Ritter Field (River Bend, NC) Stormwater Wetland Assessment for Water Quantity, Water Quality, and Phosphorus Deposition

Monitoring from June 2007 to June 2008

Submitted:
September 30 2008

Submitted to:

NCDENR-EEP
1652 Mail Service Center
Raleigh, NC 27699-1652

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EXECUTIVE SUMMARY

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, resulting in a reduced number of rainfall and runoff events. 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, respectively, were collected and statistically compared. The wetland significantly ($p<0.05$) reduced peak flow rates by 80% and runoff volumes by 54%. 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 a significant difference ($p>0.05$) between inflow and outflow concentrations for only one of the previously mentioned pollutants: Inflow concentrations of OP were significantly greater ($p<0.05$) than outflow concentrations. There was a significant difference ($p<0.05$) between inflow and outflow loads for only two of the previously mentioned pollutants: Inflow loads for OP and $NH_{2\text{-}3}$-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, it

appears the differences between inflow and outflow loadings, particularly TKN and TP, are becoming 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 when compared to 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. Additionally, 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, $NO_{2\text{-}3}$-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.

Phosphorus (P) deposition was also monitored by taking soil samples at specific locations in the wetland every 2 months for a year. 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 was no longer removing P effectively due to P saturation.

PROJECT BACKGROUND

Project Objectives

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. Evaluate the performance of a stormwater wetland when compared to nearby in-stream concentrations of TKN, $NO_{2\text{-}3}$-N, NH_4-N, TP, OP and TSS.
3. Evaluate the performance of a stormwater wetland by comparing influent and effluent concentrations of TKN, $NO_{2\text{-}3}$-N, NH_4-N, TP, OP and TSS with other North Carolina stormwater wetlands.
4. Determine where phosphorus deposition occurs within a stormwater wetland.

Project Structure, Restoration Type, and Approach

The River Bend wetland was first constructed in 1998 with a 30.4 ha (75 ac) watershed consisting of 0.2 ha (0.5 ac) residential lots. Between 1998 and 2006 the town of River Bend expanded the watershed by approximately 16.1 ha (40 ac) by adding ditched beside roads along the perimeter of the original watershed. As a result the wetland was undersized (Figure 1). To remedy the situation, the wetland was resized in March 2007 to meet the standard design recommendations for a stormwater wetland, (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 various species were planted in the wetland (Table 1). Soon afterward, a late season freeze occurred in April , killing the majority of the plants in the wetland. The wetland was replanted in June, with approximately 1000 plants of the same variety as the original planting plan. Figure 2 shows the River Bend wetland immediately after resizing and planting

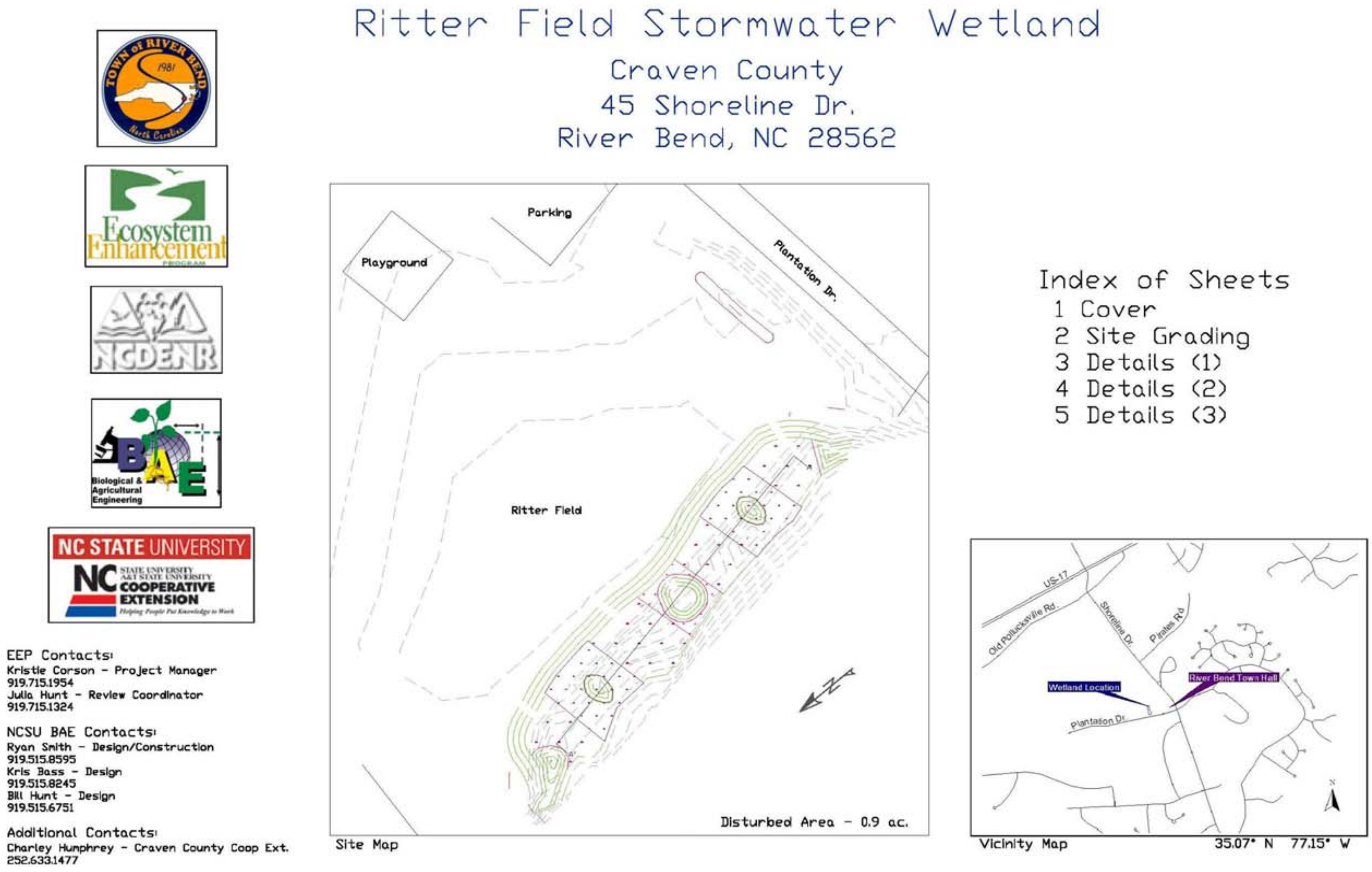
Figure 1. River Bend wetland before being resized and reconstructed.

Figure 2. Pictured left the River Bend wetland post resizing and planting. Pictured right the River Bend wetland in July, 2008.

Location and Setting

The selected site was a 0.14 hectare (0.34 acre) stormwater treatment wetland constructed in River Bend, NC, located in Craven County, 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. 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. 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. The NRCS Web Soil Survey (WSS) reported five different soil series within the watershed: 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 ranging from 10 to 70 feet (NRCS 2002).

Figure 3. Location and setting of the River Bend Wetland



Project History and Background

Table 1. Project contacts.

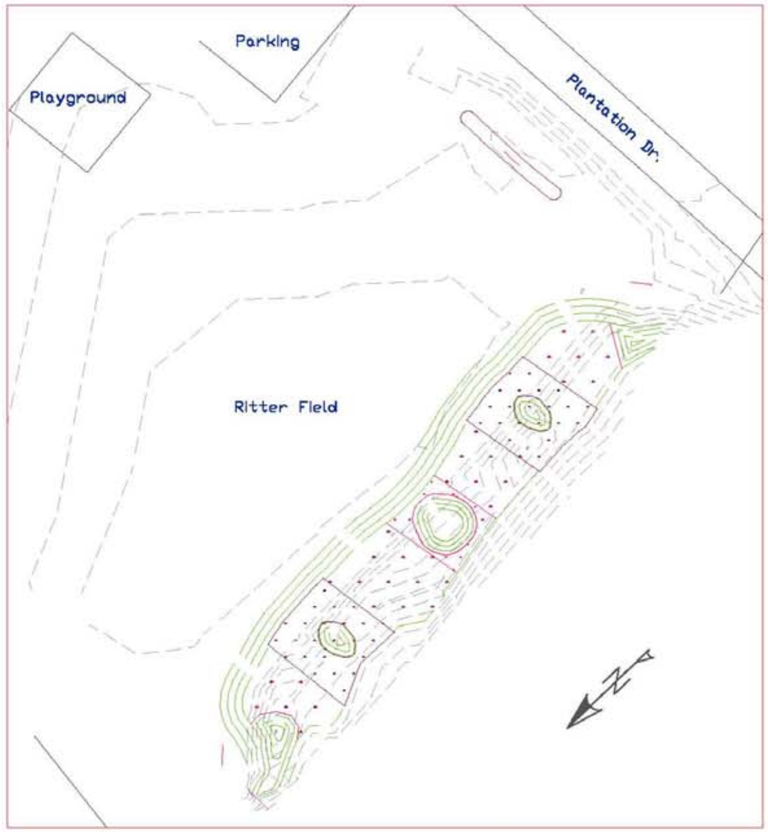
Project Contacts River Bend / Project #	
Designer Ryan Smith	BAE NCSU / Weaver Labs, Campus Box 7625, Raleigh, NC 27695 Ryan Smith 919-515-8595
Construction Contractor Pete Rollins	Pete Rollins Contractor / 3755 HWY 55 W New Bern, NC 28562 Pete Rollins 252-637-2948
Planting Contractor Mellow Marsh Farm	Mellow Marsh Farm / 1312 Woody Store Road, Siler City, NC 27344 Joan McLean 919-742-1200
Monitoring Performers Hayes Lenhart	BAE NCSU / Weaver Labs, Campus Box 7625, Raleigh, NC 27695 Hayes Lenhart 919-515-6751

Table 2. Project background table

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	54
Physiographic Region	Coastal Plain
Ecoregion	63h
Dominant soil types	Conetoe, Goldsboro, Masontown, Tarboro and Udorthents series
NCDWQ Sub-basin	NEU8
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)

Monitoring Plan View

The following four pages contain construction documents for the River Bend wetland.



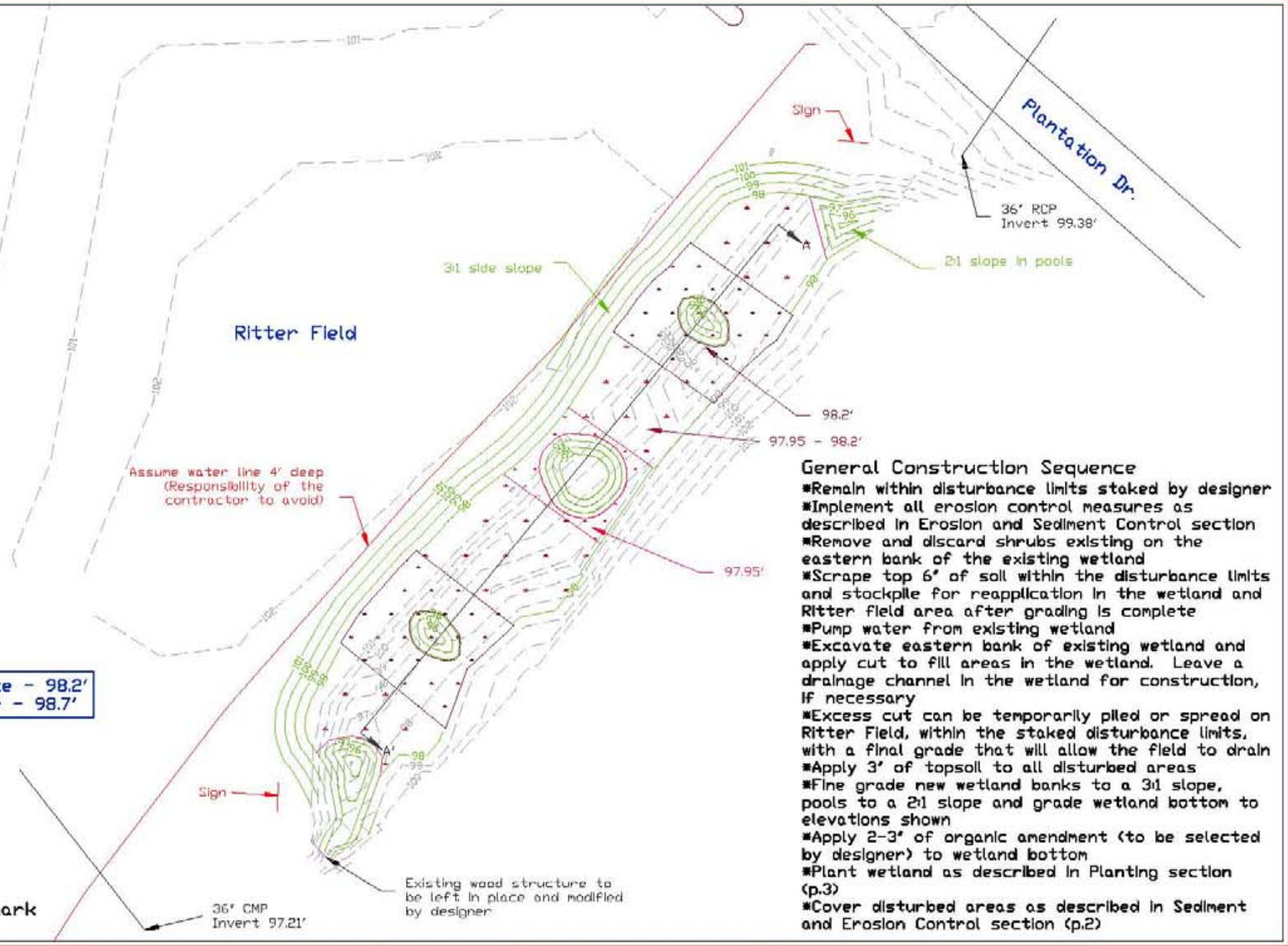
Ritter Field Stormwater Wetland
45 Shoreline Dr.
River Bend, NC 28562

Figure 4. Construction plans for the River Bend wetland.

Sediment and Erosion 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.

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, 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. Apply blanket per manufactures instructions using staple pattern A (See p.4 detail).



Normal Pool Water Surface - 98.2'
Flood Pool Water Surface - 98.7'

General Construction Sequence

- Remain within disturbance limits staked by designer
- Implement all erosion control measures as described in Erosion and Sediment Control section
- 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 (p.3)
- Cover disturbed areas as described in Sediment and Erosion Control section (p.2)

Note: All elevations in plans relative to designer's benchmark

Ecosystem Enhancement Program

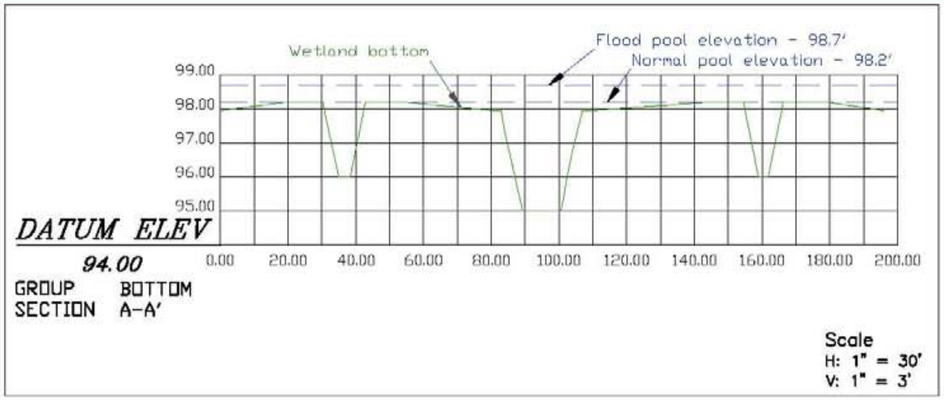
30 0 30 60

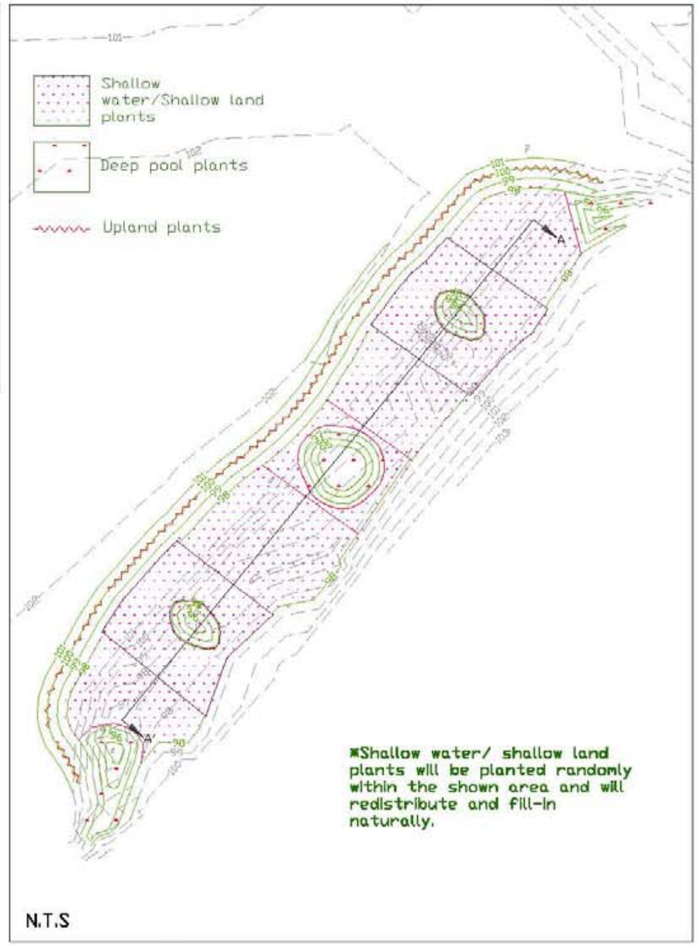
Scale
H: 1" = 30'
V: N/A

Drawn by: RAS
Designed by: RAS
Reviewed by: WFH, KLB
Date: 10/2005
File Name: river_bend.dwg

Site Grading
Ritter Field Wetland
River Bend, NC
Sheet 2/4

NC STATE UNIVERSITY
NC State University A&T State University Cooperative Extension





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.

Ecosystem Enhancement

Scale
See details

Drawn by: RAS
Designed by: RAS
Reviewed by: WFH, KLB
Date: 10/2005
File Name: river_bend.dwg

Details
Ritter Field Wetland
River Bend, NC
Sheet 3/4

NC STATE UNIVERSITY
NC STATE UNIVERSITY A&T STATE UNIVERSITY COOPERATIVE EXTENSION

Erosion Control Blanket
SLOPE INSTALLATION

NORTH AMERICAN GREEN
EROSION CONTROL Products
Guaranteed SOLUTIONS
14649 HIGHWAY 41 NORTH
EVANSVILLE, IN 47725
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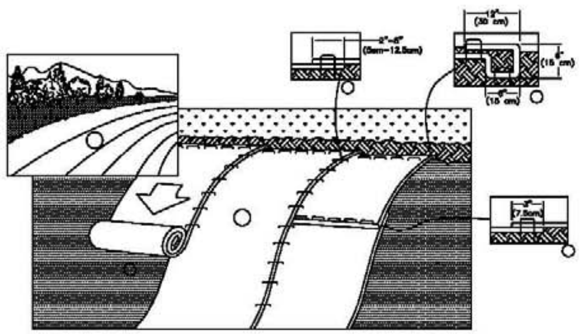

1. PREPARE SOIL BEFORE INSTALLING ROLLED EROSION CONTROL PRODUCTS (RECP's), INCLUDING ANY NECESSARY APPLICATION OF LIME, FERTILIZER, AND SEED.
   NOTE: WHEN USING CELL-O-SEED DO NOT SEED PREPARED AREA. CELL-O-SEED MUST BE INSTALLED WITH PAPER SIDE DOWN.
2. BEGIN AT THE TOP OF THE SLOPE BY ANCHORING THE RECP's IN A 6" (15 CM) DEEP X 6" (15 CM) WIDE TRENCH WITH APPROXIMATELY 12" (30cm) OF RECP's EXTENDED BEYOND THE UP-SLOPE PORTION OF THE TRENCH. ANCHOR THE RECP's WITH A ROW OF STAPLES/STAKES APPROXIMATELY 12" (30 CM) APART IN THE BOTTOM OF THE TRENCH. BACKFILL AND COMPACT THE TRENCH AFTER STAPLING. APPLY SEED TO COMPACTED SOIL AND FOLD REMAINING 12" (30 CM) PORTION OF RECP's BACK OVER SEED AND COMPACTED SOIL. SECURE RECP's OVER COMPACTED SOIL WITH A ROW OF STAPLES/STAKES SPACED APPROXIMATELY 12" (30 CM) APART ACROSS THE WIDTH OF THE RECP's.
3. ROLL THE RECP's (A.) DOWN OR (B.) HORIZONTALLY ACROSS THE SLOPE. RECP's WILL UNROLL WITH APPROPRIATE SIDE AGAINST THE SOIL SURFACE. ALL RECP's MUST BE SECURELY FASTENED TO SOIL SURFACE BY PLACING STAPLES/STAKES IN APPROPRIATE LOCATIONS AS SHOWN IN THE STAPLE PATTERN GUIDE. WHEN USING THE DOT SYSTEM™, STAPLES/STAKES SHOULD BE PLACED THROUGH EACH OF THE COLORED DOTS CORRESPONDING TO THE APPROPRIATE STAPLE PATTERN.
4. THE EDGES OF PARALLEL RECP's MUST BE STAPLED WITH APPROXIMATELY 2" - 5" (5 CM - 12.5 CM) OVERLAP DEPENDING ON RECP's TYPE.
5. CONSECUTIVE RECP's SPLICED DOWN THE SLOPE MUST BE PLACED END OVER END (SHINGLE STYLE) WITH AN APPROXIMATE 3" (7.5 CM) OVERLAP. STAPLE THROUGH OVERLAPPED AREA, APPROXIMATELY 12" (30 CM) APART ACROSS ENTIRE RECP's WIDTH.
   NOTE:
   *IN LOOSE SOIL CONDITIONS, THE USE OF STAPLE OR STAKE LENGTHS GREATER THAN 6" (15 CM) MAY BE NECESSARY TO PROPERLY SECURE THE RECP's.

STAPLE PATTERN GUIDE
6.67' (2.03 M) WIDE ROLLS

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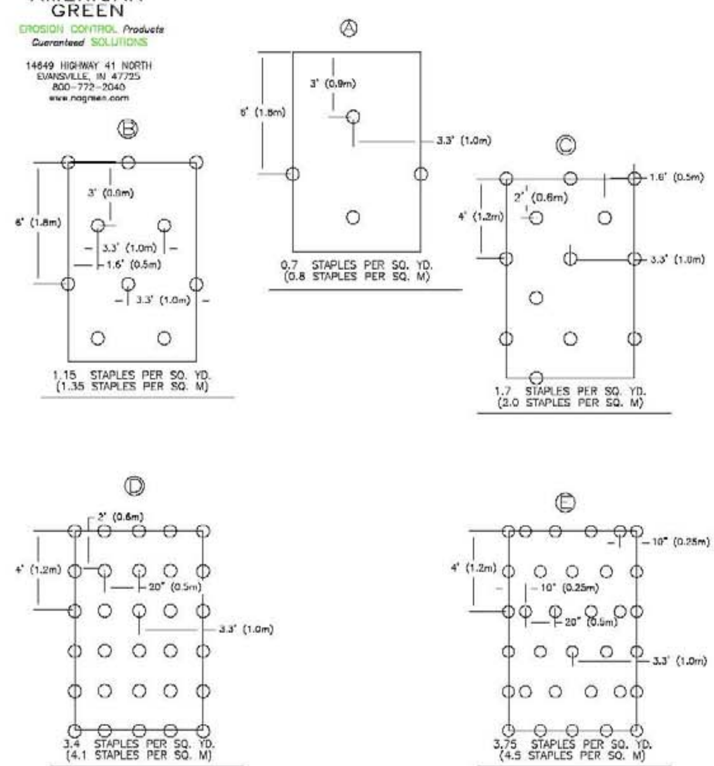

Ecosystem Enhancement Program	Scale H: N.T.S V: N.T.S	Drawn by: RAS Designed by: RAS Reviewed by: WFH, KLB Date: 10/2005 File Name: river_bend.dwg	Details Ritter Field Wetland River Bend, NC Sheet 4/4	NC STATE UNIVERSITY NC COOPERATIVE EXTENSION

PROJECT CONDITION AND MONITORING RESULTS

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® (SAS), a 1-way Analysis of Variance (ANOVA) table was used to identify the significant ($p<0.001$) difference in inflow and outflow peak flows, as well as runoff volumes ($p<0.05$) The wetland reduced runoff volumes by an average of 54% (Table 3).

SAS was used to develop a completely randomized split-block design (CRSPD), which indicated there was no significant difference ($p>0.05$) between growing and non-growing season runoff volumes or peak flows. This was likely due to the drought conditions that impacted the site during the course of this study.

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. It is hypothesized that the relationship between outflow and antecent dry period was due primarily to the drought conditions.

Figure 5 shows the relationship between inflow and outflow volumes on a log-log scale. There appears to be a positive correlation between the inflow and outflow 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 via seepage and ET losses during the inter-event period.

Table 3. 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

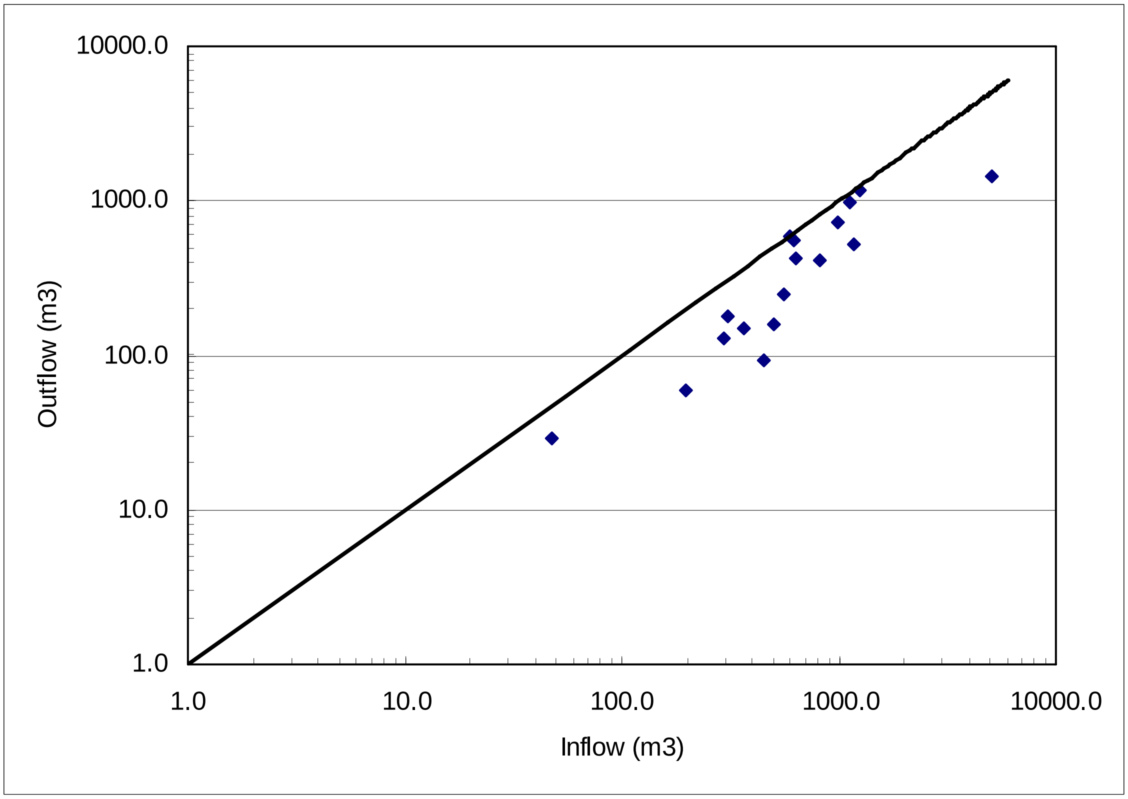

Figure 5. Log-Log inflow volumes vs. outflow volumes.

Water Quality

A "traditional" way of examining the wetland's impact on water quality by comparing inflow and outflow concentration and loads is first presented. Afterwards, there are discussions on two alternative means of assessing how well the wetland performed. Eleven storms were used to compare concentrations and loadings of TKN, $NO_{2\text{-}3}$-N, NH_4-N, TN, TP, OP and TSS.

A 1-way Analysis of Variance (ANOVA) table was generated using SAS for each pollutant: TKN, $NO_{2\text{-}3}$-N, NH_4-N, TP, OP and TSS. This ANOVA table was used to determine that a significant difference ($p<0.05$) existed between inflow and outflow concentrations and loads for only one of the aforementioned pollutants. Inflow concentrations for OP were significantly greater ($p<0.05$) than outflow concentrations.

Inflow loads were significantly larger ($p<0.05$) than outflow loads for OP and $NH_{2\text{-}3}$-N. 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 (i.e. not reducing) TKN, NH_4-N, TN, TP and TSS; however, concentrations of $NO_{2\text{-}3}$-N and Ortho P are being reduced (Table 4). The wetland is reducing loadings of all pollutants (Table 4). These load reduction are a direct result of the significant reduction between inflow and outflow volumes.

Table 4. 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
$NO_{2\text{-}3}$-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 $NO_{2\text{-}3}$-N

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.

The first stream monitoring location, station number J8690000 (N 35.06364, W 77.46107) (Figure 6), 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 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 (NCDEM, 1983).

The next stream monitoring location, station number J8730000 (N 35.00993, W 77.21891) (Figure 6), 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. No samples were analyzed for TSS. 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 6), 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. A bioclass for this area is not available.

Tables 5 and 6 compare the minimum, maximum and mean influent and effluent concentrations from River Bend with the 10^{th}, 50^{th} and 90^{th} percentile concentrations from streams geographically close to the wetland and in the same Trent River watershed.

River Bend inflow and outflow concentrations for NO_{2-3}-N (0.18 and 0.16 mg/L, respectively) were 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 those in streams. Concentrations of TKN are 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 (1.30, 1.18 and 0.95 mg/L). 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. This is 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 90th percentile concentrations in these streams. The minimum TSS concentrations to and from River Bend were approximately equal to the 90^{th} percentile background concentrations.

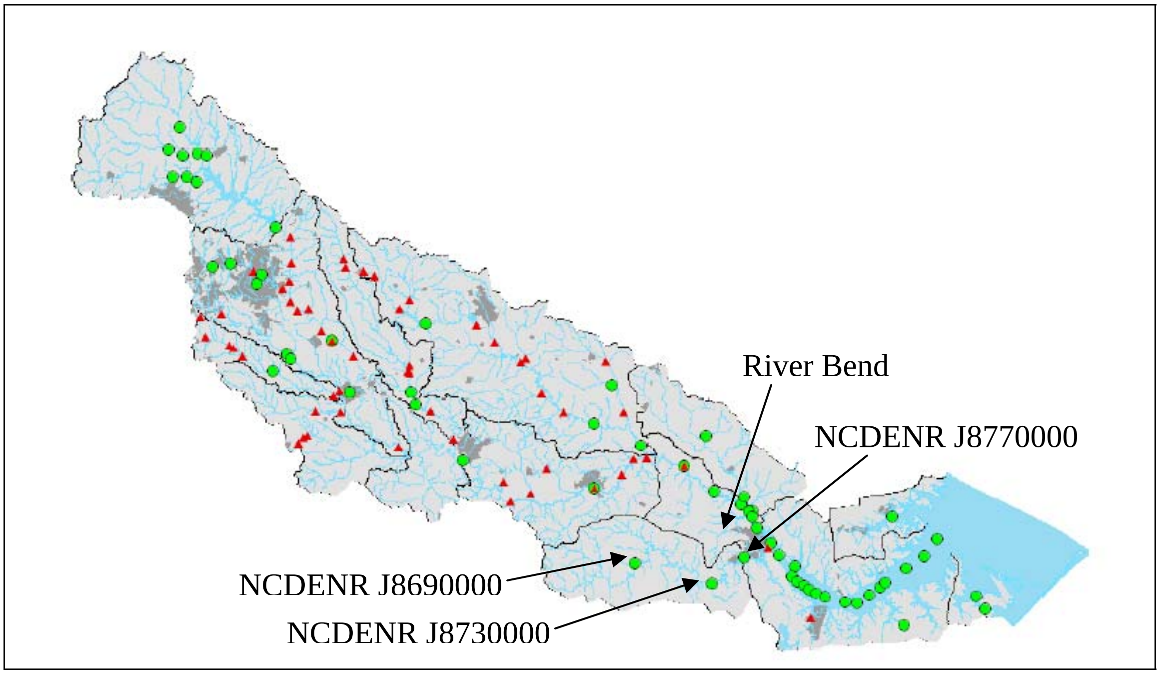

Figure 6. Location of NCDENR water quality monitoring locations (NCDENR 2006).

Table 5. 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 6. 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

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 Tables 7 and 8 below.

Table 7. 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 8. 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 all pollutants except TKN, NH_4-N, and TN. For TKN, 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_{2-3}-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 might not be capable of reducing the pollutant load by a significant 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 with more established vegetation.

By 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.

Phosphorus Deposition

Soil samples were collected spatially across the wetland from April 2007 to April 2008 and analyzed for P content. From these samples it was possible to make some determinations on the fate of influent phosphorus. 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 potential.

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 7). 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 consist 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 8, 9 and 10).

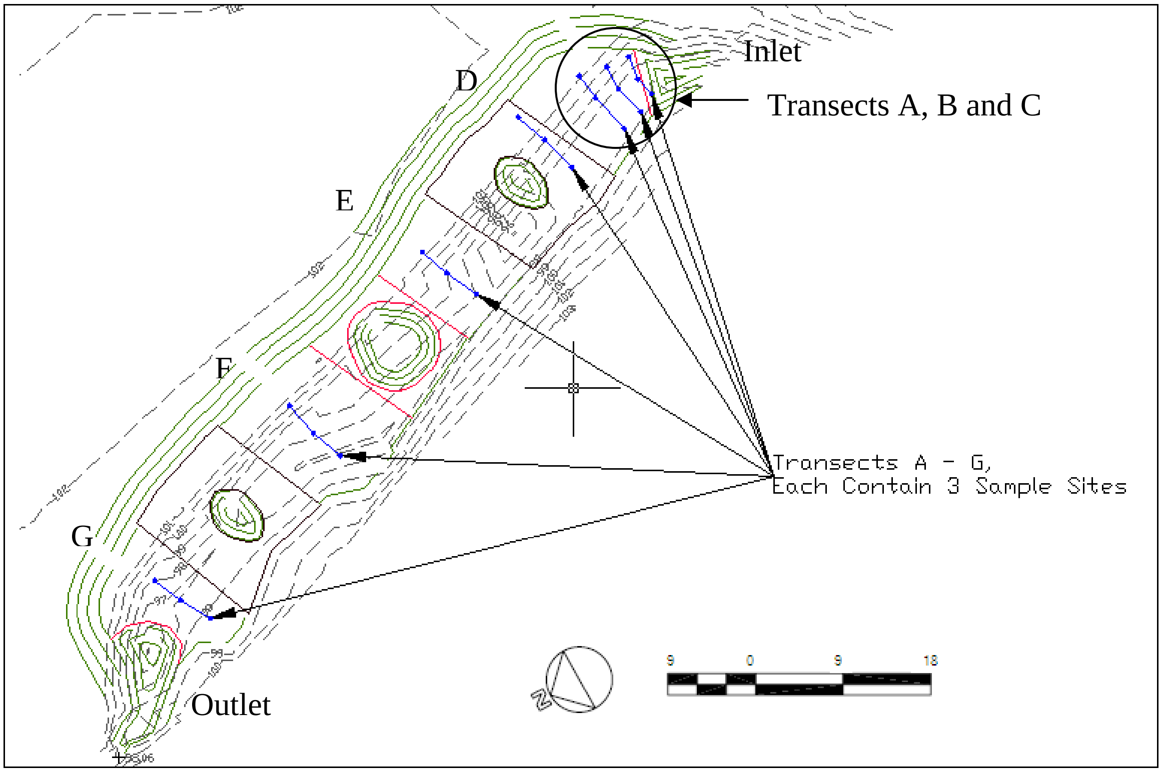

Figure 7. AutoCAD® drawing of soil sampling locations in the River Bend wetland (SI unit scale).

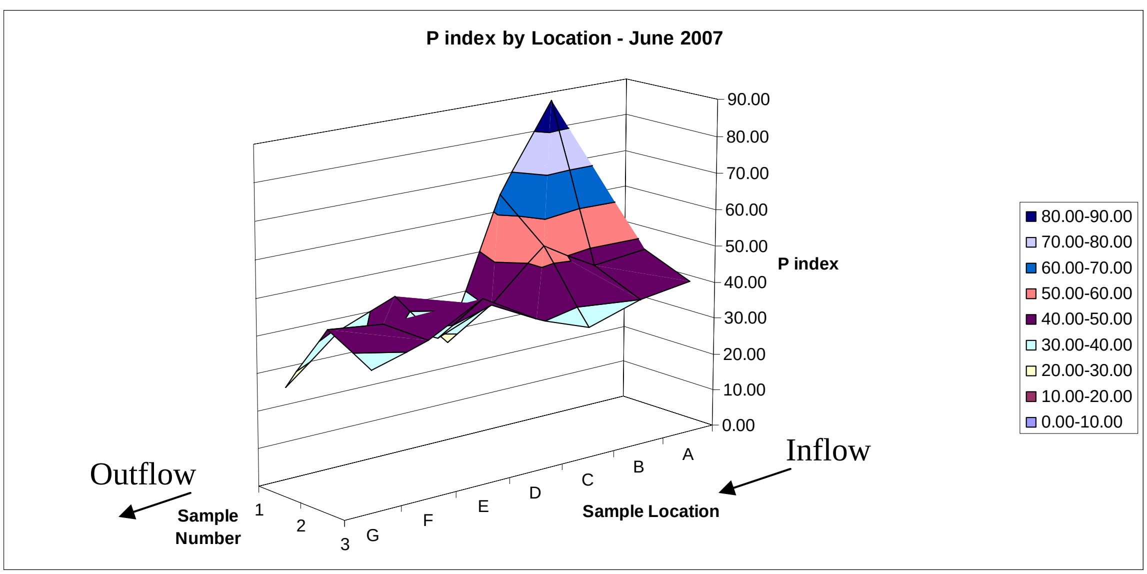

Figure 8. P index values by location for June 2007.

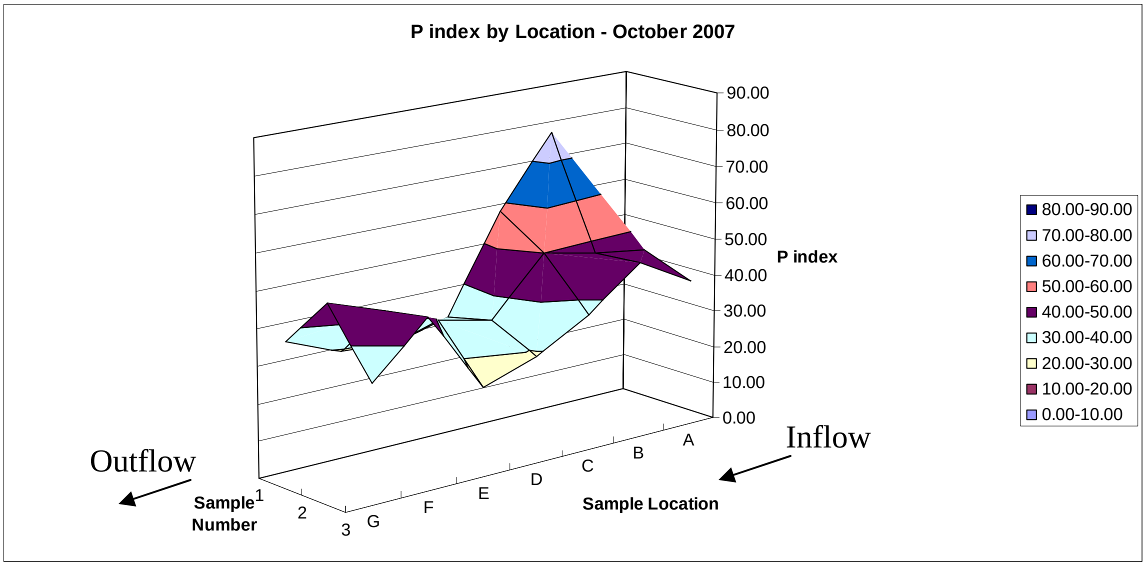

Figure 9. P index values by location for October 2007.

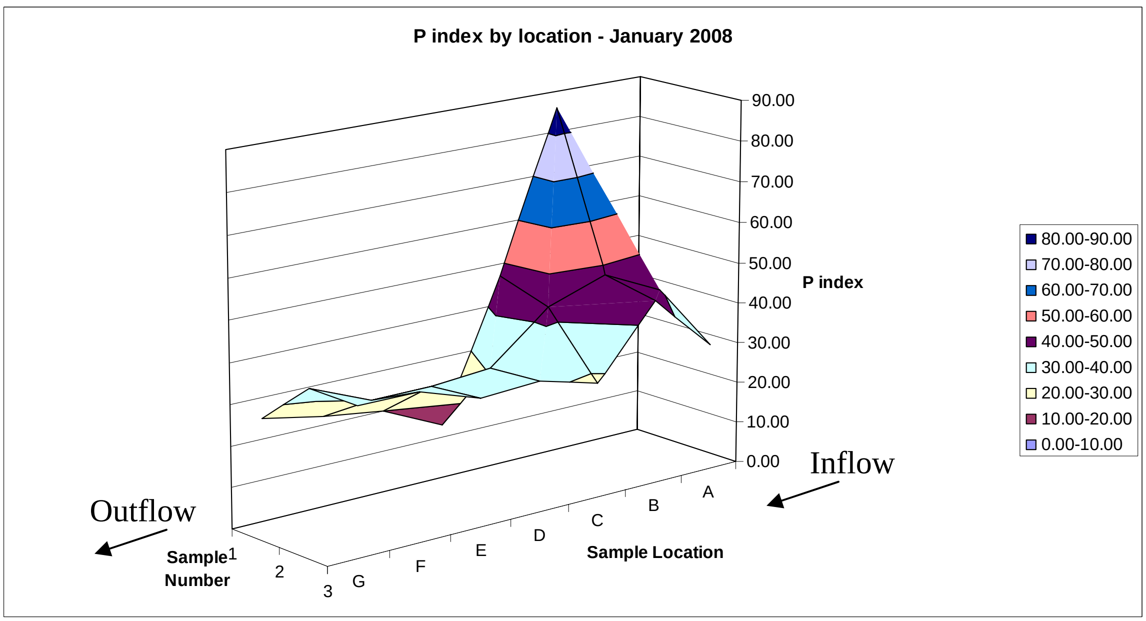

Figure 10. P index values by location for January 2008.

There is a consistent P peak between transects A and C. Based on the data from Figures 8, 9 and 10 there does not appear to be any substantial change in P value throughout the year. P is being deposited as inflow enters the wetland, thereby keeping the high P index values from spreading to the rest of the wetland. The minor fluctuations around the peak and at other transects were not discernibly consistent. However, this data shows is a spatial distribution of P significantly concentrated near the inlet of the wetland.

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 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 Recommendations

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; and
- 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 in environments similar to those at River Bend.

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 reductions were 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; and

- 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; and
- River Bend's mean outflow concentrations of TKN, NO_{2-3}-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.

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); and
- 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.

METHODOLOGY

Water Quality and Quantity

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 11 and 12), 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 13). 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 12 and 14) 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 13). 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 9 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), with samples 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.

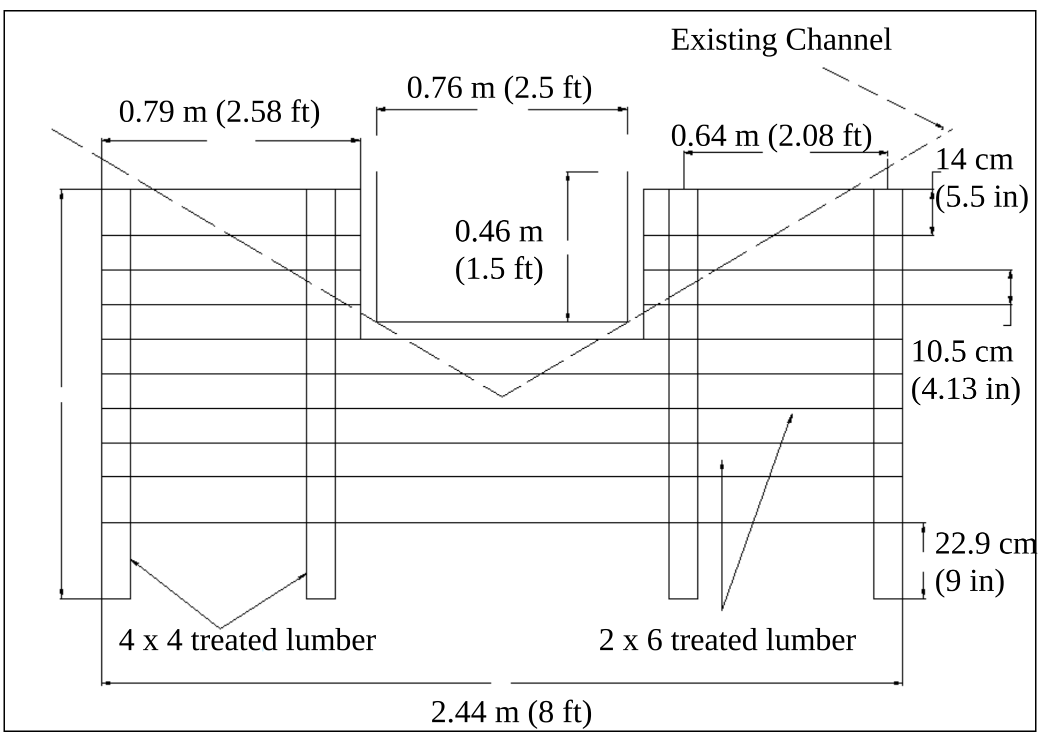

Figure 11. Inlet structural drawing.

Figure 12. From left: inflow and outflow weirs.

Figure 13. From left: inflow and outflow monitoring setup.

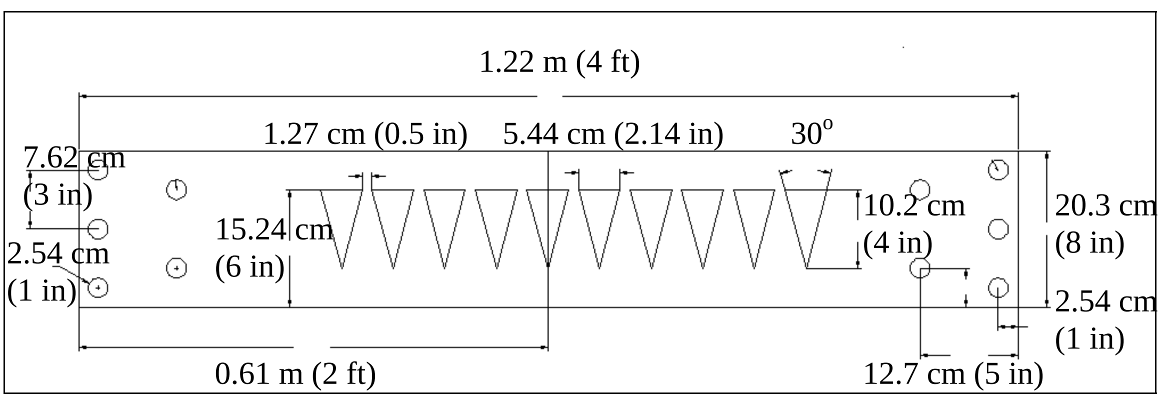

Figure 14. Outlet structural drawing.

Table 9. 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 ($NO_{2\text{-}3}$-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.

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 7). Sample locations were marked using pvc pipe hammered into the ground to insure consistent sampling (Figure 15).

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 15. Soil sampling locations marked by PVC pipe.

REFERENCES

Bass, K. L. 2000. Evaluation of a Small In-Stream Constructed Wetland in North Carolina's Coastal Plain. M.S. thesis. North Carolina State University, Raleigh, NC, USA.

Breen, P. F. 1990. A mass balance method for assessing the potential of artificial wetlands for wastewater treatment. Water Research 24:689-697.

Hardy, D. H., M. R. Tucker, J. K. Messick and C. Stokes. 2003. Understanding the Soil Test Report. N.C. Department of Agriculture & Consumer Services Agronomic Division, Raleigh, NC, USA.

Hunt, W. F., M. R. Burchell, J. D. Wright and K. L. Bass. 2007. Stormwater Wetland Design Update: Zones, Vegetation, Soil, and Outlet Guidance. North Carolina Cooperative Extension, N.C. State University, Raleigh, NC, USA. AGW-588-12.

Hunt, W. F., A. R. Jarrett, J. T. Smith and L. J. Sharkey. 2006. Evaluating Bioretention Hydrology and Nutrient Removal at Three Field Sites in North Carolina. ASCE Journal of Irrigation and Drainage Engineering 132:600-608.

Johnson, J. L. 2006. Evaluation of Stormwater and Wet Pond Forebay Design and Stormwater Wetland Pollutant Removal Efficiency. MS Thesis. North Carolina State University, Raleigh, NC, USA.

Kadlec, R. H. 1995. Overview: surface flow constructed wetlands. Water Science and Technology 32:1-12.

Kadlec, R. H. 1999. The limits of phosphorus removal in wetlands. Wetlands Ecology and Management 7:165-175.

Line, D. E., G. D. Jennings, M. B. Shaffer, J. Calabria and W. F. Hunt. 2008. Evaluating the Effectiveness of Two Stormwater Wetlands in North Carolina. Transactions of the ASABE 51:521-528.

MDDER. 1999. Low-Impact Development Design Strategies. Maryland Department of Environmental Resource Programs and Planning Division, Largo, MD, USA.

Mehlich, A. 1984. Mehlich-3 soil test extractant: a modification of Mehlich-2 extractant. Communications in Soil Science and Plant Analysis 15:1409-1416.

NC Division of Environmental Management. 1983. Basic water monitoring program, data review 1981- 1982. Report No. 83-10, 209 pp.

NCDENR. 2006. Basinwide Assessment Report Neuse River Basin. North Carolina Department of Environmental and Natural Resources, Raleigh, NC, USA.

NRCS. 2002. Official Series Description - CONETOE Series. Raleigh, NC: Natural Resorurces and Conservation Service. Available at: http://ortho.ftw.nrcs.usda.gov/osd/dat/C/CONETOE.html. Accessed May 1, 2008

Richardson, C. J., S. Qian, C. B. Craft and R. G. Qualls. 1996. Predictive models for phosphorus retention in wetlands. Wetlands Ecology and Management 4:159-175.

SAS. 2008. SAS User's Guide: Statistics. 9.1. Cary, NC, USA.: SAS Institute, Inc.

External

(Bass 2000, Hunt et al. 2006, Johnson 2006, Kadlec 1999, Line et al. 2008),