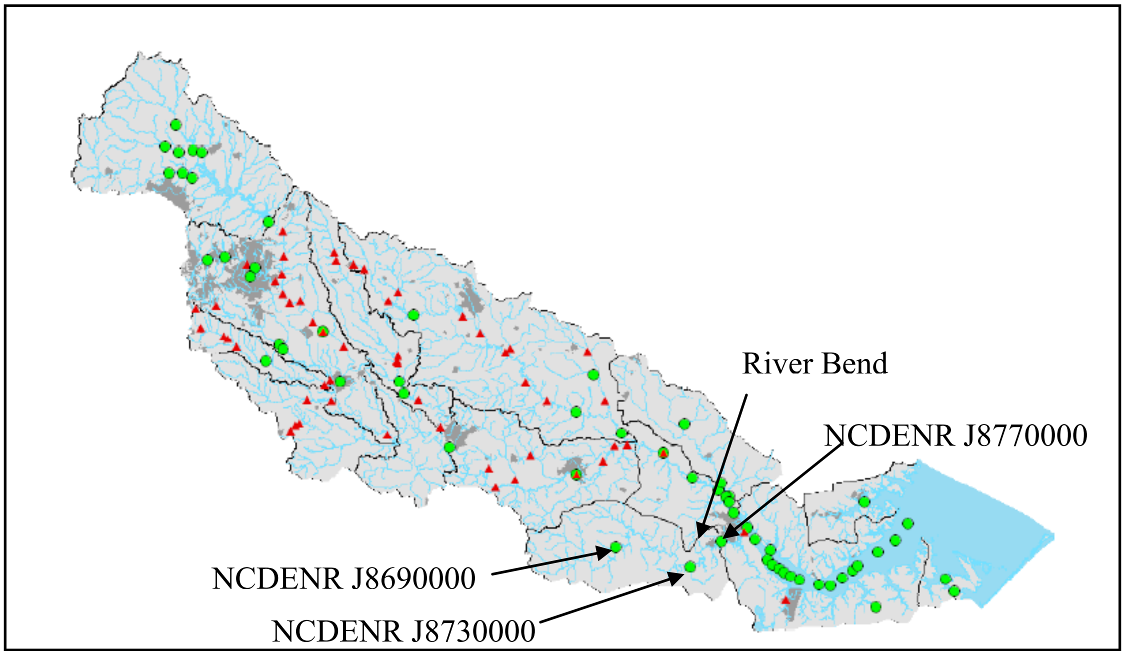

Figure 24. Location of NCDENR water quality monitoring locations (NCDENR 2006).

Table 14. Location and description information for NCDENR sample sites (NCDENR 2006).

Location	Lat	Long	Distance From River Bend (km)	NC Stream Index	BioClass	Sampling Location
NCDENR J8690000	35.0636	-77.4611	13	27-101-(1)	Moderate	Trent River
NCDENR J8730000	35.0099	-77.2189	10	27-101-(1)	Moderate	Trent River
NCDENR J8770000	35.0751	-77.1144	3	27-101-(31)	NA	Trent River

Table 15. Comparison of River Bend influent/effluent N concentrations and local stream concentrations (NCDENR 2006).

	TKN mg/L			$NO_{2\text{-}3}$-N mg/L			NH4-N mg/L			TN mg/L[1]		
Location	**10**	**50**	**90**	**10**	**50**	**90**	**10**	**50**	**90**	**10**	**50**	**90**
NCDENR J8690000	0.35	0.66	0.90	0.22	0.64	1.22	0.02	0.03	0.21	0.57	1.30	2.12
NCDENR J8730000	0.41	0.57	0.76	0.38	0.61	0.89	0.02	0.04	0.07	0.79	1.18	1.65
NCDENR J8770000	0.45	0.61	0.81	0.02	0.34	0.63	0.02	0.04	0.18	0.47	0.95	1.44
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
River Bend Inflow	0.40	0.55	0.66	0.01	0.18	0.57	0.02	0.06	0.18	0.41	0.73	1.23
River Bend Outflow	0.47	0.95	2.46	0.10	0.16	0.55	0.03	0.08	0.17	0.57	1.11	3.01

[1] TN is the sum of TKN and $NO_{2\text{-}3}$-N

Table 16. Comparison of River Bend influent/effluent P and TSS concentrations and local stream concentrations (NCDENR 2006).

	TP mg/L			TSS mg/L		
Location	**10**	**50**	**90**	**10**	**50**	**90**
NCDENR J8690000	0.04	0.08	0.21	2	4	7
NCDENR J8730000	0.07	0.12	0.16	NA	NA	NA
NCDENR J8770000	0.08	0.13	0.18	2	4	10
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**
River Bend Inflow	0.14	0.23	0.53	8	31	96
River Bend Outflow	0.13	0.23	0.48	11	40	89

River Bend inflow and outflow concentrations for $NO_{2\text{-}3}$-N were 0.18 and 0.16 mg/L, respectively, much lower than the neighboring stream concentrations of 0.64, 0.61, and 0.34 mg/L. River Bend NH_4-N concentrations were similar to these streams. Concentrations of TKN appear to be similar when comparing inflow concentrations; however, outflow TKN concentrations from River Bend are greater than those of background streams. River Bend inflow and outflow TN concentrations were 0.73 and 1.11 mg/L, which compared similarly to concentrations in the neighboring streams of 1.30, 1.18 and 0.95 mg/L, respectively. The mean River Bend inflow concentration was lower than all three other streams, while the average outflow concentration is only greater than NCDENR J8770000. From this comparison it appeared as though River Bend is both receiving and exporting low concentrations of TN, further evidence to support the possibility of irreducible concentrations.

The River Bend wetland tended to receive and release higher concentrations of TP and TSS when compared to streams in the surrounding watershed. Mean TP concentrations to and from River Bend were greater than the 90% high concentrations in these streams. The minimum TSS concentrations to and from River Bend were approximately equal to the 90th percentile background concentrations.

Water Quality Comparisons: Constructed wetlands in North Carolina

Another way to assess the River Bend wetland's results was to compare its influent and effluent concentrations to similar wetlands studies in North Carolina.

Bass (2000) evaluated the performance of an in-stream constructed wetland in North Carolinas coastal plain. The wetland received drainage water from a 240 hectare (600 ac) watershed consisting of both urban and agricultural land uses. Water quality samples were collected from August 1997 through December 1999.

Johnson (2006) evaluated the performance of a stormwater wetland located in Charlotte, NC, in the Catawba River Basin. The wetland received stormwater from a 6.4 ha

(15.8 ac) watershed consisting of residential developments and school property. Water quality samples were collected from September 2004 to December 2005.

Line et al. (2008) studied the effectiveness of two stormwater wetlands in North Carolina. The first wetland named CMS is located in the Piedmont of North Carolina. The wetland received stormwater from a 9.6 ha (23.7 ac) watershed consisting of a large school building, parking lots and hardwood tree stands. Water quality samples were collected from April to August 2006. The second wetland named UNC is located in Asheville, NC, situated in the mountains. The wetland received stormwater from a 4.1 ha (10.1 ac) watershed consisting of a parking lot, manicured grass lands and hardwood tree stands.

The International Stormwater Best Management Practices (BMP) Database is a website (http://www.bmpdatabase.org/) that provides performance analysis and information for various types of stormwater BMPs. Summary influent and effluent mean concentrations of various pollutants for 19 different constructed wetlands evaluated by the BMP database and the three previously mentioned wetland studies are presented in Table 17 below.

Table 17. Mean N concentrations for various wetland studies.

	Mean TKN (mg/L)		Mean $NO_{2\text{-}3}$-N (mg/L)		Mean NH4-N (mg/L)		Mean TN (mg/L)	
Author	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Bass (2000)	2.1	1.9	0.6	0.2	0.6	0.4	2.7	2.1
Johnson (2006)	1.57	0.87	0.74	0.5	0.31	0.12	2.31	1.37
Line et al. (2008) CMS	0.96	0.87	0.15	0.13	0.21	0.14	1.11	1.00
Line et al. (2008) UNC	0.33	0.79	0.33	0.15	0.14	0.08	0.66	0.94
BMP Database	1.11	1.05	0.37	0.13	na	na	1.48	1.18
River Bend	0.55	0.94	0.18	0.17	0.05	0.08	0.73	1.11

Table 18. Mean P and TSS concentrations for various wetland studies.

	Mean TP mg/L		Mean Ortho P mg/L		Mean TSS mg/L	
Author	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Bass (2000)	0.37	0.57	0.27	0.42	na	na
Johnson (2006)	0.44	0.2	na	na	71	24
Line et al. (2008) CMS	1.68	0.99	na	na	38	18
Line et al. (2008) UNC	0.27	0.12	na	na	100	31
BMP Database	0.27	0.11	na	na	31	13
River Bend	0.23	0.23	0.15	0.09	31	41

There is a clear difference between the River Bend study and all other wetlands presented with respect to inflow concentrations. River Bend received lower TSS and nutrient concentrations compared to other studies for a majority of the pollutants. For TKN, NH_4-N, and TN, influent concentrations at River Bend were lower than the *effluent* concentrations from all other sites. When examining all studies, only one mean inflow concentration (TKN at UNC) was lower than those at River Bend. For all other nutrient species, the River Bend wetland's influent concentrations were less than that of the effluent concentrations from at least one of these other studies. This may help to explain why the River Bend wetland may not be performing as well as other constructed wetlands when a reduction efficiency metric is used. River Bend outflow concentrations of TKN, $NO_{2\text{-}3}$-N, NH_4-N, TN, TP and OP were also less than outflow concentrations from at least one or more of these other wetlands. Arguably, influent concentrations measured at the River Bend wetland could be close to irreducible concentrations. The wetland may essentially be releasing base concentrations of pollutants and should not be expected to reduce the pollutant load by a significant or substantial amount.

The mean TSS outflow concentration of 41 mg/L for River Bend was higher than all of the other studies. However, the mean inflow concentration was equal to the smallest value from the other studies, 31 mg/L. Based on the previous TSS discussion, it is not surprising that the effluent TSS concentrations for River Bend were higher than wetlands in which a greater time to establish vegetation existed.

Based on both assessing a BMP's performance relative to background concentrations in nearby waters and by comparing effluent concentrations among similar practices, it is apparent that calculating percent reduction values for stormwater BMPs' may not always be the best way of evaluating how well they are functioning. This is an important point, as most BMPs are consistently judged on how well they are reducing concentrations and loads. Even though the River Bend wetland was exporting pollutants on a concentration basis, it still reduced pollutant loads, and performed reasonably well given the influent concentrations. Instead of focusing on reduction percentages as a way of evaluating BMP performance, BMPs should also be evaluated in the context of the environment around them.

Nitrogen sources and sinks

To help determine the source of the excess TN, a soil and plant analysis for TN was performed on the River Bend wetland. By determining the amount of TN in both of these components, the source of the TN could be more reliably identified. Results from plant harvesting yielded approximately 3.6 kg (8 lbs) of TN in the above and belowground biomass combined. Soil sample results from areas X, Y and Z yielded 13 kg (29 lbs), 43 kg (95 lbs) and 15 kg (33 lbs) of TN, respectively, for a total of 71 kg (157 lbs).

As a result of plant harvesting taking place on October 1, 2007, and soil samples being taken on June 12, 2008, a precise TN budget was not feasible. However, if these TN values are compared with inflow and outflow loads from the time of vegetation establishment to harvesting, it is apparent that the soil could be the largest source of TN in the water column. Figure 25 displays the relative values of TN for inflow, outflow, plant sequestration and soil.

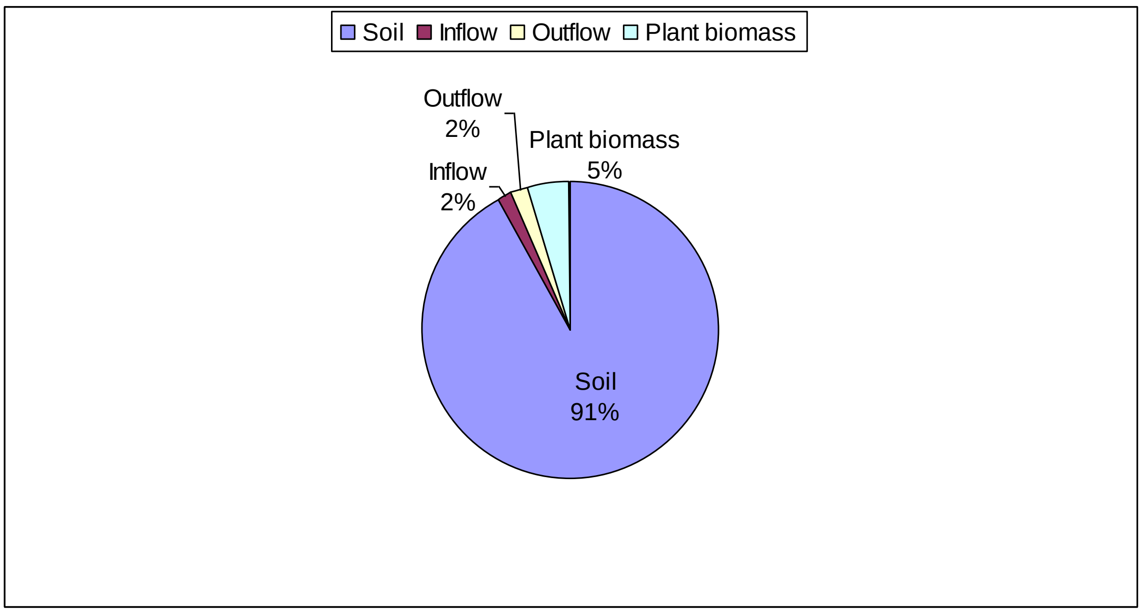

Figure 25. Percent TN for all nitrogen sources and sinks.

Based on Figure 25 it is evident that the wetland soil is a substantial TN source. Typical organic N soil concentrations for natural freshwater wetlands are between 100 and 1000 g N m^{-2} (Howard-William and Downes 1993), while the River Bend wetland has a TN concentration of around 51 g TN m^{-2} in the top 10 cm of soil. Typical irreducible background concentrations for most wetlands are around 1.5 mg L^{-1} (Kadlec and Knight 1995). The River Bend wetland only exports a concentration greater than 1.5 mg/L once, during event 3. Again this comparison establishes the fact that there is limited N coming into this wetland and outflow concentrations are close to irreducible.

This may also help to explain why high amounts of TKN are being exported from the system. Organic N in the sediment is possibly being suspended into the water column due to the immaturity of the wetland plants as described in the TSS water quality results section. Because the largest fluxes of N initially occur with TKN, it is unlikely that the major source of N is from the diffusion of $NO_{2\text{-}3}$-N from the soil into the water column (Richardson and Verpraskas 2001).

Phosphorus Deposition

Soil samples were collected spatially across the wetland and temporally from April 2007 to April 2008. From these samples it was possible to make some determinations on the fate of influent phosphorus. To accomplish this, the soil P-index for each sample was repeatedly measured. The P index is a way to report levels of P that fall into one of 5 ranges. The index ranges are as follow: 0-10 is very low; 11-25 is low; 26-50 is medium; 51-100 is high; and 100+ is very high (Hardy et al. 2003). Based on results from Hunt et al. (2006) a low P-index soil will have a high P sorption potential, while a soil with a high P index will have a much lower capacity for P sorption. If the soil is in the low to medium range there is still potential for P removal. However, once the soil reaches a high to very high P-index there is a substantial reduction in P removal.

SAS System for Windows version 9.1® was used to determine if there was a significant difference between the average P indexes for transects A to C and D to G (Figure

11). This was performed by first averaging the three P indexes for each transect for each month. Next a proc mixed procedure was used to fit an autoregressive correlation structure to repeated measures over time from the same location. The correlation between two measurements from the same location is modeled at ρ^t, where "t" is the time unit between measured P indexes for each location. Transects were split into two regions, region one and region two consisting of transects A, B, C, and D, E, F, and G respectively. The reason for the divide at this location was to help determine if a significant amount of P was located in the soil area closer to the entrance of the wetland when compared with the remaining soil area. It was determined soil within transects A to C had significantly greater ($p<0.05$) P index values when compared to soil P index values from transects D to G. The following graphs illustrate examples of P index data collected from June 2007 to January 2008 (Figures 26, 27 and 28).

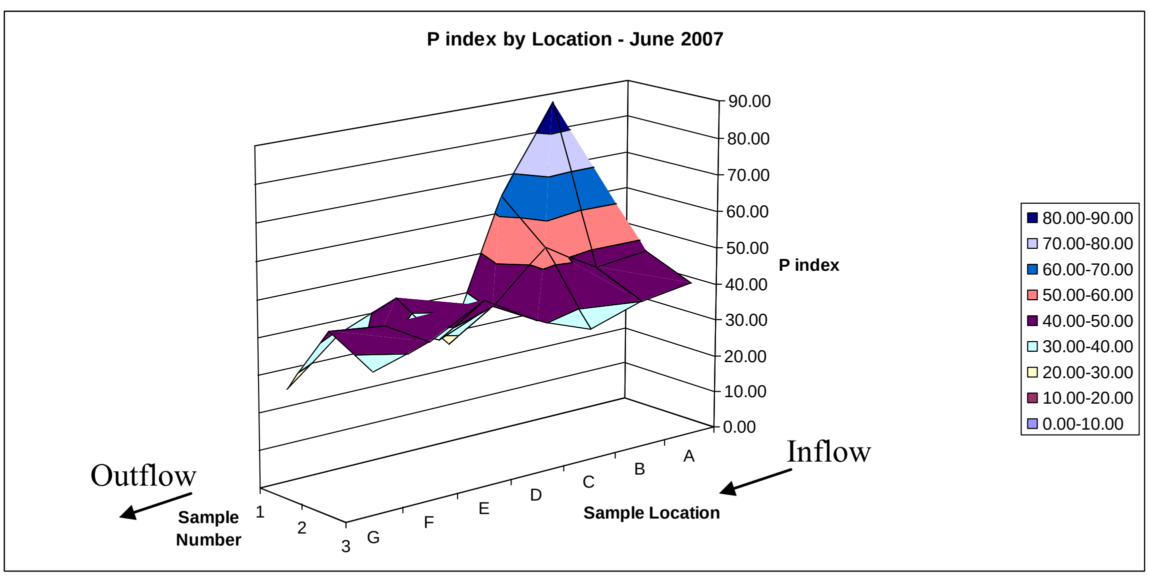

Figure 26. P index values by location for June 2007.

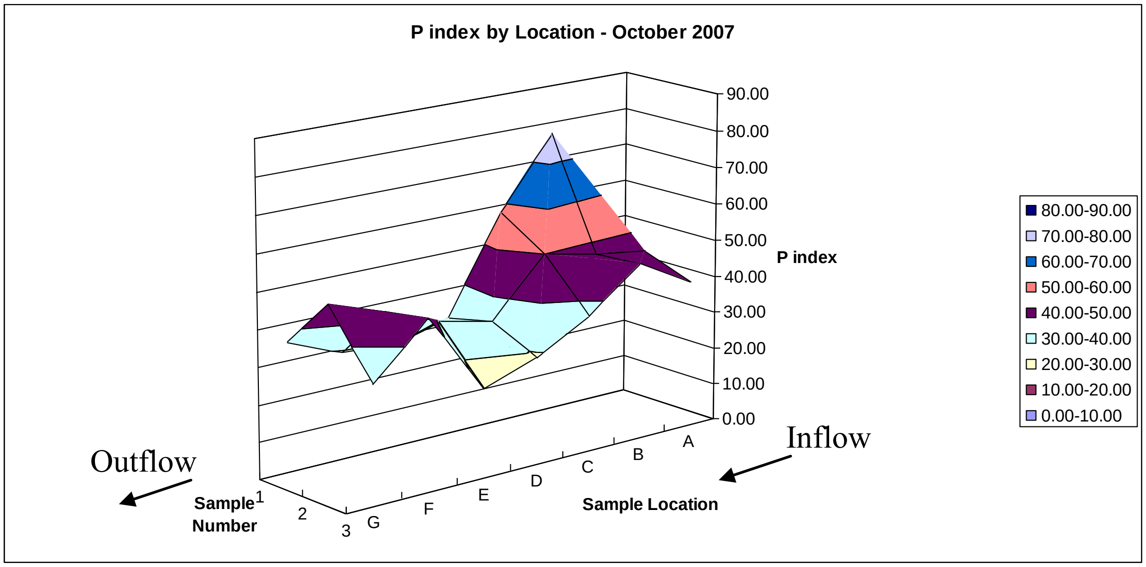

Figure 27. P index values by location for October 2007.

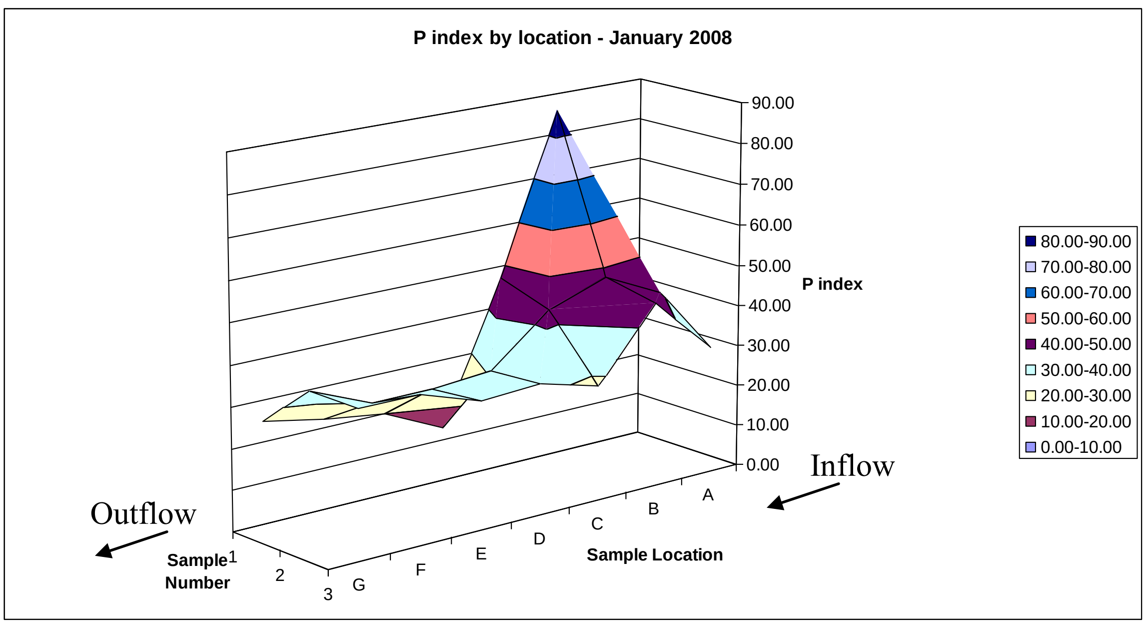

Figure 28. P index values by location for January 2008.

There is a consistent P peak between transects A and C. Based on the data from Figures 26, 27 and 28 there does not appear to be any substantial change in P value throughout the year. The high P index values are not spreading to the rest of the wetland due to P deposition. There is some fluctuation around the peak and at other transects but nothing that was discernibly consistent. However, what this does show is a spatial distribution of P significantly concentrated near the inlet of the wetland.

As discussed earlier, it has been shown constructed wetlands can eventually become over saturated with P, resulting in ineffective P removal thereafter(Breen 1990, Kadlec 1995, Richardson et al. 1996). This wetland follows the general trends set by Kadlec (1999); high concentrations of P are located at the entrance to the wetland, while P concentrations decline as a function of the distance from the inlet.

One possible strategy to remediate P saturation in constructed wetlands would be to remove the top layer of wetland soil in this area of high P concentration on an annual or semi-annual basis once the wetland is no longer providing efficient P treatment. The removed soil could then be replaced with a low P index soil allowing for continued sorption of P.

CONCLUSIONS AND RECOMENDATIONS

Based on the results from this study there are some general conclusions that can be drawn. For each conclusion and recommendation it should be remembered that this study took place during one of the most severe droughts in NC history. Also, this wetland was monitored immediately after the second wetland planting and plants had little time to mature before monitoring began.

Water Quantity

Based on the results from the water quantity section the following conclusions were drawn.

- This wetland is performing its function to reduce peak flows and runoff volumes by 80% and 54%, respectively.
- Currently, stormwater wetlands are not considered a Low Impact Development (LID) practice (MDDER 1999). A primary goal of LID is to reduce peak flows and runoff volumes. For the two largest events on April 5, 2008, and March 6, 2008, peak flows were reduced by 68% and 71%, respectively. Based on the water quantity results from this study, it is evident that stormwater wetlands could be considered a LID practice, at least in sandier in-situ soils.

Water Quality

Based on the results from the water quality section the following conclusions were drawn.

- The outflow concentrations for TKN, NH4-N, TN and TSS were increased by 70%, 53%, 51% and 30%, respectively, while TP concentrations remained stable.
- Only $NO_{2\text{-}3}$-N and Ortho P concentrations were reduced, by 9% and 39%, respectively; however, only OP was significant ($p>0.05$).

- The total load reduction from 11 storms for TKN, $NO_{2\text{-}3}$-N, NH4-N, TN, TP, Ortho P and TSS were 35%, 41%, 42%, 36%, 47%, 61% and 49%, respectively. Based on these numbers, the wetland is providing a positive impact on water quality by reducing the mass loadings exported downstream.
- The primary reason for the positive load reduction was the wetland's ability to significantly reduce inflow volumes. Even though there was an increase in concentrations on the outflow side, the high volume reduction resulted in a decrease in total loads. This is an important function of this wetland to improve water quality.

Upon comparison of the River Bend wetland's pollutant concentrations with those from neighboring streams and rivers of Moderate BioClass, and similar stormwater wetland studies in NC, the following conclusions were drawn.

- The River Bend wetland is not negatively affecting water quality.
- River Bend's mean influent concentrations for TKN and TN were consistently lower than effluent concentrations in nearly all of the referenced studies. Influent N concentrations to River Bend may have been close to irreducible concentrations.
- River Bend's mean outflow concentrations of TKN, $NO_{2\text{-}3}$-N, NH_4-N, TN, TP, and OP, were less than the effluent from at least one or more of the compared studies. Perhaps this wetland should not be expected to reduce concentrations that are already low.

- Assessing this wetland only on pollutant concentration reduction would be insufficient and not accurately reflect the somewhat unique situation occurring at the River Bend wetland.

Based on water quality monitoring it appears there was an apparent "start up effect" associated with N species that immediately followed wetland reconstruction. Effluent concentrations of all forms of N were initially relatively high before eventually declining as the wetland matured. The possible reasons for this are:

- The algal bloom following the reconstruction of the River Bend wetland acted as a source of N from within the wetland.
- Due to the relatively young age of the plants that did survive or were replaced, the wetland was not functioning well at the beginning of the study. The observed addition of TSS may have aided in the export of organic N from the wetland, due to soil organic matter being suspended in the water column. Once the plants began to establish, the wetland was better able to improve N species and TSS removal.

Phosphorus Deposition

Based on P water quality results and the P-index graphs for the wetland soil the following conclusions were drawn.

- It appears this wetland is no longer reducing P concentrations. The wetland is receiving loads greater than Richardson et al.'s (1997) 1 g m^{-2} yr^{-1} upper threshold.

- The wetland has a stable decreasing P gradient from inlet to outlet, indicating an inability to remove P (Kadlec 1999).
- A maintenance strategy to increase P removal is needed for this wetland.

One simple strategy to determine whether a wetland is removing P is to take the P-index of soils in the forebay. A high P-index rating in the substrate indicates the wetland is no longer removing P. Replacing the soil at the inlet with soil having a low P-index is then recommended.

CHAPTER 3

NITROGEN ACCUMULATION IN FIVE WETLAND PLANT SPECIES IN TWO CONSTRUCTED STORMWATER WETLANDS

ABSTRACT

As the use of constructed stormwater wetlands to treat stormwater runoff becomes more frequent, strategies for maintaining their pollutant removal over time must be examined. One potential strategy is plant harvesting to remove nutrients that would otherwise be deposited back into the wetland during senescence. Vegetation was harvested in two stormwater wetlands located in Smithfield and Pactolus, North Carolina, to evaluate the ability of five wetland plant species to sequester nitrogen. Biomass samples from harvested emergent vegetation for *Pontederia cordata* (Pickerelweed), *Saururus cernuus* (Lizard Tail), *Scirpus cyperinus* (Wool Grass), *Sagittaria latifolia* (Arrowhead) and *Schoenoplectus tabernaemontani* (Softstem Bulrush) were collected in September and October 2007 and analyzed for nutrient content on a % N of biomass basis. At the Pactolus wetland the *Pontederia cordata*, *Scirpus cyperinus* and *Schoenoplectus tabernaemontani* biomass retained significantly ($p<0.05$) more nitrogen than *Sagittaria latifolia* and *Saururus cernuus*. At the Smithfield wetland, *Pontederia cordata* and *Sagittaria latifolia* biomass retained significantly more nitrogen than *Scirpus cyperinus* and *Saururus cernuus*. Wetland maturity had a direct relationship to harvestable nitrogen which could explain the change in significance of *Scirpus cyperinus* and *Sagittaria latifolia* between the two wetlands. A positive relationship was noticeable between the density of harvested biomass and nitrogen

removal for two species. A model for estimating total nitrogen loading in Coastal Plain watersheds in North Carolina was used to determine that harvested vegetation from a wetland in the Tar-Pamlico River basin could potentially account for 21% of nitrogen entering the Pactolus wetland on an annual basis. The implementation of stormwater wetland harvesting as a maintenance activity appears to be a potentially important practice for nitrogen removal.

INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) targets stormwater runoff as one of the largest sources of pollution to waterways (USEPA 1996). Stormwater has been shown to transport pesticides, oils, heavy metals, nutrients and a variety of other contaminants (Bannerman et al. 1993, Flint and Davis 2007). In many estuaries, such as the Chesapeake Bay and North Carolina's Albemarle and Pamlico Sounds, excess nutrient loads, in part associated with development, have an important negative impact on fishery health (Abler et al. 2002, Stanley 1987). Line et al. (2002) found that average total nitrogen, phosphorus, and sediment export from various developed land uses was 269, 302, and 256 percent greater, respectively, than wooded lots of similar size. Wu et al. (1998) showed total nitrogen loadings from NC highways are 1.4 to 2.3 times higher than data averaged from 10 various U.S. highways. Total phosphorus loading at one site was 3 times greater than this average.

Constructed wetlands have become a popular stormwater best management practice (BMP) due to their ability to substantially reduce nutrient levels. This has been shown in wastewater treatment (Busnardo et al. 1992, Tanner 1996) and subsequently in stormwater

(Kohler et al. 2004, Struck et al. 2004). Wetlands also tend to be the most inexpensive stormwater BMP for large watersheds on a per hectare treated basis (Wossink and Hunt 2003). The processes by which wetlands remove nitrogen is well documented (Reddy et al. 1989). Two major components in this process are denitrification and plant uptake. Stengel et al. (1987) attributed 75 to 90 percent of wetland nitrate loss to denitrification. Cooke (1994) found denitrification to be responsible for 60 and 70 percent of nitrate loss in two wetland microcosms. The importance of nitrogen removal by fixation when compared to denitrification in wetlands has been debated. Researchers have argued that bacterial denitrification is the primary process in treatment wetlands to remove nitrate (Bachand and Horne 1999, Ingersoll and Baker 1998). Tanner (2001) found only 6 to 11 percent of nitrogen removal could be attributed to plant uptake after three growing seasons in a wastewater treatment wetland. In another wastewater treatment study, Gersberg et al. (1986) found plant uptake accounted for 12 to 16 percent of nitrogen removal.

Most wetland plant uptake studies have examined a limited variety of plants such as *Typha latifola* (Cattail), *Schoenoplectus tabernaemontani* (Softstem bulrush) and *Phragmites communis* (Common reed) (Gersberg et al. 1986, Tanner 1996, Tanner 2001) and have focused on wastewater treatment systems. These wetland plants are common in many U.S. climates and have not demonstrated an ability to sequester substantial amounts of nitrogen (>25%) from wastewater input. As a result and despite a research focus on wastewater, wetland plant harvesting has not been recommended as a management strategy for nitrogen removal in *stormwater* treatment wetlands. Furthermore, most wetland plants native to regions such as the Southeast and Mid-Atlantic have yet to be researched to determine nutrient harvest potential. Moreover, vegetation types specifically recommended for stormwater treatment wetlands have not been examined. The purpose of this study was to determine the amount of nitrogen sequestration associated with 5 species common to and commonly recommended for stormwater wetlands in North Carolina (Hunt et al. 2007). By quantifying the amount of nitrogen uptake, it would be possible to (1) refine selection of wetland vegetation and (2) assess the potential importance of wetland plant harvesting to nutrient removal by stormwater wetlands.

SITE DESCRIPTION

Two field studies were used as part of this study in Smithfield and Pactolus, NC. The 0.09 hectare (0.21 acre) Smithfield-Selma High School stormwater treatment wetland is located in Johnston County, NC (Figure 29, Table 18). Constructed and planted in 2001, the wetland treats runoff from an 11 hectare (27 acre) watershed consisting of a parking lot, rooftops and grass fields. The relative permeability of the watershed, as described by the NRCS curve number (CN) method, was 87 (Johnson 2006), indicating a moderately impermeable watershed. Based on historical averages from meteorological station number 317994, Smithfield, located approximately 4 km (2.5 miles) from the Smithfield wetland, the average annual temperature is 15.3^{o}C (59.7^{o}F) ranging from a normal monthly minimum temperature of -1.39^{o}C (29.5^{o}F) in January to normal monthly maximum of 32.2^{o}C (89.9^{o}F) in July. Average annual precipitation is 1204 mm (47.4 in.), ranging from a monthly mean of 82.3 mm (3.24 in.) in April to 131 mm (5.14 in.) in July (NCCO 2008).

Figure 29. Stormwater wetland at Smithfield-Selma High School in September, 2007

Table 18. Description of Smithfield and Pactolus wetlands and watersheds

Wetland Location	Smithfield-Selma High School	Pactolus Elementary School
Latitude and Longitude	N 35 ° 31' 51.0", W 78 ° 19' 34.6"	N 35 ° 37' 19.1", W 77 ° 13' 25.3"
Wetland Area	0.09 ha (0.21 ac)	0.08 ha (0.20 ac)
Watershed Area	11 ha (27 ac)	3.6 ha (9 ac)
Watershed CN	87	86
Rainfall Event Captured	1.27 cm (0.5 in)	2.54 cm (1 in)
Ponding Depth	7.6 cm (3 in)	15.3 cm (6 in)
Capture Volume	10.8 m^3 (381 ft^3)	20.6 m^3 (727 ft^3)
Vegetation included on original planting plan	*Asclepias incarnata* (Swamp Milkweed) *Cephalanthus occidentalis* (Button Bush) *Clethra alnifolia* (Pepperbush) *Hibiscus coccineus* (Texas Star) *Hibiscus moscheutos* (Swamp Mallow) *Fraxinus pennsylvanica* (Green Ash) *Ilex verticillata* (Sparkleberry) *Itea virginica* (Virginia Sweetspire) *Juncus effuses* (Common rush) *Kosteletzkya virginica* (Marsh Mallow) *Magnolia virginica* (Sweetbay Magnolia) *Nelumbo lutea* (Yellow Lotus) *Nuphar luteum* (Cow Lily/Spadderdock) *Nyphaea odorata* (Water lily) *Peltandra virginica* (Arrow Arum) *Pontederia cordata* (Pickerelweed) *Sagittaria latifolia* (Arrowhead) *Saururus cernuus* (Lizard’s tail) *Scirpus cyperinus* (Wool Grass) *Taxodium distichum* (Bald Cypress)	*Hibiscus moscheutus* (Rose Mallow) *Juncus effusus* (Soft Rush) *Lobelia cardinalis* (Cardinal Flower) *Nuphar luteum* (Spatterdock) *Peltandra virginica* (Arrow arum) *Pontederia cordata* (Pickerel weed) *Saururus cernuus* (Lizard Tail) *Sagittaria latifolia* (Arrowhead) *Scirpus cyperinus* (Wool Grass) *Schoenoplectus tabernaemontani* (Softstem Bulrush)
Vegetation analyzed	*Sagittaria latifolia* (Arrowhead) *Pontederia cordata* (Pickerelweed) *Scirpus cyperinus* (Wool Grass) *Saururus cernuus* (Lizard's Tail)	*Sagittaria latifolia* (Arrowhead) *Pontederia cordata* (Pickerelweed) *Scirpus cyperinus* (Wool Grass) *Saururus cernuus* (Lizard's Tail) *Schoenoplectus tabernaemontani* (Softstem Bulrush)
Date harvested	September 28, 2007	October 3, 2007

The 0.08 hectare (0.20 acre) Pactolus Elementary School wetland is located in Pitt County, NC (Figure 30, Table 18). Constructed and planted in 2006, the wetland treats

runoff from a 3.6 hectare (9 acre) watershed consisting of a parking lot, rooftops, and farmland (CN=86). Based on historical averages from meteorological station number 313638, Greenville, located approximately 18 km (11 miles) from the Pactolus wetland, the average annual temperature is 16.1°C (60.9°F) ranging from a normal monthly minimum temperature of -0.4°C (31.3°F) in January to a normal monthly high of 31.7°C (89.1°F) in July. Average annual precipitation is 1252 mm (49.3 in.), ranging from a monthly mean of 71mm (2.79 in.) in November to 150 mm (5.89 in.) in August (NCCO 2008).

Figure 30. Stormwater wetland at Pactolus Elementary School in September, 2007

MATERIALS AND METHODS

In September of 2007, a vegetation survey was performed on both wetlands using a Sokkia Set 530R total station and Carlson Explorer data collector to generate an AutoCAD drawing of localized monocultures for five different wetland plant species, *Pontederia* *cordata* (pickerelweed), *Sagittaria latifolia* (arrowhead), *Saururus cernuus* (lizard tail), *Scirpus cyperinus* (wool grass) and *Schoenoplectus tabernaemontani* (softstem bulrush). *Schoenoplectus tabernaemontani* was only present at the Pactolus wetland. Vertical and horizontal lines spaced 0.5 meters apart were oriented on top of each AutoCAD drawing to establish a 0.25 m^2 grid system (Figure 31). Complete 0.25 m^2 squares that fell within monocultures were each assigned a number beginning with one. A set of numbers was generated for each plant type. A random number generator then selected five sampling locations (n=5) from each set to be harvested. For example, in the Smithfield wetland *Sagittaria latifolia*, which had 66 full 0.5 x 0.5 meter squares, squares 22, 39, 47, 51, and 59 were randomly selected for harvesting. Below ground biomass was harvested from the square associated with the first random number generated.

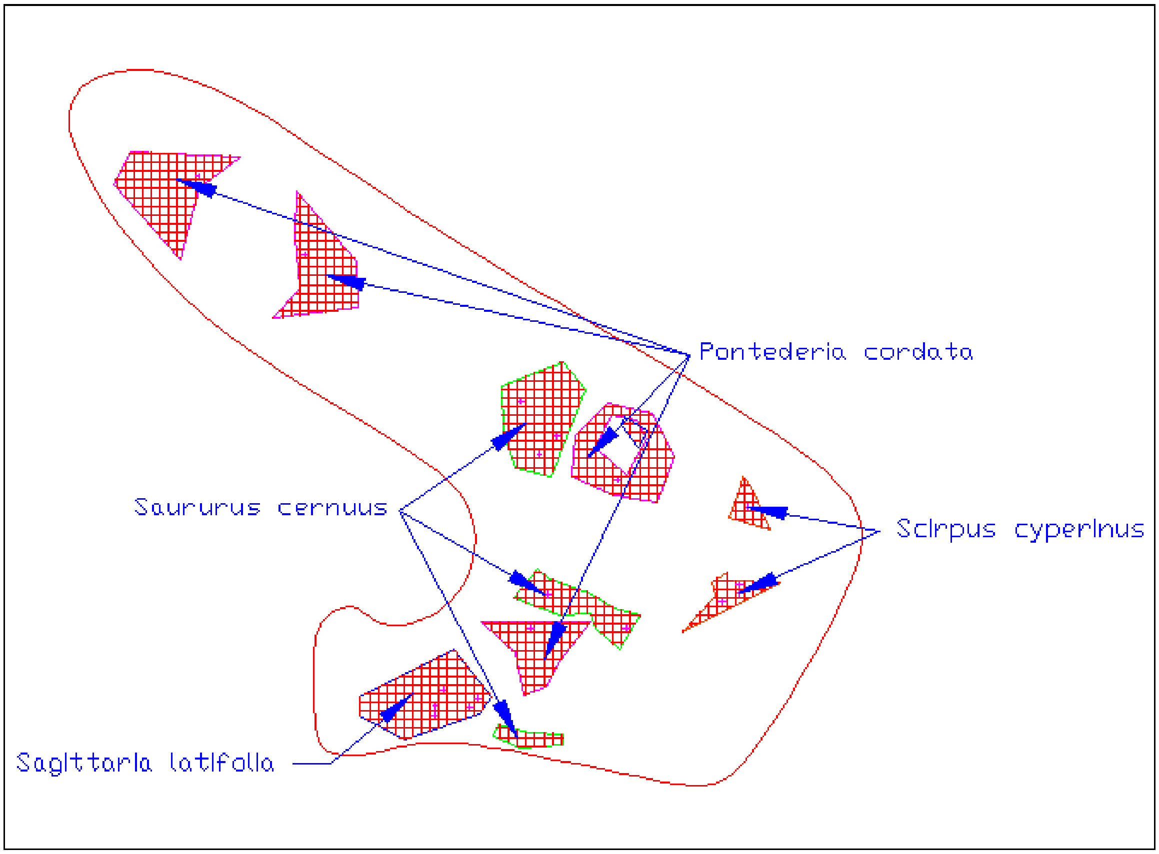

Figure 31. AutoCAD drawing displaying monoculture of each vegetation type for the Smithfield wetland

Plant harvesting took place on September 28, 2007, and October 3, 2007, for the Smithfield and Pactolus wetlands, respectively. The exact location of each square was located using the total station, and a 0.25 m^2 frame was placed at this location (Figure 32). The plant biomass within this frame was cut at the waterline, or normal pool elevation. The waterline was chosen because it is the most practical location to harvest vegetation if a complete vegetation harvest were to occur. By cutting at the waterline, the plants root structure is essentially intact, reducing erosion potential within the wetland, and allowed for full regrowth the following growing season. Above ground biomass was collected and kept separate for each square. Below ground biomass harvesting involved removing and bagging all of the roots associated with above ground biomass within the square. Excess soil was washed off the root mass before being bagged. Below ground samples were stored and analyzed separately from their matching above ground specimens.

Figure 32. Picture of 0.5 x 0.5 meter frame during harvesting of *Pontederia cordata*

After harvesting was complete, the samples were rinsed and placed in an oven to dry at 80^{o}C (176^{o}F) for at least 24 hours in accordance with the N.C. Department of Agriculture (NCDA), Agronomics Division, lab protocol (Campbell 1992, Campbell and Plank 1992). All samples were then individually ground using a laboratory Wiley mill through a 20 mesh screen (1mm) and then weighed. Mineral nutrient analysis of the plant biomass was conducted by the NCDA, Agronomics Division, Raleigh, NC. Total Nitrogen (TN) was determined by oxygen combustion with an elemental analyzer (NA1500; CE Elantech Instruments, Milan, Italy).

RESULTS AND DISCUSSION

Mean above ground biomass (g m^{-2}) collected for *Pontederia cordata*, *Sagittaria latifolia, Saururus cernuus, Scirpus cyperinus* and *Schoenoplectus tabernaemontani* at the Pactolus wetland was: 901, 229, 275, 1847 and 882, respectively (Table 19). Smithfield values were 414, 307, 308 and 454, respectively, not including *Schoenoplectus tabernaemontani* (Table 20).

Mean nitrogen content (g m^{-2}) for *Pontederia cordata*, *Sagittaria latifolia, Saururus cernuus, Scirpus cyperinus* and *Schoenoplectus tabernaemontani* at the Pactolus wetland was: 11.9, 6.1, 5.8, 12.7 and 11.1, respectively (Table 19). Smithfield values were 8.9, 8.0, 3.1 and 3.4, respectively, not including *Schoenoplectus tabernaemontani* (Table 20).

Biomass root to shoot ratios for *Pontederia cordata*, *Sagittaria latifolia, Saururus cernuus, Scirpus cyperinus* and *Schoenoplectus tabernaemontani* at the Pactolus wetland were: 1.6, 1.2, 1.2, 0.4, and 1.2, respectively (Table 21). Smithfield values were 1.7, 0.5, 2.6 and 0.7 respectively, not including *Schoenoplectus tabernaemontani* (Table 22).

Nitrogen root to shoot ratios for *Pontederia cordata*, *Sagittaria latifolia, Saururus cernuus, Scirpus cyperinus* and *Schoenoplectus tabernaemontani* at the Pactolus wetland were: 0.7, 0.6, 0.6, 0.2 and 0.5, respectively (Table 21). Smithfield values were 0.8, 0.4, 2.5 and 0.6, respectively, not including *Schoenoplectus tabernaemontani* (Table 22). For all species except for *Saururus cernuus* in Smithfield, it is evident that most of the N sequestered is in the above ground biomass. Therefore, it appears above ground harvesting would remove the majority of N, while below ground harvesting would not be as beneficial.

Tanner (2001) studied nutrient uptake of *Schoenoplectus tabernaemontani* in wastewater wetlands. Tanner reported biomass root:shoot ratios between 0.6 and 0.7. At the Pactolus wetland the root to shoot ratio for *Schoenoplectus tabernaemontani* was 1.2. However, the values from Tanner's study were low compared to ratios between 1 and 3, values generally reported for tall emergent macrophytes living in lower nutrient conditions (Tanner 2001). Tanner (1996) studied nutrient plant uptake of eight emergent wetland species (Schoenoplectus validus, Phragmites australis, Glyceria maxima, Baumea articulata, Bolboschoenus fluviatilis, Cyperus involucratus, Juncus effusus and Zizania latifolia) for use in constructed wetlands. Nitrogen root:shoot ratios for these eight species ranged from 0.8 to 1.14. Ratios from the Pactolus and Smithfield wetland are generally lower than these values meaning less N storage in the roots. One possible explanation for this difference may be due to luxury uptake. Plants from Tanner (1996) were being batch-fed dairy farm water with a high N concentration weekly and may have had the opportunity to uptake large amounts of N. Stormwater wetlands do not typically receive water with such a high concentration of N, and the plants may not get the benefit of luxury N uptake.

Burchell (2003) established a series of wetland mesocosm experiments to determine if adding organic matter to soils in constructed wetlands would increase NO_3^--N treatment. At the end of this study *Schoenoplectus tabernaemontani* was harvested from the mesocosms and root:shoot ratios were calculated. These ratios ranged from 0.53 to 1.5. These mesocosms were being delivered NO_3^--N concentrations ranging from 10 to 120 mg/L (Burchell II 2003). Like Tanner (1996), these plants had the benefit of receiving large concentrations of N and luxury uptake appears to take place in the roots of the plants as the root:shoot ratios for Tanner (1996) and Burchell (2003) are typically higher than those calculated from this study, with the exception of *Saururus cernuus* from the Smithfield wetland.

Table 19. Pactolus mean above (n=5) and below (n=1) ground biomass and N sequestration.

Pactolus Wetland					
	Pontederia cordata	*Sagittaria latifolia*	*Scirpus cyperinus*	*Saururus cernuus*	*Schoenoplectus tabernaemontani*
Above Ground Mean Biomass (g/m^2)	901	228	1847	275	882
Below Ground Biomass (g/m^2)	1693	132	555	258	607
Above Ground Mean N (g/m^2)	12	6	13	6	11
Below Ground N (g/m^2)	13	2	2	3	4

Table 20. Smithfield mean above (n=5) and below (n=1) ground biomass and N sequestration.

Smithfield Wetland				
	Pontederia cordata	*Sagittaria latifolia*	*Scirpus cyperinus*	*Saururus cernuus*
Above Ground Mean Biomass (g/m^2)	414	307	454	308
Below Ground Biomass (g/m^2)	958	206	287	753
Above Ground Mean N (g/m^2)	9	8	3	3
Below Ground N (g/m^2)	11	4	2	7

Table 21. Pactolus above and below ground biomass, N sequestration and Root to Shoot ratios for specific plant samples (n=1) with both above and below ground harvesting.

Pactolus Wetland						
Plant Species	BG[1] Biomass (g/m^2)	AG[2] Biomass (g/m^2)	Biomass Root:Shoot Ratios	BG N Content (g/m^2)	AG N Content (g/m^2)	N Root:Shoot Ratios
Sagittaria latifolia	132	115	1.1	2	3	0.6
Pontederia cordata	1692	1033	1.6	13	19	0.7
Scirpus cyperinus	555	1278	0.4	2	14	0.2
Saururus cernuus	258	219	1.2	3	5	0.6
Schoenopletus tabernaemontani	607	514	1.2	4	8	0.5

[1] Below Ground
[2] Above Ground

Table 22. Smithfield above and below ground biomass, N sequestration and Root to Shoot ratios for specific plant samples (n=1) with both above and below ground harvesting.

Smithfield Wetland						
Plant Species	BG[1] Biomass (g/m^2)	AG[2] Biomass (g/m^2)	Biomass Root:Shoot Ratios	BG N Content (g/m^2)	AG N Content (g/m^2)	N Root:Shoot Ratios
Sagittaria latifolia	206	385	0.5	4.0	10.0	0.4
Pontederia cordata	958	557	1.7	11.2	14.4	0.8
Scirpus cyperinus	287	436	0.7	2.4	4.2	0.6
Saururus cernuus	753	292	2.6	7.2	2.9	2.5

[1] Below Ground
[2] Above Ground

A statistical analysis for the above ground nitrogen content was performed on the mean nitrogen content values. No statistical analysis was performed on below ground N content as the purpose of this research was to determine potential N removal by above ground harvesting. During initial analysis, an interaction was discovered between the two variables nitrogen content and wetland location. This interaction suggests that the amount of nitrogen a particular species sequesters will depend on the wetland in which it is located. Therefore statistically, an overall 1-way ANOVA to included nitrogen content of vegetation from both wetlands could not be justified. Instead the SAS System for Windows version 9.1® was used to generate two separate 1-way ANOVA tables for the individual wetlands (SAS 2008). The results determined if there was a significant difference between plant nitrogen content with respect to each wetland. Data points for each wetland were normally distributed based on SAS residual plots, justifying the use of a 1-way ANOVA.

The statistical analysis conducted for the Smithfield wetland concluded *Pontederia cordata* and *Sagittaria latifolia* above ground biomass contained significantly greater nitrogen on a per m^2 basis than *Scirpus cyperinus* and *Saururus cernuus* ($p<0.05$). Analysis for the Pactolus wetland concluded *Pontederia cordata*, *Scirpus cyperinus* and *Schoenoplectus tabernaemontani* above ground biomass contained significantly greater nitrogen on a per m^2 basis than *Sagittaria latifolia* and *Saururus cernuus* ($p<0.05$) (Table 23).

Table 23. Summary statistics

Smithfield-Selma High School		
Pontederia cordata	Significantly greater than (p<0.05)	*Scirpus cyperinus*
Sagittaria latifolia		*Saururus cernuus*
Pactolus Elementary School		
Pontederia cordata	Significantly greater than (p<0.05)	*Sagittaria latifolia*
Scirpus cyperinus		*Saururus cernuus*
Schoenoplectus tabernaemontani		

The strong interaction effect between wetland and nitrogen content was likely a direct result of the inconsistencies that existed for *Sagittaria latifolia* and *Scirpus cyperinus*.

Harvestable biomass appears to be the primary factor for this discrepancy. Four times more harvestable *Scirpus cyperinus* biomass was found in Pactolus than at Smithfield, resulting in more nitrogen removal on a g/m^2 basis in Pactolus (Table 20 and 21). Conversely, harvestable *Sagittaria latifolia* biomass at Pactolus was less than at Smithfield. This appeared to be due to the immaturity of the *Sagittaria latifolia* at Pactolus. Monocultures of *Sagittaria latifolia* at Smithfield had higher plant density and noticeably larger sagittate leaves compared with those at Pactolus (Figure 33). Despite the fact nitrogen content in the biomass for *Sagittaria latifolia* at both sites were similar (Tables 24 and 25), 6.08 and 8.00 g N m^{-2} at Pactolus and Smithfield, respectively, the nitrogen content of *Sagittaria latifolia* ended up being significantly less than 3 other species at Pactolus.

Table 24. Percent nitrogen in biomass from plant species in the Pactolus wetland.

Pactolus Wetland					
Sample Number	*Pontederia cordata* (% N)	*Sagittaria latifolia* (% N)	*Scirpus cyperinus* (% N)	*Saururus cernuus* (% N)	*Schoenopletus tabernaemontani* (% N)
1	1.82%	2.61%	1.12%	2.32%	1.63%
2	1.65%	2.55%	0.69%	2.11%	1.23%
3	1.13%	2.55%	0.84%	2.21%	1.56%
4	0.90%	2.87%	0.35%	2.04%	0.87%
5	1.13%	2.55%	0.91%	2.03%	1.19%
Mean	1.33%	2.63%	0.78%	2.14%	1.30%
Roots	0.77%	1.42%	0.39%	1.11%	0.70%

Table 25. Percent nitrogen in biomass from plant species in the Smithfield wetland.

Smithfield Wetland				
Sample Number	*Pontederia cordata* (% N)	*Sagittaria latifolia* (% N)	*Scirpus cyperinus* (% N)	*Saururus cernuus* (% N)
1	2.59%	2.60%	0.97%	1.00%
2	1.89%	2.65%	0.62%	0.74%
3	2.21%	2.45%	0.67%	0.96%
4	2.43%	2.24%	0.65%	1.09%
5	1.45%	3.08%	1.04%	1.29%
Mean	2.11%	2.60%	0.79%	1.02%
Roots	1.17%	1.94%	0.85%	0.96%

Figure 33. *Sagitarria latifolia* was noticeably denser at the older Smithfield-Selma Wetland (left) than the less mature Pactolus Wetland (right). Both wetlands are pictured in September 2007.

Comparison of modeled annual nitrogen load with harvested nitrogen

To estimate whether harvesting of wetland vegetation would have a substantial impact on nitrogen removal from stormwater wetlands, a nitrogen loading model for the Tar-Pamlico River basin was used to generate an annual TN loading for the Pactolus wetland (NCDWQ 2008). The model is based on the Simple Method of N calculation and predicts nutrient loads associated with various land uses in small watershed (NCDWQ 2007). The nutrient concentrations associated with various land uses in the model are based on data from research projects in and surrounding the Tar-Pamlico River basin where the Pactolus wetland is located. Based on model output, the Pactolus wetland would receive an annual TN loading of 35.5 kg yr^{-1} (78.25 lbs yr^{-1}) from the varied land uses in its watershed. Using the data presented herein and assuming that the 0.08 ha (0.2 acre) wetland is equally covered by these five species, excluding the 21% of the wetland dedicated to deep water, harvesting could potentially sequester approximately 6.4 kg (14 lbs) of N, almost 18% of the TN. With equal coverage of *Pontederia cordata*, *Scirpus cyperinus* and *Schoenoplectus tabernaemontani*, the three highest N sequestering species, harvesting could potentially remove as much as 9.5 kg (21 lbs) of N, almost 22% of the TN predicted to enter the wetland on an annual basis. This percentage could increase if harvesting were to include deep water species such as *Nuphar lutea* (Spatterdock) and *Nymphaea odorata* (Water lily).

The previous analysis was not performed to imply these plants are responsible for sequestering 18% of the nitrogen that was delivered to the system via stormwater. Wetland plant species can uptake nitrogen into their roots from sediments and into their shoots from the water column (Denny 1972). The transfer of N from sediments to plant and dead plant litter to the water is known as the nutrient "pump" effect (Howard-William 1985). Harvesting plant biomass limits this pump effect by not allowing biomass to senesce back into the wetland; therefore, the amount of N in the system becomes more limited.

This could prove to be problematic for future plant growth as plants reuse senesced nutrients for enhanced growth (Howard-William 1985). Conversely, it has been found that up to 70% of trapped N can enter the wetland via particulate matter during storm flows (Wolaver et al. 1983). From this, it is reasonable to assume that at least some of the N brought in by stormwater will be sequestered by the wetland plants. Upon comparison between the amount of N in the biomass and the amount of N in the stormwater there should be enough N to satisfy plant growth on a yearly basis.

Another concern with harvesting biomass is the loss of a carbon source for bacteria to use in the denitrification process. Bacteria need an organic carbon source to perform denitrification (Ingersoll and Baker 1998, Patrick and Reddy 1976). A portion of this carbon source can come from the biomass that has senesced back into the wetland, providing a continual carbon source. Harvesting biomass would eliminate this carbon source. However depending on the location of the wetland detritus material from trees and other vegetation will enter the wetland, providing a continuous carbon source. If the wetland is in an area without trees then it maybe it should not be recommended that harvesting occur on an annual basis. A more appropriate time frame could be a bi-annual or tri-annual basis to ensure an adequate carbon source to facilitate denitrification. More research is needed to determine an appropriate harvesting schedule.

CONCLUSIONS

There are four major conclusions associated with this research project.

1. The amount of N able to be removed from stormwater wetlands by harvesting plant biomass is not insubstantial, possibly as much as 22% of total inflow N. Harvesting of stormwater wetland vegetation on an regular basis could be an important maintenance activity for optimizing nitrogen removal.

2. Nutrient plant uptake can differ significantly by plant species. Of the 5 species researched *Pontederia cordata* and *Schoenoplectus tabernaemontani* seem to be the best at sequestering N in above ground harvestable biomass.
3. It appears stormwater wetland plants retain most of their N in their above ground biomass. When the root:shoot ratios of this stormwater wetland was compared with those from wastewater wetland studies it appears luxury uptake tends to occur in the roots of wetland plant species.
4. Plant density appears to have an impact on the amount of N sequestered by vegetation, illustrated by the positive relationship between biomass harvested and nitrogen removed for *Sagittaria latifolia* and *Scirpus cyperinus*. Some species seem to reach maturity more quickly than others. For example, *Pontederia cordata* appeared to mature much quicker than *Sagittaria latifolia* resulting in higher N sequestration. Therefore, if plant harvesting is to occur, it should be after species have matured and established high density monocultures. If a stormwater wetland is expected to have its vegetation harvested on a 1 to 2 year basis, perhaps certain species of vegetation should be initially planted to optimize harvested N.

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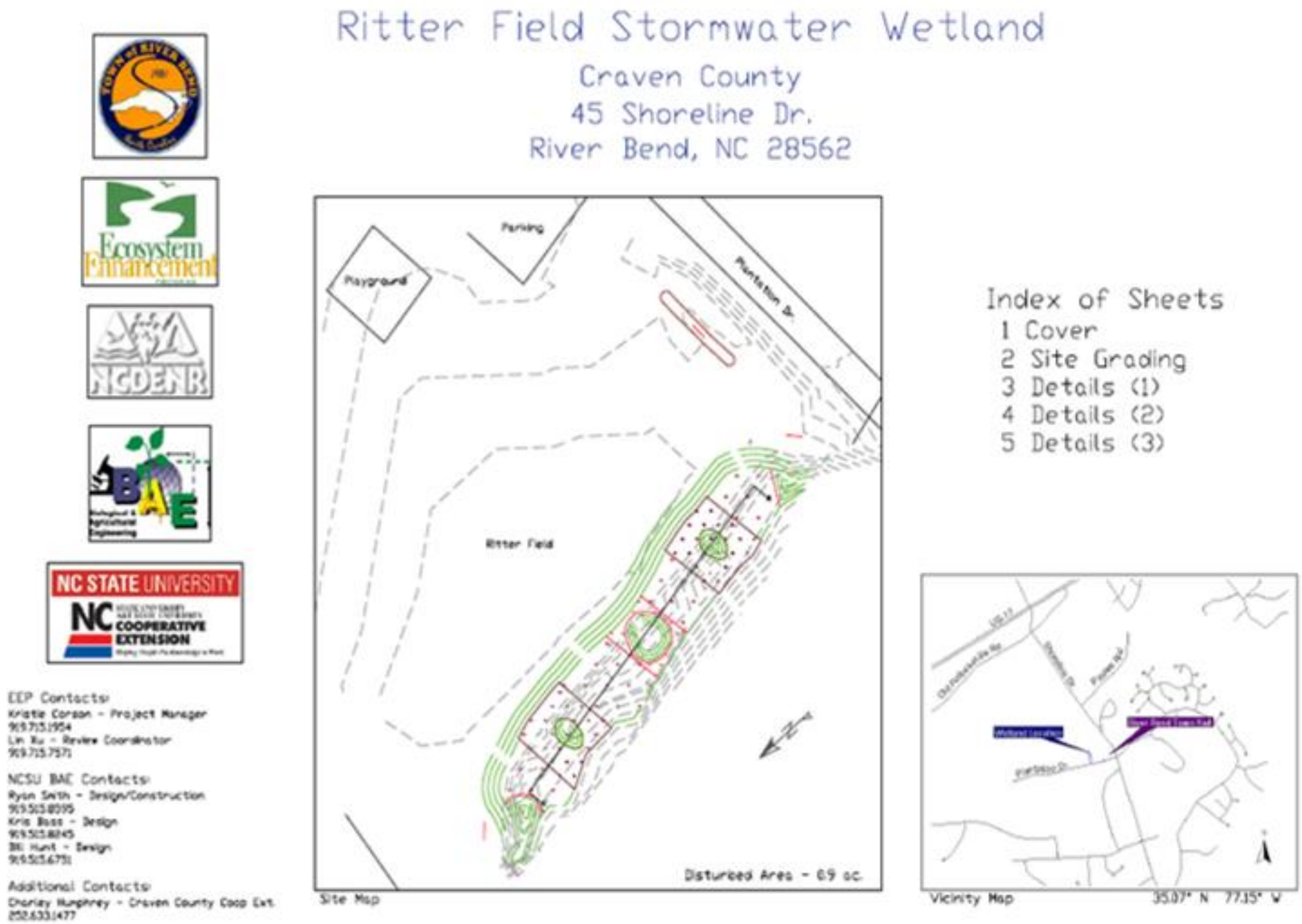
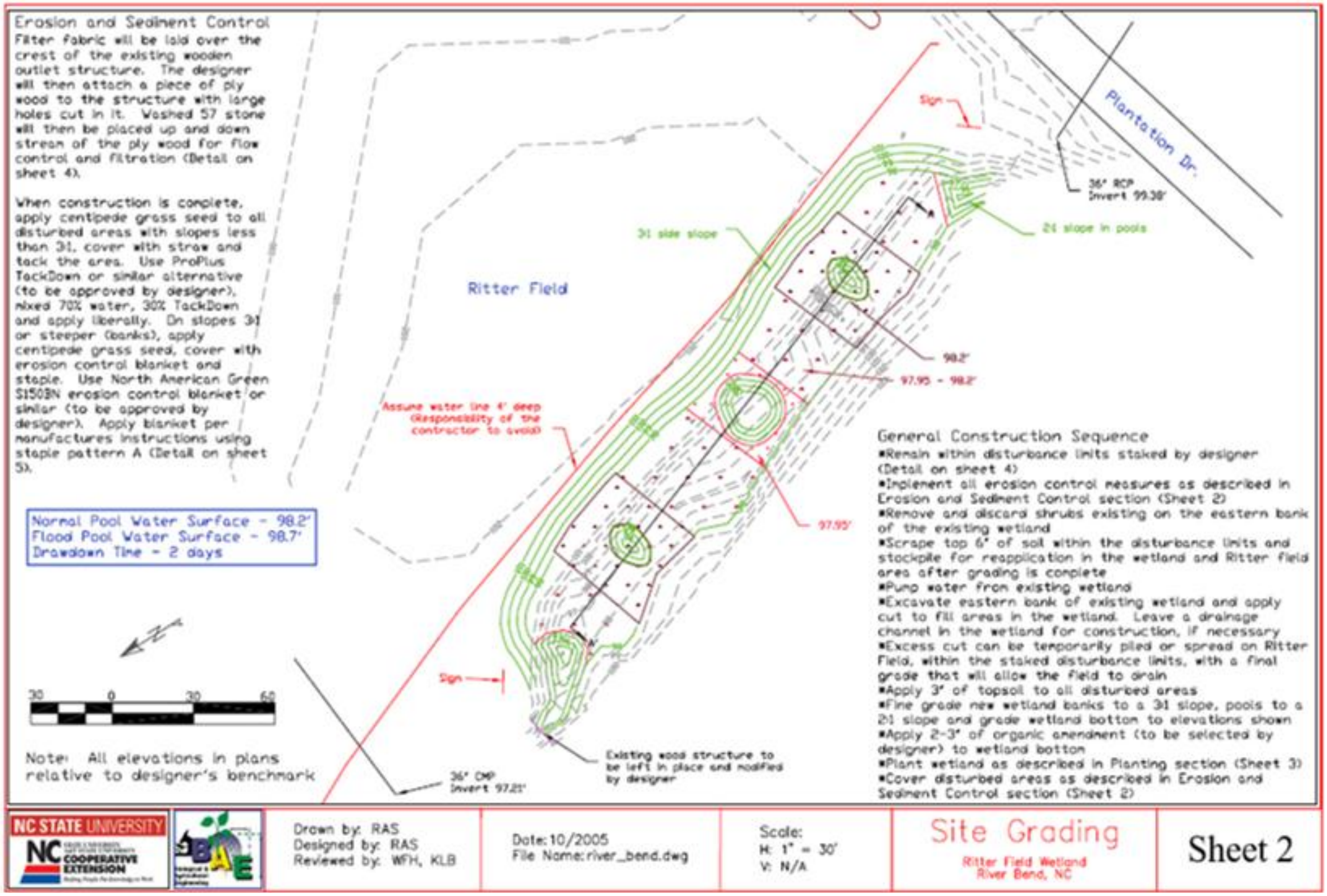
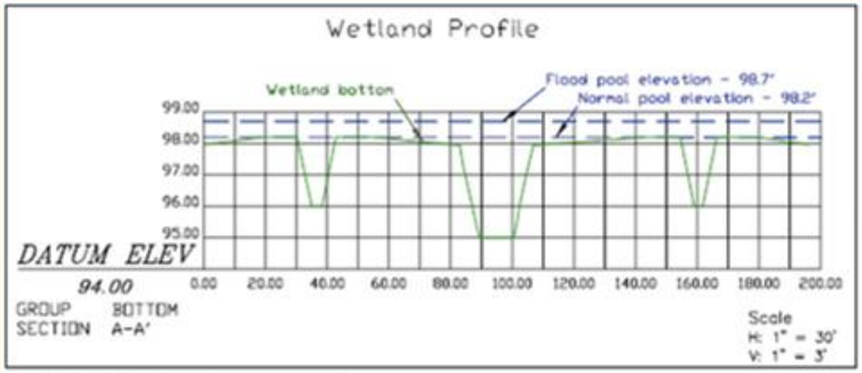
APPENDICIES

APPENDIX A: Documents relating to the design and construction of the River Bend wetland.

A.1: Construction documents relating to the River Bend wetland




Erosion and Sediment Control
Filter fabric will be laid over the crest of the existing wooden outlet structure. The designer will then attach a piece of ply wood to the structure with large holes cut in it. Washed 57 stone will then be placed up and down stream of the ply wood for flow control and filtration (Detail on sheet 4).
When construction is complete, apply centipede grass seed to all disturbed areas with slopes less than 3:1, cover with straw and tack the area. Use ProPlus TackDown or similar alternative (to be approved by designer), mixed 70% water, 30% TackDown and apply liberally. On slopes 3:1 or steeper (banks), apply centipede grass seed, cover with erosion control blanket and staple. Use North American Green S150BN erosion control blanket or similar (to be approved by designer). Apply blanket per manufactures instructions using staple pattern A (Detail on sheet 5).
Normal Pool Water Surface - 98.2'
Flood Pool Water Surface - 98.7'
Drawdown Time - 2 days
Ritter Field
Plantation Dr.
Sign
36" RCP Invert 99.38'
2:1 slope in pools
3:1 side slope
98.2'
97.95 - 98.2'
97.95'
Assume water line 4' deep (Responsibility of the contractor to avoid)
Sign
30 0 30 60
Note: All elevations in plans relative to designer's benchmark
36" CMP Invert 97.21'
Existing wood structure to be left in place and modified by designer
General Construction Sequence
•Remain within disturbance limits staked by designer (Detail on sheet 4)
•Implement all erosion control measures as described in Erosion and Sediment Control section (Sheet 2)
•Remove and discard shrubs existing on the eastern bank of the existing wetland
•Scrape top 6" of soil within the disturbance limits and stockpile for reapplication in the wetland and Ritter field area after grading is complete
•Pump water from existing wetland
•Excavate eastern bank of existing wetland and apply cut to fill areas in the wetland. Leave a drainage channel in the wetland for construction, if necessary
•Excess cut can be temporarily piled or spread on Ritter Field, within the staked disturbance limits, with a final grade that will allow the field to drain
•Apply 3" of topsoil to all disturbed areas
•Fine grade new wetland banks to a 3:1 slope, pools to a 2:1 slope and grade wetland bottom to elevations shown
•Apply 2-3" of organic amendment (to be selected by designer) to wetland bottom
•Plant wetland as described in Planting section (Sheet 3)
•Cover disturbed areas as described in Erosion and Sediment Control section (Sheet 2)
NC STATE UNIVERSITY
NC COOPERATIVE EXTENSION
Drawn by: RAS
Designed by: RAS
Reviewed by: WFH, KLB
Date: 10/2005
File Name: river_bend.dwg
Scale:
H: 1" = 30'
V: N/A
Site Grading
Ritter Field Wetland
River Bend, NC
Sheet 2



Material Estimates

*Water lily - 9
*Spatterdock - 9
*Pickerelweed - 555
*Lizard's tail - 455
*Arrow arum - 455
*Duck potato - 355
*Rush - 450
*Woolgrass - 450
*Soft stem bulrush - 455
*Marsh mallow - 20
*Cardinal flower - 35
*Pink fetterbush - 15
*Sweet pepperbush - 5

*480 cy of soil applied to Ritter Field

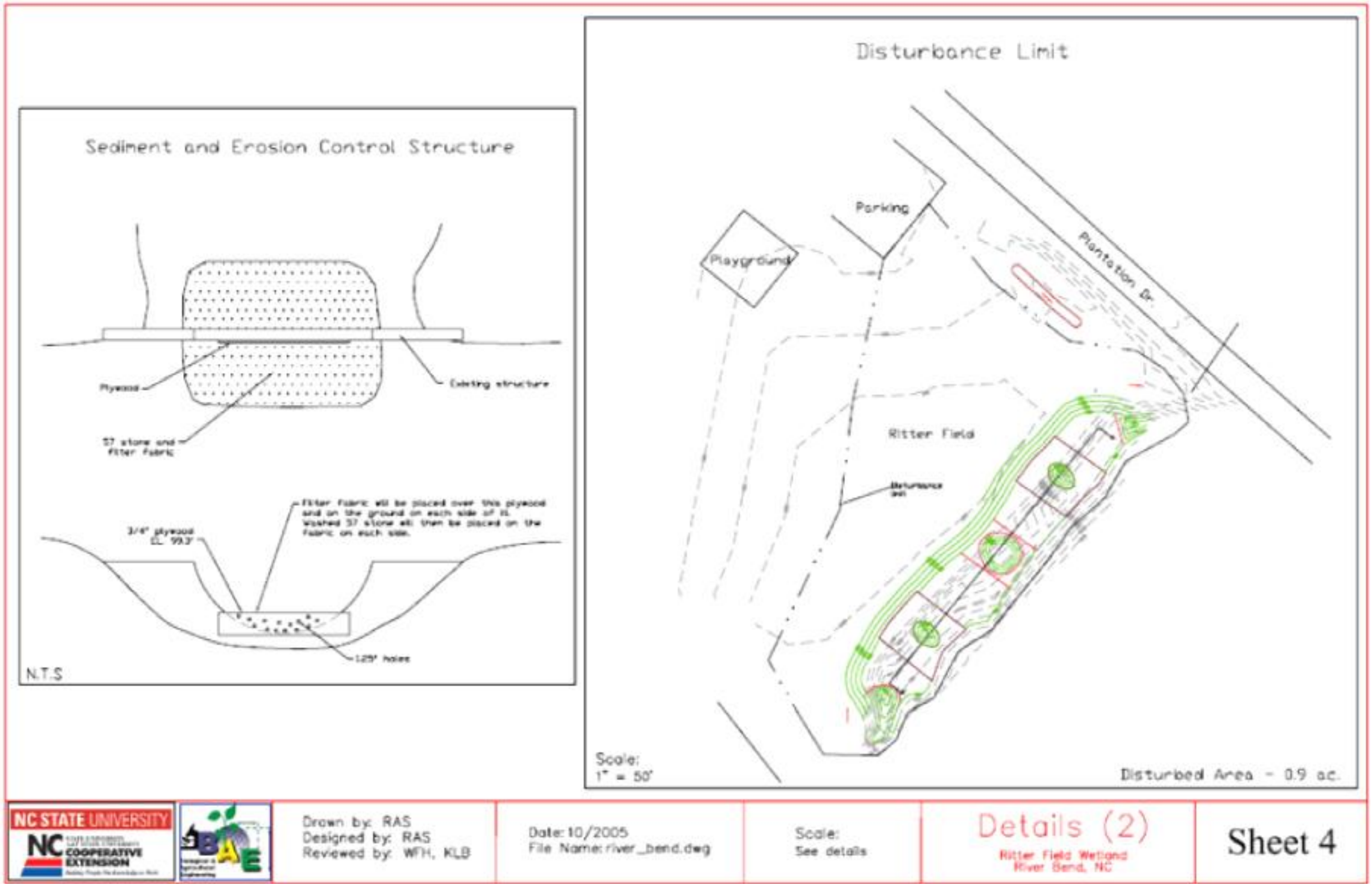
*Centipede seed - for 2/3 ac
*Straw - for 2/3 ac
*Tacking - 1 case (5 gal. total)
*Erosion control blanket - 6 100' roles, standard width
*Staples - 1 box of 1000
*Organic Amendment - 65 cy
*Fertilizer - for 7200 sf

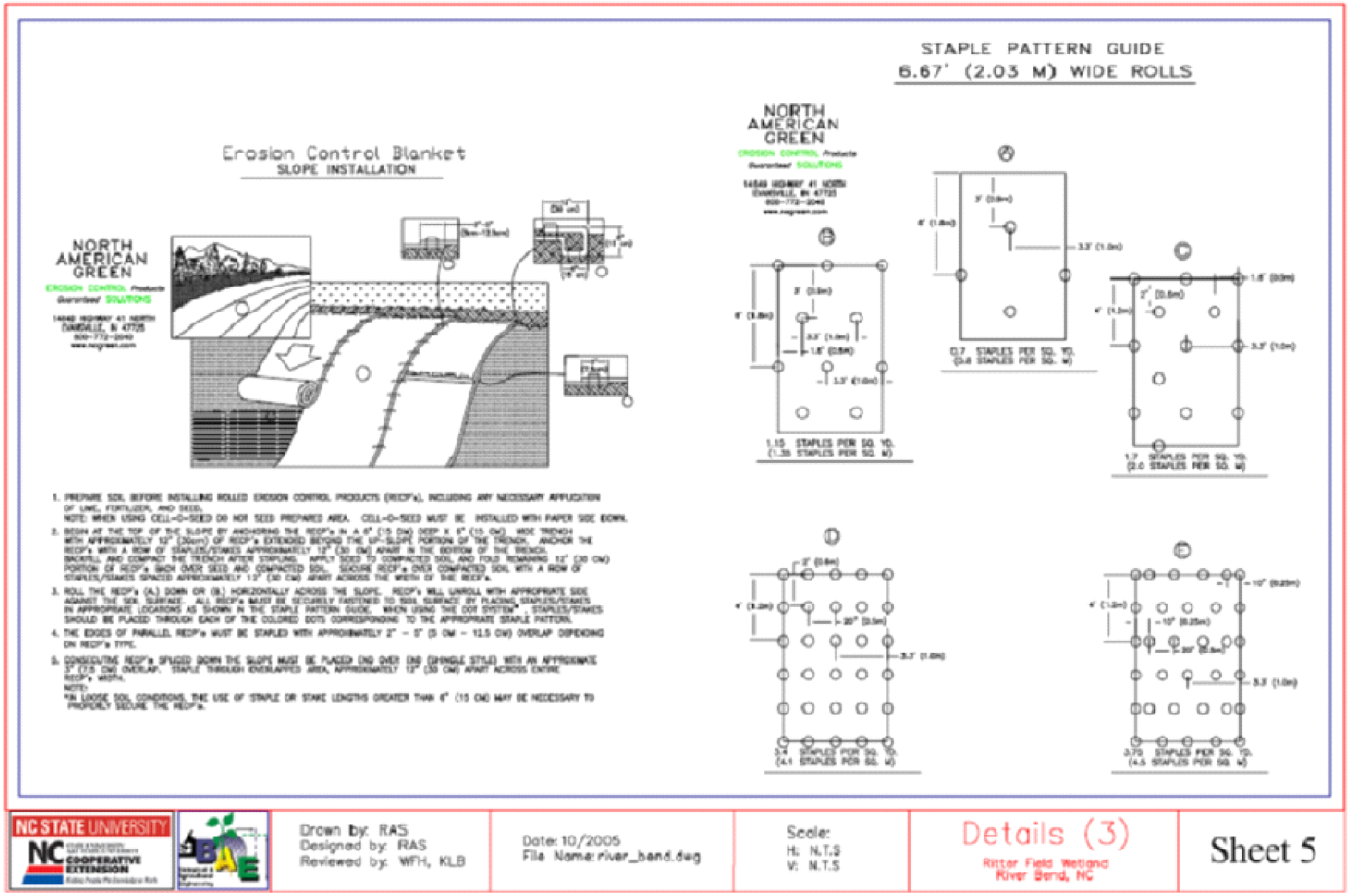
*57 stone - 700 lbs (1/3 ton)
*Filter fabric - 100 sf

Planting

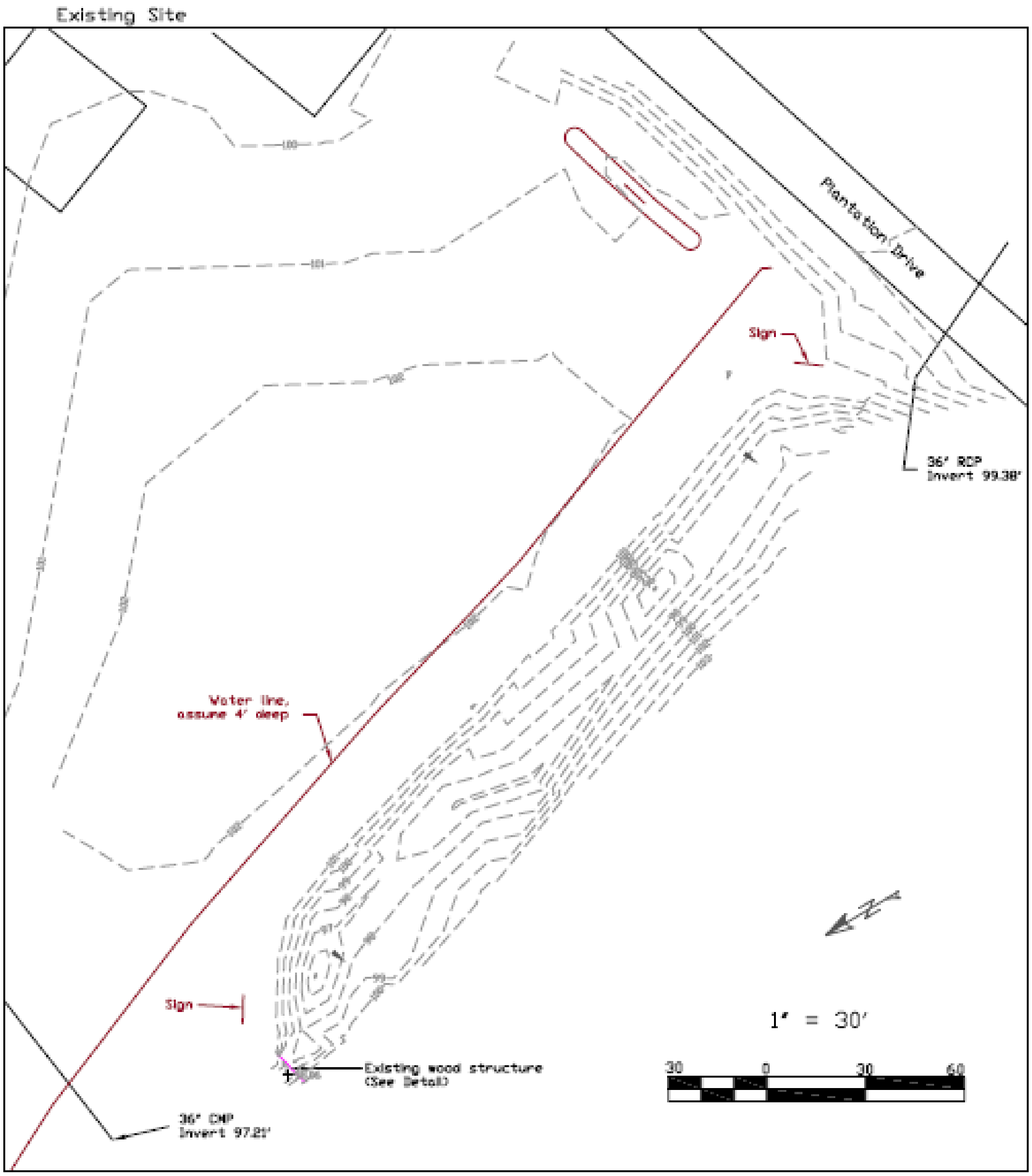
*In deep pools plant water lily and spatterdock, 3 each per pool.
*In elevations 97.95-98.2' plant pickerelweed (Pontederia cordata), lizard's tail (Saururus cernuus), arrow arrum (Peltandra virginica), duck potato (Sagittaria latifolia), rush (Juncus effusus), woolgrass (Scirpus cyperinus), soft stem bulrush (Scirpus validus). Plant on 18" centers in groups of 7-10 and randomize the groups
*On banks, around elevation 100', plant cardinal flower (Lobelia cardinalis), marsh mallows (Hibiscus moscheutos), pink fetterbush (lyonia lucida) and sweet pepperbush (Clethra alnifolia) spaced around 4' apart.
*Fertilize within 24 hours of planting with no imminent rainfall using 10-10-10 at 20 lbs per 1000 sf.

NC STATE UNIVERSITY NC COOPERATIVE EXTENSION	Drawn by: RAS Designed by: RAS Reviewed by: WFH, KLB	Date: 10/2005 File Name: river_bend.dwg	Scale: See details	Details (1) Ritter Field Wetland River Bend, NC	Sheet 3


Sediment and Erosion Control Structure
Plywood
Existing structure
57 stone and filter fabric
Filter fabric will be placed over this plywood and on the ground on each side of it. Washed 57 stone will then be placed on the fabric on each side.
3/4" plywood EL 99.3'
1.25" holes
N.T.S
Disturbance Limit
Parking
Playground
Plantation Dr.
Ritter Field
Scale: 1" = 50'
Disturbed Area - 0.9 ac.
NC STATE UNIVERSITY
NC COOPERATIVE EXTENSION
Drawn by: RAS
Designed by: RAS
Reviewed by: WFH, KLB
Date: 10/2005
File Name: river_bend.dwg
Scale: See details
Details (2)
Ritter Field Wetland
River Bend, NC
Sheet 4


STAPLE PATTERN GUIDE
6.67' (2.03 M) WIDE ROLLS
NORTH AMERICAN GREEN
Erosion Control Blanket
SLOPE INSTALLATION
NORTH AMERICAN GREEN
1.15 STAPLES PER SQ. YD.
1.7 STAPLES PER SQ. YD.
Drawn by: RAS
Designed by: RAS
Reviewed by: WFH, KLB
Date: 10/2005
File Name: river_band.dwg
Scale:
H: N.T.S
V: N.T.S
Details (3)
Ritter Field Wetland
River Bend, NC
Sheet 5

Ritter Field Stormwater Wetland Modification
River Bend, NC



A.2: River Bend wetland project statement

RIVER BEND PROJECT STATEMENT

Site Location

River Basin: Neuse
CU: 03020204
14-digit HU: 03020204010100
County: Craven
Municipality: River Bend
Receiving Water: Unnamed tributary to the Trent River; 27-101-(31); 030411
DWQ Classification of Receiving Water: Trent - SB Sw NSW
Use Support Rating for Receiving Water: Trent - FS

(See attached site location map, Figure 1)

Watershed Description

Drainage Area: 115 acres
Soils: Mostly Conetoe; Some Tarboro, Goldsboro, Udorthents, Masontown
Land Use: Primarily ½ acre residential, with some golf course and commercial areas
Average Watershed Slope: 1.5%
Pre-BMP Nutrient Loading Estimate: TN- 484 lb/ac/yr, TP- 75 lb/ac/yr

(See attached watershed view, Figure 2)

Site Description

Current Property Owners: Town of River Bend
Owners Willing to Cooperate: Yes
Land Area Available: 0.8 acres
Accessibility: Accessible from Plantation Dr.
Site Constraints: There is a 6 inch water line running through the middle of the available area, 5-6 feet deep

(See attached site layout, Figure 3)

BMP Recommendation

Type of BMP Recommended: Constructed wetland
Approximate BMP Surface Area: ¼ acre
Permits Required: None
Post-BMP Nutrient Export Estimate: TN- 291 lb/ac/yr (40% reduction), TP-49 lb/ac/yr (35% reduction)
Project Notes: This site was selected because it will treat a large, fully developed watershed. There is currently an undersized, under-performing BMP at the site that can be expanded and modified for improved water quality benefit to the receiving water. The current property owner is very interested in the project for treatment benefit and also improved aesthetics, as the site is heavily trafficked.

A constructed wetland would work well in the area because of a consistent water source from the large watershed and the visual appeal a wetland would bring. The wetland could likely fit on one side of the existing water line crossing the site, but it could easily expand to another cell on the other side of the line since the line is so deep.

Ecosystem Enhancement Program NCDENR NC STATE UNIVERSITY NC COOPERATIVE EXTENSION

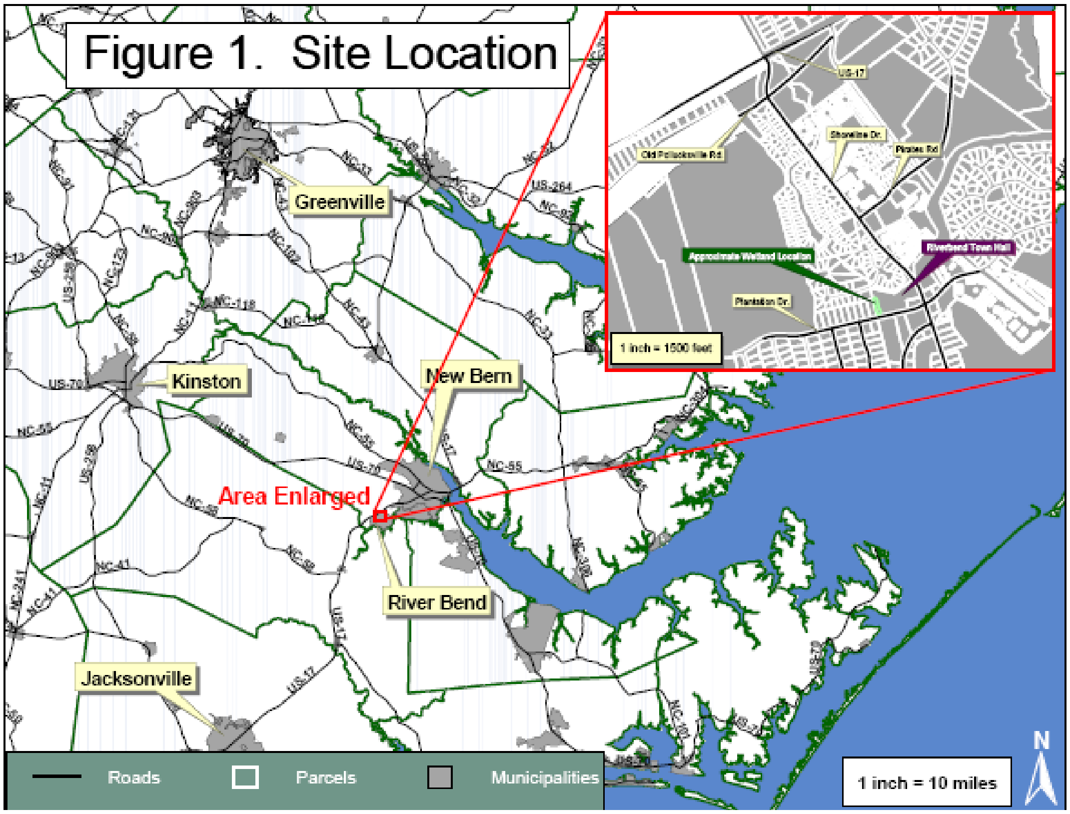
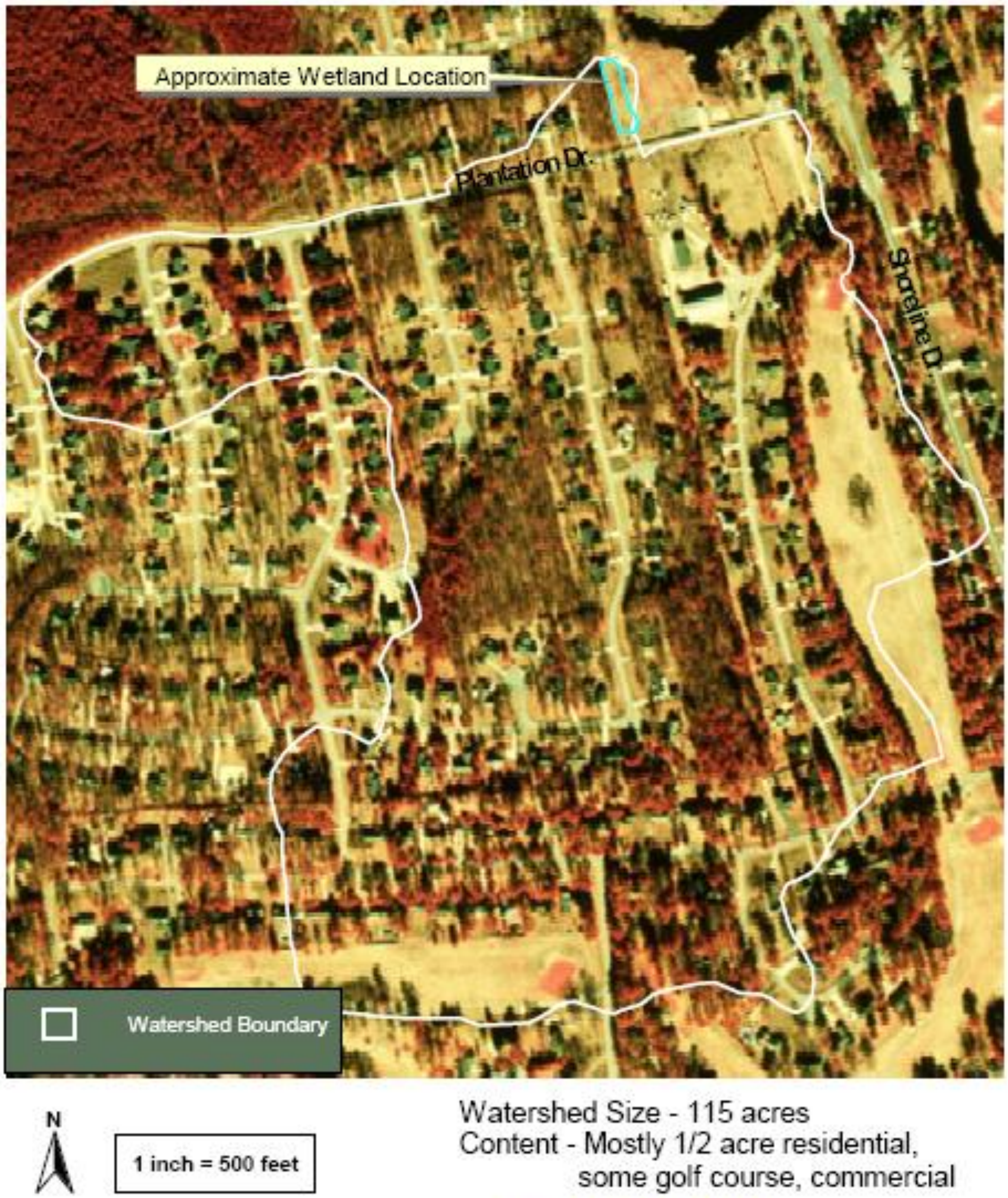


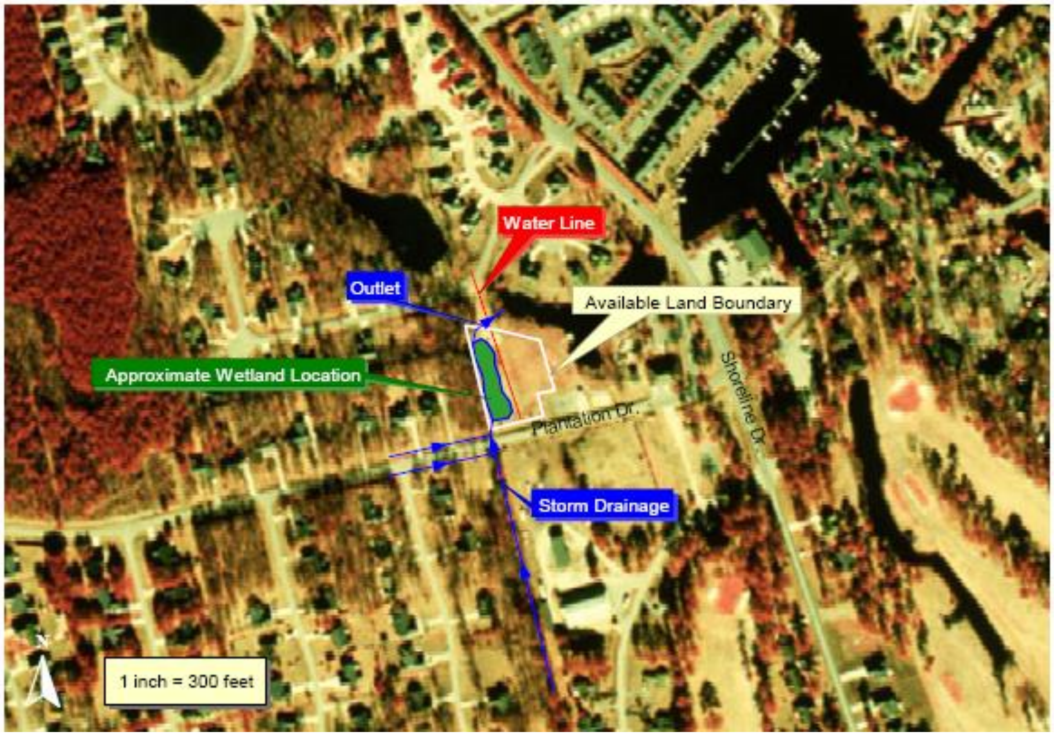
Figure 1. Site Location
Greenville
Kinston
New Bern
Area Enlarged
River Bend
Jacksonville
US-17
Old Pollocksville Rd.
Shoreline Dr.
Pirates Rd
Approximate Wetland Location
Riverbend Town Hall
Plantation Dr.
1 inch = 1500 feet
Roads
Parcels
Municipalities
1 inch = 10 miles
N

Figure 2. Watershed View



Watershed Size - 115 acres
Content - Mostly 1/2 acre residential, some golf course, commercial

Figure 3. Site Layout



APPENDIX B: Water quantity and quality results from all storms during monitoring period.

B.1: Inflow water quantity measurements during monitoring period.

Dates		Rainfall				Runoff		
Storm Date	Collection Date	Manual (cm)	ISCO (cm)	15 min peak (cm/hr)	Approx. Duration (hrs:min)	Volume (m3)	Peak (m3/s)	Approx. Duration (hrs:min)
7-Jul-07	9-Jul-07	na	na	na	na	615.7	0.1	6:30
10-Jul-07	11-Jul-07	2.18	1.96	0.58	2:15	309.8	0.0	6:30
11-Jul-07	17-Jul-07	5.41	1.80	1.17	3:00	596.5	0.1	11:00
13-Jul-07		0.00	2.51	1.85	1:45	1132.5	0.2	13:00
15-Jul-07		0.00	0.18	0.08	1:45	na	na	na
16-Jul-07		0.00	0.25	0.18	1:30	na	na	na
17-Jul-07	20-Jul-07	1.27	0.03	0.03	0:30	na	na	na
17-Jul-07		0.00	0.38	0.10	2:15	na	na	na
18-Jul-07		0.00	0.10	0.05	0:45	na	na	na
20-Jul-07		0.00	0.91	0.53	2:15	na	na	na
28-Jul-07	30-Jul-07	3.12	2.16	0.81	2:15	293.6	0.1	5:00
28-Jul-07		0.00	0.13	0.10	1:00	na	na	na
29-Jul-07		0.00	0.08	0.05	0:45	na	na	na
30-Jul-07		0.00	0.13	0.05	1:45	na	na	na
10-Aug-07	16-Aug-07	1.45	1.42	0.84	1:15	0.0	0.0	0:00:00
21-Aug-07	27-Aug-07	5.00	1.04	0.53	2:15	na	na	na
26-Aug-07		0.00	3.40	0.91	3:30	832.5	0.1	5:15
31-Aug-07	13-Sep-07	3.63	0.05	0.05	0:30	0.0	0.0	na
15-Sep-07	17-Sep-07	1.80	na	na	na	56.0	0.0	3:45
20-Sep-07	21-Sep-07	1.35	na	na	na	0.0	0.0	0:00
22-Sep-07	1-Oct-07	0.00	0.36	0.03	0:30	na	na	na
6-Oct-07	17-Oct-07	1.40	1.24	0.48	1:30	0.0	0.0	0:00
10-Oct-07		0.00	0.03	0.03	0:30	na	na	na
18-Oct-07	24-Oct-07	1.19	0.89	0.41	1:30	na	na	na
24-Oct-07		0.00	0.03	0.03	0:30	na	na	na
25-Oct-07	26-Oct-07	3.38	na	na	na	7.4	0.0	2:30
27-Oct-07	29-Oct-07	2.13	na	na	na	365.9	0.1	6:30
23-Nov-07	26-Nov-07	1.27	0.10	0.05	1:30	na	na	na
26-Nov-07		0.00	0.41	0.15	3:00	na	na	na
29-Nov-07	12-Dec-07	0.36	0.05	0.05	0:30	na	na	na
3-Dec-07		0.00	0.08	0.03	1:30	na	na	na
16-Dec-07	17-Dec-07	4.09	4.01	0.74	6:00	667.2	0.1	6:30
21-Dec-07	8-Jan-08	3.18	1.07	0.10	7:30	4.7	0.0	1:45
26-Dec-07		0.00	0.81	0.13	5:30	na	na	na
30-Dec-07		0.00	1.32	0.66	2:00	147.0	0.0	5:00
11-Jan-08	15-Jan-08	1.68	0.58	0.25	2:30	na	na	na

12-Jan-08		0.00	0.69	0.30	3:30	na	na	na
17-Jan-08	21-Jan-08	3.89	0.91	0.10	12:00	na	na	na
19-Jan-08		0.00	2.92	0.13	17:00	1240.2	0.0	21:00
23-Jan-08	2-Feb-08	1.91	0.41	0.13	4:30	na	na	na
30-Jan-08		0.00	0.36	0.10	3:00	na	na	na
1-Feb-08		0.00	0.71	0.46	1:45	na	na	na
13-Feb-08	14-Feb-08	3.28	3.00	0.25	11:00	631.3	0.1	12:00
18-Feb-08	19-Feb-08	1.40	1.17	0.33	3:00	47.3	0.0	3:30
22-Feb-08	24-Feb-08	2.54	2.57	0.18	15:00	992.0	0.0	20:00
26-Feb-08	6-Mar-08	2.82	0.46	0.20	1:30	na	na	na
5-Mar-08		0.00	2.21	1.50	1:30	649.7	0.1	9:00
7-Mar-08	10-Mar-08	2.06	1.78	0.38	8:30	560.6	0.0	25:00
15-Mar-08	17-Mar-08	1.52	1.65	0.51	3:00	196.9	0.0	7:00
20-Mar-08	3-Apr-08	3.86	0.46	0.10	3:30	na	na	na
1-Apr-08		0.00	3.00	0.69	4:00	817.3	0.2	9:00
5-Apr-08	8-Apr-08	5.51	5.13	0.41	11:00	5021.3	0.2	29:00
12-Apr-08	23-Apr-08	3.25	0.79	0.69	2:00	na	na	na
22-Apr-08		0.00	3.00	0.53	9:30	449.4	0.0	22:00
27-Apr-08	12-May-08	6.76	0.56	0.08	6:00	na	na	na
6-May-08		0.00	4.37	na	na	1169.5	0.2	9:00
11-May-08		0.00	1.83	na	na	504.8	0.0	11:30

B.2: Outflow water quantity measurements during monitoring period.

Dates		Runoff		
Storm Date	**Collection Date**	**Volume (m^3)**	**Peak (m^3/s)**	**Approx. Duration (hrs:min)**
7-Jul-07	9-Jul-07	547.3	0.04	16:00
10-Jul-07	11-Jul-07	178.6	0.01	20:00
11-Jul-07	17-Jul-07	587.5	0.02	15:00
13-Jul-07	17-Jul-07	976.7	0.10	11:00
15-Jul-07		na	na	na
16-Jul-07		na	na	na
17-Jul-07	20-Jul-07	na	na	na
17-Jul-07		na	na	na
18-Jul-07		na	na	na
20-Jul-07		na	na	na
28-Jul-07	30-Jul-07	127.7	0.01	13:00
28-Jul-07	30-Jul-07	na	na	na
29-Jul-07	30-Jul-07	na	na	na
30-Jul-07	30-Jul-07	na	na	na
10-Aug-07	16-Aug-07	0.0	na	na
21-Aug-07	27-Aug-07	na	na	na
26-Aug-07		371.6	0.04	6:00
31-Aug-07	13-Sep-07	0.0	na	na
15-Sep-07	17-Sep-07	0.0	0.00	0:00

20-Sep-07	21-Sep-07	0.0	0.00	0:00
22-Sep-07	1-Oct-07	na	na	na
6-Oct-07	17-Oct-07	na	na	na
10-Oct-07		na	na	na
18-Oct-07	24-Oct-07	na	na	na
24-Oct-07		na	na	na
25-Oct-07	26-Oct-07	0.0	0.00	0:00
27-Oct-07	29-Oct-07	150.2	0.01	20:00
23-Nov-07	26-Nov-07	na	na	na
26-Nov-07		na	na	na
29-Nov-07	12-Dec-07	na	na	na
3-Dec-07		na	na	na
16-Dec-07	17-Dec-07	1939.1	0.04	21:00
21-Dec-07	8-Jan-08	0.0	0.00	0:00
26-Dec-07		na	na	na
30-Dec-07		0.0	0.00	0:00
11-Jan-08	15-Jan-08	na	na	na
12-Jan-08		na	na	na
17-Jan-08	21-Jan-08	na	na	na
19-Jan-08		1153.5	0.02	30:00
23-Jan-08	2-Feb-08	na	na	na
30-Jan-08		na	na	na
1-Feb-08		na	na	na
13-Feb-08	14-Feb-08	419.0	0.02	23:00
18-Feb-08	19-Feb-08	28.8	0.00	13:00
22-Feb-08	24-Feb-08	716.9	0.02	32:00
26-Feb-08	6-Mar-08	na	na	na
5-Mar-08		1048.6	0.03	23:00
7-Mar-08	10-Mar-08	251.1	0.01	25:00
15-Mar-08	17-Mar-08	60.1	0.00	15:00
20-Mar-08	3-Apr-08	na	na	na
1-Apr-08		413.0	0.02	13:00
5-Apr-08	8-Apr-08	1427.4	0.06	25:00
12-Apr-08	23-Apr-08	na	na	na
22-Apr-08		93.9	0.00	21:00
27-Apr-08	12-May-08	na	na	na
6-May-08		528.8	0.06	10:00
11-May-08		160.5	0.01	15:00

B.3: Inflow water quality concentrations

Dates		Sample Analysis						COMMENTS
Storm Date	Collection Date	TKN µg/L	NO_{2-3} µg/L	NH_4 µg/L	TP µg/L	Ortho P µg/L	TSS mg/L	
7-Jul-07	9-Jul-07	620	330	30	240	140	52	Sample Analyzed
10-Jul-07	11-Jul-07	600	250	30	180	100	20	Sample Analyzed

11-Jul-07	17-Jul-07							Did not use sample Ants nested in outlet sampler.
13-Jul-07								
15-Jul-07								
16-Jul-07								
17-Jul-07	20-Jul-07							No Sample Collected ants no longer a problem
17-Jul-07								
18-Jul-07								
20-Jul-07								
28-Jul-07	30-Jul-07	510	370	80	180	110	27	Sample Analyzed. Marc Hortsman performed sampling.
28-Jul-07								
29-Jul-07								
30-Jul-07								
10-Aug-07	16-Aug-07							No Sample
21-Aug-07	27-Aug-07							Outflow has been bypassing weir for unknown amount of time. Sample Analyzed Repaired Aug 31st
26-Aug-07		660*	260*	20*	270*	210*	34*	
31-Aug-07	13-Sep-07							Replaced desiccant and adjusted out level to -0.2. Hurricane Gabrielle Sept 9th, no sample
15-Sep-07	17-Sep-07	660	570	40	210	160	30	Rain gage cord was severed by mower. Sample collected at inlet, no sample at outlet.
20-Sep-07	21-Sep-07							Rain gage cord repaired. Rain gauge tested, no sample.
22-Sep-07	1-Oct-07							No Sample
6-Oct-07	17-Oct-07							No Sample
10-Oct-07								
18-Oct-07	24-Oct-07							No Sample
24-Oct-07								
25-Oct-07	26-Oct-07							Rain gage not working. No sample collected
27-Oct-07	29-Oct-07	530	60	60	200	130	22	Sample, rain gage not working. Spider nest caused malfunction, discovered on 11/7/07
23-Nov-07	26-Nov-07							No Sample
26-Nov-07								No Sample
29-Nov-07	12-Dec-07							No Sample
3-Dec-07								No Sample
16-Dec-07	17-Dec-07	560*	80*	20*	530*	370*	41*	Sample analyzed. Leaves have blocked the outlet structure
21-Dec-07	8-Jan-08							Inflow but no outflow sample
26-Dec-07								
30-Dec-07								
11-Jan-08	15-Jan-08							No Samples
12-Jan-08								
17-Jan-08	21-Jan-08							Samples Analyzed
19-Jan-08		400	80	40	270	250	15	
23-Jan-08	2-Feb-08							No Samples
30-Jan-08								
1-Feb-08								
13-Feb-08	14-Feb-08							Outflow sample analyzed, no inflow sample due to ISCO malfunction

18-Feb-08	19-Feb-08							Inflow but no outflow sample
22-Feb-08	24-Feb-08	440	150	50	200	150	8	Inflow and outflow analyzed
26-Feb-08	6-Mar-08							
5-Mar-08		630	80	60	300	130	96	Inflow and outflow analyzed
7-Mar-08	10-Mar-08							No Samples
15-Mar-08	17-Mar-08							No Samples
20-Mar-08	3-Apr-08							
1-Apr-08		*410	*10	*40	*140	*70	*23	Inflow and outflow analyzed
5-Apr-08	8-Apr-08	560	10	60	150	100	30	Inflow and outflow analyzed
12-Apr-08	23-Apr-08							
22-Apr-08								Sample at inlet only
27-Apr-08	12-May-08							
6-May-08								Surprise storm, samples discarded due to prolonged sitting time
11-May-08		590	290	40	180	120	28	Collected and Analyzed samples, rain gage clogged

* Sample was not included in any analysis.

B.4: Outflow water quality concentrations

Dates		Sample Analysis					
Storm Date	Collection Date	TKN µg/L	$NO_{2\text{-}3}$ µg/L	NH_4 µg/L	TP µg/L	Ortho P µg/L	TSS mg/L
7-Jul-07	9-Jul-07	990	350	110	250	90	89
10-Jul-07	11-Jul-07	1180	220	50	190	30	33
11-Jul-07	17-Jul-07						
13-Jul-07							
15-Jul-07							
16-Jul-07							
17-Jul-07	20-Jul-07						
17-Jul-07							
18-Jul-07							
20-Jul-07							
28-Jul-07	30-Jul-07	2460	550	170	240	80	45
28-Jul-07							
29-Jul-07							
30-Jul-07							
10-Aug-07	16-Aug-07						
21-Aug-07	27-Aug-07						
26-Aug-07		910*	340*	40*	280*	140*	53*
31-Aug-07	13-Sep-07						
15-Sep-07	17-Sep-07						
20-Sep-07	21-Sep-07						
22-Sep-07	1-Oct-07						
6-Oct-07	17-Oct-07						
10-Oct-07							
18-Oct-07	24-Oct-07						
24-Oct-07							

25-Oct-07	26-Oct-07						
27-Oct-07	29-Oct-07	1080	250	150	190	90	26
23-Nov-07	26-Nov-07						
26-Nov-07							
29-Nov-07	12-Dec-07						
3-Dec-07							
16-Dec-07	17-Dec-07	1050*	40*	40*	480*	200*	59*
21-Dec-07	8-Jan-08						
26-Dec-07							
30-Dec-07							
11-Jan-08	15-Jan-08						
12-Jan-08							
17-Jan-08	21-Jan-08						
19-Jan-08		470	80	60	240	190	11
23-Jan-08	2-Feb-08						
30-Jan-08							
1-Feb-08							
13-Feb-08	14-Feb-08						
18-Feb-08	19-Feb-08						
22-Feb-08	24-Feb-08	490	30	30	150	80	11
26-Feb-08	6-Mar-08						
5-Mar-08		780	30	80	280	60	88
7-Mar-08	10-Mar-08						
15-Mar-08	17-Mar-08						
20-Mar-08	3-Apr-08						
1-Apr-08		680*	10*	60*	150*	30*	35*
5-Apr-08	8-Apr-08	690	30	70	190	90	20
12-Apr-08	23-Apr-08						
22-Apr-08							
27-Apr-08	12-May-08						
6-May-08							
11-May-08		871	206	133	215	85	43

* Sample was not included in any analysis.

APPENDIX C: Soil sampling reports for phosphorus and nitrogen during monitoring period.

C.1: Phosphorus content and index values during monitoring period.

Sampled March 28, 2007				Sampled June 4, 2007			
Sample ID	P (mg/dm^3)	P-I	Average P-I Values	Sample ID	P (mg/dm^3)	P-I	Average P-I Values
A1	57.9	48	47	A1	61.9	52	47
A2	56.7	47		A2	56.5	47	
A3	54.5	45		A3	50.1	42	
B1	91.5	76	54	B1	105.0	88	58
B2	64.6	54		B2	54.8	46	
B3	39.9	33		B3	48.0	40	
C1	66.6	56	47	C1	77.5	65	51
C2	66.5	55		C2	64.6	54	
C3	37.6	31		C3	42.6	36	
D1	24.7	21	30	D1	32.2	27	36
D2	43.0	36		D2	49.2	41	
D3	39.6	33		D3	49.0	41	
E1	53.4	45	45	E1	51.3	43	43
E2	55.6	46		E2	42.3	35	
E3	53.8	45		E3	59.6	50	
F1	41.9	35	40	F1	44.1	37	40
F2	57.5	48		F2	50.4	42	
F3	45.4	38		F3	50.0	42	
G1	25.1	21	31	G1	29.6	25	35
G2	52.9	44		G2	52.7	44	
G3	33.2	28		G3	44.6	37	

Sampled August 3, 2007				Sampled October 4, 2007			
Sample ID	P (mg/dm^3)	P-I	Average P-I Values	Sample ID	P (mg/dm^3)	P-I	Average P-I Values
A1	70.2	59	52	A1	57.6	48	44
A2	61.1	51		A2	54.0	45	
A3	55.9	47		A3	48.0	40	
B1	98.7	82	56	B1	92.4	77	57
B2	60.0	50		B2	56.4	47	
B3	42.6	36		B3	57.6	48	
C1	73.4	61	49	C1	69.6	58	48
C2	61.8	52		C2	60.0	50	
C3	41.2	34		C3	44.4	37	
D1	64.2	54	47	D1	38.4	32	32
D2	54.1	45		D2	42.0	35	
D3	51.3	43		D3	34.8	29	

E1	44.6	37	39	E1	33.6	28	30
E2	52.9	44		E2	45.6	38	
E3	44.3	37		E3	28.8	24	
F1	22.7	19	36	F1	34.8	29	40
F2	53.0	44		F2	52.8	44	
F3	53.9	45		F3	55.2	46	
G1	*	*	36	G1	42.0	35	39
G2	54.3	45		G2	58.8	49	
G3	33.0	28		G3	38.4	32	

* Misplaced lab sample.

Sampled January 15, 2007				Sampled April 8, 2007*			
Sample ID	P (mg/dm^3)	P-I	Average P-I Values	Sample ID	P (mg/dm^3)	P-I	Average P-I Values
A1	49.2	41	38	A1	54.0	45	40
A2	49.2	41		A2	51.6	43	
A3	37.2	31		A3	39.6	33	
B1	103.2	86	60	B1	100.8	84	56
B2	57.6	48		B2	54.0	45	
B3	54.0	45		B3	48.0	40	
C1	56.4	47	39	C1	50.4	42	40
C2	51.6	43		C2	55.2	46	
C3	33.6	28		C3	37.2	31	
D1	15.6	13	25	D1	36.0	30	31
D2	37.2	31		D2	42.0	35	
D3	38.4	32		D3	32.4	27	
E1	24.0	20	27	E1	31.2	26	29
E2	36.0	30		E2	40.8	34	
E3	37.2	31		E3	33.6	28	
F1	26.4	22	29	F1	30.0	25	31
F2	36.0	30		F2	34.8	29	
F3	43.2	36		F3	45.6	38	
G1	30.0	25	32	G1	36.0	30	34
G2	43.2	36		G2	50.4	42	
G3	43.2	36		G3	34.8	29	

* Not used in statistical analysis due to late delivery of data.

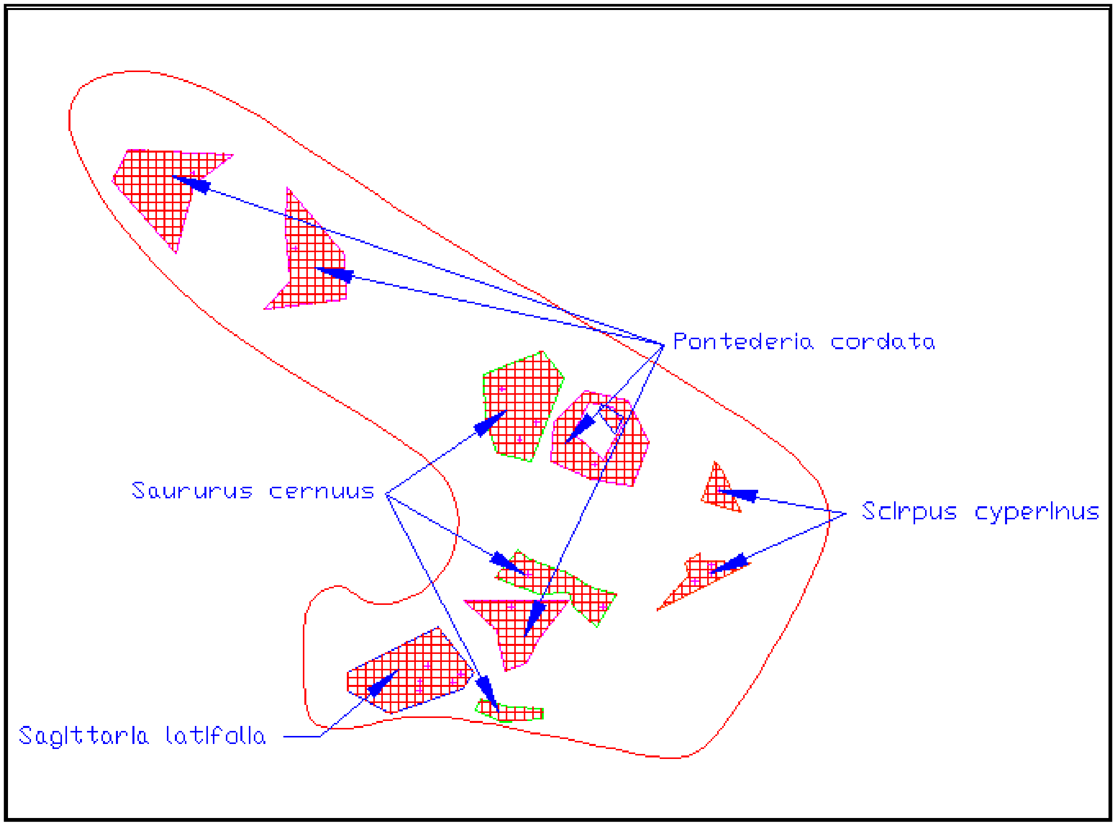
C.2: Nitrogen content values for soil samples.

Sample Area	TN (mg/kg)	Bulk Density* (g/cm^3)	mg TN/cm^3	Depth (cm)	Wetland Area (m^2)	TN (kg)
X	211	1.3	0.27	10	458	12.6
Y	714	1.3	0.93	10	458	42.5
Z	259	1.3	0.34	10	458	15.4
					TOTAL	70.5

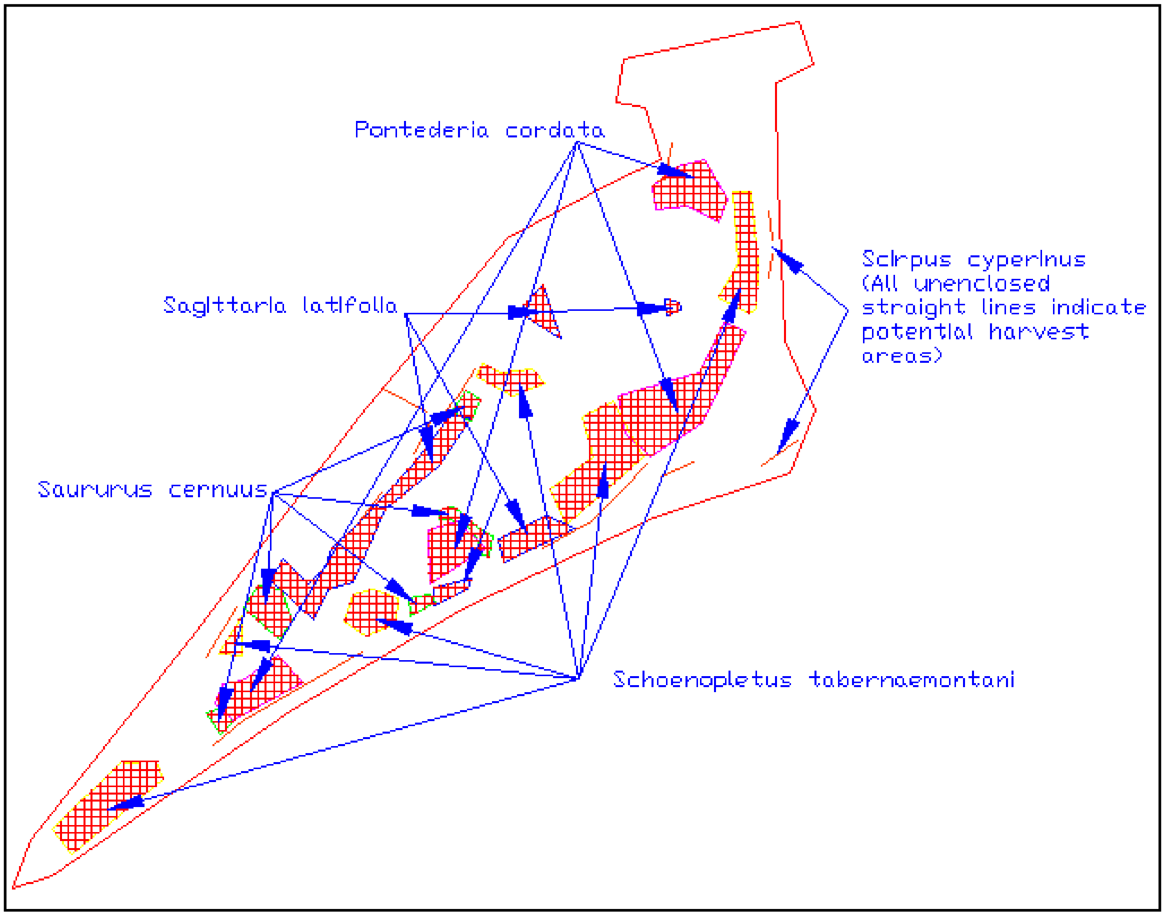
* Value averaged from P-index reports.

APPENDIX D: Vegetation surveys from the Smithfield and Pactolus wetlands

D.1: Vegetation survey from the Smithfield wetland



D.2: Vegetation survey from the Pactolus wetland



APPENDIX E: Plant sample data for the River Bend, Smithfield and Pactolus wetlands.

E.1: Plant sample data for the River Bend wetland.

Riverbend wetland					
Plant Sample	Dry Weight (g)	Above Ground Biomass (g/m^2)	Sample Size (mg)	% N per sample	Total N (g/m^2)
RB1	57.9	231.6	8.0	1.34%	3.1
RB2	45.1	180.3	8.0	1.12%	2.0
RB3	19.8	79.2	8.0	1.10%	0.9
RB4	85.5	342.0	8.0	0.76%	2.6
RB5	41.6	166.3	8.0	1.42%	2.4
RB6	58.4	233.6	8.0	1.12%	2.6
RB7	53.8	215.0	8.0	0.68%	1.5
RB8	12.4	49.6	8.0	1.84%	0.9
RB9	NSA	NSA	8.0	0.00%	0.0
RB10	NSA	NSA	8.0	0.00%	0.0
RB11	NSA	NSA	8.0	0.00%	0.0
RB12	3.5	14.1	8.0	3.91%	0.6
RB13	8.2	32.8	8.0	1.49%	0.5
RB14	3.4	13.6	8.0	2.39%	0.3
RB15	70.2	280.8	8.0	1.89%	5.3
RB16	1.7	6.8	8.0	2.19%	0.1
RB17	5.4	21.7	8.0	2.46%	0.5
RB18	102.6	410.4	8.0	1.17%	4.8
RB19	10.6	42.4	8.0	2.36%	1.0
RB20	17.8	71.3	8.0	2.13%	1.5
RB21	6.9	27.5	8.0	1.24%	0.3
RB22	19.2	76.8	8.0	1.49%	1.1
RB23	10.8	43.3	8.0	1.75%	0.8
RB24	2.7	10.9	8.0	0.55%	0.1
RB25	8.4	33.5	8.0	1.81%	0.6
RB2R	30.6	122.4	8.0	0.60%	0.7
RB5R	20.6	82.5	8.0	0.63%	0.5
RB15R	121.7	486.8	8.0	0.87%	4.2
RB19R	7.2	28.8	8.0	1.05%	0.3
RB20R	12.9	51.6	8.0	0.82%	0.4

E.2: Plant sample data for the Smithfield wetland.

	Smithfield wetland						
	Plant Sample	Dry Weight (g)	Above Ground Biomass (g/m^2)	Sample Size (mg)	% N per sample	Total N (g/m^2)	Mean N (g/m^2)
Sagittaria latifolia	SFAH1	96.2	384.6	8.0	2.60%	10.0	8.00
	SFAH2	85.1	340.4	8.0	2.65%	9.0	
	SFAH3	76.2	304.9	8.0	2.45%	7.5	
	SFAH4	60.9	243.5	8.0	2.24%	5.5	
	SFAH5	65.5	262.1	8.0	3.08%	8.1	
Pontederia cordata	SFPW1	139.2	556.9	8.0	2.59%	14.4	8.85
	SFPW2	125.9	503.6	8.0	1.89%	9.5	
	SFPW3	63.0	252.2	8.0	2.21%	5.6	
	SFPW4	97.0	388.0	8.0	2.43%	9.4	
	SFPW5	91.7	366.7	8.0	1.45%	5.3	
Scirpus cyperinus	SFWG1	109.1	436.3	8.0	0.97%	4.2	3.43
	SFWG2	143.6	574.6	8.0	0.62%	3.6	
	SFWG3	83.9	335.4	8.0	0.67%	2.2	
	SFWG4	160.1	640.4	8.0	0.65%	4.2	
	SFWG5	70.6	282.6	8.0	1.04%	2.9	
Saururus cernuus	SFLT1	72.9	291.7	8.0	1.00%	2.9	3.08
	SFLT2	91.8	367.2	8.0	0.74%	2.7	
	SFLT3	64.2	256.6	8.0	0.96%	2.5	
	SFLT4	91.9	367.5	8.0	1.09%	4.0	
	SFLT5	63.9	255.6	8.0	1.29%	3.3	
Roots	SFAHR1	51.4	205.6	8.0	1.94%	4.0	na
	SFPWR1	239.5	958.1	8.0	1.17%	11.2	
	SFWGR1	71.6	286.6	8.0	0.85%	2.4	
	SFLTR1	188.4	753.4	8.0	0.96%	7.2	

E.3: Plant sample data for the Pactolus wetland.

	Pactolus wetland						
	Plant Sample	Dry Weight (g)	Above Ground Biomass (g/m^2)	Sample Size (mg)	% N per sample	Total N (g/m^2)	Mean N (g/m^2)
Sagittaria latifolia	PAH1	28.6	114.6	8.0	2.61%	3.0	6.08
	PAH2	58.0	231.9	8.0	2.55%	5.9	
	PAH3	81.1	324.3	8.0	2.55%	8.3	

	PAH4	90.7	362.8	8.0	2.87%	10.4	
	PAH5	27.8	111.4	8.0	2.55%	2.8	
Pontederia cordata	PPW1	258.4	1033.4	8.0	1.82%	18.8	11.91
	PPW2	183.9	735.7	8.0	1.65%	12.1	
	PPW3	193.3	773.2	8.0	1.13%	8.7	
	PPW4	251.6	1006.3	8.0	0.90%	9.1	
	PPW5	238.6	954.4	8.0	1.13%	10.8	
Scirpus cyperinus	PWG1	319.5	1278.0	8.0	1.12%	14.3	12.67
	PWG2	413.2	1652.9	8.0	0.69%	11.4	
	PWG3	477.4	1909.6	8.0	0.84%	16.0	
	PWG4	637.3	2549.2	8.0	0.35%	8.9	
	PWG5*	859.4	3437.7	8.0	0.91%	31.3	
Saururus cernuus	PLT1	54.6	218.6	8.0	2.32%	5.1	5.82
	PLT2	61.2	244.7	8.0	2.11%	5.2	
	PLT3	45.0	180.1	8.0	2.21%	4.0	
	PLT4	70.8	283.0	8.0	2.04%	5.8	
	PLT5	112.4	449.4	8.0	2.03%	9.1	
Schoenopletus tabernaemontani	PSS1	128.5	513.9	8.0	1.63%	8.4	11.08
	PSS2	313.9	1255.5	8.0	1.23%	15.4	
	PSS3	207.1	828.6	8.0	1.56%	12.9	
	PSS4	224.7	898.8	8.0	0.87%	7.8	
	PSS5	227.8	911.1	8.0	1.19%	10.8	
Roots	PAHR1	32.9	131.6	8.0	1.42%	1.9	na
	PPWR1	423.1	1692.5	8.0	0.77%	13.0	
	PWGR1	138.7	554.8	8.0	0.39%	2.2	
	PLTR1	64.4	257.7	8.0	1.11%	2.9	
	PSSR1	151.8	607.1	8.0	0.70%	4.2	

* Sample not used in statistical analysis. Statistically the sample was considered an extreme outlier and not an accurate representative data point.

APPENDIX F: SAS® water quantity analysis code and output.

F.1: SAS® water quantity analysis code for runoff volume comparison.

```
options ls=75;
/*Runoff Volume
Location = (Inflow = I, Outflow = O)
Volume = cf
*/
data flowin;
input Location $ Pollutant Season Volume;
event=_n_;
cards;
I   1   1 21744
I   1   1 10940.4
I   1   1 21064.1
I   1   1 39992.1
I   1   1 10367
I   1   1 0
I   1   1 0
I   1   1 1978
I   1   1 0
I   1   2 261.1
I   1   2 12922.1
I   1   2 167
I   1   2 5193
I   1   2 43796
I   1   2 22293
I   1   2 1672
I   1   2 35033
I   1   2 19796.3
I   1   1 6954.3
I   1   1 28863.5
I   1   1 177324
I   1   1 15872
I   1   1 41300
I   1   1 17827.1
;
run;
data flowout;
input Location $ Pollutant Season Volume;
event=_n_;
cards;
O   1   1 19328.5
O   1   1 6308.5
O   1   1 20747
O   1   1 34490.6
O   1   1 4510.60
O   1   1 0
O   1   1 0
O   1   1 0
```

```
O  1  1 0
O  1  2 0
O  1  2 5303.90
O  1  2 0.00
O  1  2 0.00
O  1  2 40736
O  1  2 14797
O  1  2 1017
O  1  2 25315.6
O  1  2 8868.8
O  1  1 2121.90
O  1  1 14586.0
O  1  1 50409.5
O  1  1 3317.1
O  1  1 18673
O  1  1 5668
;
run;
data allflow;
   set flowin flowout;
run;
proc sort data=allflow;
   by pollutant;
run;
proc glm data=allflow;
      by pollutant;
      class event location;
      model volume=location event;
      lsmeans location;
run;
```

F.1: SAS® water quantity analysis output for runoff volume comparison.

```
                              The SAS System

------------------------------ Pollutant=1 ------------------------------

                             The GLM Procedure

                          Class Level Information

Class         Levels  Values

event             24  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
                      22 23 24

Location           2  I O


                  Number of Observations Read          48
                  Number of Observations Used          48
```

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure

Dependent Variable: Volume

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	24	28281245026	1178385209	3.66	0.0014
Error	23	7407104619	322048027		
Corrected Total	47	35688349645			

R-Square	Coeff Var	Root MSE	Volume Mean
0.792450	106.1406	17945.70	16907.48

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	1399258832	1399258832	4.34	0.0484
event	23	26881986194	1168782008	3.63	0.0015

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure

Dependent Variable: Volume

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	1399258832	1399258832	4.34	0.0484
event	23	26881986194	1168782008	3.63	0.0015

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure
Least Squares Means

Location	Volume LSMEAN
I	22306.6667
O	11508.2917

F.3: SAS® water quantity analysis code for peak flow comparison.

```
options ls=75;
/*Peak Inflow Outflow
Location = (Inflow = I, Outflow = O)
Peak flow = cfs
*/
data flowin;
input Location $ Pollutant Season Flow;
event=_n_;
cards;
I  1  1 3.70
I  1  1     1.65
I  1  1 2.05
I  1  1 7.30
I  1  1 2.59
I  1  1 0
I  1  1 0
I  1  1 0.45
I  1  1 0
I  1  2 0.05
I  1  2 2.00
I  1  2 0.04
I  1  2 0.85
I  1  2 1.67
I  1  2 1.83
I  1  2 0.30
I  1  2 1.65
I  1  2 1.69
I  1  2 1.32
I  1  1 5.67
I  1  1 6.17
I  1  1 0.93
I  1  1 7.65
I  1  1 1.67
;
run;
data flowout;
input Location $ Pollutant Season Flow;
event=_n_;
cards;
O  1  1 1.27
O  1  1 0.29
O  1  1 0.72
O  1  1 3.63
O  1  1 0.31
O  1  1 0.00
```

```
O   1   1 0.00
O   1   1 0.00
O   1   1 0.00
O   1   2 0.00
O   1   2 0.23
O   1   2 0.00
O   1   2 0.00
O   1   2 0.81
O   1   2 0.63
O   1   2 0.01
O   1   2 0.67
O   1   2 0.32
O   1   2 0.06
O   1   1 0.78
O   1   1 2.00
O   1   1 0.06
O   1   1 2.23
O   1   1 0.29
;
run;
data allflow;
   set flowin flowout;
run;
proc sort data=allflow;
   by pollutant;
run;
proc glm data=allflow;
      by pollutant;
      class event location;
      model flow=location event;
      lsmeans location;
run;
```

F.4: SAS® water quantity analysis output for peak flow comparison.

```
                              The SAS System

------------------------------ Pollutant=1 ------------------------------

                             The GLM Procedure

                          Class Level Information

Class        Levels  Values

event            24  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
                     22 23 24

Location          2  I O

                   Number of Observations Read          48
                   Number of Observations Used          48
```

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure

Dependent Variable: Flow

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	24	141.0716250	5.8779844	4.87	0.0002
Error	23	27.7423667	1.2061899		
Corrected Total	47	168.8139917			

R-Square	Coeff Var	Root MSE	Flow Mean
0.835663	80.43455	1.098267	1.365417

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	28.3976333	28.3976333	23.54	<.0001
event	23	112.6739917	4.8988692	4.06	0.0007

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure

Dependent Variable: Flow

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	28.3976333	28.3976333	23.54	<.0001
event	23	112.6739917	4.8988692	4.06	0.0007

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure
Least Squares Means

Location	Flow LSMEAN
I	2.13458333
O	0.59625000

APPENDIX G: SAS® code and output of water quality water data.

SUMMARY

There are 8 sections within appendix G. Sections G.1 and G.2 display the code and output for the proc glm procedure based on water quality concentration data (mg/L). The proc glm procedure provides an Analysis of Variance (ANOVA) to test for significance between concentrations and locations. Section G.3 and G.4 display the code and output for the mixed procedure based on water quality concentration data. The proc mixed procedure provides a completely randomized split block design (CRSPD) to test for significance between location and season. Sections G.5, G.6, G.7 and G.8 display the same procedures based on water quality load data (lbs). All pollutants are represented by a pollutant number in the SAS code and output by; pollutant 1= TKN, pollutant 2= $NO_{3\text{-}2}$-N, pollutant 3= NH_4-N, pollutant 4= TP, pollutant 5= Ortho P, pollutant 6 = TSS and pollutant 7= TN. Inflow and outflow locations are represented in the SAS code and output by; I = inflow and O = outflow. Seasons are represented in the SAS code and output by; 1 = growing season and 2 = non-growing season.

G.1: SAS® code for proc glm procedure associated with concentrations.

```
options ls=75;
/* Water Quality Data
  Location =  Location (Inflow = I  Outflow = O)
  Pollutant =  Type (1= TKN, 2 = Nitrate Nitrite, 3 = Ammonium, 4 = TP
             5= Ortho P, 6 = TSS, 7 = TN)
  concentration = mg/L
*/
data poll1in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  1  1 0.62
I  1  1 0.60
I  1  1 0.51
I  1  1 0.66
I  1  2 0.53
I  1  2 0.40
I  1  2 0.44
I  1  2 0.55
I  1  1 0.41
I  1  1 0.56
I  1  1 0.59
;
run;
data poll1out;
input Location $ Pollutant Season Concentration;
```

```
event=_n_;
cards;
O  1  1 0.99
O  1  1 1.18
O  1  1 2.46
O  1  1 0.00
O  1  2 1.08
O  1  2 0.47
O  1  2 0.49
O  1  2 0.56
O  1  1 0.68
O  1  1 0.69
O  1  1 0.87
;
data poll2in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  2  1 0.33
I  2  1 0.25
I  2  1 0.37
I  2  1 0.57
I  2  2 0.06
I  2  2 0.08
I  2  2 0.15
I  2  2 0.02
I  2  1 0.01
I  2  1 0.01
I  2  1 0.29
;
run;
data poll2out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  2  1 0.35
O  2  1 0.22
O  2  1 0.55
O  2  1 0.00
O  2  2 0.25
O  2  2 0.08
O  2  2 0.03
O  2  2 0.02
O  2  1 0.01
O  2  1 0.03
O  2  1 0.21
;
run;
data poll3in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  3  1 0.03
```

```
I   3   1  0.03
I   3   1  0.08
I   3   1  0.04
I   3   2  0.06
I   3   2  0.04
I   3   2  0.05
I   3   2  0.18
I   3   1  0.04
I   3   1  0.06
I   3   1  0.04
;
run;
data poll3out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   3   1  0.11
O   3   1  0.05
O   3   1  0.17
O   3   1  0.00
O   3   2  0.15
O   3   2  0.06
O   3   2  0.03
O   3   2  0.07
O   3   1  0.06
O   3   1  0.07
O   3   1  0.13
;
run;
data poll4in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   4   1  0.24
I   4   1  0.18
I   4   1  0.18
I   4   1  0.21
I   4   2  0.20
I   4   2  0.27
I   4   2  0.20
I   4   2  0.16
I   4   1  0.14
I   4   1  0.15
I   4   1  0.18
;
run;
data poll4out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   4   1  0.25
O   4   1  0.19
O   4   1  0.24
```

```
O   4   1  0.00
O   4   2  0.19
O   4   2  0.24
O   4   2  0.15
O   4   2  0.13
O   4   1  0.15
O   4   1  0.19
O   4   1  0.22
;
run;
data poll5in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   5   1  0.14
I   5   1  0.10
I   5   1  0.11
I   5   1  0.16
I   5   2  0.13
I   5   2  0.25
I   5   2  0.15
I   5   2  0.09
I   5   1  0.07
I   5   1  0.10
I   5   1  0.12
;
run;
data poll5out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   5   1  0.09
O   5   1  0.03
O   5   1  0.08
O   5   1  0.00
O   5   2  0.09
O   5   2  0.19
O   5   2  0.08
O   5   2  0.05
O   5   1  0.03
O   5   1  0.09
O   5   1  0.09
;
run;
data poll6in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   6   1  52
I   6   1  20
I   6   1  27
I   6   1  30
I   6   2  22
```

```
I   6   2 15
I   6   2 8
I   6   2 11
I   6   1 23
I   6   1 30
I   6   1 28
;
run;
data poll6out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   6   1 89
O   6   1 33
O   6   1 45
O   6   1 0
O   6   2 26
O   6   2 11
O   6   2 11
O   6   2 14
O   6   1 35
O   6   1 20
O   6   1 43
;
run;
data poll7in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   7   1 0.95
I   7   1 0.85
I   7   1 0.88
I   7   1 1.23
I   7   2 0.59
I   7   2 0.48
I   7   2 0.59
I   7   2 0.57
I   7   1 0.42
I   7   1 0.57
I   7   1 0.88
;
run;
data poll7out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   7   1 1.34
O   7   1 1.40
O   7   1 3.01
O   7   1 0.00
O   7   2 1.33
O   7   2 0.55
O   7   2 0.52
```

```
O   7   2 0.58
O   7   1 0.69
O   7   1 0.72
O   7   1 1.08
;
run;
data all7;
   set poll1in poll1out poll2in poll2out poll3in poll3out poll4in poll4out
poll5in poll5out poll6in poll6out poll7in poll7out;
run;
proc sort data=all7;
   by pollutant;
run;
proc glm data=all7;
   by pollutant;
   class event location;
   model concentration=location event;
   lsmeans location;
run;
```

G.2: SAS® output for proc glm procedure associated with concentrations.

```
                              The SAS System

------------------------------ Pollutant=1 ------------------------------

                             The GLM Procedure

                         Class Level Information

             Class          Levels    Values

             event              11    1 2 3 4 5 6 7 8 9 10 11

             Location            2    I O


                  Number of Observations Read          22
                  Number of Observations Used          22

                              The SAS System
```

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	2.56552727	0.23322975	1.16	0.4098
Error	10	2.00570909	0.20057091		
Corrected Total	21	4.57123636			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.561233	64.22902	0.447851	0.697273

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.58909091	0.58909091	2.94	0.1173
event	10	1.97643636	0.19764364	0.99	0.5090

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.58909091	0.58909091	2.94	0.1173
event	10	1.97643636	0.19764364	0.99	0.5090

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure

Least Squares Means

Location	Concentration LSMEAN
I	0.53363636
O	0.86090909

The SAS System

------------------------------ Pollutant=2 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read	22
Number of Observations Used	22

The SAS System

------------------------------ Pollutant=2 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.45024091	0.04093099	2.04	0.1364
Error	10	0.20103636	0.02010364		
Corrected Total	21	0.65127727			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.691320	80.18819	0.141787	0.176818

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.00691364	0.00691364	0.34	0.5706
event	10	0.44332727	0.04433273	2.21	0.1142

The SAS System

------------------------------ Pollutant=2 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.00691364	0.00691364	0.34	0.5706
event	10	0.44332727	0.04433273	2.21	0.1142

The SAS System

------------------------------ Pollutant=2 ------------------------------

The GLM Procedure

Least Squares Means

Location	Concentration LSMEAN
I	0.19454545
O	0.15909091

The SAS System

------------------------------ Pollutant=3 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read	22
Number of Observations Used	22

The SAS System

------------------------------ Pollutant=3 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.02808636	0.00255331	1.26	0.3600
Error	10	0.02020909	0.00202091		
Corrected Total	21	0.04829545			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.581553	63.80642	0.044955	0.070455

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.00284091	0.00284091	1.41	0.2632
event	10	0.02524545	0.00252455	1.25	0.3659

------------------------------- Pollutant=3 -------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.00284091	0.00284091	1.41	0.2632
event	10	0.02524545	0.00252455	1.25	0.3659

The SAS System

------------------------------- Pollutant=3 -------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	0.05909091
O	0.08181818

The SAS System

------------------------------- Pollutant=4 -------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read	22
Number of Observations Used	22

The SAS System

------------------------------- Pollutant=4 -------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.03990909	0.00362810	1.36	0.3169
Error	10	0.02663636	0.00266364		
Corrected Total	21	0.06654545			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.599727	27.96624	0.051610	0.184545

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.00116364	0.00116364	0.44	0.5236
event	10	0.03874545	0.00387455	1.45	0.2822

The SAS System

------------------------------- Pollutant=4 -------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.00116364	0.00116364	0.44	0.5236
event	10	0.03874545	0.00387455	1.45	0.2822

The SAS System

------------------------------- Pollutant=4 -------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	0.19181818
O	0.17727273

The SAS System

------------------------------ Pollutant=5 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read	22
Number of Observations Used	22

------------------------------ Pollutant=5 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.05639091	0.00512645	6.63	0.0029
Error	10	0.00773636	0.00077364		
Corrected Total	21	0.06412727			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.879359	27.31764	0.027814	0.101818

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.01636364	0.01636364	21.15	0.0010
event	10	0.04002727	0.00400273	5.17	0.0079

The SAS System

------------------------------ Pollutant=5 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.01636364	0.01636364	21.15	0.0010
event	10	0.04002727	0.00400273	5.17	0.0079

------------------------------ Pollutant=5 ------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	0.12909091
O	0.07454545

The SAS System

------------------------------ Pollutant=6 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read	22
Number of Observations Used	22

The SAS System

------------------------------ Pollutant=6 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	6007.590909	546.144628	3.71	0.0240
Error	10	1471.363636	147.136364		
Corrected Total	21	7478.954545			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.803266	45.00160	12.12998	26.95455

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	169.136364	169.136364	1.15	0.3088
event	10	5838.454545	583.845455	3.97	0.0201

The SAS System

------------------------------ Pollutant=6 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	169.136364	169.136364	1.15	0.3088
event	10	5838.454545	583.845455	3.97	0.0201

The SAS System

------------------------------ Pollutant=6 ------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	24.1818182
O	29.7272727

The SAS System

------------------------------ Pollutant=7 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read	22
Number of Observations Used	22

The SAS System

------------------------------ Pollutant=7 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	4.15525000	0.37775000	1.21	0.3873
Error	10	3.13028182	0.31302818		
Corrected Total	21	7.28553182			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.570343	64.00813	0.559489	0.874091

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.46836818	0.46836818	1.50	0.2493
event	10	3.68688182	0.36868818	1.18	0.4004

The SAS System

```
------------------------------ Pollutant=7 ------------------------------

                             The GLM Procedure

Dependent Variable: Concentration

 Source                     DF    Type III SS    Mean Square  F Value  Pr > F

 Location                    1     0.46836818     0.46836818     1.50  0.2493
 event                      10     3.68688182     0.36868818     1.18  0.4004

                              The SAS System

------------------------------ Pollutant=7 ------------------------------

                             The GLM Procedure
                            Least Squares Means

                                      Concentration
                         Location            LSMEAN

                         I               0.72818182
                         O               1.02000000
```

G.3: SAS® code for proc mixed procedure associated with concentrations.

```
options ls=75;
/* Water Quality Data
  Location =  Location (Inflow = I  Outflow = O)
  Pollutant =  Type (1= TKN, 2 = Nitrate Nitrite, 3 = Ammonium, 4 = TP
            5= Ortho P, 6 = TSS, 7 = TN)
  concentration = mg/L
*/
data poll1in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  1  1 0.62
I  1  1 0.60
I  1  1 0.51
I  1  1 0.66
I  1  2 0.53
I  1  2 0.40
I  1  2 0.44
I  1  2 0.55
I  1  1 0.41
I  1  1 0.56
I  1  1 0.59
;
```

```
run;
data poll1out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  1  1 0.99
O  1  1 1.18
O  1  1 2.46
O  1  1 0.00
O  1  2 1.08
O  1  2 0.47
O  1  2 0.49
O  1  2 0.56
O  1  1 0.68
O  1  1 0.69
O  1  1 0.87
;
run;
data poll2in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  2  1 0.33
I  2  1 0.25
I  2  1 0.37
I  2  1 0.57
I  2  2 0.06
I  2  2 0.08
I  2  2 0.15
I  2  2 0.02
I  2  1 0.01
I  2  1 0.01
I  2  1 0.29
;
run;
data poll2out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  2  1 0.35
O  2  1 0.22
O  2  1 0.55
O  2  1 0.00
O  2  2 0.25
O  2  2 0.08
O  2  2 0.03
O  2  2 0.02
O  2  1 0.01
O  2  1 0.03
O  2  1 0.21
;
run;
data poll3in;
```

```
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   3   1 0.03
I   3   1 0.03
I   3   1 0.08
I   3   1 0.04
I   3   2 0.06
I   3   2 0.04
I   3   2 0.05
I   3   2 0.18
I   3   1 0.04
I   3   1 0.06
I   3   1 0.04
;
run;
data poll3out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   3   1 0.11
O   3   1 0.05
O   3   1 0.17
O   3   1 0.00
O   3   2 0.15
O   3   2 0.06
O   3   2 0.03
O   3   2 0.07
O   3   1 0.06
O   3   1 0.07
O   3   1 0.13
;
run;
data poll4in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   4   1 0.24
I   4   1 0.18
I   4   1 0.18
I   4   1 0.21
I   4   2 0.20
I   4   2 0.27
I   4   2 0.20
I   4   2 0.16
I   4   1 0.14
I   4   1 0.15
I   4   1 0.18
;
run;
data poll4out;
input Location $ Pollutant Season Concentration;
event=_n_;
```

```
cards;
O   4   1 0.25
O   4   1 0.19
O   4   1 0.24
O   4   1 0.00
O   4   2 0.19
O   4   2 0.24
O   4   2 0.15
O   4   2 0.13
O   4   1 0.15
O   4   1 0.19
O   4   1 0.22
;
run;
data poll5in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   5   1 0.14
I   5   1 0.10
I   5   1 0.11
I   5   1 0.16
I   5   2 0.13
I   5   2 0.25
I   5   2 0.15
I   5   2 0.09
I   5   1 0.07
I   5   1 0.10
I   5   1 0.12
;
run;
data poll5out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   5   1 0.09
O   5   1 0.03
O   5   1 0.08
O   5   1 0.00
O   5   2 0.09
O   5   2 0.19
O   5   2 0.08
O   5   2 0.05
O   5   1 0.03
O   5   1 0.09
O   5   1 0.09
;
run;
data poll6in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   6   1 52
```

```
I   6   1 20
I   6   1 27
I   6   1 30
I   6   2 22
I   6   2 15
I   6   2 8
I   6   2 11
I   6   1 23
I   6   1 30
I   6   1 28
;
run;
data poll6out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   6   1 89
O   6   1 33
O   6   1 45
O   6   1 0
O   6   2 26
O   6   2 11
O   6   2 11
O   6   2 14
O   6   1 35
O   6   1 20
O   6   1 43
;
run;
data poll7in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   7   1 0.95
I   7   1 0.85
I   7   1 0.88
I   7   1 1.23
I   7   2 0.59
I   7   2 0.48
I   7   2 0.59
I   7   2 0.57
I   7   1 0.42
I   7   1 0.57
I   7   1 0.88
;
run;
data poll7out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   7   1 1.34
O   7   1 1.40
O   7   1 3.01
```

```
O  7  1 0.00
O  7  2 1.33
O  7  2 0.55
O  7  2 0.52
O  7  2 0.58
O  7  1 0.69
O  7  1 0.72
O  7  1 1.08
;
run;
data all7;
   set poll1in poll1out poll2in poll2out poll3in poll3out poll4in poll4out
poll5in poll5out poll6in poll6out poll7in poll7out;
run;
proc sort data=all7;
   by pollutant;
run;
ods trace on;
proc mixed data=all7;
   by pollutant;
   class event location season;
   model concentration=location|season;
   random event(season);
   lsmeans location*season/slice=season;
   ods output lsmeans=lsm tests3=t3 slices=slices;
run;
```

G.4: SAS® output for proc mixed procedure associated with concentrations.

```
------------------------------ Pollutant=1 ------------------------------

                            The Mixed Procedure

                            Model Information

          Data Set                     WORK.ALL7
          Dependent Variable           Concentration
          Covariance Structure         Variance Components
          Estimation Method            REML
          Residual Variance Method     Profile
          Fixed Effects SE Method      Model-Based
          Degrees of Freedom Method    Containment

                         Class Level Information

           Class       Levels    Values

           event           11    1 2 3 4 5 6 7 8 9 10 11
           Location         2    I O
           Season           2    1 2

                                Dimensions

                    Covariance Parameters             2
                    Columns in X                      9
                    Columns in Z                     11

------------------------------ Pollutant=1 ------------------------------

                            The Mixed Procedure

                                Dimensions

                    Subjects                          1
                    Max Obs Per Subject              22

                          Number of Observations

                Number of Observations Read              22
                Number of Observations Used              22
                Number of Observations Not Used           0

                             Iteration History

        Iteration    Evaluations    -2 Res Log Like       Criterion

                0              1        29.19372216
                1              1        29.19372216      0.00000000

                        Convergence criteria met.
```

The SAS System

------------------------------ Pollutant=1 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0
Residual	0.2047

Fit Statistics

-2 Res Log Likelihood	29.2
AIC (smaller is better)	31.2
AICC (smaller is better)	31.4
BIC (smaller is better)	31.6

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	2.14	0.1772
Season	1	9	1.07	0.3270
Location*Season	1	9	0.38	0.5530

The SAS System

------------------------------ Pollutant=1 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.5643	0.1710	9	3.30
Location*Season	I	2	0.4800	0.2262	9	2.12
Location*Season	O	1	0.9814	0.1710	9	5.74
Location*Season	O	2	0.6500	0.2262	9	2.87

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0092
Location*Season	I	2	0.0628
Location*Season	O	1	0.0003
Location*Season	O	2	0.0184

The SAS System

------------------------------- Pollutant=1 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	2.98	0.1186
Location*Season	2	1	9	0.28	0.6080

The SAS System

------------------------------- Pollutant=2 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL7
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-5.62589220	
1	1	-6.34948644	0.00000000

Convergence criteria met.

The SAS System

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure
Covariance Parameter
Estimates

Cov Parm	Estimate
event(Season)	0.008221
Residual	0.02136

Fit Statistics

-2 Res Log Likelihood	-6.3
AIC (smaller is better)	-2.3
AICC (smaller is better)	-1.5
BIC (smaller is better)	-1.6

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	0.14	0.7184
Season	1	9	2.73	0.1330
Location*Season	1	9	0.41	0.5367

The SAS System

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.2614	0.06501	9	4.02
Location*Season	I	2	0.07750	0.08599	9	0.90
Location*Season	O	1	0.1957	0.06501	9	3.01
Location*Season	O	2	0.09500	0.08599	9	1.10

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0030
Location*Season	I	2	0.3909
Location*Season	O	1	0.0147
Location*Season	O	2	0.2979

The SAS System

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	0.71	0.4220
Location*Season	2	1	9	0.03	0.8693

The SAS System

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL7
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

The SAS System

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-51.38801436	
1	1	-51.59436080	0.00000000

Convergence criteria met.

The SAS System

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0.000350
Residual	0.001977

Fit Statistics

-2 Res Log Likelihood	-51.6
AIC (smaller is better)	-47.6
AICC (smaller is better)	-46.8
BIC (smaller is better)	-46.8

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	0.73	0.4164
Season	1	9	0.43	0.5294
Location*Season	1	9	1.22	0.2976

The SAS System

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.04571	0.01823	9	2.51
Location*Season	I	2	0.08250	0.02412	9	3.42
Location*Season	O	1	0.08429	0.01823	9	4.62
Location*Season	O	2	0.07750	0.02412	9	3.21

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0335
Location*Season	I	2	0.0076
Location*Season	O	1	0.0013
Location*Season	O	2	0.0106

The SAS System

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	2.63	0.1391
Location*Season	2	1	9	0.03	0.8772

The SAS System

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL7
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-43.80645971	
1	1	-44.13379446	0.00000000

Convergence criteria met.

The SAS System

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0.000670
Residual	0.002876

Fit Statistics

-2 Res Log Likelihood	-44.1
AIC (smaller is better)	-40.1
AICC (smaller is better)	-39.3
BIC (smaller is better)	-39.3

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	0.56	0.4717
Season	1	9	0.19	0.6743
Location*Season	1	9	0.26	0.6217

The SAS System

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.1829	0.02251	9	8.12
Location*Season	I	2	0.2075	0.02978	9	6.97
Location*Season	O	1	0.1771	0.02251	9	7.87
Location*Season	O	2	0.1775	0.02978	9	5.96

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	<.0001
Location*Season	I	2	<.0001
Location*Season	O	1	<.0001
Location*Season	O	2	0.0002

The SAS System

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	0.04	0.8464
Location*Season	2	1	9	0.63	0.4492

The SAS System

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL7
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-52.84656681	
1	1	-56.86595964	0.00000000

Convergence criteria met.

The SAS System

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0.001288
Residual	0.000858

Fit Statistics

-2 Res Log Likelihood	-56.9
AIC (smaller is better)	-52.9
AICC (smaller is better)	-52.1
BIC (smaller is better)	-52.1

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	17.37	0.0024
Season	1	9	2.66	0.1377
Location*Season	1	9	0.02	0.9042

The SAS System

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.1143	0.01751	9	6.53
Location*Season	I	2	0.1550	0.02316	9	6.69
Location*Season	O	1	0.05857	0.01751	9	3.35
Location*Season	O	2	0.1025	0.02316	9	4.43

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0001
Location*Season	I	2	<.0001
Location*Season	O	1	0.0086
Location*Season	O	2	0.0017

The SAS System

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	12.66	0.0061
Location*Season	2	1	9	6.42	0.0320

The SAS System

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL7
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

The SAS System

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	160.36707606	
1	1	158.09086814	0.00000000

Convergence criteria met.

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Covariance Parameter
Estimates

Cov Parm	Estimate
event(Season)	141.44
Residual	157.77

Fit Statistics

-2 Res Log Likelihood	158.1
AIC (smaller is better)	162.1
AICC (smaller is better)	162.9
BIC (smaller is better)	162.9

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	0.71	0.4224
Season	1	9	4.25	0.0693
Location*Season	1	9	0.33	0.5820

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	30.0000	6.5380	9	4.59
Location*Season	I	2	14.0000	8.6489	9	1.62
Location*Season	O	1	37.8571	6.5380	9	5.79
Location*Season	O	2	15.5000	8.6489	9	1.79

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0013
Location*Season	I	2	0.1400
Location*Season	O	1	0.0003
Location*Season	O	2	0.1067

The SAS System

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	1.37	0.2719
Location*Season	2	1	9	0.03	0.8696

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL7
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

The SAS System

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	38.44105615	
1	1	38.44105615	0.00000000

Convergence criteria met.

The SAS System

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0
Residual	0.3421

Fit Statistics

-2 Res Log Likelihood	38.4
AIC (smaller is better)	40.4
AICC (smaller is better)	40.7
BIC (smaller is better)	40.8

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	1.08	0.3257
Season	1	9	1.82	0.2098
Location*Season	1	9	0.10	0.7591

The SAS System

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.8257	0.2211	9	3.73
Location*Season	I	2	0.5575	0.2925	9	1.91
Location*Season	O	1	1.1771	0.2211	9	5.32
Location*Season	O	2	0.7450	0.2925	9	2.55

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0047
Location*Season	I	2	0.0890
Location*Season	O	1	0.0005
Location*Season	O	2	0.0313

```
                              The SAS System

------------------------------ Pollutant=7 ------------------------------

                            The Mixed Procedure

                          Tests of Effect Slices

                                        Num       Den
      Effect              Season         DF        DF     F Value     Pr > F

      Location*Season     1               1         9        1.26     0.2901
      Location*Season     2               1         9        0.21     0.6610
```

G.5: SAS® code for proc glm procedure associated with loads.

```
options ls=75;
/* Water Quality Data
  Location =  Location (Inflow = I  Outflow = O)
  Pollutant =  Type (1= TKN, 2 = Nitrate Nitrite, 3 = Ammonium, 4 = TP
            5= Ortho P, 6 = TSS, 7 = TN)
  Concentration (load) = lbs
*/
data poll1in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  1  1 0.84
I  1  1 0.41
I  1  1 0.33
I  1  1 0.08
I  1  2 0.43
I  1  2 1.10
I  1  2 0.96
I  1  2 0.68
I  1  1 0.74
I  1  1 6.22
I  1  1 0.66
;
run;
data poll1out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  1  1 1.20
O  1  1 0.47
O  1  1 0.69
O  1  1 0.00
O  1  2 0.36
O  1  2 1.20
O  1  2 0.78
```

```
O  1  2 0.31
O  1  1 0.62
O  1  1 2.18
O  1  1 0.31
;
run;
data poll2in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  2  1 0.45
I  2  1 0.17
I  2  1 0.24
I  2  1 0.07
I  2  2 0.05
I  2  2 0.22
I  2  2 0.33
I  2  2 0.02
I  2  1 0.02
I  2  1 0.11
I  2  1 0.32
;
run;
data poll2out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  2  1 0.42
O  2  1 0.09
O  2  1 0.16
O  2  1 0.00
O  2  2 0.08
O  2  2 0.20
O  2  2 0.05
O  2  2 0.01
O  2  1 0.01
O  2  1 0.09
O  2  1 0.07
;
run;
data poll3in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  3  1 0.04
I  3  1 0.02
I  3  1 0.05
I  3  1 0.00
I  3  2 0.05
I  3  2 0.11
I  3  2 0.11
I  3  2 0.22
I  3  1 0.07
```

```
I   3   1  0.67
I   3   1  0.04
;
run;
data poll3out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   3   1  0.13
O   3   1  0.02
O   3   1  0.05
O   3   1  0.00
O   3   2  0.05
O   3   2  0.15
O   3   2  0.05
O   3   2  0.04
O   3   1  0.05
O   3   1  0.22
O   3   1  0.05
;
data poll4in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   4   1  0.33
I   4   1  0.12
I   4   1  0.12
I   4   1  0.03
I   4   2  0.16
I   4   2  0.74
I   4   2  0.44
I   4   2  0.20
I   4   1  0.25
I   4   1  1.66
I   4   1  0.20
;
run;
data poll4out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   4   1  0.30
O   4   1  0.08
O   4   1  0.07
O   4   1  0.00
O   4   2  0.06
O   4   2  0.61
O   4   2  0.24
O   4   2  0.07
O   4   1  0.14
O   4   1  0.60
O   4   1  0.08
;
```

```
run;
data poll5in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  5  1 0.19
I  5  1 0.07
I  5  1 0.07
I  5  1 0.02
I  5  2 0.11
I  5  2 0.69
I  5  2 0.33
I  5  2 0.11
I  5  1 0.13
I  5  1 1.11
I  5  1 0.13
;
run;
data poll5out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  5  1 0.11
O  5  1 0.01
O  5  1 0.02
O  5  1 0.00
O  5  2 0.03
O  5  2 0.48
O  5  2 0.13
O  5  2 0.03
O  5  1 0.03
O  5  1 0.28
O  5  1 0.03
;
run;
data poll6in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  6  1 70.77
I  6  1 13.69
I  6  1 17.52
I  6  1 3.71
I  6  2 17.79
I  6  2 41.12
I  6  2 17.54
I  6  2 13.63
I  6  1 41.55
I  6  1 332.95
I  6  1 31.24
;
run;
data poll6out;
```

```
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  6  1 107.67
O  6  1 13.03
O  6  1 12.70
O  6  1 0.00
O  6  2 8.63
O  6  2 28.05
O  6  2 17.43
O  6  2 7.77
O  6  1 31.95
O  6  1 63.10
O  6  1 15.25
;
run;
data poll7in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  7  1 1.29
I  7  1 0.58
I  7  1 0.57
I  7  1 0.15
I  7  2 0.48
I  7  2 1.32
I  7  2 1.29
I  7  2 0.71
I  7  1 0.76
I  7  1 6.33
I  7  1 0.98
;
run;
data poll7out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  7  1 1.62
O  7  1 0.55
O  7  1 0.85
O  7  1 0.00
O  7  2 0.44
O  7  2 1.40
O  7  2 0.82
O  7  2 0.32
O  7  1 0.63
O  7  1 2.27
O  7  1 0.38
;
run;
data all7;
   set poll1in poll1out poll2in poll2out poll3in poll3out poll4in poll4out
poll5in poll5out poll6in poll6out poll7in poll7out;
```

```
run;
proc sort data=all7;
   by pollutant;
run;
ods trace on;

proc glm data=all7;
   by pollutant;
   class event location;
   model concentration=location event;
   lsmeans location;
run;
```

G.6: SAS® output for proc glm procedure associated with loads.

```
                              The SAS System

------------------------------ Pollutant=1 ------------------------------

                             The GLM Procedure

                         Class Level Information

             Class         Levels    Values

             event             11    1 2 3 4 5 6 7 8 9 10 11

             Location           2    I O


                  Number of Observations Read          22
                  Number of Observations Used          22

                              The SAS System

------------------------------ Pollutant=1 ------------------------------

                             The GLM Procedure

Dependent Variable: Concentration

                                        Sum of
 Source                      DF        Squares   Mean Square  F Value  Pr > F

 Model                       11    26.24682273    2.38607479     3.14  0.0411

 Error                       10     7.60372727    0.76037273

 Corrected Total             21    33.85055000


        R-Square     Coeff Var      Root MSE    Concentration Mean

        0.775374      93.26134      0.871994              0.935000


 Source                      DF      Type I SS   Mean Square  F Value  Pr > F

 Location                     1     0.85222273    0.85222273     1.12  0.3146
 event                       10    25.39460000    2.53946000     3.34  0.0352
```

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.85222273	0.85222273	1.12	0.3146
event	10	25.39460000	2.53946000	3.34	0.0352

The SAS System

------------------------------ Pollutant=1 ------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	1.13181818
O	0.73818182

The SAS System

------------------------------ Pollutant=2 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read 22
Number of Observations Used 22

The SAS System

------------------------------ Pollutant=2 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.33140909	0.03012810	6.01	0.0042
Error	10	0.05013636	0.00501364		
Corrected Total	21	0.38154545			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.868597	48.98600	0.070807	0.144545

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.03056364	0.03056364	6.10	0.0332
event	10	0.30084545	0.03008455	6.00	0.0045

The SAS System

------------------------------ Pollutant=2 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.03056364	0.03056364	6.10	0.0332
event	10	0.30084545	0.03008455	6.00	0.0045

------------------------------- Pollutant=2 ------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	0.18181818
O	0.10727273

The SAS System

------------------------------- Pollutant=3 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read	22
Number of Observations Used	22

------------------------------- Pollutant=3 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.30971364	0.02815579	2.57	0.0742
Error	10	0.10958182	0.01095818		
Corrected Total	21	0.41929545			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.738653	105.1593	0.104681	0.099545

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.01476818	0.01476818	1.35	0.2726
event	10	0.29494545	0.02949455	2.69	0.0671

------------------------------ Pollutant=3 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.01476818	0.01476818	1.35	0.2726
event	10	0.29494545	0.02949455	2.69	0.0671

The SAS System

------------------------------ Pollutant=3 ------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	0.12545455
O	0.07363636

The SAS System

------------------------------ Pollutant=4 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read	22
Number of Observations Used	22

The SAS System

------------------------------- Pollutant=4 -------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	2.37046364	0.21549669	4.92	0.0089
Error	10	0.43808182	0.04380818		
Corrected Total	21	2.80854545			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.844018	70.84137	0.209304	0.295455

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.18181818	0.18181818	4.15	0.0690
event	10	2.18864545	0.21886455	5.00	0.0090

The SAS System

------------------------------- Pollutant=4 -------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.18181818	0.18181818	4.15	0.0690
event	10	2.18864545	0.21886455	5.00	0.0090

The SAS System

------------------------------- Pollutant=4 -------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	0.38636364
O	0.20454545

```
------------------------------ Pollutant=5 ------------------------------

                            The GLM Procedure

                        Class Level Information

             Class         Levels    Values

             event             11    1 2 3 4 5 6 7 8 9 10 11

             Location           2    I O


                  Number of Observations Read          22
                  Number of Observations Used          22

                             The SAS System

------------------------------ Pollutant=5 ------------------------------

                            The GLM Procedure

Dependent Variable: Concentration

                                         Sum of
 Source                      DF         Squares    Mean Square   F Value   Pr > F

 Model                       11      1.23504091     0.11227645      4.31   0.0144

 Error                       10      0.26043636     0.02604364

 Corrected Total             21      1.49547727


        R-Square     Coeff Var      Root MSE    Concentration Mean

        0.825851      86.38367      0.161380              0.186818


 Source                      DF       Type I SS    Mean Square   F Value   Pr > F

 Location                     1      0.14891364     0.14891364      5.72   0.0379
 event                       10      1.08612727     0.10861273      4.17   0.0170

                             The SAS System
```

------------------------------ Pollutant=5 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	0.14891364	0.14891364	5.72	0.0379
event	10	1.08612727	0.10861273	4.17	0.0170

------------------------------ Pollutant=5 ------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	0.26909091
O	0.10454545

The SAS System

------------------------------ Pollutant=6 ------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read 22
Number of Observations Used 22

The SAS System

------------------------------ Pollutant=6 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	69112.2761	6282.9342	1.88	0.1651
Error	10	33446.8314	3344.6831		
Corrected Total	21	102559.1075			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.673878	140.2652	57.83324	41.23136

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	3980.66204	3980.66204	1.19	0.3009
event	10	65131.61401	6513.16140	1.95	0.1542

------------------------------ Pollutant=6 ------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	3980.66204	3980.66204	1.19	0.3009
event	10	65131.61401	6513.16140	1.95	0.1542

The SAS System

------------------------------ Pollutant=6 ------------------------------

The GLM Procedure
Least Squares Means

Location	Concentration LSMEAN
I	54.6827273
O	27.7800000

The SAS System

------------------------------- Pollutant=7 -------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O

Number of Observations Read 22
Number of Observations Used 22

The SAS System

------------------------------- Pollutant=7 -------------------------------

The GLM Procedure

Dependent Variable: Concentration

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	27.24373636	2.47670331	3.30	0.0351
Error	10	7.50644545	0.75064455		
Corrected Total	21	34.75018182			

R-Square	Coeff Var	Root MSE	Concentration Mean
0.783988	80.28957	0.866397	1.079091

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	1.21965455	1.21965455	1.62	0.2312
event	10	26.02408182	2.60240818	3.47	0.0313

The SAS System

```
------------------------------ Pollutant=7 ------------------------------

                             The GLM Procedure

Dependent Variable: Concentration

 Source                       DF    Type III SS    Mean Square  F Value  Pr > F

 Location                      1     1.21965455     1.21965455     1.62  0.2312
 event                        10    26.02408182     2.60240818     3.47  0.0313

                              The SAS System

------------------------------ Pollutant=7 ------------------------------

                             The GLM Procedure
                            Least Squares Means

                                     Concentration
                         Location           LSMEAN

                         I              1.31454545
                         O              0.84363636
```

G.7: SAS® code for proc mixed procedure associated with loads.

```
options ls=75;
/* Water Quality Data
  Location =  Location (Inflow = I  Outflow = O)
  Pollutant =  Type (1= TKN, 2 = Nitrate Nitrite, 3 = Ammonium, 4 = TP
            5= Ortho P, 6 = TSS, 7 = TN)
  Concentration (load) = lbs
*/
data poll1in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  1  1 0.84
I  1  1 0.41
I  1  1 0.33
I  1  1 0.08
I  1  2 0.43
I  1  2 1.10
I  1  2 0.96
I  1  2 0.68
I  1  1 0.74
I  1  1 6.22
I  1  1 0.66
;
run;
data poll1out;
input Location $ Pollutant Season Concentration;
```

```
event=_n_;
cards;
O  1  1 1.20
O  1  1 0.47
O  1  1 0.69
O  1  1 0.00
O  1  2 0.36
O  1  2 1.20
O  1  2 0.78
O  1  2 0.31
O  1  1 0.62
O  1  1 2.18
O  1  1 0.31
;
run;
data poll2in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I  2  1 0.45
I  2  1 0.17
I  2  1 0.24
I  2  1 0.07
I  2  2 0.05
I  2  2 0.22
I  2  2 0.33
I  2  2 0.02
I  2  1 0.02
I  2  1 0.11
I  2  1 0.32
;
run;
data poll2out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O  2  1 0.42
O  2  1 0.09
O  2  1 0.16
O  2  1 0.00
O  2  2 0.08
O  2  2 0.20
O  2  2 0.05
O  2  2 0.01
O  2  1 0.01
O  2  1 0.09
O  2  1 0.07
;
run;
data poll3in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
```

```
I   3   1  0.04
I   3   1  0.02
I   3   1  0.05
I   3   1  0.00
I   3   2  0.05
I   3   2  0.11
I   3   2  0.11
I   3   2  0.22
I   3   1  0.07
I   3   1  0.67
I   3   1  0.04
;
run;
data poll3out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   3   1  0.13
O   3   1  0.02
O   3   1  0.05
O   3   1  0.00
O   3   2  0.05
O   3   2  0.15
O   3   2  0.05
O   3   2  0.04
O   3   1  0.05
O   3   1  0.22
O   3   1  0.05
;
data poll4in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   4   1  0.33
I   4   1  0.12
I   4   1  0.12
I   4   1  0.03
I   4   2  0.16
I   4   2  0.74
I   4   2  0.44
I   4   2  0.20
I   4   1  0.25
I   4   1  1.66
I   4   1  0.20
;
run;
data poll4out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   4   1  0.30
O   4   1  0.08
O   4   1  0.07
```

```
O   4   1  0.00
O   4   2  0.06
O   4   2  0.61
O   4   2  0.24
O   4   2  0.07
O   4   1  0.14
O   4   1  0.60
O   4   1  0.08
;
run;
data poll5in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   5   1  0.19
I   5   1  0.07
I   5   1  0.07
I   5   1  0.02
I   5   2  0.11
I   5   2  0.69
I   5   2  0.33
I   5   2  0.11
I   5   1  0.13
I   5   1  1.11
I   5   1  0.13
;
run;
data poll5out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   5   1  0.11
O   5   1  0.01
O   5   1  0.02
O   5   1  0.00
O   5   2  0.03
O   5   2  0.48
O   5   2  0.13
O   5   2  0.03
O   5   1  0.03
O   5   1  0.28
O   5   1  0.03
;
run;
data poll6in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   6   1  70.77
I   6   1  13.69
I   6   1  17.52
I   6   1  3.71
I   6   2  17.79
```

```
I   6   2 41.12
I   6   2 17.54
I   6   2 13.63
I   6   1 41.55
I   6   1 332.95
I   6   1 31.24
;
run;
data poll6out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   6   1 107.67
O   6   1 13.03
O   6   1 12.70
O   6   1 0.00
O   6   2 8.63
O   6   2 28.05
O   6   2 17.43
O   6   2 7.77
O   6   1 31.95
O   6   1 63.10
O   6   1 15.25
;
run;
data poll7in;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
I   7   1 1.29
I   7   1 0.58
I   7   1 0.57
I   7   1 0.15
I   7   2 0.48
I   7   2 1.32
I   7   2 1.29
I   7   2 0.71
I   7   1 0.76
I   7   1 6.33
I   7   1 0.98
;
run;
data poll7out;
input Location $ Pollutant Season Concentration;
event=_n_;
cards;
O   7   1 1.62
O   7   1 0.55
O   7   1 0.85
O   7   1 0.00
O   7   2 0.44
O   7   2 1.40
O   7   2 0.82
```

```
O   7   2 0.32
O   7   1 0.63
O   7   1 2.27
O   7   1 0.38
;
run;
data all7;
   set poll1in poll1out poll2in poll2out poll3in poll3out poll4in poll4out
poll5in poll5out poll6in poll6out poll7in poll7out;
run;
proc sort data=all7;
   by pollutant;
run;
ods trace on;
proc mixed data=all7;
   by pollutant;
   class event location season;
   model concentration=location|season;
   random event(season);
   lsmeans location*season/slice=season;
   ods output lsmeans=lsm tests3=t3 slices=slices;
run;
```

G.8: SAS® output for proc mixed procedure associated with loads.

```
                              The SAS System

------------------------------ Pollutant=1 ------------------------------
                           The Mixed Procedure
                           Model Information

          Data Set                     WORK.ALL6
          Dependent Variable           Concentration
          Covariance Structure         Variance Components
          Estimation Method            REML
          Residual Variance Method     Profile
          Fixed Effects SE Method      Model-Based
          Degrees of Freedom Method    Containment

                        Class Level Information

           Class        Levels    Values

           event            11    1 2 3 4 5 6 7 8 9 10 11
           Location          2    I O
           Season            2    1 2

                                Dimensions

                    Covariance Parameters            2
                    Columns in X                     9
                    Columns in Z                    11
```

------------------------------ Pollutant=1 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	68.23646942	
1	1	65.10848288	0.00000000

Convergence criteria met.

------------------------------ Pollutant=1 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0.9704
Residual	0.8206

Fit Statistics

-2 Res Log Likelihood	65.1
AIC (smaller is better)	69.1
AICC (smaller is better)	69.9
BIC (smaller is better)	69.9

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	0.71	0.4228
Season	1	9	0.20	0.6684
Location*Season	1	9	0.27	0.6183

The SAS System

------------------------------ Pollutant=1 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	1.3257	0.5058	9	2.62
Location*Season	I	2	0.7925	0.6691	9	1.18
Location*Season	O	1	0.7814	0.5058	9	1.54
Location*Season	O	2	0.6625	0.6691	9	0.99

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0278
Location*Season	I	2	0.2666
Location*Season	O	1	0.1568
Location*Season	O	2	0.3480

The SAS System

------------------------------ Pollutant=1 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	1.26	0.2901
Location*Season	2	1	9	0.04	0.8437

The SAS System

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL6
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

The SAS System

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-13.52295888	
1	1	-19.79249916	0.00000000

Convergence criteria met.

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0.01351
Residual	0.005563

Fit Statistics

-2 Res Log Likelihood	-19.8
AIC (smaller is better)	-15.8
AICC (smaller is better)	-15.0
BIC (smaller is better)	-15.0

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	4.95	0.0531
Season	1	9	0.23	0.6412
Location*Season	1	9	0.01	0.9163

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.1971	0.05220	9	3.78
Location*Season	I	2	0.1550	0.06906	9	2.24
Location*Season	O	1	0.1200	0.05220	9	2.30
Location*Season	O	2	0.08500	0.06906	9	1.23

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0044
Location*Season	I	2	0.0515
Location*Season	O	1	0.0471
Location*Season	O	2	0.2496

The SAS System

------------------------------ Pollutant=2 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	3.74	0.0850
Location*Season	2	1	9	1.76	0.2171

The SAS System

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL6
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-10.57394852	
1	1	-12.69474248	0.00000000

Convergence criteria met.

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Covariance Parameter
Estimates

Cov Parm	Estimate
event(Season)	0.01030
Residual	0.01217

Fit Statistics

-2 Res Log Likelihood	-12.7
AIC (smaller is better)	-8.7
AICC (smaller is better)	-7.9
BIC (smaller is better)	-7.9

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	1.11	0.3204
Season	1	9	0.00	0.9689
Location*Season	1	9	0.00	0.9773

The SAS System

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.1271	0.05666	9	2.24
Location*Season	I	2	0.1225	0.07495	9	1.63
Location*Season	O	1	0.07429	0.05666	9	1.31
Location*Season	O	2	0.07250	0.07495	9	0.97

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0515
Location*Season	I	2	0.1366
Location*Season	O	1	0.2223
Location*Season	O	2	0.3587

------------------------------ Pollutant=3 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	0.80	0.3935
Location*Season	2	1	9	0.41	0.5376

The SAS System

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL6
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	23.03208902	
1	1	17.68415565	0.00000000

Convergence criteria met.

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0.09729
Residual	0.04807

Fit Statistics

-2 Res Log Likelihood	17.7
AIC (smaller is better)	21.7
AICC (smaller is better)	22.5
BIC (smaller is better)	22.5

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	3.16	0.1090
Season	1	9	0.02	0.8912
Location*Season	1	9	0.11	0.7430

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.3871	0.1441	9	2.69
Location*Season	I	2	0.3850	0.1906	9	2.02
Location*Season	O	1	0.1814	0.1441	9	1.26
Location*Season	O	2	0.2450	0.1906	9	1.29

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0249
Location*Season	I	2	0.0742
Location*Season	O	1	0.2397
Location*Season	O	2	0.2308

The SAS System

------------------------------ Pollutant=4 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	3.08	0.1131
Location*Season	2	1	9	0.82	0.3900

The SAS System

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL6
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	10.59554249	
1	1	6.49279112	0.00000000

Convergence criteria met.

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	0.04407
Residual	0.02877

Fit Statistics

-2 Res Log Likelihood	6.5
AIC (smaller is better)	10.5
AICC (smaller is better)	11.3
BIC (smaller is better)	11.3

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	4.52	0.0624
Season	1	9	0.29	0.6033
Location*Season	1	9	0.05	0.8229

The SAS System

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	0.2457	0.1020	9	2.41
Location*Season	I	2	0.3100	0.1349	9	2.30
Location*Season	O	1	0.06857	0.1020	9	0.67
Location*Season	O	2	0.1675	0.1349	9	1.24

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0393
Location*Season	I	2	0.0472
Location*Season	O	1	0.5183
Location*Season	O	2	0.2459

------------------------------ Pollutant=5 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	3.82	0.0824
Location*Season	2	1	9	1.41	0.2652

The SAS System

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL6
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	211.27902856	
1	1	210.47067310	0.00000000

Convergence criteria met.

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Covariance Parameter
Estimates

Cov Parm	Estimate
event(Season)	1483.75
Residual	3578.68

Fit Statistics

-2 Res Log Likelihood	210.5
AIC (smaller is better)	214.5
AICC (smaller is better)	215.3
BIC (smaller is better)	215.3

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	0.73	0.4151
Season	1	9	0.95	0.3553
Location*Season	1	9	0.35	0.5708

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	73.0614	26.8925	9	2.72
Location*Season	I	2	22.5200	35.5754	9	0.63
Location*Season	O	1	34.8143	26.8925	9	1.29
Location*Season	O	2	15.4700	35.5754	9	0.43

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0237
Location*Season	I	2	0.5425
Location*Season	O	1	0.2277
Location*Season	O	2	0.6739

------------------------------ Pollutant=6 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	1.43	0.2622
Location*Season	2	1	9	0.03	0.8713

The SAS System

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Model Information

Data Set	WORK.ALL7
Dependent Variable	Concentration
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
event	11	1 2 3 4 5 6 7 8 9 10 11
Location	2	I O
Season	2	1 2

Dimensions

Covariance Parameters	2
Columns in X	9
Columns in Z	11

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Dimensions

Subjects	1
Max Obs Per Subject	22

Number of Observations

Number of Observations Read	22
Number of Observations Used	22
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	68.45591263	
1	1	65.16249404	0.00000000

Convergence criteria met.

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
event(Season)	1.0036
Residual	0.8094

Fit Statistics

-2 Res Log Likelihood	65.2
AIC (smaller is better)	69.2
AICC (smaller is better)	70.0
BIC (smaller is better)	70.0

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Location	1	9	1.08	0.3263
Season	1	9	0.24	0.6364
Location*Season	1	9	0.27	0.6129

The SAS System

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Least Squares Means

Effect	Location	Season	Estimate	Standard Error	DF	t Value
Location*Season	I	1	1.5229	0.5089	9	2.99
Location*Season	I	2	0.9500	0.6732	9	1.41
Location*Season	O	1	0.9000	0.5089	9	1.77
Location*Season	O	2	0.7450	0.6732	9	1.11

Least Squares Means

Effect	Location	Season	Pr > |t|
Location*Season	I	1	0.0151
Location*Season	I	2	0.1918
Location*Season	O	1	0.1108
Location*Season	O	2	0.2972

------------------------------ Pollutant=7 ------------------------------

The Mixed Procedure

Tests of Effect Slices

Effect	Season	Num DF	Den DF	F Value	Pr > F
Location*Season	1	1	9	1.68	0.2275
Location*Season	2	1	9	0.10	0.7546

APPENDIX H: SAS® code and output for phosphorus deposition.

H.1: SAS® code for phosphorus deposition.

```
/*Phosphorus Monitoring
Location = (A, B, C, D, E, F, G)
Pindex = phosphorus index
*/

data phosphorus;
input location $ month avgpindex;
if location < "D" then region="in "; else if location >= "D" then
region="out";
cards;
A 1 46.97
B 1 54.44
C 1 47.42
D 1 29.81
E 1 45.22
F 1 40.22
G 1 30.89
A 2 46.81
B 2 57.72
C 2 51.31
D 2 36.22
E 2 42.56
F 2 40.14
G 2 35.25
A 3 52.00
B 3 55.92
C 3 49.00
D 3 47.11
E 3 39.39
F 3 36.00
G 3 36.38
A 4 44.33
B 4 57.33
C 4 48.33
D 4 32.00
E 4 30.00
F 4 39.67
G 4 38.67
A 5 37.67
B 5 59.67
C 5 39.33
D 5 25.33
E 5 27.00
F 5 29.33
G 5 32.33
;
run;
```

```
proc mixed data=phosphorus;
      class region location month;
      model avgpindex = region|month;
      repeated month / subject=location type=ar(1);
run;
```

H.2: SAS® output for phosphorus deposition.

```
                              The SAS System

                            The Mixed Procedure

                             Model Information

         Data Set                     WORK.PHOSPHORUS
         Dependent Variable           avgpindex
         Covariance Structure         Autoregressive
         Subject Effect               location
         Estimation Method            REML
         Residual Variance Method     Profile
         Fixed Effects SE Method      Model-Based
         Degrees of Freedom Method    Between-Within


                          Class Level Information

          Class        Levels    Values

          region            2    in out
          location          7    A B C D E F G
          month             5    1 2 3 4 5


                                Dimensions

                   Covariance Parameters              2
                   Columns in X                      18
                   Columns in Z                       0
                   Subjects                           7
                   Max Obs Per Subject                5
```

The SAS System

The Mixed Procedure

Number of Observations

Number of Observations Read	35
Number of Observations Used	35
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	172.56105993	
1	2	166.90332161	0.00017123
2	1	166.89278352	0.00000012
3	1	166.89277603	0.00000000

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
AR(1)	location	0.5591
Residual		38.1197

The SAS System

The Mixed Procedure

Fit Statistics

-2 Res Log Likelihood	166.9
AIC (smaller is better)	170.9
AICC (smaller is better)	171.4
BIC (smaller is better)	170.8

Null Model Likelihood Ratio Test

DF	Chi-Square	Pr > ChiSq
1	5.67	0.0173

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
region	1	5	18.54	0.0077
month	4	20	2.83	0.0518
region*month	4	20	0.18	0.9478

APPENDIX I: SAS® code and output for the Smithfield and Pactolus wetland plant study.

I.1: SAS® code for the Smithfield and Pactolus wetland plant study.

```
/* Plant Analysis Data
      Wetland = Wetland Location (A = Smithfield B = Pactolus)
      Plant = Plant Type (1 = Arrow Head, 2 = Pickerlweed, , 3 =
Woolgrass,4 = Lizard Tail, 5 = Soft Stem Bulrush)
      Nitrogen = Nitrogen accumulation (g/m^2)
*/
data ComparisonOfNitrogenAccumulation;
input Wetland $ Plant Nitrogen;
cards;
A  1  10.00
A  1  9.02
A  1  7.47
A  1  5.45
A  1  8.07
A  2  14.42
A  2  9.52
A  2  5.57
A  2  9.43
A  2  5.32
A  3  4.23
A  3  3.56
A  3  2.25
A  3  4.16
A  3  2.94
A  4  2.92
A  4  2.72
A  4  2.46
A  4  4.01
A  4  3.30
B  1  2.99
B  1  5.91
B  1  8.27
B  1  10.41
B  1  2.84
B  2  18.81
B  2  12.14
B  2  8.74
B  2  9.06
B  2  10.79
B  3  14.31
B  3  11.41
B  3  16.04
B  3  8.92
B  4  5.07
B  4  5.16
B  4  3.98
```

```
B   4   5.77
B   4   9.12
B   5   8.38
B   5   15.44
B   5   12.93
B   5   7.82
B   5   10.84
;
proc glm
data = ComparisonOfNitrogenAccumulation;
      title 'Interaction and Main Effects of Within Each Wetland';
      by Wetland;
      class Plant;
      model Nitrogen = Plant;
      lsmeans Plant/pdiff;
      run;
```

I.2: SAS® output for the Smithfield and Pactolus wetland plant study.

```
---------------------------------------- Wetland=A -------------------------------------

                                    The GLM Procedure
                                Class Level Information

                             Class          Levels    Values

                             Plant               4    1 2 3 4

                          Number of Observations Read          20
                          Number of Observations Used          20

                    Interaction and Main Effects of Within Each Wetland

---------------------------------------- Wetland=A -------------------------------------

                                    The GLM Procedure
Dependent Variable: Nitrogen

                                               Sum of
    Source                      DF           Squares     Mean Square    F Value    Pr > F

    Model                        3       135.8534600      45.2844867      10.19    0.0005
    Error                       16        71.1333200       4.4458325
    Corrected Total             19       206.9867800

                   R-Square     Coeff Var      Root MSE    Nitrogen Mean

                   0.656339      36.09852      2.108514         5.841000

    Source                      DF         Type I SS     Mean Square    F Value    Pr > F

    Plant                        3       135.8534600      45.2844867      10.19    0.0005
```

Interaction and Main Effects of Within Each Wetland

--------------------------------------- Wetland=A --------------------------------------

The GLM Procedure

Dependent Variable: Nitrogen

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Plant	3	135.8534600	45.2844867	10.19	0.0005

Interaction and Main Effects of Within Each Wetland

--------------------------------------- Wetland=A --------------------------------------

The GLM Procedure
Least Squares Means

Plant	Nitrogen LSMEAN	LSMEAN Number
1	8.00200000	1
2	8.85200000	2
3	3.42800000	3
4	3.08200000	4

Least Squares Means for effect Plant
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Nitrogen

i/j	1	2	3	4
1		0.5329	0.0034	0.0020
2	0.5329		0.0009	0.0005
3	0.0034	0.0009		0.7986
4	0.0020	0.0005	0.7986	

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

Interaction and Main Effects of Within Each Wetland

--------------------------------------- Wetland=B --------------------------------------

The GLM Procedure

Class Level Information

Class	Levels	Values
Plant	5	1 2 3 4 5

Number of Observations Read	24
Number of Observations Used	24

Interaction and Main Effects of Within Each Wetland

--------------------------------------- Wetland=B --------------------------------------

The GLM Procedure

Dependent Variable: Nitrogen

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	207.4203825	51.8550956	5.02	0.0062
Error	19	196.0882800	10.3204358		
Corrected Total	23	403.5086625			

R-Square	Coeff Var	Root MSE	Nitrogen Mean
0.514042	34.24430	3.212544	9.381250

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Plant	4	207.4203825	51.8550956	5.02	0.0062

Interaction and Main Effects of Within Each Wetland

--------------------------------------- Wetland=B --------------------------------------

The GLM Procedure

Dependent Variable: Nitrogen

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Plant	4	207.4203825	51.8550956	5.02	0.0062

Interaction and Main Effects of Within Each Wetland

--------------------------------------- Wetland=B --------------------------------------

The GLM Procedure

Least Squares Means

Plant	Nitrogen LSMEAN	LSMEAN Number
1	6.0840000	1
2	11.9080000	2
3	12.6700000	3
4	5.8200000	4
5	11.0820000	5

Least Squares Means for effect Plant
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Nitrogen

i/j	1	2	3	4	5
1		0.0099	0.0065	0.8980	0.0237
2	0.0099		0.7275	0.0074	0.6889
3	0.0065	0.7275		0.0049	0.4702
4	0.8980	0.0074	0.0049		0.0180
5	0.0237	0.6889	0.4702	0.0180	

APPENDIX J: Model used to generate an annual nitrogen load for the Pactolus wetland

Coastal Plain of the Tar-Pamlico River Basin:

Includes Greenville and Washington as well as Pitt and Beaufort Counties

Total Nitrogen and Total Phosphorus Loading Calculation Worksheet (Automated)

Project Name:			
Date:			
By:		Checked By:	

Directions (same for pre-development and post-development tables):

> Enter the acres of each type of land cover in the green boxes. The spreadsheet will calculate all of the values in light blue.

> Compare total areas of development in pre- and post- tables for consistency (bottom of column (2)), and also for consistency with the site plans. If all of these values are not the same, there is an error that must be corrected.

> Unless drainage onto the development from offsite is diverted around or through the site, offsite catchment area draining in must be included in the acreage values and treated.

Post-development:

(1) Type of Land Cover	(2) Area (acres)	(3) S.M. Formula (0.51 + 9.1 I)	(4) Average EMC of TN (mg/L)	(5) Column (2) * (3) * (4)	(6) Average EMC of TP (mg/L)	(7) Column (2) * (3) * (6)
Transportation impervious	3.20	4.62	2.60	38.44	0.19	2.81
Roof impervious	0.87	4.62	1.95	7.84	0.11	0.44
Managed pervious	4.74	4.62	1.42	31.10	0.28	6.13
Wooded pervious	0.20	4.62	0.94	0.87	0.14	0.13
Fraction Impervious (I) =	0.45		TN Loading (lb/yr) =	78.25	TP Loading (lb/yr) =	9.51
Total Area of Development =	9.01		TN Exp. Coeff. (lb/ac/yr) =	8.69	TP Exp. Coeff. (lb/ac/yr) =	1.06

Note: The nutrient loading goals are 4.0 lb/ac/yr for TN and 0.4 lb/ac/yr for TP. If the post-development nutrient loading is below these levels, then no BMP is necessary. Otherwise, the next worksheet calculates post-development TN and TP loadings after BMPs are installed.