CITY of CHARLOTTE
Pilot BMP Monitoring Program

Bruns Ave. Elementary School Wetland
Final Monitoring Report

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City of Charlotte-Storm Water Services

Purpose

The purpose of this report is to document monitoring and data analysis activities undertaken by the City of Charlotte, NC and NC State University to determine the effectiveness and stormwater treatment capabilities of the Bruns Ave. Elementary School Constructed Wetland.

Introduction

Stormwater wetlands are designed for several reasons: improving water quality, improving flood control, enhancing wildlife habitat, and providing education and recreation. Wetlands in general, and stormwater wetlands in particular, use several mechanisms to remove pollutants. Stormwater wetlands employ perhaps more ways to remove sediment, nutrients, metals and chemicals, and even bacteria than any other structural BMP. These mechanisms include sedimentation, filtration, adsorption, microbial activity (nitrification and denitrification), and plant uptake. Where stormwater regulations are implemented, wetlands are often used to remediate the impact of newly constructed imperious area. In North Carolina, properly designed wetlands are an accepted BMP for the removal of total suspended solids (TSS), total nitrogen (TN), and total phosphorous (TP). NCDENR gives wetlands credit for 85% TSS removal, 40% TN removal, and 35% TP removal (NCDENR, 2006).

Site Description

The Bruns Ave. Elementary School wetland project is a 0.13 ha (0.32 ac) stormwater wetland that was constructed in 2002 as part of the City of Charlotte stormwater best management practice initiative (Figure 1). The wetland was designed to be flow-through; therefore there is no peak-flow mitigation. There is no overflow bypass, so it receives all of the watershed's runoff. Post-construction, several wetland species were planted in the wetland including bull rush, arrowhead, pickerelweed, and soft rush.

The 6.4-ha (15.8-ac) contributing watershed, shown in Figure 2, consists of grassed, wooded and impervious areas of the school grounds, as well as single- and multi-family residences. Impervious area within the watershed is approximately 60% of the total area. Table 1 outlines the watershed characteristics for the three contributing sub-watersheds. The primary inlet captures a 2.0-ha (4.9-ac) watershed with a curve number (CN) of 74 while the secondary inlet captures a smaller, more impervious 1.9-ha (4.7-ac) watershed that has a CN of 81. As shown in Figure 1, the remaining watershed consists of over 2.5-ha (6.2-ac) of grassed area and playground immediately surrounding the wetland. This area could not be monitored because stormwater from this area arrived at the wetland via overland flow instead of through any stormwater conveyance.

Figure 1. Bruns Ave. School Wetland, downstream view

Figure 2. Aerial view of Bruns Ave. School Wetland and contributing watershed during construction

Table 1. Contributing watershed characteristics

Watershed	Area (ha)	Curve Number
Primary Inlet	2.0	74
Secondary Inlet	1.9	81
Local Contribution	2.5	92
Total	6.4	83

Monitoring Plan and Data Analysis

The primary inlet, secondary inlet, and the outlet were equipped with flow monitoring devices and automatic samplers for water quality sample collection (Table 2). The primary inlet channel was fitted with a 120-degree v-notch weir and an ISCO model 720 bubbler to measure runoff during storm events. Also at the primary inlet, an ISCO model 673 tipping bucket rain gage was installed to measure rainfall. An ISCO model 730 area-velocity meter was installed to measure flow inside the 0.61 m (24 in.) reinforced concrete pipe (RCP) culvert at the secondary inlet. The outlet channel, shown in Figure 3, was equipped with another ISCO model 720 bubbler that measured flow over the 120-degree v-notch weir.

Table 2. Flow monitoring equipment installed at the Bruns Ave. School Wetland

Location	Device	Instrument	Bottle Configuration	Rain Gage
Primary Inlet	120 degree v-notch weir	ISCO model 720 bubbler	24-100 mL Propak containers	ISCO model 673 tipping bucket
Secondary Inlet	24 in. RCP culvert	ISCO model 730 area-velocity meter	24-100 mL Propak containers	
Outlet	120 degree v-notch weir	ISCO model 720 bubbler	24-100 mL Propak containers	

Figure 3. Weir at the outlet of Bruns Ave. School Wetland

Beginning in September 2004, grab samples and event-based flow composite water quality samples were collected at the primary inlet, secondary inlet, and outlet of the wetland. All pollutants, with the exception of fecal coliform, were composite water quality samples collected by automatic samplers. ISCO 6712 samplers were installed at both inlets and the outlet. ISCO flow monitoring equipment triggered 200 mL aliquots during storm events, with errors typically being ±5% of the average volume in a set (ISCO, 2005).

Flow paced sampling was programmed such that aliquots would be taken at each monitoring station throughout a given storm for events up to 50 mm (2 in.). Aliquots were combined to create a composite sample (Table 3) for each storm event. Samples were collected in accordance with Stormwater Best

Management Practice (BMP) Monitoring Protocol for the City of Charlotte and Mecklenburg County Stormwater Services (Smith et al., 2004).

Table 3. Automatic sampler settings for inlet and outlet ISCO 6712 samplers

Location	Sample Volume (mL)	Pacing (m^3)	Pacing (ft^3)
Primary Inlet	200	1.1	40
Secondary Inlet	200	1.6	57
Outlet	200	2.5	90

Estimating pollutant concentrations for the local watershed

The monitoring equipment at the wetland only collected water quality samples at the primary and secondary inlets; the runoff and associated pollutants of the local 2.5-ha (6.2-ac) watershed were not accounted for. To account for all inflow, the concentration of the runoff pollutants was estimated for the local watershed (NCDENR, 2005). The local watershed consisted of two sub watersheds, each having three different land uses. The pollutant export concentrations associated with each land use were area-weighted to estimate the mean concentration for the entire watershed, as shown in Table 4.

Table 4. Pollutant concentrations for various land uses used to estimate local watershed pollutant contributions at Bruns Ave. School stormwater wetland (NCDENR, 2005)

			Concentration, mg/L							
	Area		NH4	NO3-2	TKN	TN	TP	TSS	Cu	Zn
Subwatershed 1	2.27	acres								
Urban Open	60%	1.362	0.1	0.4	0.7	1.1	0.2	20	5.7	25.4
Medium density Res	20%	0.454	0.2	0.6	1.1	1.7	0.2	30.5	9.7	59.4
Commercial	20%	0.454	0.4	0.9	2	3.1	0.4	54.2	20.4	188.7
		Weighted	**0.2**	**0.5**	**1.0**	**1.6**	**0.24**	**28.9**	**9.4**	**64.9**
			Concentration, mg/L							
	Area		**NH4**	**NO3-2**	**TKN**	**TN**	**TP**	**TSS**	**Cu**	**Zn**
Subwatershed 2	3.95	acres								
Medium Density Res	10%	0.395	0.2	0.6	1.1	1.7	0.2	30.5	9.7	59.4
Woods	30%	1.185	0.1	0.4	0.7	1.1	0.2	19.7	5.6	24.8
Commercial	60%	2.37	0.4	0.9	2	3.1	0.4	54.2	20.4	188.7
		Weighted	**0.3**	**0.7**	**1.5**	**2.4**	**0.3**	**41.5**	**14.9**	**126.6**
			Concentration, mg/L							
Total 1 + 2	**Area (ac)**		**NH4**	**NO3-2**	**TKN**	**TN**	**TP**	**TSS**	**Cu**	**Zn**
		Mean	**0.2**	**0.7**	**1.3**	**2.1**	**0.3**	**36.9**	**12.9**	**104.1**
	6.22	**Minimum[1]**	**0.1**	**0.4**	**0.7**	**1.1**	**0.2**	**19.7**	**5.6**	**24.8**

[1] Minimum corresponds to the minimum concentration possible for the watershed based on land use data

Water Quality Analysis

All influent and effluent samples were tested for a variety of pollutants including nutrients, bacteria and trace metals (Table 5). All collected samples were either refrigerated or acidified with H_2SO_4 within 24 hrs.

Table 5. Parameters included in water quality testing

Parameter	Abbreviation
Flow	---
Oil and Grease	O&G
Fecal Coliform	FC
E.coli	*E.coli*
Ammonia - Nitrogen	NH_4^+
Nitrate + Nitrite - Nitrogen	$NO_3^- + NO_2^-$
Total Kiedejal Nitrogen	TKN
Total Nitrogen	TN
Total Phosphate	TP
Total Suspended Solids	TSS
Copper	Cu
Zinc	Zn
Manganese	Mn

Statistical Analysis

Water quality and quantity data were used to compute event mean concentrations (EMCs) and determine the efficiency ratio for each pollutant. For BES, concentrations were converted to influent and effluent mass loadings. The efficiency ratio (ER) for each pollutant was determined using the following equation:

$$ER = 1 - [\text{Effluent EMC} / \text{Influent EMC}] \qquad \text{(Equation 1)}$$

Log transformations were used to normalize all data. Statistical significance of pollutant reduction was tested using a general linearized model (GLM) in SAS for Windows v. 8.02 (2003).

Data Analysis Results

The U.S. EPA recommends a two-fold approach in determining wetland BMP wetland pollutant removal efficiency. First, average inlet and outlet EMCs are determined to calculate a removal efficiency ratio. In addition, parallel probability plots are constructed to determine the effect of influent concentrations on the removal efficiency. This comparison is used to determine if a pollutant is being removed to the minimum detectable level by water quality testing and if the pollutant has an irreducible limit.

Between September 2004 and December 2005, 15 runoff-producing events were monitored. A storm number was assigned to each rainfall event (Table 6). The influent and effluent runoff volumes for all 15 storms are shown in Figure 4. Rainfall depths ranged between 11 mm (0.43 in.) and 101 mm (3.97 in.), with an average depth of 36 mm (1.41 in.).

The runoff volume data were not normally distributed; therefore, a log transformation was used prior to statistical testing. For the majority of the storms, the effluent volume was greater than the total influent volume, although the difference was not statistically significant (p=0.59). The higher outflow is the result of the 2.5-ha (6.2-ac) local watershed, which enters the wetland though overland flow and is therefore not measured at either of the monitored inlets. Although Inlet 1 is labeled as the primary inlet, the total runoff entering through this inlet was smaller than that entering through the secondary inlet. This can be attributed to the higher percentage of impervious area in the watershed that supplies the secondary inlet.

Storms 3, 5, 14, and 15 had a higher inflow volume than outflow volume. This may be the result of error associated with the flow monitoring equipment such as faulty water level measurement at either the inlet or outlet.

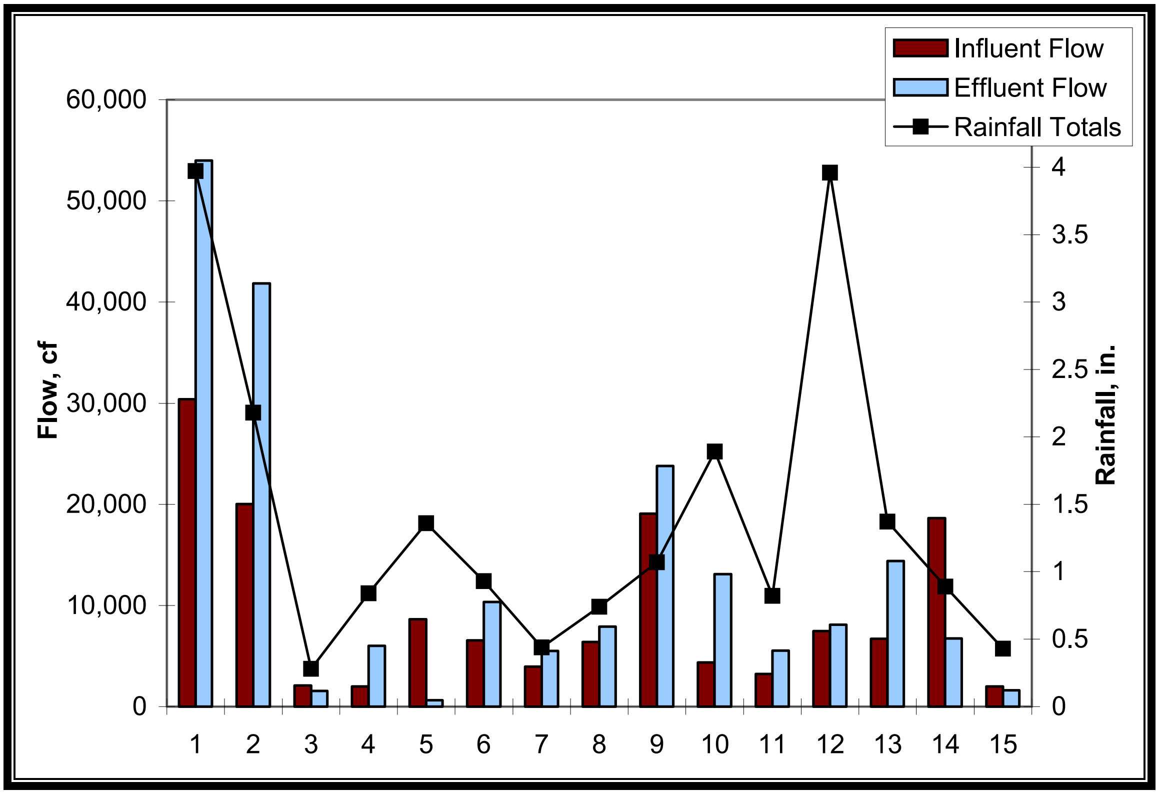

Figure 4. Total volume and rainfall amount for each monitored event at Bruns Ave. School Wetland

Table 6. Storm numbers assigned to each storm event at the Bruns Ave. School Wetland

Event Date	Storm Number	Rainfall Amount (in.)
7-Sep-04	1	3.97
27-Sep-04	2	2.18
13-Oct-04	3	0.28
4-Nov-04	4	0.84
9-Dec-04	5	1.36
14-Jan-05	6	0.93
25-Feb-05	7	0.44
8-Mar-05	8	0.74
13-Apr-05	9	1.07
1-Jun-05	10	1.89
28-Jun-05	11	0.82
6-Oct-05	12	3.96
5-Dec-05	13	1.37
16-Dec-05	14	0.89
29-Dec-05	15	0.43

Monitored Water Quality Results

The water quality data for the Bruns Ave. School stormwater wetland are reported as both concentrations and mass loadings. An average influent concentration was calculated for each event based on the quantity of flow and the respective concentration measured at each of the inlets (weighted average based on flow); the effluent concentration was not manipulated as there was only one outlet. Event means were calculated to determine the efficiency ratio of each pollutant based on Equation 1. Statistical significance of pollutant reductions was determined using a general linearized model. Table 7 summarizes the monitoring results for each pollutant.

Table 7. EMCs and statistical significance of pollutant concentration reductions, *not* including local watershed contributions

Parameter	Units	# of Samples	Influent EMC	Effluent EMC	ER	p-value	Significant ($p < 0.05$)
Flow Volume	ft^3	15	9400	13400	-42%	0.64	No
FC	col./100 mL	14	36800	10900	70%	0.01	Yes
E. coli	MPN/100 mL	10	2220	1530	29%	0.58	No
O&G	ppm	14	6.4	5.4	15%	0.01	Yes
NH_4^+	ppm	15	0.31	0.12	62%	< 0.01	Yes
NO_3 + NO_2	ppm	15	0.74	0.50	32%	< 0.01	Yes
TKN	ppm	15	1.57	0.87	45%	< 0.01	Yes
TN	ppm	15	2.36	1.40	40%	< 0.01	Yes
TP	ppm	15	0.44	0.20	55%	< 0.01	Yes
TSS	ppm	15	70.6	24.2	66%	< 0.01	Yes
Copper	ppb	15	7.70	7.26	6%	0.41	No
Iron	ppb	11	2330	1720	26%	0.61	No
Manganese	ppb	11	83.0	97.8	-18%	0.83	No
Zinc	ppb	15	46.54	20.07	57%	0.41	Yes

Grab samples were collected during 14 storm events throughout the monitoring period to test for fecal coliform (FC) concentrations entering and leaving the stormwater wetland. Grab samples were not collected for rainfall event 10 on June 10, 2004. Influent FC concentrations ranged between 290 colonies/100mL and 234,000 colonies/100mL, with the highest concentrations generally occurring during the larger rainfall events. The range of effluent concentrations was 190 – 50,000 colonies/100mL. Even though the Bruns Ave

School stormwater wetland significantly (p=0.01) decreased influent FC concentrations (a 70% concentration reduction), the majority of the effluent concentrations were above the NC standard of 200 colonies/100mL.

Grab samples taken during seven storm events determined the amount of *E.coli* in the influent and effluent stormwater. Although the ER was 20%, the wetland did not significantly reduce the influent *E.coli* concentration (P=0.58). Figure 5 compares the removal efficiencies of *E.coli* and fecal coliforms for events 7-9 and 12-15. There is no apparent relationship between the removal of *E.coli* and fecal coliforms. In fact, for storms 8, 12 and 15, there was a reduction of fecal coliforms, but an increase in *E.coli*. There are a limited number of published studies to support these findings; more bacterial analysis of stormwater BMPs is needed. The affect of stormwater wetland treatment on *E.coli* concentrations is becoming increasingly important, as state regulations begin using this parameter to regulate water quality in recreational waters.

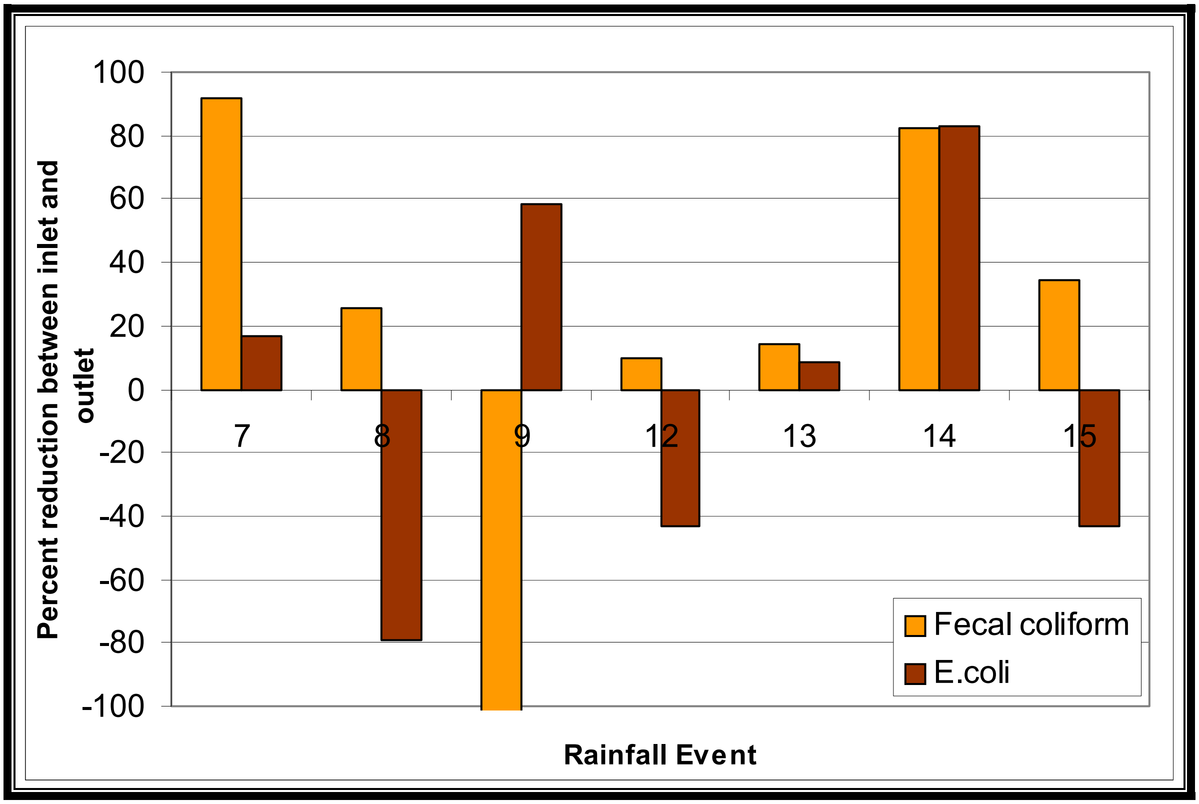

Figure 5. Percent reduction of FC and *E.coli* concentrations for the specified rainfall events

Table 7 shows that effluent concentrations at the wetland were significantly ($p < 0.01$) lower than the influent concentrations for all nitrogen and phosphorus parameters, including TKN, TN and TP. Concentration reductions were 45%, 40% and 55%, respectively. TSS concentrations also significantly ($p < 0.01$) decreased, with a concentration reduction of over 65%. Of the four metals, only zinc was significantly ($p = 0.41$) reduced (ER = 0.57). Iron concentrations were reduced by 26%, while copper concentrations were reduced by only 6%. The ERs for iron and zinc may have been affected by the minimum detectable limits for the water quality tests, which were 5 ppb for iron and 10 ppb for zinc. Copper concentrations were not detected to be at or below the MDL for any monitoring events; therefore, this was not a factor in the low ER.

The influent and effluent mass loadings of each pollutant were calculated by multiplying concentrations by their respective total flow volume (Table 8). Effluent NH_4^+ concentrations were significantly ($p<0.01$) lower than influent concentrations by an average of 62.5%; mass reductions were significant ($p=0.03$), but only decreased by 49%. The effluent concentration and mass loading of TSS and TP were both significantly lower than the influent ($p<0.01$ and $p=0.03$ respectively). Although the concentrations of $NO_{2\text{-}3}^-$, TKN and TN significantly decreased between the wetland inlet and outlet, the change in mass loadings was not significant.

Table 8. EMCs and statistical significance of pollutant mass load reductions

Parameter	Influent EMC	Effluent EMC	Efficiency Ratio (%)	Distribution	p-value	Significant ($p < 0.05$)
NH_4^+	100.2	50.8	49.3%	Log	0.048	YES
$NO_3 + NO_2$	191.4	172.3	10.0%	Log	0.37	NO
TKN	462.9	374.8	19.0%	Log	0.13	NO
TN	684.5	588.2	14.1%	Log	0.19	NO
TP	152.1	101.8	33.1%	Log	0.03	YES
TSS	23174.6	11775.9	49.2%	Log	< 0.01	YES
Copper	2.2	2.8	-23.9%	Log	0.74	NO
Iron	832.9	978.1	-17.4%	Log	0.82	NO
Manganese	23.2	43.0	-85.6%	Log	0.45	NO
Zinc	10.6	7.6	28.8%	Log	0.03	YES

Parallel probability plots were constructed to illustrate the pollutant efficiency ratio (ER) as affected by the influent and effluent concentrations. The only plot with an indication of concentration effect on ER was that for NH_4^+ (Figure 6). The data indicated that as influent concentration increases, the ER also increases. The minimum detectable level is also visible (0.05 mg/L); and for most storms, the effluent pollutants are between 0.05 and 0.10 mg/L.

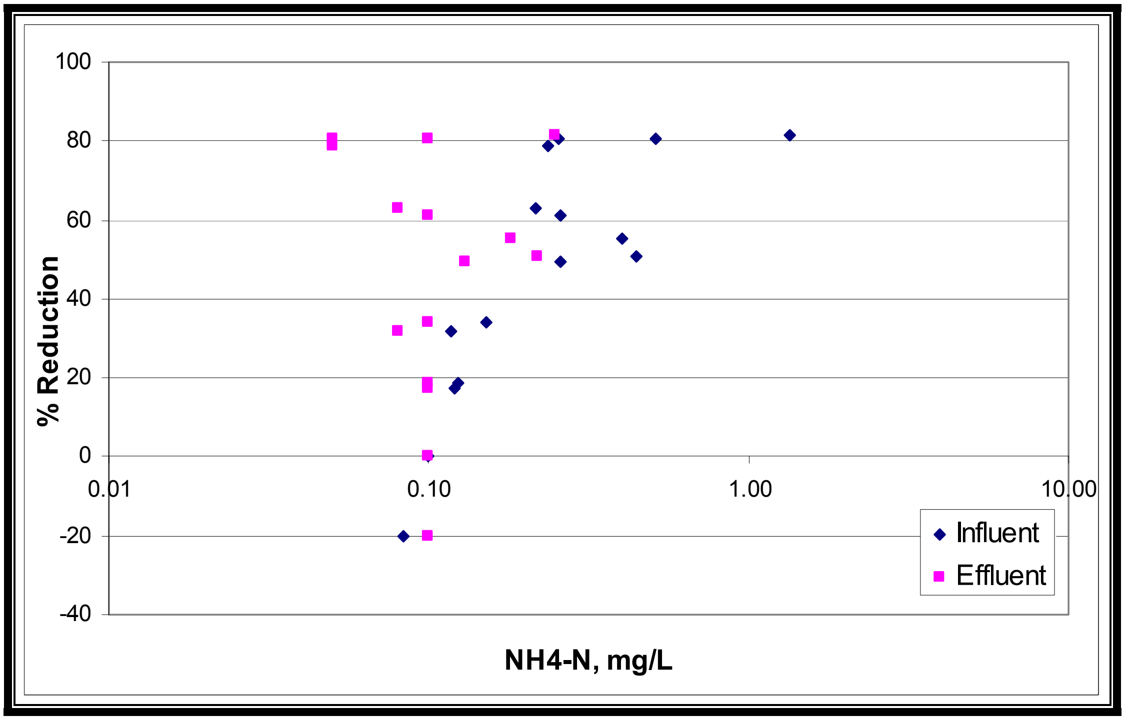

Figure 6. Parallel probability plot for NH4-N concentrations

Up to eight growing season samples and up to seven dormant season samples were collected during monitoring period (Tables 9 and 10). There was not a significant seasonal effect on the concentration or mass loading removal efficiency of any pollutants tested. A number of the pollutants, including TP, did show higher removal efficiencies during the growing season; Bass (2000) also found that TP concentrations are generally higher during the growing season. Since the number of samples collected for each season was small, more data would be required to make an informed judgment on this subject.

Table 9. Concentration efficiency ratios for growing and dormant seasons

Parameter	Units	Growing		Dormant		Statistiscs	
		# samples	ER	# samples	ER	p-value	Significant Season Effect?
Flow Volume	cu. ft.	8	-67%	7	7%	0.26	No
Fecal Coliform	col/100ml	7	72%	7	61%	0.84	No
E-Coli	MPN/100ml	3	25%	4	34%	0.53	No
Oil & Grease	ppm	7	16%	7	14%	0.39	No
NH_4^+	ppm	8	62%	7	63%	0.12	No
$NO_3^- + NO_2^-$	ppm	8	28%	7	35%	0.67	No
TKN	ppm	8	47%	7	42%	1.00	No
TN	ppm	8	42%	7	39%	0.99	No
TP	ppm	8	60%	7	46%	0.26	No
TSS	ppm	8	69%	7	61%	0.51	No
Cu	ppb	8	12%	7	0%	0.48	No
Fe	ppb	7	30%	4	18%	0.49	No
Mn	ppb	7	-35%	4	10%	0.34	No
Zn	ppb	8	55%	7	58%	0.93	No

Table 10. Mass efficiency ratios for growing and dormant seasons

Parameter	Units	Growing		Dormant		Statistiscs	
		# samples	ER	# samples	ER	p-value	Significant Season Effect?
Oil & Grease	g	7	19%	7	23%	0.36	No
NH_4^+	g	8	42%	7	65%	0.07	No
$NO_3^- + NO_2^-$	g	8	10%	7	36%	0.25	No
TKN	g	8	13%	7	37%	0.30	No
TN	g	8	4%	7	36%	0.29	No
TP	g	8	29%	7	46%	0.52	No
TSS	g	8	45%	7	64%	0.52	No
Cu	g	8	-33%	7	-1%	0.39	No
Fe	g	7	-23%	4	16%	0.48	No
Mn	g	7	-112%	4	11%	0.29	No
Zn	g	8	15%	7	50%	0.31	No

Water Quality Results Including Local Watershed Contribution

The results presented in the previous section did not include influent flow or pollutants contributed by the local 2.5-ha watershed. It was possible that the inclusion of the local watershed's runoff could change the analysis discussed above. To account for this, influent pollutant concentrations of NH_4^+, $NO_3^- + NO_2^-$

, TKN, TN, TP, TSS, Cu and Zn were estimated using data from NCDENR (2005).

For the analysis of concentration reduction, the estimated local watershed concentration for a given pollutant was included in the calculation of average influent concentration. There was no base flow at the site, thus the local watershed flow was estimated by the difference between outflow and inflow. Due to this estimation, all the inflow and outflow from the wetland can be accounted for. Since the inflow is equal to the outflow in this estimation, mass balances are not needed to compare the influent and effluent pollutant concentrations. The ER developed for each pollutant can be used to estimate wetland efficiency without any further mass balance. The four storms where inflow exceeded outflow are not included in this analysis.

With the exception of copper and zinc, when the local watershed contribution was included, the efficiency ratio decreased. This is because the estimated concentrations for the local watershed were less than the monitored concentrations (Table 11). The influent concentrations of all of the pollutants included in this analysis were significantly reduced by averaging the pollutant concentrations from the local watershed and the monitored data.

The impact of dilution due to the local watershed was not exhibited in copper or zinc. The increased ER for both copper and zinc can be attributed to the high concentration estimated for the local watershed land uses (NCDENR, 2005). The addition of the higher concentration to the weighted average increased the influent EMC, therefore increasing the ER by 0.21 for copper and 0.11 for zinc.

Table 11. Water quality results including the mean possible concentration for the local watershed

Parameter	Units	# samples	Influent EMC	Effluent EMC	ER	Statistiscs	
						p-value	Significant?
NH_4^+	ppm	11	0.27	0.11	58%	< 0.01	Yes
$NO_3^- + NO_2^-$	ppm	11	0.67	0.52	22%	0.02	Yes
TKN	ppm	11	1.48	0.93	37%	< 0.01	Yes
TN	ppm	11	2.14	1.38	36%	< 0.01	Yes
TP	ppm	11	0.38	0.21	43%	< 0.01	Yes
TSS	ppm	11	58.24	25.45	56%	< 0.01	Yes
Cu	ppb	11	9.90	7.19	27%	< 0.01	Yes
Zn	ppb	11	68.16	21.55	68%	< 0.01	Yes

The seasonal affect on stormwater quality treatment was also tested while incorporating pollutant concentrations from the local watershed into the influent average (Table 12). Unlike in the previous analysis, the NH_4^+ efficiency was determined to significantly increase during the dormant season. There was no significant seasonal affect on any of the other pollutants. Similar to the previous seasonal analysis, there was insufficient data for both seasons to draw conclusions.

Table 12. Seasonal water quality results including the mean concentration for the local watershed

Parameter	Units	Growing		Dormant		Statistiscs	
		# samples	ER	# samples	ER	p-value	Significant Season Effect?
NH_4^+	ppm	7	52%	4	66%	0.04	Yes
$NO_3^- + NO_2^-$	ppm	7	27%	4	16%	0.32	No
TKN	ppm	7	38%	4	36%	0.81	No
TN	ppm	7	39%	4	31%	0.49	No
TP	ppm	7	46%	4	37%	0.57	No
TSS	ppm	7	58%	4	53%	0.88	No
Cu	ppb	7	26%	4	30%	0.70	No
Zn	ppb	7	69%	4	67%	0.82	No

To produce the minimum ERs possible by the Bruns Ave. School wetland (worst scenario regarding wetland pollutant removal), the minimum concentration for the local watershed was added to the weighted influent concentration (Table 13). By using the smallest possible concentration for the local watershed, the most conservative estimate for each pollutant's ER could be calculated. This inclusion decreased the ERs from the previous analysis but all influent concentrations were still significantly reduced. Additionally, there was no seasonal affect on any pollutants other than NH_4^+ (Table 14).

Table 13. Water quality results including the minimum possible concentration for the local watershed

Parameter	Units	# samples	Influent EMC	Effluent EMC	ER	Statistiscs	
						p-value	Significant ?
NH_4^+	ppm	11	0.21	0.11	46%	< 0.01	Yes
$NO_3^- + NO_2^-$	ppm	11	0.57	0.52	8%	0.28	No
TKN	ppm	11	1.24	0.93	25%	< 0.01	Yes
TN	ppm	11	1.74	1.38	21%	0.01	Yes
TP	ppm	11	0.34	0.21	37%	< 0.01	Yes
TSS	ppm	11	51.39	25.45	50%	< 0.01	Yes
Cu	ppb	11	7.01	7.19	-3%	0.68	No
Zn	ppb	11	36.78	21.55	41%	< 0.01	Yes

Table 14. Seasonal water quality results including the minimum possible concentration for the local watershed

Parameter	Units	Growing		Dormant		Statistiscs	
		# samples	ER	# samples	ER	p-value	Significant Season Effect?
NH_4^+	ppm	7	39%	4	56%	0.04	Yes
$NO_3^- + NO_2^-$	ppm	7	14%	4	2%	0.30	No
TKN	ppm	7	28%	4	20%	0.89	No
TN	ppm	7	26%	4	13%	0.30	No
TP	ppm	7	42%	4	28%	0.38	No
TSS	ppm	7	53%	4	44%	0.81	No
Cu	ppb	7	-2%	4	-3%	0.94	No
Zn	ppb	7	43%	4	40%	0.61	No

Table 15 presents the Bruns Ave. School stormwater wetland efficiency ratios for the following data sets, in order from least conservative to most conservative: (1.) effluent and weighted influent concentrations from monitoring only, (2.) effluent and weighted influent concentrations, including mean concentration possible from local contributing watershed, and (3.) effluent and weighted influent concentrations, including minimum concentration possible from local contributing watershed. This variation of the ERs illustrates the importance of including the estimated pollutant concentrations from the local watershed, even though the estimate may vary from the actual export levels.

Table 15. Summary of efficiency ratios for Bruns Ave. School Wetland, highlighted values are conservative estimate of wetland removal efficiency

Pollutant	Monitoring ER[1]	Mean Conc. ER[2]	Minimum Conc. ER[3]
O&G	15%[4]	---	---
FC	70%	---	---
E.coli	29%[4]	---	---
NH_4^+	62%	58%	46%
$NO_3^- + NO_2^-$	32%	22%	8%
TKN	45%	37%	25%
TN	40%	36%	21%
TP	55%	43%	37%
TSS	66%	56%	50%
Cu	6%[4]	27%	-3%
Zn	57%	68%	41%
Mn	-18%[4]	---	---
Fe	26%[4]	---	---

1. Efficiency ratios for Bruns Ave. School Wetland using only data collected from monitoring

2. Efficiency ratios for Bruns Ave. School Wetland using data collected from monitoring and mean concentrations contributed from the local watershed

3. Efficiency ratios for Bruns Ave. School Wetland using data collected from monitoring and minimum possible concentrations contributed from the local watershed

4. ERs do not indicate statistically significant reduction

Ignoring the local watershed contribution overestimated the removal efficiency of the Bruns Ave. School wetland. Therefore, the minimum efficiency ratios (calculated while including the minimum possible pollutant concentrations for the local watershed) were identified as the most conservative estimate of the wetland pollutant removal efficiencies. For the pollutants that were not included in those calculations, the ERs determined from the monitored water quality data were accepted as an estimate of the wetland removal capacity.

Conclusions

Due to the uncertainty associated with the watershed feeding the wetland by way of overland flow, it is most appropriate to present the efficiency ratios, where possible, in terms of a range. Table 15 provides estimations of wetland pollutant removal based on multiple analysis methods. Based on this table, Table 16 was developed. Due to the estimations of pollutant loading contributed by the watershed that could not be monitored, the efficiency ratios that were developed can be compared to mass removal estimations provided by the State of North Carolina.

Table 16. Estimation of Wetland Pollutant Removal Based on Multiple Analysis Methods

Pollutant	Low Estimated ER	High Estimated ER	Best Estimate ER
O&G	---	---	15%
FC	---	---	70%
E.coli	---	---	29%
NH_4^+	46%	62%	55%
$NO_3^- + NO_2^-$	8%	32%	20%
TKN	25%	45%	35%
TN	21%	40%	35%
TP	37%	55%	45%
TSS	50%	66%	55%
Cu	-3%	27%	5%
Zn	41%	68%	55%
Mn	---	---	-18%
Fe	---	---	26%

Ammonia (NH_4^+) concentrations were reduced between 46 and 62%. The best estimate of ammonia removal is 55%. Nitrate – nitrite ($NO_3^- + NO_2^-$) concentrations were reduced between 8 and 32%, with an estimated 20% removal. These two pollutants are removed in different environments within the wetland, ammonia being converted to nitrate-nitrite in aerobic conditions, and nitrate-nitrite being converted to nitrogen gas in anaerobic environments. Reductions in both of these pollutants indicate the presence of both these environments within the wetland, which is consistent with well-functioning stormwater wetlands. The concentration of TN decreased by an estimated 21 to 40 %, and likely decreased by approximately 35%. North Carolina State standards indicate that stormwater wetlands remove approximately 40% of the TN that they receive. Due to uncertainties with monitoring, this wetland seems to have TN removal consist with state standards. Although temperature affects microbial activity and thus nitrogen conversions, no seasonal impact was found in regard to TN removal within the wetland.

The TP entering this wetland is removed by 37 to 55%, with an estimated removal of 45%. State standards assume TP removal within wetland to be approximately 35%, which is lower than the estimated performance of this wetland. It should be noted that even the lowest estimated TP removal (37%) is above the state standard. No seasonal impact was found in the TP analysis.

TSS removal ranged between 50 and 66%, with an estimated reduction of 55%. This value likely falls short of the state assigned 85% TSS removal. However, it is NCSU BAE's opinion that the 85% TSS removal standard is not reflective of what *any* stormwater practice can reliably remove (including wet ponds, bioretention, etc.). If a more realistic, and obtainable, standard of 70% is considered, this stormwater wetland only very slightly underperformed.

Metals removal within the wetland varied based on type. For Mn and Fe, no estimate of runoff concentration was available; therefore the only estimate of removal was obtained via the monitored data. The estimate of removal for Mn and Fe was -18% and 26% respectively, however, the accuracy of these estimates is in question due to the additional watershed feeding the wetland that could not be accounted for.

For Cu, removal estimates ranged between -3 and 27% with an estimate of approximately 5%. For Zn, removal estimates ranged between 42 and 68% with an estimated removal of 55%. It is apparent from these results that metal removal rates within wetlands can vary depending on the type of metal being treated. It is possible that the dramatic difference in metal removal rates is dependent on the influent concentration. The apparent addition of Mn that the wetland exhibits has unknown causes. The lack of copper removal by the Bruns Ave. School stormwater wetland is particularly important because of its location in the Catawba River Basin, where high copper levels are impairing streams. The effluent EMC at the wetland was 7.24 μg/L (based on monitored results); the mandated level of concern in the Catawba Basin is 7 μg/L (NCDENR, 2005).

Since TSS, but not Cu, had significant mass and concentration reductions, this study further supports the findings of Walker (2002); processes other than sedimentation affected the removal of heavy metals from the Bruns Ave. School stormwater wetland.

No estimation of Oil and Grease, FC, and E. coli coming from the unmonitored watershed was available. Thus, estimates made from monitoring data were used to develop efficiency ratios for these pollutants. Stormwater wetlands are not identified by NCDENR (2005) as an effective method of removing oil and grease pollutants; however, these results indicate that this BMP shows promise in this area. Plants and soil particles in the stormwater wetland acted as a filter to remove oil and grease from the water surface. Although the measured removal efficiency was significant, the oil and grease contribution from the local watershed could not be quantified, leading to some uncertainty regarding actual pollutant removal efficiency.

The number of influent and effluent fecal coliforms and *E.coli* were quantified at the Bruns Ave. School wetland. Even though both are removed via the same processes, mainly exposure to solar radiation in the shallow land zone, there was significant reduction of FC but not *E.coli*. The results showed that the species *E.coli* was not significantly ($p>0.05$) removed by the stormwater wetland, even though the general group, fecal coliforms, was. This is an important finding since some regulations are beginning to move towards *E.coli* as the primary indicator bacteria. Because of the limited number of *E.coli* and FC samples (11 and 14 storms, respectively), more data are required for conclusive results.

Overall, the Bruns Ave. School wetland showed the ability to effectively treat a number of pollutants including sediment, nutrients, and some forms of metals. State standards indicate that stormwater wetlands can remove 40% of influent TN, 35% of influent TP, and 85% of influent TSS; Bruns Ave. School wetland was able to remove 35%, 45%, and 55% respectively. This indicates that this wetland adequately performs in 2 of these 3 categories, with the 85% TSS removal being a likely overestimation of what *any* BMP can reliably remove.

APPENDIX A

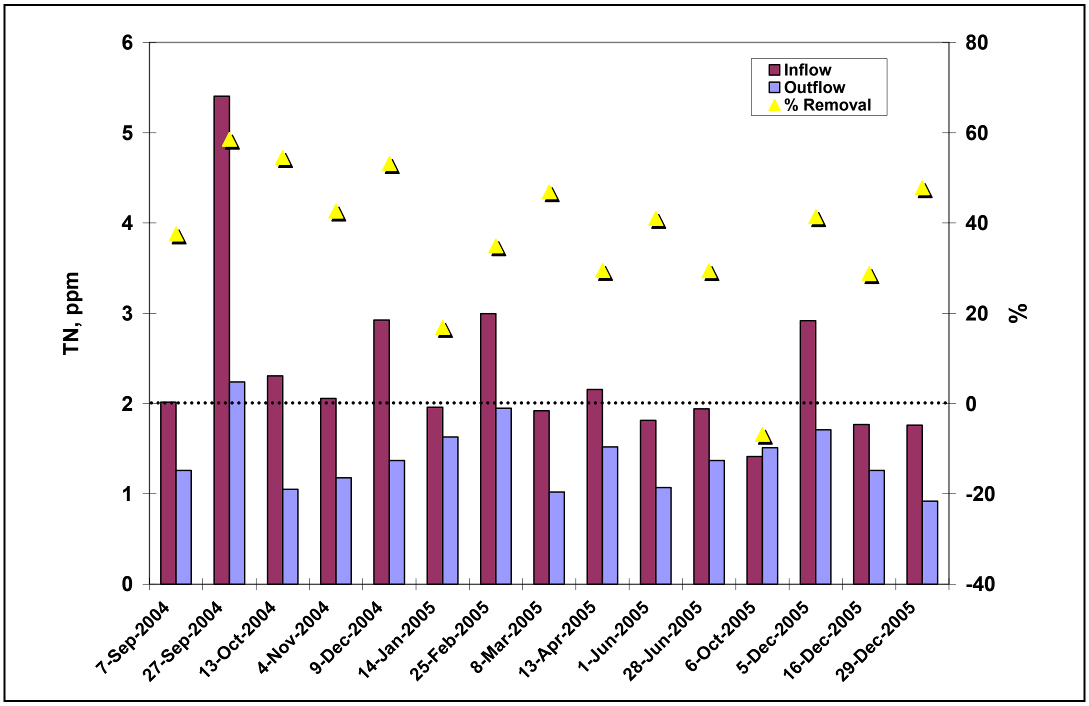

Figure A1: Change in TN concentration due to BMP treatment by storm event.

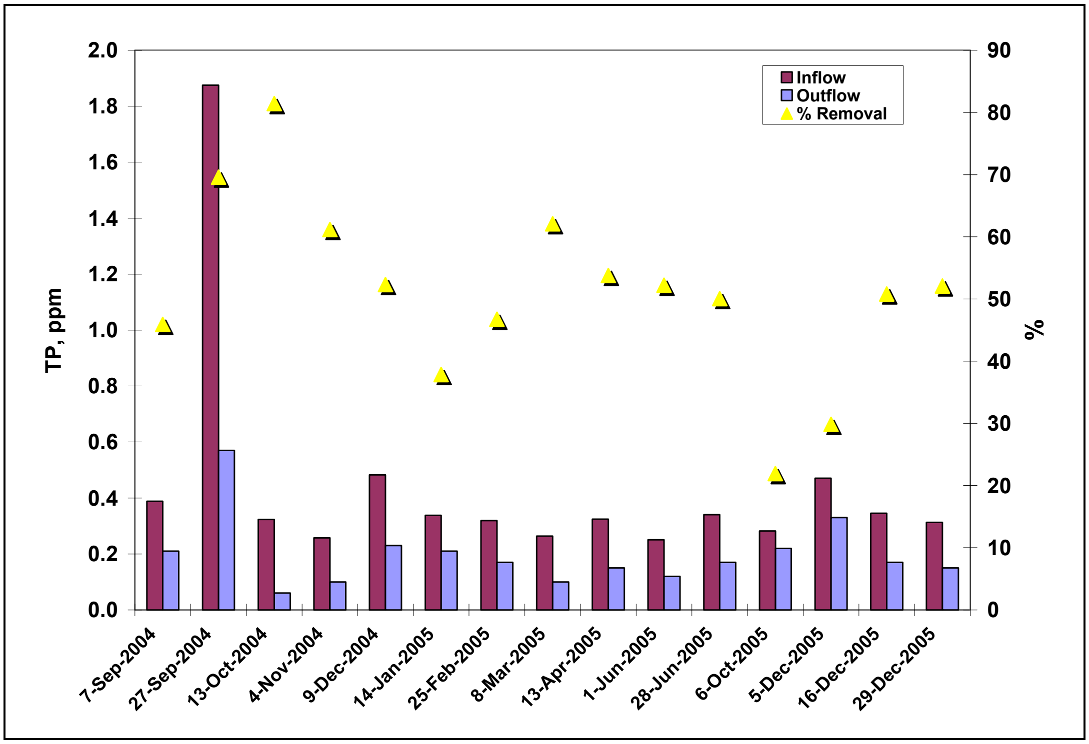

Figure A2: Change in TP concentration due to BMP treatment by storm event.

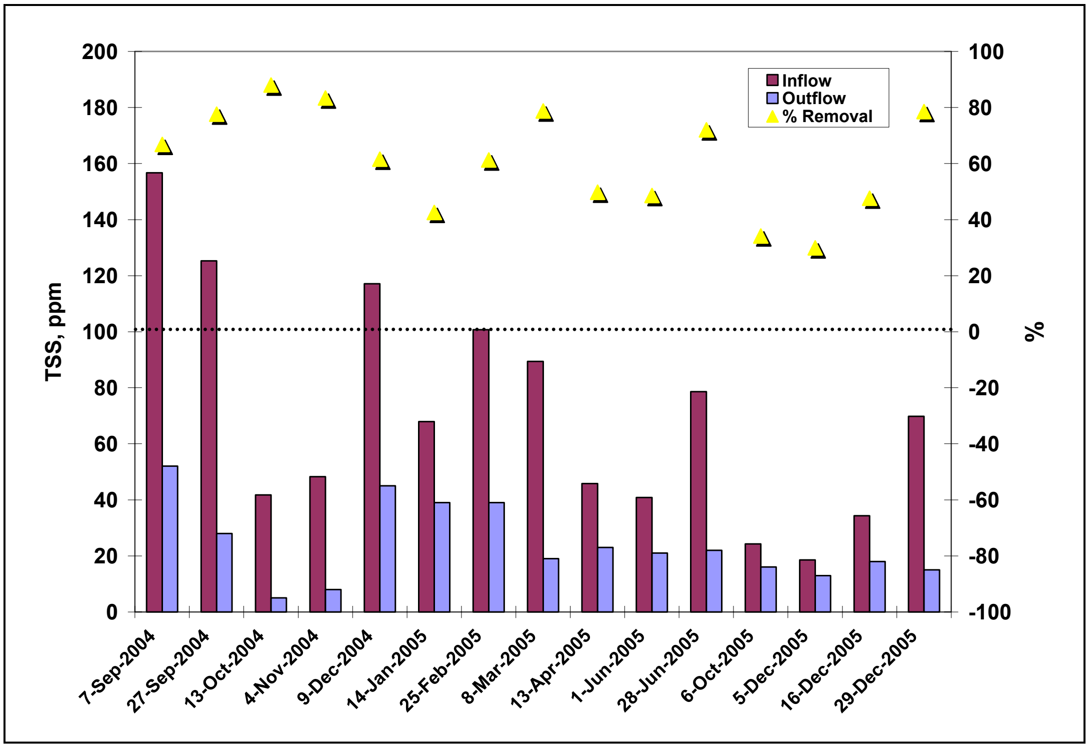

Figure A3: Change in TSS concentration due to BMP treatment by storm event.

APPENDIX B

Monitoring Protocol

Stormwater BMP performance Monitoring Protocol for:

Bruns Ave Wetland

Description of Site:

The Bruns Ave stormwater wetland is located adjacent to the Bruns Avenue Elementary school. The wetland receives runoff from two separate inlet locations. These are named the primary inlet and the secondary inlet. The primary inlet is located at the end of the wetland farthest away from the school. The secondary inlet is located at the outlet of a storm culvert adjacent to the parking area between the school and the wetland. The wetland outlets into a "created stream reach" adjacent to the school building.

Watershed Characteristics

Area:	15.8 acres
Description	residential lots and streets

Sampling equipment

120 degree v-notch weirs have been installed to allow accurate measurement of flow at the outlet and the primary inlet. Bubblers will be used at both locations to determine flow rate. The 24" RCP culvert will be used as the primary device at the secondary outlet. An area velocity meter will be used as the secondary device at this location.

<u>Primary Inlet Sampler</u>

Primary device:	120 degree v-notch weir
Secondary Device:	ISCO model 720 bubbler
Bottle Configuration	24 1000mL Propak containers
Rain gage	ISCO model 673 tipping bucket

<u>Secondary Inlet Sampler</u>

Primary device:	24" RCP culvert
Secondary Device:	ISCO model 730 Area-Velocity meter
Bottle Configuration	24 1000mL Propak containers

<u>Outlet Sampler</u>

Primary Device:	120 degree v-notch weir
Secondary Device:	ISCO Model 720 Bubbler

Bottle Configuration 24 1000mL Propak containers

Sampler settings

Primary Inlet Sampler

Sample Volume	200 mL
Distribution	5/bottle
Pacing	40 Cu Ft.
Set point enable	None

Secondary Inlet Sampler

Sample Volume	200 mL
Distribution	5/bottle
Pacing	57 Cu Ft.
Set point enable	None

Outlet Sampler

Sample Volume	200mL
Distribution	5/bottle
Pacing	90 cu ft
Set point enable	none

As monitoring efforts continue it is very likely that the user will need to adjust the sampler settings based on monitoring results. The user should keep detailed records of all changes to the sampler settings. One easy way to accomplish this is to printout the settings once data has been transferred to a PC.

Sample Collection and Analysis

Samples should be collected in accordance with Stormwater Best Management Practice (BMP) Monitoring Protocol for the City of Charlotte and Mecklenburg County Stormwater Services.

General Monitoring Protocol

Introduction

The protocols discussed here are for use by City of Charlotte and Mecklenburg County Water Quality personnel in setting up and operating the stormwater BMP monitoring program. The monitoring program is detailed in the parent document "Stormwater Best Management Practice (BMP) Monitoring Plan for the City of Charlotte"

Equipment Set-up

For this study, 1-2 events per month will be monitored at each site. As a result, equipment may be left on site between sampling events or transported to laboratory or storage areas between events for security purposes. Monitoring personnel should regularly check weather forecasts to determine when to plan for a monitoring event. When a precipitation event is expected, sampling equipment should be installed at the monitoring stations according to the individual site monitoring protocols provided. It is imperative that the sampling equipment be installed and started prior to the beginning of the storm event. Failure to measure and capture the initial stages of the storm hydrograph may cause the "first flush" to be missed.

The use of ISCO refrigerated single bottle samplers may be used later in the study if future budgets allow. All samplers used for this study will be configured with 24 1000ml pro-pak containers. New pro-pak containers should be used for each sampling event. Two different types of flow measurement modules will be used depending on the type of primary structure available for monitoring

Programming

Each sampler station will be programmed to collect up to 96 individual aliquots during a storm event. Each aliquot will be 200 mL. in volume. Where flow measurement is possible, each sampling aliquot will be triggered by a known volume of water passing the primary device. The volume of flow to trigger sample collection will vary by site depending on watershed size and characteristic.

Sample and data collection

Due to sample hold time requirements of some chemical analysis, it is important that monitoring personnel collect samples and transport them to the laboratory in a timely manner. For the analysis recommended in the study plan, samples should be delivered to the lab no more than 48 hours after sample collection by the automatic sampler if no refrigeration or cooling of samples is done. Additionally, samples should not be collected/retrieved from the sampler until the runoff hydrograph has ceased or flow has resumed to base flow levels. It may take a couple of sampling events for the monitoring personnel to get a good "feel" for how each BMP responds to storm events. Until that time the progress of the sampling may need to be checked frequently. Inflow sampling may be completed just after cessation of the precipitation event while outflow samples may take 24-48 hours after rain has stopped to complete. As a result it may be convenient to collect the inflow samples then collect the outflow samples several hours or a couple of days later.

As described above, samples are collected in 24 1,000mL containers. In order for samples to be flow weighted these individual samples will need to be composited in a large clean container; however, future use of single bottle samplers will likely reduce the need for this step. The mixing container should be large enough to contain 24,000mL plus some extra room to avoid spills. Once the composited sample has been well mixed, samples for analysis should be placed in the appropriate container as supplied by the analysis laboratory.

Chain of custody forms should be filled in accordance with Mecklenburg County Laboratory requirements.

Collection of rainfall and flow data is not as time dependent as sample collection. However it is advised that data be transferred to the appropriate PC or storage media as soon as possible.

Data Transfer

Sample analysis results as well as flow and rainfall data should be transferred to NCSU personnel on a quarterly basis or when requested. Transfer may be completed electronically via email or by file transfer**.**