Retrofitting with Bioretention and a Swale to Treat Bridge Deck Stormwater Runoff

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Preface

This final report has been written to satisfy NCDOT research contract 2009-29: "Monitoring of Prospective Birdge Deck Runoff BMPs: Bioretention and Bioswale." The research funding was spurred by the passage of Session Law 2008-107, *The Current Operations and Capital Improvements Act of 2008*, by the North Carolina General Assembly which required research into and installation of stormwater control measures for bridge decks. This study was designed to determine the hydrologic and water quality impacts of purposefully undersized bioretention, a standard bioretention basin, and a swale. The authors wish to thank NCDOT and URS Corporation for their aid throughout the project.

Executive Summary

Stormwater runoff from roadways is a source of surface water pollution in North Carolina. The North Carolina Department of Transportation (NCDOT) is required to implement stormwater control measures (SCMs) in the linear environment. NCDOT has specific interest in runoff from bridge decks, which is often discharged directly to a stream below. The research presented herein focuses on retrofit stormwater SCMs for bridge deck runoff management. Two bioretention basins and a swale were constructed in the easement of a bridge deck on I-540 at Mango Creek in Knightdale, North Carolina. One bioretention basin was sized to capture (without overtopping) runoff from the 0.7 inch event. The second basin was undersized by one-half (as compared to the large cell) and captured runoff from the 0.4 inch event. Undersized bioretention basins might often be used in retrofit situations when space is limited; therefore, it is important to understand how an undersized bioretention basin performs with respect to hydrology and water quality. Both bioretention basins employed 20 in (51 cm) of fill media, and had an internal water storage layer (IWS) of 2 ft (0.6 m) including the gravel drainage layer. The swale was designed to convey the ten-year storm event without overtopping. Runoff was piped from the northbound and southbound lanes to the bioretention basins and swale, respectively.

Data collection began in October 2009 and continued through April 2010. Weirs and stage recorders were used to monitor inflow to and outflow from each SCM. Flow-proportional, composite water quality samples were obtained at the inlet and outlet of each SCM. Monitored water quality parameters included TKN, $NO_{2,3}$-N, NH_4-N, TN, TP, TSS, Cu, Zn, and Pb. TN was calculated by summing TKN and $NO_{2,3}$-N. For small storms [those with less than 1 in (25 mm) rainfall depth], flow volume reductions for the large and small bioretention basins were 69% and 47%, respectively. This shows the hydrologic importance of properly sizing bioretention basins when space is available. However, *some* benefit is also associated with undersized systems, if space is too limited to allow for "full sizing." There was a 23% volume reduction benefit associated with the swale.

Average concentrations of TN (0.74 mg/L), TP (0.12 mg/L), and TSS (32 mg/L) from the bridge decks were relatively low when compared to other highways and paved surfaces previously monitored in North Carolina. Median effluent concentrations for the large bioretention basin were lower than those for the small bioretention basin for all nutrient forms and sediment. Pollutant loads of TN, TP, and TSS were reduced to a greater extent by the large bioretention basin due to improved volumetric runoff reductions. The swale had similar influent and effluent concentrations for TN and TP, while TSS concentrations were reduced by 22%. Because reductions in flow volume for the swale were minimal, poor pollutant load reduction resulted. When compared to target concentrations established by marrying benthic health and ambient

water quality (McNett et al. 2010), outflow concentrations achieved "good" water quality status for the large bioretention basin and the small bioretention basin. For the swale, a smaller percentage of storms reached the "good" water quality status for TP, TN, and TSS.

In summary, both bioretention basins provided water quality and hydrology benefits. The large bioretention basin performed better than the undersized-by-half (small) basin. The swale was unable to provide much improvement in water quality, except for some modest TSS removal. When using a percent reduction metric, the swale and bioretention performance was probably limited by low influent concentrations from the bridge deck.

Introduction

The North Carolina Department of Transportation (NCDOT) is required through its NPDES Permit to treat stormwater runoff from its facilities across North Carolina. NCDOT has installed many retrofit stormwater practices across North Carolina and has researched the hydrologic and water quality function of several. Research has and is currently being done on runoff from highways throughout the U.S. and has also been completed on runoff from bridge decks throughout North Carolina. In 2008, a total of 79,438 miles of paved highways existed in North Carolina (NCDOT 2009). The NCDOT currently maintains 12,712 bridges, which ranks 13th in the US. According to information provided by the NCDOT Bridge Maintenance Unit, 10,481 of these bridges pass over waterways, making it pertinent to gather information about stormwater from bridges, which often discharge directly to these surface waters through scupper drains.

During fiscal year 2008, the North Carolina General Assembly passed Session Law 2008-107. Section 25.18 of this law requires the NCDOT to study the effect of bridge deck runoff from 50 bridges dispersed throughout the three ecoregions of North Carolina. It also mandates that NCDOT study the feasibility and effectiveness of various stormwater SCMs to treat priority pollutants from bridge decks. The results of the study presented herein are one of several efforts made to comply with the Session Law.

While runoff from highways has been studied in detail throughout the world, little research has been completed to characterize bridge deck runoff. A study in Charlotte, NC (Wu et al. 1998) found that an urban bridge deck had a mean runoff coefficient of 0.71. Mean TN, TP and TSS concentrations were 2.24 mg/L, 0.43 mg/L, and 283 mg/L, respectively. Mean Cu and Pb concentrations were 24.2 µg/L and 21.0 µg/L. TN and TSS loads from the bridge deck were substantially larger than those from two other highways in the study (one rural and one urban).

Another bridge deck runoff study was completed in Baton Rouge, LA on an overpass on Interstate-10 (Sansalone et al. 2005). Results showed that EMCs of TSS (138 mg/L to 561 mg/L) and COD (128 to 1440 mg/L) were greater than from untreated wastewater in the area. Two bridge decks were studied in southeastern China (Gan et al. 2007). TN from the bridges was extremely elevated, with mean concentrations of 7.32 mg/L and 4.81 mg/L. Mean TP concentrations were 0.39 mg/L and 0.18 mg/L; mean TSS concentrations were 138 mg/L and 416 mg/L.

Yousef et al. (1984) studied two bridge decks in central Florida; bridge deck runoff was shown to have elevated heavy metals concentrations when compared to nearby surface water bodies. Marsalek et al. (1997) contend that uncontrolled discharges from bridge decks could substantially impact receiving water bodies, and that stormwater SCMs are needed to remediate these discharges. Two SCMs (bioretention basins and swales) that could be used to treat bridge deck runoff are discussed in more detail below.

Bioretention

Bioretention performance has been evaluated both in the laboratory and in the field (Kim et al. 2003; Hsieh and Davis 2005; Davis et al. 2006; Dietz and Clausen 2006; Hunt et al. 2006; Davis 2007; Hsieh et al. 2007; Hunt et al. 2008; Li et al. 2009). Research shows that effluent concentrations of TN, TP, TSS, hydrocarbons, and heavy metals are low in comparison to other stormwater SCMs (Hunt et al. 2009). Also, bioretention can effectively mitigate peak flow rates and volumes through exfiltration of stormwater to the *in situ* soil. For these reasons, bioretention has become one of the most popular SCMs for new construction and in retrofit applications. Pollutant removal and hydrologic improvements from bioretention studies are presented in Table 1. To date, no research has been completed on intentionally undersized bioretention basins. Undersized bioretention retrofits have the potential for widespread use in instances when dense urbanization does not allow for a full sized bioretention basin designed to capture a 1 to 1.5 inch storm (per NCDENR requirements) to be implemented (NCDENR 2007). This study in particular explores the possibility of implementing undersized bioretention basins in the limited space available underneath bridge decks.

Table 1. Pollutant removal and hydrologic mitigation from bioretention studies in the Mid-Atlantic USA.

TN Removal				
Site Location	Load Reduction (%)	Influent Conc. (mg/L)	Effluent Conc. (mg/L)	Reference
Louisburg, NC	65	1.7	1.25	Li et al. (2009)
Greensboro, NC	40	1.35	4.38	Hunt et al. (2006)
Charlotte, NC	N/A	1.68	1.14	Hunt et al. (2008)
Graham, NC	56	1.66	0.76	Passeport et al. (2009)
Graham, NC	47	1.66	0.76	Passeport et al. (2009)
TP Removal				
Louisburg, NC	69	0.28	0.18	Li et al. (2009)
Greensboro, NC	-240	0.11	0.56	Hunt et al. (2006)
Charlotte, NC	N/A	0.19	0.13	Hunt et al. (2008)
College Park, MD	79	0.61	0.15	Davis (2007)
College Park, MD	77	0.61	0.17	Davis (2007)
Graham, NC	53	0.14	0.05	Passeport et al. (2009)
Graham, NC	68	0.14	0.06	Passeport et al. (2009)
TSS Removal				
Charlotte, NC	N/A	49.5	20	Hunt et al. (2008)
College Park, MD	59	34	18	Davis (2007)
College Park, MD	54	34	13	Davis (2007)

The two grassed bioretention basins studied by Passeport et al. (2009) in Graham, North Carolina mitigated flow, albeit slightly (18% peak flow rate reduction for North basin and 14% peak flow rate reduction for South basin), for nearly all of the storms tested as a result of evapotranspiration, exfiltration beneath the basins, and storage within the soil media. Davis (2008) studied two bioretention basins which delayed peak flow by two hours from the time of water entry to the time effluent was detected from the underdrains. These cells also reduced peak flow rates by 63 and 44%. Some smaller storms were entirely captured, resulting in no outflow.

Swales

A research team in Northern Sweden studied several different grassed swales (Backstrom 2002; Backstrom 2003). They found that the swales retained significant amounts of particulate matter during high pollutant loading events. For instance, a removal efficiency of greater than 50% was achieved when influent suspended solids concentrations were over 100 mg/L. However, when the swales received TSS concentrations less than 40 mg/L, pollutant concentrations increased as the water moved through a dry swale. Their results also suggest that TSS is not permanently held in a swale and may become re-suspended within the flow. Particles smaller than 25 µm were not trapped efficiently. TSS concentrations were reduced by 79-98% in two laboratory swales and seven field swales (Backstrom, 2003). Dissolved pollutants in these swales did not receive any perceptible treatment, and the observed swales acted as a source for Cu, Pb, and Zn during flows containing low influent concentrations. The highest removal efficiencies were found for Zn, while the event mean concentrations (EMCs) of dissolved Cu were two to four times higher in swale runoff than in road runoff (Backstrom, 2003). The swales studied were regarded as facilities that buffer pollutant load extremes, but were not able to consistently reduce pollutant loads (Backstrom, 2006).

Export of nitrogen and phosphorus was observed at two field tested swales treating highway runoff (Maitland and Epcot swales) in Florida (Yousef et al. 1985; Yousef et al. 1987). While concentrations of dissolved heavy metals decreased with increasing swale length, similar conclusions could not be made for N and P species. Hydrologic data showed the Maitland swale had average loading rates ranging from 0.036 to 0.154 m^3/m^2-hr, while average runoff rates ranged from 0.0 to 0.068 m^3/m^2-hr. For the Epcot swale, average loading rates ranged from 0.053 to 0.105 m^3/m^2-hr, while average runoff rates fell between 0.039 and 0.071 m^3/m^2-hr. For the Epcot site, it was determined that 90% of the input flow left the swale as runoff when the swale soil was saturated (Yousef et al. 1987).

Two swales were studied along highway medians in Virginia (Kaighn and Yu 1996). TSS concentrations were reduced by 30% and 49%, while mixed results were observed for COD, TP, and Zn. The authors noted that significant variability exists in the swale literature, but that swale design should generally be based upon length, cross-sectional shape, slope, design flow rate, type of vegetation, and infiltration rate of the soil. In another field test of dry swales, Yu et al. (2001) showed that check dams along the swale substantially improve performance for TSS and COD. Mass of TN was reduced by 13%-24%, while TP reductions ranged from 29%-77% at four swales in Taiwan. Kercher et al. (1983) argued that swales are preferable to traditional curb-gutter-pipe systems because they help to reduce pollutant loading and require less land area than conventional systems.

Research Goals

The goals of this research were threefold: (1) Examine the quality and quantity of runoff from a raised bridge deck located on I-540 in Knightdale, North Carolina; (2) Examine the impact that a large bioretention basin and a small bioretention basin has on bridge deck runoff; and (3) Examine the impact of a swale on bridge deck runoff.

Methods

To determine the quality and quantity of bridge deck runoff, monitoring was undertaken at a site in Knightdale, North Carolina (Figure 1). The site is located just south of the intersection of I-540 and the US 64 bypass. Both the northbound and southbound lanes of the bridge at the intersection of I-540 and Mango Creek were monitored for hydrologic and water quality parameters.

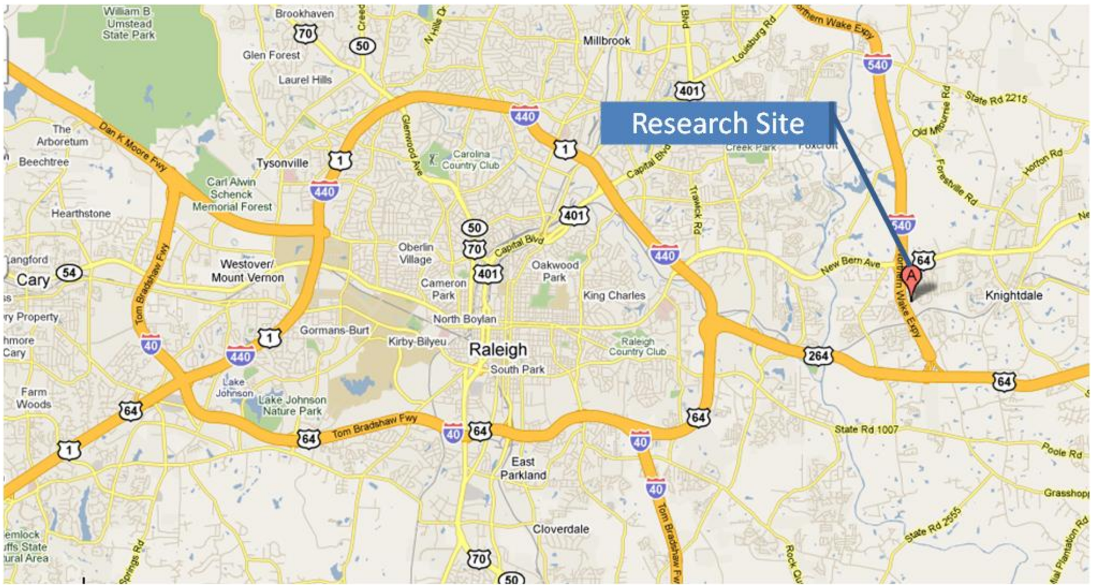

Figure 1. Location of Mango Creek research site (from Google Maps).

The bridge deck over Mango Creek is three lanes in both directions, with an associated emergency lane (Figure 2). Each bridge deck is roughly 60 ft (18 m) wide with a total approximate area of 78,619 ft^2 (7,304 m^2). The bridge decks have 6 in (15.2 cm) diameter scuppers at approximately 11 ft (3.4 m) intervals. A portion of the bridge's drainage system was retrofitted to route stormwater from the scuppers to three stormwater SCMs: a swale, a large bioretention basin, and a bioretention basin with one-half of the surface area of the large basin (hereafter the "small basin"). The existing scuppers on both the northbound and southbound bridge deck were retrofitted to drain to 12 in (30.5 cm) diameter PVC pipe (Figure 3). The pipe under the southbound lanes discharged to the swale. The flow from the pipe under the northbound lanes was split proportionally in a distribution box, and discharged to both the small and large bioretention basins (Figure 2). The flow from the bridge deck entered the distribution box through a 15 in (38.1 cm) HDPE pipe. HDPE inlet pipes, both 12 in (30.5 cm) in diameter, were used to convey flow from the distribution box to the bioretention basins. A fourth 12 in (30.5 cm) diameter opening within the distribution box was kept closed with a sluice gate throughout the duration of the study to prevent flow from entering a fourth LID structure. Cinder blocks were placed within the distribution box to help still the flow and prevent "short circuiting" from occurring.

Figure 2. Mango Creek bridge deck (northbound lanes) and distribution box.

Figure 3. Pictures of closed drainage systems for bioretention and swale.

The bioretention basins were designed by URS Corporation with a 9 in (23 cm) ponding depth, 20 in (51 cm) soil media depth, and a 2 ft (0.6 m) deep IWS layer. The bottoms of the basins contained 12 in (30.5 cm) of No. 57 stone which surrounded the two 6 in (15.24 cm) diameter perforated underdrains. This gravel layer constituted a fraction of the IWS zone. The engineered soil media met the current NC DENR regulations of 85-88% sand, 8-12% silt and clay, and 3-5% organic matter (NC DENR 2007). Both bioretention basins were vegetated with Centipede grass sod and had rock-lined forebays to still stormwater as it entered the basins (Figure 4). Other selected characteristics of the two bioretention basins are presented in Table 2. The design surface area of the small bioretention basin was one-half that of the large basin. The system storage volume (i.e. the sum of bowl storage, forebay storage, and soil and gravel layer storage) of the small basin was 55.6% of the system storage volume of the large basin.

Figure 4. Large (left) and small (right) bioretention basins at Mango Creek.

Table 2. Characteristics of large and small bioretention basins.

Characteristic	Large Bioretention Basin	Small Bioretention Basin
Length (ft)	100.1	70.9
Width (ft)	20.0	14.1
Surface Area (ft^2)	2002.1	1001.0
System Storage Volume (ft^3)	5431.4	3022.9

The swale at the Mango Creek bridge deck was designed by URS Corporation to safely convey the 10-year storm (Figure 5). A rock-lined forebay and straw wattles were used to still flow as it entered the swale. The swale had a v-shaped geometry with a 1.1 sinuosity, 2% longitudinal slope, and 120 ft (36.6 m) length measured from the entrance of the swale to the pipe which routed water from the rock check dam into the outlet structure of the swale (Figure 5). The swale was vegetated with tall fescue sod.

Figure 5. Swale at Mango Creek and the swale outlet pipe.

Monitoring of hydrologic parameters was undertaken at six locations. The inlet to both bioretention basins and the swale were fitted with a compound weir (Figure 6, at left), with a 120° v-notch lower portion and a rectangular upper portion. The same weirs were used to measure outflow from the bioretention basins inside drop inlets; outflow rates were measured as the combination of overflow and underdrain flow. A wooden weir box with a slightly larger compound weir (120° v-notch lower portion with rectangular upper portion) was used to measure flow rates at the outlet of the swale (Figure 6, at right). ISCO 730 bubbler modules were used to measure the depth of flow over each weir and to calculate flow rate using a derived step-wise stage-discharge relationship, which was field verified. Rainfall and hydrology data were analyzed using Teledyne ISCO Flowlink software.

Figure 6. Monitoring installation at inlet (left) and outlet (right) of swale.

Monitoring of water quality occurred at five locations: the inlet and outlet of the swale, at the inlet to one bioretention basin, and at both bioretention basin outlets (Figures 7 and 8). It was assumed that the quality of the water entering both bioretention basins was the same due to its shared source. The flow volumes calculated using the bubbler-weir combination were used by an ISCO 6712 water quality sampler to take flow-proportional, composite samples at each sampling location. Laboratory analysis was performed for total suspended solids (TSS), total Kjeldahl nitrogen (TKN), ammonium-nitrogen (NH_4-N), nitrate- and nitrite-nitrogen (NO_{2-3}-N), total phosphorous (TP). Zinc (Zn), copper (Cu), and lead (Pb) concentrations were measured in their total and dissolved states. Total Nitrogen (TN) was calculated by summing TKN and NO_{2-3}-N.

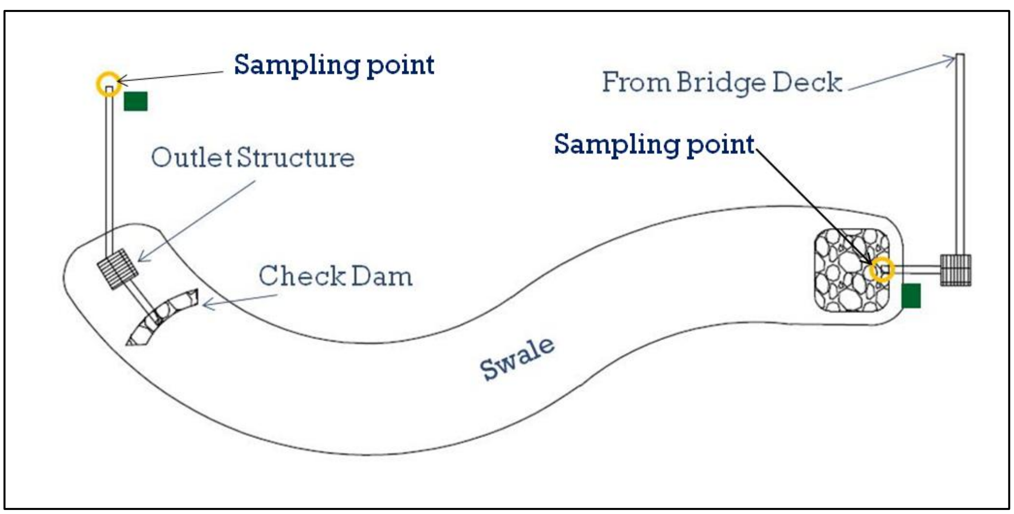

Figure 7. Sampling points at swale.

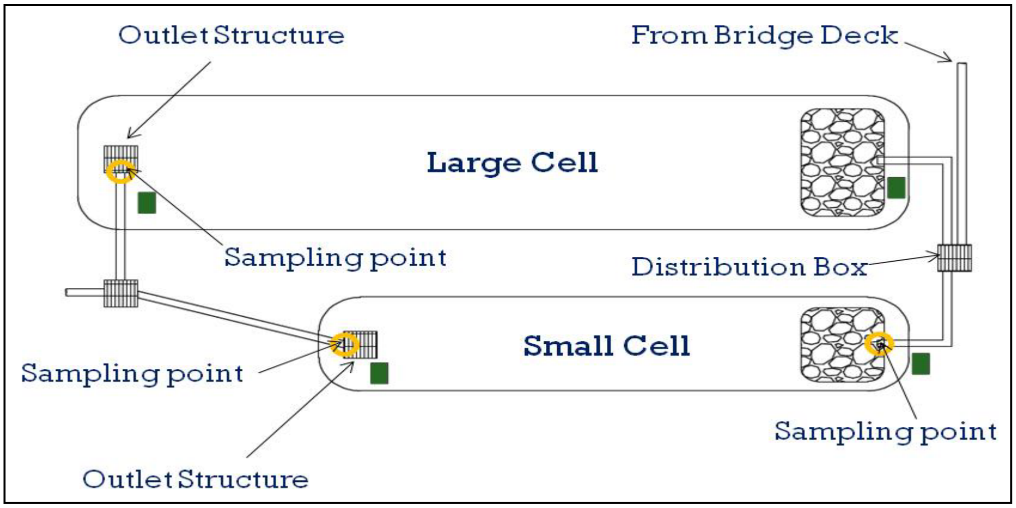

Figure 8. Sampling points at bioretention basins.

Water quality samples were taken to test for the presence of total Zn, Cu, and Pb by filling 15 mL pre-acidified, capped tubes with a well-mixed composite water sample. A 15mL acidified sample was also collected from each sampling point to test for dissolved Zn, Cu, and Pb. Dissolved metal samples were filtered on-site through a syringe-driven 0.45 μm filter unit (33 mm diameter) that was first pre-rinsed with ultra-pure water (water that is highly purified and low in ions, particulate matter, and organic matter) (Figure 9). The nutrient samples were collected in 125 mL pre-acidified bottles. A 1000 mL sample was collected for TSS. The laboratory techniques followed for the analysis of nutrients, sediment, and metals are shown in Table 3.


Figure 9. Filtration of water sample for dissolved metals.

Table 3. Nutrient, sediment, and metals analysis techniques.

Constituent	Laboratory Testing Methods	Detection Limits/ Reporting Limits
Lead	Std Method 3111B (APHA, 1998)	DL = 30 μg/L
Zinc	Std Method 3111B (APHA, 1998)	DL = 2 μg/L
Copper	Std Method 3111B (APHA, 1998)	DL =2 μg/L
Ammonium Nitrogen	Std Method 4500 NH3 H (APHA, 1998)	RL = 0.007 mg/L
Total Kjeldahl Nitrogen	EPA Method 351.1 (US EPA, 1993)	RL = 0.140 mg/L
Nitrate + Nitrite Nitrogen	Std Method 4500 NO3 F (APHA, 1998)	RL = 0.0056 mg/L
Total Phosphorous	Std Method 4500 P F (APHA, 1998)	RL = 0.010 mg/L
Total Suspended Solids	Std Method 2540 D (APHA, 1998)	RL = 1 mg/L

The samples collected for nutrient and TSS analysis were taken to the North Carolina State University Center for Applied Aquatic Ecology. The metals samples were taken to the North Carolina State University Environmental Analysis Lab. Sample collection took place within 24 hours of the end of the rain event, and was undertaken in order of least-polluted sampling point to most-polluted sampling point in an attempt to eliminate the introduction of external contamination during sampling. Several pairs of latex gloves were also worn and discarded throughout the sampling process. Once the samples were collected, they were immediately put on ice for preservation during transport. The sample tubing through which the aliquots pass en route to the composite sample jar was rinsed with deionized water after approximately every third sampling event.

Results and Discussion

Sampled Storms

Data collection began in October 2009 and data collected through April 2010 was been analyzed. To date, 12, 15, and 16 storms have been collected for nutrient and TSS analysis at the large bioretention basin, the small bioretention basin, and the swale, respectively. Seven storms have been sampled for metals. A summary of rainfall depths, sample collection type, and sample collection location is presented in Table 4. Table 17 of Appendix A shows all the rainfall data recorded during the monitoring period, including storms that were not sampled for pollutants.

Table 4. Summary of sampled storm events.

Storm Event #	Date Sampled	Rainfall Depth (in)	Large Bioretention Sample	Small Bioretention Sample	Swale Sample
1	11/2/2009	1.01	N,T[1]		N,T
2	11/13/2009	4.24	N,T	N,T	
4,5	11/20/2009	0.32		N,T	N,T
6	11/24/2009	0.51	N,T	N,T	N,T
8	12/4/2009	1.41	N,T	N,T	N,T
9	12/7/2009	0.42		N,T	N,T
10	12/10/2009	1.58	N,T	N,T	N,T
11	12/14/2009	0.26		N,T	

16	1/18/2010	1.41	N,T	N,T	N,T
17	1/23/2010	0.97	N,T	N,T	N,T
18	1/26/2010	0.81	N,T	N,T	N,T
23	2/10/2010	0.26	M	N, T, M	N, T, M
26	2/23/2010	0.23			N, M
27	3/3/2010	0.52	N, T, M	N, T, M	N, T, M
28,29	3/12/2010**[2]**	0.12			N, T, M
30,31	3/14/2010	0.48	N, T, M	N, T, M	N, T, M
33	3/30/2010	1.91	N, T, M	N, T, M	N, T, M
34	4/10/2010	1.41	N, T, M	N, T, M	N, T, M

[1] N = nutrients, T = TSS, M = metals
[2] On 3/12, 3/14, 3/30, and 4/10, nutrient and TSS samples were collected but were not analyzed for this report.

Bridge Deck Water Quality

For NCDOT, it is important to enumerate the differences between runoff quality from roadways and bridge decks so that appropriate treatment technologies can be used to improve water quality. In the subsequent water quality tables, the rows labeled “bioretention inlet” and “swale inlet” represent the water quality of the northbound and southbound bridge decks, respectively (Tables 5, 6, 11, and 12). Pollutant concentrations from each bridge deck were similar for all nitrogen and phosphorus species; median TSS concentrations from the northbound and southbound bridge decks were 20 mg/L and 36 mg/L, respectively. Concentrations of TN, TP, and TSS from the Mango Creek bridge decks were well below those from bridge decks studied in Charlotte, NC (mean EMCs of TN = 2.24 mg/L, TP = 0.43 mg/L, and TSS = 283 mg/L for 31 storm events) (Wu et al. 1998). TSS concentrations were also well below the 138 mg/L median EMC value reported in a bridge deck study in China (Gan et al. 2007) and below the 225 mg/L median EMC value reported in a bridge deck study in Louisiana (Sansalone et al. 2005). Perhaps this was due to differences in age, dustfall and/or maintenance of the bridge decks. The bridge deck at Mango Creek produced relatively cleaner stormwater than other bridge decks in the literature; these smaller concentrations will lead to reduced performance for the bioretention basins and swale when using the percent concentration reduction metric as an evaluation tool.

Bioretention Results

Hydrology

Hydrologic measurements were recorded for 14 storm events for the large bioretention basin and 18 storm events for the small bioretention basin, all with rainfall depths between 0.2 and 1 in (0.51 and 2.54 cm). For the large bioretention basin, the largest storm event with no outflow had a rainfall depth of 0.51 in (1.30 cm). For the small basin, the largest storm event that was entirely captured had a rainfall depth of 0.34 in (0.86 cm). Cumulative volume reductions were 68.9% for the large basin and 47.0% for the small basin. The inflow volumes were considered to be the sum of direct rainfall and highway runoff volumes. These data show the importance of bioretention basins designed and constructed to meet NCDENR guidelines when considering optimal hydrologic performance; the small basin’s storage volume lead to a consistently greater fraction of outflow. However, a site specific evaluation would be necessary to determine whether the small bioretention basin produced outflows that were adequately reduced and protective for the receiving offsite stream, or if a full sized bioretention basin would be necessary to meet the desired hydrologic benefits.

In some instances, the outflow peaks were higher than the inflow peaks in the large basin. This may have been due to an underestimation of the inflow peaks during larger storm events (e.g., the 1.4 in (3.56 cm) events which took place on December 12, 2009 and April 8, 2010) which may have been a result of inaccurate water level readings due pressurized, full-pipe flow passing over the weirs. Another culprit may have been the short antecedent dry periods for these storms which would not have allowed for the soil media to completely drain before the next storm event occurred. This also occurred within the small basin for storms approaching 1 in (2.54 cm) (e.g. the events which took place on January 21, 2010 and March 28, 2010). Flow volume and peak flow data can be found in Tables 22 and 23 in Appendix A.

Nutrients

Bioretention has been shown to be an effective tool for reducing nutrient concentrations from urban stormwater (Kim et al. 2003; Hsieh and Davis 2005; Davis et al. 2006; Dietz and Clausen 2006; Hunt et al. 2006; Davis 2007; Hsieh et al. 2007; Hunt et al. 2008; Li et al. 2009). Mean and median effluent concentrations for the large and small bioretention basins at Mango Creek are presented in Tables 5 and 6, respectively.

In all cases, the median effluent concentrations from the large bioretention basin were lower than those from the small bioretention basin. For TP, the small bioretention basin produced nearly the same median effluent concentration as that of the large basin. When compared to small bioretention basins, full sized bioretention basins treat a greater fraction of the stormwater, resulting in lower mean and median effluent concentrations

Table 5. Mean nutrient concentrations for the bioretention basins at Mango Creek.

Sampling Location	**Mean Concentration (mg/L)**					
	TKN	**$NO_{2,3}$-N**	**TN**	**NH_4-N**	**TP**	**TSS**
Bioretention Inlet	0.44	0.27	0.71	0.12	0.08	23
Small Bioretention Outlet	0.27	0.18	0.45	0.05	0.09	14
Large Bioretention Outlet	0.21	0.12	0.33	0.04	0.07	9

Table 6. Median nutrient concentrations for the bioretention basins at Mango Creek.

Sampling Location	**Median Concentration (mg/L)**					
	TKN	**NO_{2-3}-N**	**TN**	**NH_4-N**	**TP**	**TSS**
Bioretention Inlet	0.34	0.24	0.66	0.11	0.07	20
Small Bioretention Outlet	0.26	0.16	0.45	0.05	0.08	13
Large Bioretention Outlet	0.21	0.10	0.35	0.03	0.07	7

Table 7 shows the *p* values obtained by performing a paired Student's t-test on nutrient and TSS concentrations. All data were log-transformed. The bold values indicate a significant difference between the inlet and outlet concentrations (p value < 0.05) of the original paired data. The original data are presented in Appendix A (Table 18). For statistical purposes, any data (typically TKN) that was below the reportable limit were changed to one-half the value of the reportable limit (i.e. 0.07 mg/L for TKN with RL = 0.14 mg/L), as in Antweiler and Taylor (2008). A Student's t-test was also performed to determine if there was a significant difference in outflow concentrations between the bioretention basin outlets (Table 7). The bold values indicate a significant difference between the outlet concentrations (p value < 0.05) of the original paired data.

Table 7. Statistical comparison of pollutant concentrations for bioretention basins.

Constituent	***p* values**		
	Bioretention Inlet to Small Basin Outlet	**Bioretention Inlet to Large Basin Outlet**	**Large Basin Outlet to Small Basin Outlet**
TKN	0.0525	**0.0268**[1]	**0.024**
$NO_{2,3}$-N	**0.0001**	**0.0001**	0.064
TN	**0.0054**	**0.0056**	**0.019**
NH_4-N	**0.0004**	**0.0022**	0.294
TP	0.0892	0.4366	**0.009**
TSS	0.1166	**0.0289**	**0.018**

[1] Bold values indicate significant difference between compared concentrations (p value < 0.05).

Figures 10 and 11 show a graphical comparison of the inflow and outflow mean nutrient and TSS concentrations for each bioretention basin along with their standard deviation. The sample sizes for these data were 13 bioretention inlet samples, 12 small basin outlet samples, and 9 large basin outlet samples. Again, in all cases except for TP, the bioretention basins decreased the concentrations of the pollutants in question, and the large bioretention basin performed to a higher degree than the small basin. This may be attributed to the greater surface area of the large basin which allowed for a greater degree of infiltration and in turn more water treatment within the basin. The small basin also had a reduced ponding volume which resulted in more overflow and a higher fraction of runoff that bypassed the bioretention basin without being treated by the soil media.

Another metric that can be used to assess stormwater SCM performance is the use of a target effluent concentration. McNett et al. (2010) characterized water quality levels by correlating various in-stream pollutant concentrations to benthic macroinvertebrate health. In the Piedmont of North Carolina, "good" water quality concentrations for TN and TP were 0.99 mg/L and 0.11 mg/L, respectively. "Good" water quality supported intolerant benthic macroinvertebrates, such as mayflies and caddisflies. These target values are shown in Figure 10 as horizontal lines. Target concentrations for TSS were based on those from the Sustainable Sites Initiative (ASLA et al., 2009); in this case a target TSS concentration of 25 mg/L is used in Figure 11.

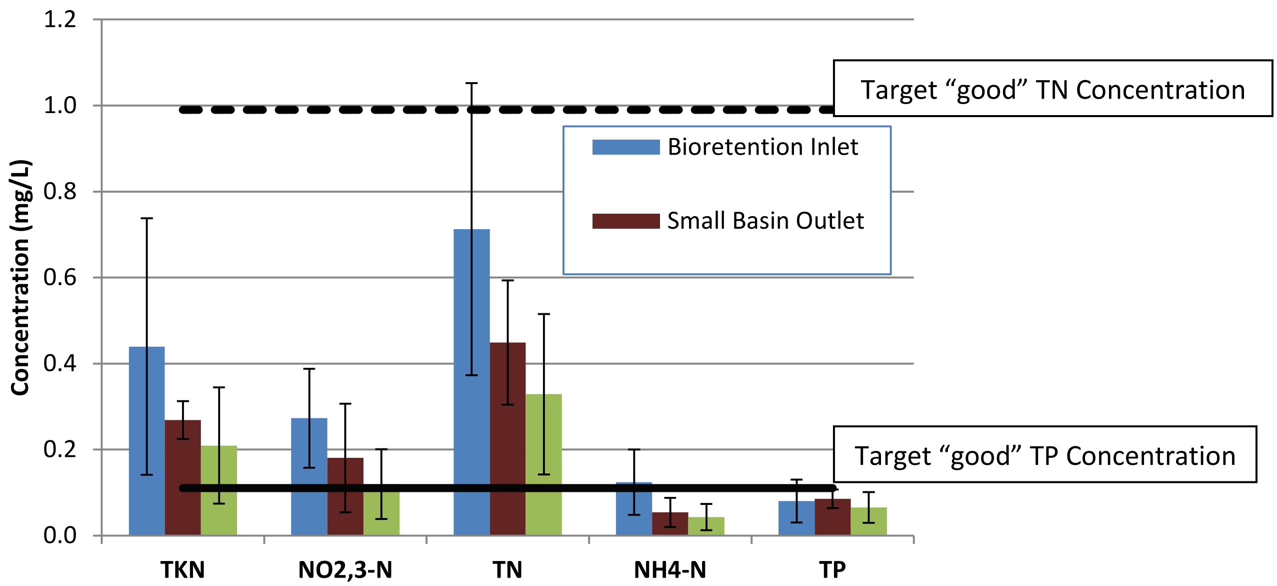

Figure 10. Average influent and effluent nutrient concentrations in the large and small bioretention basins at Mango Creek.

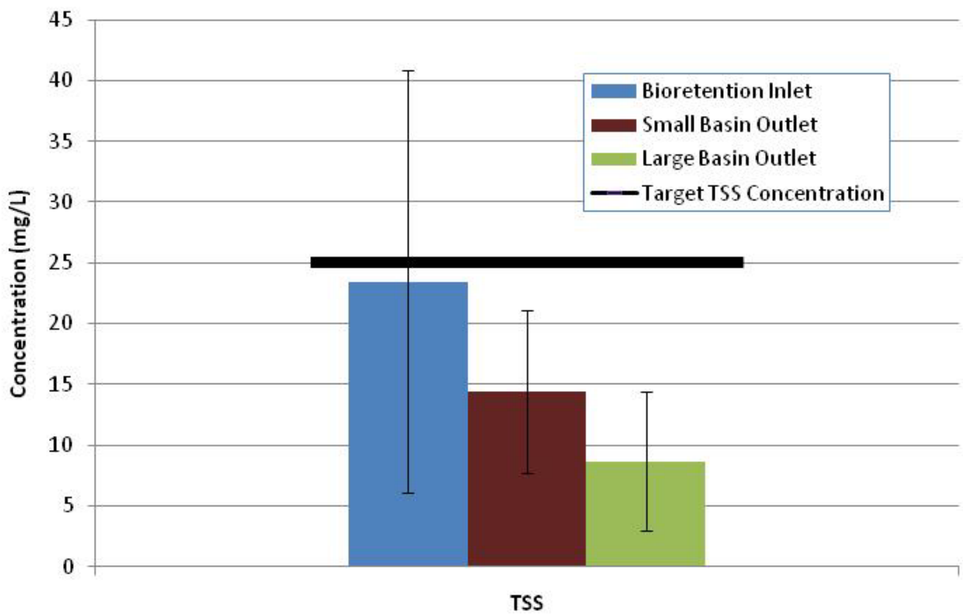

Figure 11. Average influent and effluent TSS concentrations in the large and small bioretention basins at Mango Creek.

It is clear from Figures 10 and 11 that the runoff coming from the bridge deck was quite clean relative to target concentrations, as TN, TP, and TSS were already below the target concentrations before the runoff entered the bioretention basins. When analyzing the pollutant concentrations based on this metric, the bioretention basins' inability to effectively reduce the TP concentrations in the runoff was not necessarily a sign of inadequately functioning bioretention basins. One must consider the idea of irreducible concentrations, which has been suggested by Strecker et al. (2001), Lenhart and Hunt (2010), and others. The outflow from both bioretention basins was at “good” to “excellent” water quality levels (McNett et al. 2010). This also suggests that undersized bioretention basins may be an adequate retrofit alternative to full sized bioretention basins regardless of whether the space is available for a full sized basin to be installed, since the undersized basins may be capable of reducing concentrations to a level below the target concentrations.

Cumulative probability plots are created by ranking influent and effluent concentrations. Based upon these ranked data, a plot may then be created to illustrate the relative probability that a concentration will exceed a benchmark. They also illustrate the variation, expected range, and probability distribution of the data set and are therefore an excellent exploratory tool for a water quality data set. Figures 12-14 relate cumulative probabilities to “good” water quality concentrations for the Piedmont region of North Carolina. Storm events with outflow concentrations of 0 mg/L had no outflow and were therefore not sampled at the bioretention basin outlet. For TN, effluent concentrations for both the large and small basins were always below the target water quality level. For TP, one storm event for the small basin had an effluent concentration above the 0.11 mg/L benchmark, while the large basin always produced effluent concentrations below 0.11 mg/L. A similar trend was noted for TSS, where one storm event produced effluent concentrations above 25 mg/L for the small basin. It may also be noted that the influent stormwater was relatively clean in terms of TN, TP, and TSS, with almost all data points below the “good” water quality concentrations.

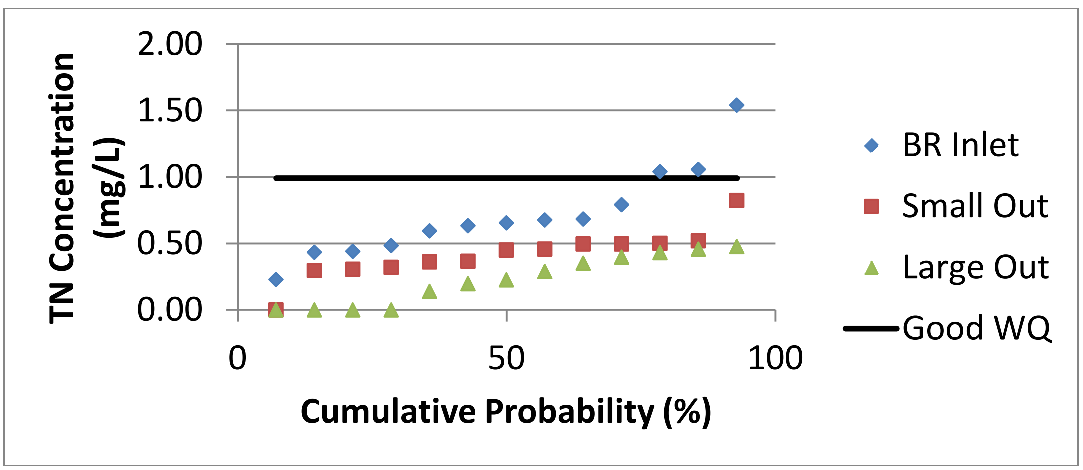

Figure 12. Bioretention Cumulative Probability Plot for TN.

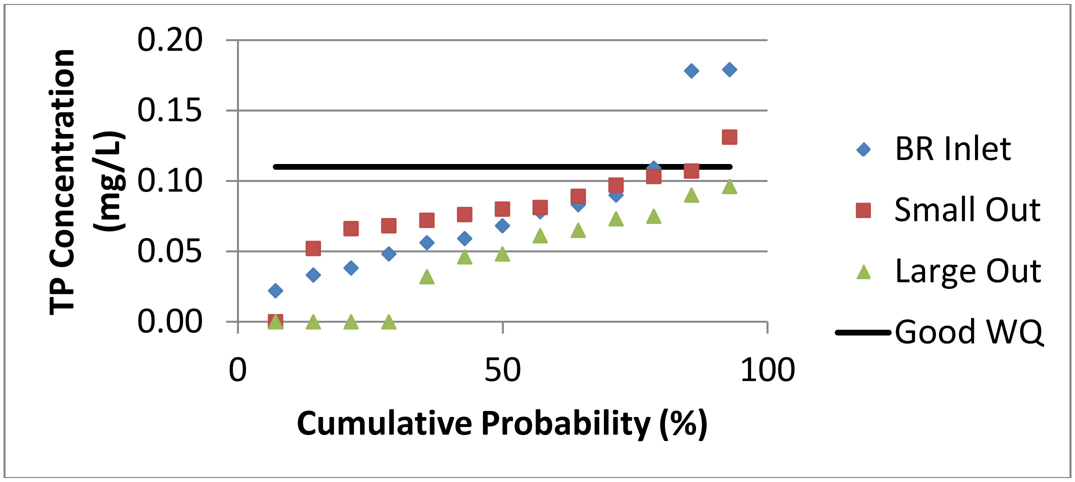

Figure 13. Bioretention Cumulative Probability Plot for TP.

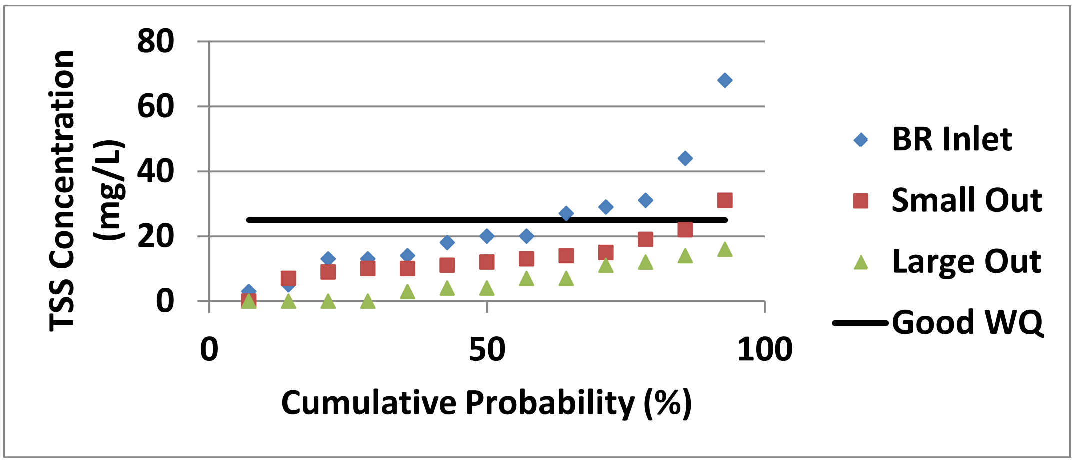

Figure 14. Bioretention Cumulative Probability Plot for TSS.

The percent mean pollutant load reductions, calculated based on inflow (including direct rainfall, see Table 24, Appendix A) and outflow volumes, are presented in Table 8. The pollutant loads per storm sampled are shown in Appendix A (Table 19 and 20) and were calculated using Equation 1.

$$C_{pollutant} * Q = \Theta \quad (1)$$

Where,

$C_{pollutant}$ = EMC of the pollutant (mg/L)

Q = flow volume (L)

Θ = pollutant load (mg).

In order to better predict pollutant loads, the reported inflow volumes (runoff + direct rainfall) for the storms sampled on 11/13/09, 12/4/09, 12/10/09, and 1/18/09 (storms # 2, 8, 10, and 16, respectively) were changed to an estimated volume which was predicted by the concept of initial abstraction. The flow data for these events was deemed unreliable due to the size of the storm (greater than 1 inch) and the inability of the monitoring equipment to accurately measure these larger storms. The initial abstraction estimate predicts the amount of expected runoff from the bridge deck per storm event by assuming some amount of surface storage on the bridge decks. This assumption was reasonable because the flows associated with the larger storms (storms over one inch) seemed to be under-predicted by the bioretention basin inlet bubbler modules due to a loss in accuracy of water level readings behind the compound weir. Inaccuracies may have also been due to higher velocities and full-pipe flow often associated with this size storm. The antecedent dry period for storm event #8 was only 1.4 days, which may have had some effect on the outflow volumes due to a decrease in infiltration and soil media storage in the basin. Event #10 had an antecedent dry period of three days, which may have had a similar effect on outflow. The antecedent dry period for storm event #2 was 20.3 days and event #16 was 16 days, making the antecedent try period an unlikely factor in the under-prediction of the inflow. An example calculation for predicting the volume of runoff based on the initial abstraction concept can be found in Appendix B.

Table 8. Percent pollutant load reductions for the bioretention basins at Mango Creek as calculated using the summation of loads technique.

Parameter	Percent Load Reduction (%)	
	Small Basin	Large Basin
No. of storms sampled	n= 11	n=12
TKN	35.1	47.8
$NO_{2,3}$-N	56.1	69.7
TN	45.1	55.6
NH_4-N	66.6	76.8
TP	-4.4	-4.6
TSS	55.3	62.8

The results in Table 8 were calculated using Equation 2.

$$\frac{\left(\Sigma\ \Theta_{in} - \Sigma\ \Theta_{out}\right)}{\left(\Sigma\ \Theta_{in}\right)} * 100 \qquad (2)$$

Where,

$\Sigma\ \Theta_{in}$ = sum of per-storm-event pollutant loads at SCM inlet for a given constituent (mg)

$\Sigma\ \Theta_{out}$ = sum of per-storm-event pollutant loads at SCM outlet for a given constituent (mg)

This technique allows the largest events, and their associated loads, to proportionally influence the result. For several of the pollutants, the percent load reduction was greater than the percent concentration reduction for the small basin (Appendix C), which illustrates the importance of considering flow volumes when determining the effectiveness of a bioretention basin. The large bioretention basin had a higher pollutant load reduction than the small basin for all pollutants except TP. The TP result might seem counter-intuitive considering the previously reported volumetric reduction associated with runoff and outflow. However, a large event [e.g., on November 14, 2009, 4.24 in (10.77 cm) rainfall depth] with a clean inflow concentration (0.02

mg/L of TP) that was accompanied by relatively higher outflow concentrations (0.08 to 0.10 mg/L for the small and large basins, respectively) would proportionally outweigh a small storm with a minor improvement in concentration.

Another way to compare load reduction is to present a mean load reduction of all monitored storm events (Equation 3). This method allows each storm to have an equally weighted effect on load reduction.

$$\frac{\left(\sum_{i=1}^{n} \frac{(\Theta_{in} - \Theta_{out})}{\Theta_{in}}\right)}{n} * 100 \qquad (3)$$

Where,

Θ_{in} = pollutant load at SCM inlet for a given constituent during a given storm (mg)

Θ_{out} = pollutant load at the SCM outlet for a given constituent during a given storm (mg)

n = total number of storm events.

Mean load reduction results are summarized in Table 9. These results show a more positive performance, because large storm events have less influence. For instance, the flow volume associated with the 4.24 inch (10.77 cm) storm on November 13, 2009 constitutes 37% of the total flow data used to calculate the summation of loads, but only 8.3% of the total flow data used to calculate mean load reduction. This gives the increase in TP (0.02 mg/L to 0.1 mg/L) in the large bioretention basin less weight in the final load reduction percentage. Using the mean load reduction metric, the mass of TP (as well as all other nutrient forms and TSS) was reduced by both the small and large basins.

Table 9. Percent pollutant load reductions for the bioretention basins at Mango Creek as calculated using average mass reduction.

Parameter	**Mean Load Reduction (%)**	
	Small Basin	**Large Basin**
No. of storms sampled	n= 11	n=12
TKN	45.4	67.9
$NO_{2,3}$-N	62.2	78.7
TN	53.0	71.9
NH_4-N	67.9	82.0
TP	5.8	29.1
TSS	45.8	61.6

Heavy Metals

Heavy metals are an urban pollutant of concern and are often derived from vehicular wear and activity; no data exists in the literature as to how bioretention basins that have been deliberately undersized perform for reducing metal concentrations. Table 10 presents heavy metal data for five storm events for the bioretention basins. Median concentrations of total copper and zinc were reduced between the inlet and outlet of the bioretention basins. Interestingly, the small bioretention basin performed nearly or equally as well as the large basin when the effluent concentration metric was utilized. This may be an artifact of the small number of sampled storms or because metals are often trapped in the top portion of the soil column (Davis et al. 2003), making the size of the basin and media depth less influential. Too few storms were sampled for metals for a statistical analysis to be performed on the data. Since metals tend to bind to particulate matter at the near-neutral pH levels often observed in stormwater runoff, sediment-bound metals associated with TSS may have been removed by sedimentation. Another means of removal may have been the binding of metals to the fill media within the basins, particularly the clay and organic fraction (Sparks, 2003).

In contrast, the median dissolved copper concentrations remained constant through both basins. The median dissolved zinc and lead concentrations were below the detection limit, as was the total Pb concentration; therefore no conclusions could be drawn as to the removal efficiency of the basins for these constituents. The original data for the metals, as reported by the North Carolina State University Environmental Analysis Lab, can be found in Table 24 of Appendix A.

Table 10. Median total and dissolved heavy metal concentrations for the bioretention basins at Mango Creek.

Sampling Location	**Median Concentrations**					
	Total Metals (µg/L)[1]			Dissolved Metals (µg/L)		
	Cu	**Zn**	**Pb**	**Cu**	**Zn**	**Pb**
Bioretention Inlet	30	80	BDL[2]	10	BDL	BDL
Small Basin Outlet	20	30	BDL	10	BDL	BDL
Large Basin Outlet	10	30	BDL	10	BDL	BDL

[1] Detection limit (DL) for Cu and Zn was 2 µg/L. DL for Pb was 30 µg/L.
[2] BDL = Below the Detection Limit

<u>Swale Results</u>

Hydrology

Because the soils onsite were clayey and substantial soil compaction occurred during construction (Figure 15), little infiltration was expected in the swale. Sixteen storm events with reliable inflow and outflow data were monitored (Tables 26 and 27, Appendix A). The wooden weir box was not installed until December 17, 2009 which prevented adequate outflow data from being collected before that date. The cumulative volume reduction for ten storms between 0.2 and 2 inches was 23.3%. This may be attributed to the flow attenuation associated with the thick stand of grass in the swale and the check dam located at the entrance to the outlet pipe (as shown in Figure 7). This volume reduction was substantially less than the reduction achieved by both bioretention basins. No direct rainfall was included in the inflow calculations because the swale was mostly located underneath the southbound bridge deck.

Figure 15. Soil compaction in Mango Creek swale.

A leak in the stormwater runoff collection pipe which routed the southbound bridge deck runoff to the swale was observed on February 9, 2010. The NCDOT fixed the leaking pipe around March 27, 2010. The flow data between these dates were still used when considering the volume and peak flow reductions achieved by the swale, but under-predict the amount of runoff that was actually coming from the contributing watershed. The event mean concentrations collected for the storms which occurred during the time that the collection pipe was leaking *were used* for water quality analysis and were also used in mass load reduction calculations. The load reductions for the storms sampled during the pipe leak are considered accurate because the measured influent volumes and pollutant concentrations were not affected by the leak.

Nutrients

Roadside swales are nearly ubiquitous practices used to drain highways across the U.S. However, little data exist on swales used to treat stormwater runoff from bridge decks. Mean and median effluent concentrations from eleven storm events are presented in Tables 11 and 12, respectively, for the Mango Creek swale.

Table 11. Mean nutrient concentrations for the swale at Mango Creek.

Sampling Location	**Mean Concentration (mg/L)**					
	TKN	**$NO_{2,3}$-N**	**TN**	**NH_4-N**	**TP**	**TSS**
Swale Inlet	0.50	0.27	0.77	0.14	0.15	40
Swale Outlet	0.52	0.30	0.82	0.10	0.15	31

Table 12. Median nutrient concentrations for the swale at Mango Creek.

Sampling Location	**Median Concentration (mg/L)**					
	TKN	**$NO_{2\text{-}3}$-N**	**TN**	**NH_4-N**	**TP**	**TSS**
Swale Inlet	0.42	0.21	0.68	0.12	0.08	36
Swale Outlet	0.45	0.23	0.66	0.09	0.12	22

Figures 16 and 17 show a graphical comparison of the mean nutrient and TSS concentrations (respectively) in the inflow and outflow of the swale as well as their standard error. The indicators of "good" water quality in North Carolina (0.99 mg/L for TN, 0.11 mg/L for TP, and 25 mg/L for TSS) (McNett et al. 2010, ASLA 2009) are also depicted on the graphs. In the case of TP and TSS, the influent and effluent pollutant concentrations remained higher than the target concentrations, unlike what was observed for the bioretention basin TP and TSS concentrations. One possible explanation for this may be that the southbound bridge deck shook sediment off the passing cars due to an uneven bridge deck joint.

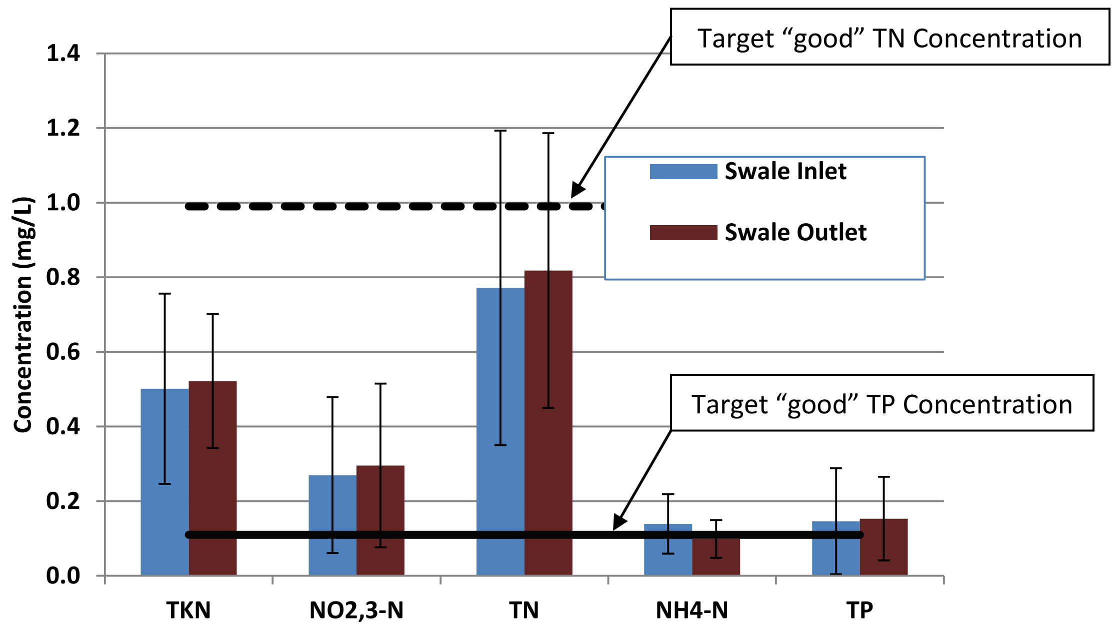

Figure 16. Average influent and effluent nutrient concentrations in the swale at Mango Creek.

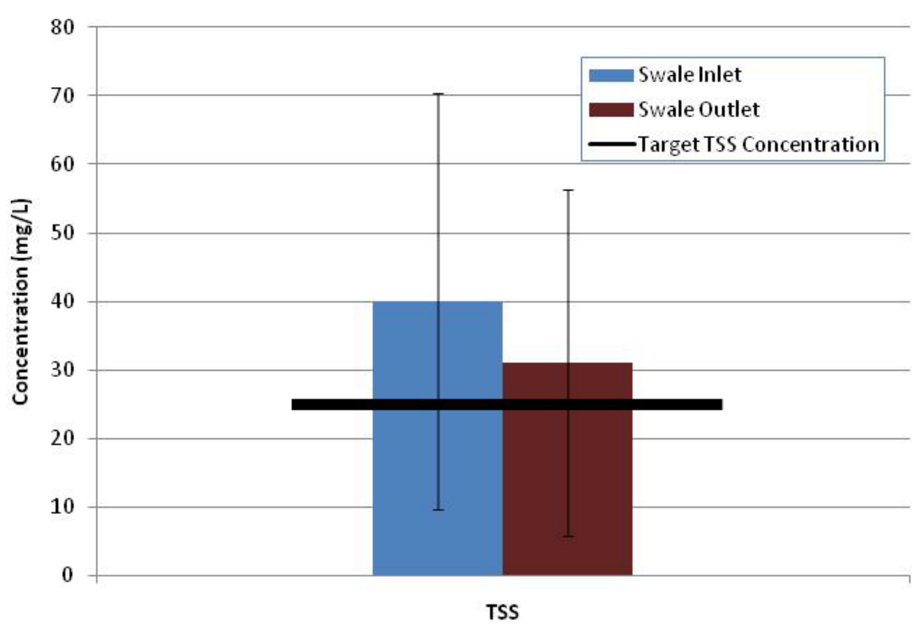

Figure 17. Average influent and effluent TSS concentrations in the swale at Mango Creek.

Table 13 shows the *p* values obtained by performing a paired Student's t-test on the log-transformed swale nutrient and TSS concentration data. The bold values indicate a significant difference between the inlet and outlet concentrations (*p* value < 0.05) of the original paired data. The original data are presented in Appendix A (Table 18). The mean concentrations of TKN, TN, $NO_{2,3}$-N, and TP were increased through the swale, but the differences in concentration between the inlet and the outlet showed no statistical significance for these constituents.

Table 13. Statistical comparison of pollutant concentrations for swale.

Constituent	*p* value
TKN	0.1061
$NO_{2,3}$-N	0.0653
TN	0.0566
NH_4-N	**0.0062**[1]
TP	0.3242
TSS	**0.0482**

[1] Bold values indicate significant difference between inlet and outlet concentrations (*p* value < 0.05).

Cumulative probability plots for TN, TP, and TSS for the swale were compared against indicators of "good" water quality in North Carolina (McNett et al. 2010). While statistically significant reductions in TN did not occur in the swale, effluent concentrations often were less than the good water quality standard for TN (Figure 18). Median TP concentrations increased in the swale, and half of the storms sampled had effluent TP concentrations greater than the "good" water quality target concentration (Figure 19). While TSS concentrations were reduced in the swale, four of the eleven sampled storms had effluent TSS concentrations above the 25 mg/L benchmark (Figure 20). Using these metrics for comparison between swales and bioretention basins, the latter systems do appear to be a more optimally performing SCM. In most cases, a similar conclusion is reached when comparing swale and bioretention performance using a load reduction metric.

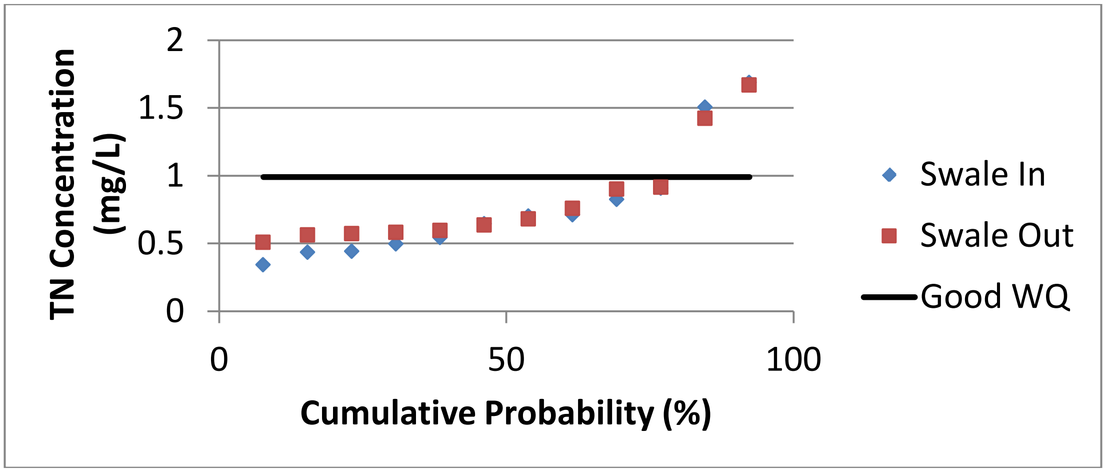

Figure 18. Swale Cumulative Probability Plot for TN.

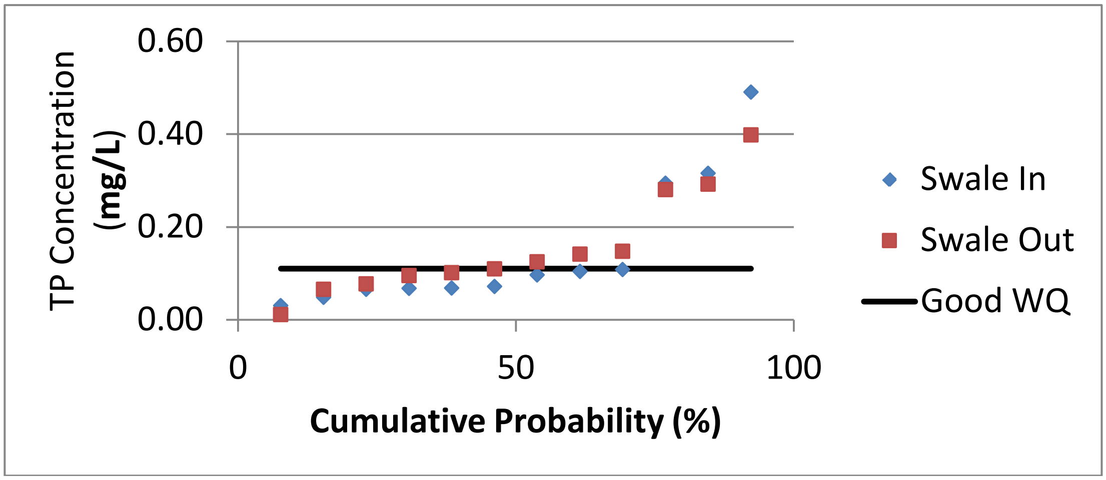

Figure 19. Swale Cumulative Probability Plot for TP.

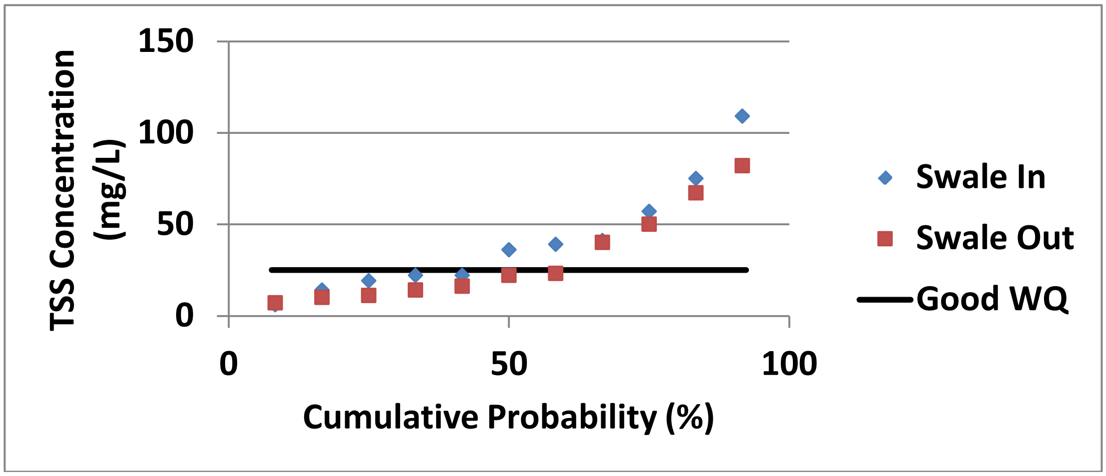

Figure 20. Swale Cumulative Probability Plot for TSS.

The average pollutant load reductions, calculated using the summation of loads technique, are presented in Table 14. The mean pollutant load reductions through the swale are presented in Table 15. Equations 2 and 3 were used to perform these calculations. These load reductions were based on the six sampled storm events associated with flow data recorded after the installation of the weir box. To calculate load reductions, the assumption was made that inflow and outflow volume was equal for sampled storms which showed an increase in volume through the swale. Overland flow from land surrounding the swale was assumed not to be a significant input and therefore was not considered as the reason for higher outflow volumes. Inflow was also set equal to outflow for storms that did not have distinguishable outflow data in the Flowlink software due to faulty bubbler module readings. Minimal flow mitigation was expected in the swale due to the tight nature of the soil and compaction during construction; therefore this conservative assumption was deemed reasonable. Inflow and outflow loads by storm event are presented in Table 25 (Appendix A).

These metrics show that the low concentrations of pollutants that entered the swale combined with minimal flow reduction resulted in a mass increase for most observed pollutants. Mass of

NH_4-N and TSS were reduced using these metrics. Removal of TSS may have been achieved by the reduced flow velocity and filtration effect associated with the thick stand of grass in the swale.

Table 14. Percent pollutant load reductions for the swale at Mango Creek calculated using the summation of loads technique.

Constituent	Percent Load Reduction (%)
TKN	0.5
$NO_{2,3}$-N	-14.4
TN	-4.5
NH_4-N	13.4
TP	-4.1
TSS	60.9

Table 15. Percent pollutant load reductions for the swale at Mango Creek calculated using average mass reduction technique.

Constituent	Mean Load Reduction (%)
TKN	-0.4
$NO_{2,3}$-N	-17.2
TN	-3.8
NH_4-N	20.1
TP	-4.1
TSS	53.5

Heavy Metals

Median heavy metals concentrations are presented in Table 16 for the seven storm events sampled at the swale. Median total copper and zinc concentrations appeared to be reduced through the swale. Perhaps this was due to the reduction in TSS concentration noted above, as heavy metals are often associated with sediment particles. Dissolved copper also appeared to be reduced based on the median concentrations. No conclusions can be drawn from the median dissolved zinc and lead concentrations reported for the swale, as most of these data were below the laboratory detection limit. The original reported data can be found in Table 21 (Appendix).

Table 16. Median total and dissolved heavy metal concentrations for the swale at Mango Creek.

Sampling Location	**Median Concentrations**					
	Total Metals (µg/L)[1]			Dissolved Metals (µg/L)		
	Cu	**Zn**	**Pb**	**Cu**	**Zn**	**Pb**
Swale Inlet	30	100	BDL	5	BDL	BDL
Swale Outlet	BDL	80	BDL	BDL	BDL	BDL

[1] Detection limit (DL) for both Cu and Zn was 2 µg/L. DL for Pb was 30 µg/L.

Conclusions

NCDOT has constructed and maintains 12,712 bridges in North Carolina. In 2008, the NC senate passed NC Bill 2008-107, which required the treatment of runoff from these bridge decks for the purpose of maintaining stream health. In this study, three stormwater SCMs were studied to ascertain their effectiveness in treating bridge deck runoff: a large bioretention basin, a small bioretention basin, and a swale. Additionally, bridge deck runoff quality was studied.

Bridge deck runoff concentrations for TN, TP, and TSS at the Mango Creek site were well below those for other bridge deck runoff studies in the literature. The large bioretention basin produced lower nutrient and TSS effluent concentrations than the small bioretention basin. The large bioretention basin reduced runoff volumes to a greater extent than the small basin (68.9% vs 47.0%) for storm events between 0.2 and 1 inch. Small bioretention basins will not reduce pollutant loads to the same extent as bioretention basins sized to NCDENR standards. However, small basins do provide a benefit and their use should be encouraged in locations with limited available space for retrofits. Small basins may also be considered as alternatives to full sized basins in areas with "cleaner" runoff.. While the t-test shows statistically that the small bioretention basin did not treat stormwater to the same degree as the large basin, the results presented do suggest that small bioretention basins should receive a portion of the credit that appropriately designed and sized bioretention basins receive. Furthermore, the percent reductions presented in Table 28 (Appendix C) show that small bioretention basins typically reduce influent concentrations by more than half of the performance of the large basin. Pollutant loading (Table 8) shows a similar trend; perhaps one-half sized bioretention should receive more than one-half the credit of a large basin.

The swale studied at Mango Creek did not substantially reduce nutrient concentrations, but did reduce TSS concentrations by 22% and runoff volumes by 23%. Concentrations of heavy metals (Cu and Zn) were reduced by both the bioretention basins and the swale. All three practices can be considered as appropriate retrofits for some locations along NCDOT rights-of-way, including land under bridge decks.

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Appendix A

Note:

MCBRLIN	=	Large basin inlet
MCBRLOUT	=	Large basin outlet
MCBRSIN	=	Small basin inlet
MCBRSOUT	=	Small basin outlet
MCSWIN	=	Swale inlet
MCSWOUT	=	Swale outlet

Table 17. Rainfall data recorded during monitoring period.

Storm Event #	Start Date	Stop Date	Start Time	Stop Time	Rainfall Depth (in)	Rainfall Depth (cm)	Antecedent Dry Pd. (days)
0	10/19/2009	10/21/2009	14:14	10:34	-	-	-
2	11/10/2009	11/13/2009	17:28	7:04	4.24	10.77	20.29
3	11/16/2009	11/16/2009	11:30	11:38	0.07	0.18	3.18
4	11/18/2009	11/18/2009	18:06	19:48	0.11	0.28	2.27
5	11/19/2009	11/19/2009	4:02	8:38	0.32	0.81	0.34
6	11/22/2009	11/23/2009	22:20	12:42	0.51	1.30	3.57
7	11/30/2009	11/30/2009	19:10	21:44	0.17	0.43	7.27
8	12/2/2009	12/3/2009	7:56	1:52	1.41	3.58	1.43
9	12/4/2009	12/5/2009	23:36	18:44	0.42	1.07	1.91
10	12/8/2009	12/9/2009	19:30	10:04	1.58	4.01	3.03
11	12/13/2009	12/13/2009	3:18	16:30	0.26	0.66	3.72
12	12/18/2009	12/19/2009	19:32	11:22	0.74	1.88	5.13
13	12/25/2009	12/25/2009	10:46	18:06	0.54	1.37	5.98
14	12/31/2009	12/31/2009	0:00	5:58	0.33	0.84	5.25
15	12/31/2009	12/31/2009	20:20	23:08	0.1	0.25	0.60
16	1/17/2010	1/18/2010	0:20	18:28	1.41	3.58	16.05
17	1/21/2010	1/22/2010	14:12	0:02	0.97	2.46	2.82
18	1/24/2010	1/25/2010	19:24	9:32	0.81	2.06	2.81
19	1/31/2010[1]	1/31/2010	13:04	14:36	0.1	0.25	6.15
20	2/2/2010	2/2/2010	10:24	15:42	0.15	0.38	1.83
21	2/2/2010	2/3/2010	23:12	1:14	0.1	0.25	0.31
22	2/5/2010	2/5/2010	8:08	23:26	1.79	4.55	2.29
23	2/9/2010	2/9/2010	13:06	17:44	0.26	0.66	3.57
24	2/13/2010	2/13/2010	16:28	19:14	0.1	0.25	3.95

Storm Event #	Start Date	Stop Date	Start Time	Stop Time	Rainfall Depth (in)	Rainfall Depth (cm)	Antecedent Dry Pd. (days)
25	2/14/2010	2/14/2010	11:00	12:40	0.07	0.18	0.66
26	2/22/2010	2/22/2010	12:10	15:50	0.23	0.58	7.98
27	3/2/2010	3/3/2010	15:18	9:10	0.52	1.32	7.98
28	3/10/2010	3/11/2010	21:34	1:16	0.1	0.25	7.52
29	3/11/2010	3/11/2010	17:00	21:56	0.12	0.30	0.66
30	3/13/2010	3/13/2010	1:44	3:42	0.48	1.22	1.16
31	3/14/2010	3/14/2010	5:40	11:02	0.1	0.25	1.08
32	3/22/2010	3/22/2010	4:42	6:22	0.54	1.37	7.74
33	3/28/2010	3/29/2010	22:48	8:32	1.91	4.85	6.68
34	4/8/2010	4/9/2010	22:04	2:48	1.41	3.58	10.56
35	4/21/2010	4/21/2010	2:22	20:16	0.34	0.86	11.98
36	4/24/2010	4/25/2010	22:04	5:58	0.31	0.79	3.08

[1] Grey boxes indicate snow events, therefore making these precipitation data unreliable.

Table 18. Nutrient and TSS concentration data as reported by the NC State University Center for Applied Aquatic Ecology.

	All values in mg/L		RL[1]= 0.140	RL= 0.0056	TKN + $NO_{2,3}$-N	RL= 0.007	RL= 0.010	RL= 1
Storm Event #	**Date Sampled**	**Sample Site**	**TKN**	**$NO_{2,3}$-N**	**TN**	**NH_4-N**	**TP**	**TSS**
1	11/2/09	MCBRSIN	1.31	0.23	1.54	0.07	0.11	20
		MCBRLOUT	0.33	0.15	0.48	0.03	0.05	7
		MCSWIN	0.48	0.22	0.70	0.03	0.07	22
		MCSWOUT	0.45	0.15	0.60	0.02	0.10	22
2	11/13/09	MCBRSIN	**0.12**	0.11	0.23[3]	0.02	0.02	3
		MCBRSOUT	0.24	0.06	0.30	0.01	0.08	7
		MCBRLOUT	0.31	0.08	0.40	0.02	0.10	14
4,5	11/20/09	MCBRSIN	0.50	0.30	0.79	0.05	0.08	29
		MCBRSOUT	0.32	0.18	0.50	0.03	0.07	15
		MCSWIN	0.62	0.21	0.83	0.10	0.10	39
		MCSWOUT	0.68	0.23	0.90	0.06	0.14	67
6	11/24/09	MCBRSIN	0.34	0.30	0.63	0.07	0.06	14
		MCBRSOUT	0.25	0.20	0.45	0.01	0.08	10
		MCBRLOUT	0.37	0.08	0.46	0.10	0.03	16
		MCSWIN	0.36	0.29	0.65	0.07	0.07	14

	All values in mg/L		RL[1]= 0.140	RL= 0.0056	TKN + $NO_{2,3}$-N	RL= 0.007	RL= 0.010	RL= 1
Storm Event #	**Date Sampled**	**Sample Site**	**TKN**	**$NO_{2,3}$-N**	**TN**	**NH_4-N**	**TP**	**TSS**
		MCSWOUT	0.45	0.31	0.76	0.07	0.08	10
8	12/4/09	MCBRSIN	0.25	0.19	0.43	0.08	0.03	13
		MCBRSOUT	0.31	0.19	0.50	0.04	0.08	12
		MCBRLOUT	0.24	0.11	0.35	0.02	0.08	11
		MCSWIN	0.59	0.13	0.71	0.31	0.07	19
		MCSWOUT	0.46	0.18	0.64	0.08	0.01	16
9	12/7/09	MCBRSIN	0.30	0.38	0.68	0.11	0.06	13
		MCBRSOUT	0.31	0.19	0.50	0.02	0.07	9
		MCSWIN	0.24	0.30	0.55	0.10	0.03	6
		MCSWOUT	0.34	0.24	0.57	0.05	0.07	7
10	12/10/09	MCBRSIN	0.27	0.17	0.44	0.11	0.05	27
		MCBRSOUT	0.34	0.12	0.46	0.07	0.10	19
		MCBRLOUT	0.21	0.08	0.29	0.03	0.07	7
		MCSWIN	0.25	0.10	0.35	0.08	0.05	41
		MCSWOUT	0.45	0.11	0.56	0.07	0.11	50
11	12/14/09	MCBRSIN	0.44	0.24	0.68	0.26	0.04	5
		MCBRSOUT	0.23	0.08	0.31	0.04	0.05	11
16	1/18/10	MCBRSIN	0.39	0.21	0.60	0.15	0.09	44
		MCBRSOUT	0.23	0.13	0.37	0.08	0.11	13
		MCBRLOUT	**0.13**[2]	0.10	0.23[3]	0.06	0.09	12
		MCSWIN	0.36	0.14	0.50	0.15	0.11	36
		MCSWOUT	0.36	0.22	0.58	0.14	0.15	11
17	1/23/10	MCBRSIN	0.31	0.35	0.66	0.14	0.08	20
		MCBRSOUT	0.29	0.23	0.52	0.12	0.10	14
		MCBRLOUT	**0.08**	0.12	0.20[3]	0.03	0.07	3
		MCSWIN	0.25	0.19	0.44	0.13	0.07	22
		MCSWOUT	0.44	0.24	0.68	0.13	0.12	14
18	1/26/10	MCBRSIN	0.29	0.19	0.48	0.09	0.07	31
		MCBRSOUT	0.21	0.11	0.32	0.09	0.09	22

	All values in mg/L		RL[1]= 0.140	RL= 0.0056	TKN + $NO_{2,3}$-N	RL= 0.007	RL= 0.010	RL= 1
Storm Event #	**Date Sampled**	**Sample Site**	**TKN**	**$NO_{2,3}$-N**	**TN**	**NH_4-N**	**TP**	**TSS**
		MCBRLOUT	**0.08**	0.06	0.14	0.02	0.06	4
		MCSWIN	0.33	0.11	0.44	0.11	0.10	57
		MCSWOUT	0.35	0.16	0.51	0.11	0.10	23
23	2/10/10	MCBRSIN	0.68	0.36	1.04	0.23	0.18	68
		MCBRSOUT	0.23	0.13	0.36	0.09	0.07	10
		MCSWIN	0.67	0.24	0.91	0.16	0.29	109
		MCSWOUT	0.61	0.31	0.92	0.12	0.29	82
26	2/23/10	MCSWIN	1.03	0.48	1.51	0.26	0.49	NS[4]
		MCSWOUT	0.91	0.51	1.43	0.20	0.40	NS
27	3/3/10	MCBRSIN	0.51	0.54	1.06	0.24	0.18	18
		MCBRSOUT	0.28	0.55	0.82	0.06	0.13	31
		MCBRLOUT	0.14	0.29	0.43	0.07	0.05	4
		MCSWIN	0.85	0.84	1.69	0.18	0.32	75
		MCSWOUT	0.76	0.91	1.67	0.16	0.28	40

[1] RL = reportable limit
[2] Bold values are less than the reportable limit
[3] Value calculated using TKN value reported by the lab that was under the reportable limit
[4] NS = not sampled

Table 19. Large bioretention basin pollutant loads by storm event.

	Large Bioretention Inlet (mg)						**Large Bioretention Outlet (mg)**					
Storm Event #	**TKN**	**$NO_{2,3}$-N**	**TN**	**NH_4-N**	**TP**	**TSS**	**TKN**	**$NO_{2,3}$-N**	**TN**	**NH_4-N**	**TP**	**TSS**
2	34936	29583	64519	4790	6198	845227	52242	13643	65884	3327	15972	2329241
4,5	9325	5565	14890	846	1466	545220	0	0	0	0	0	0
6	7632	6767	14399	1640	1344	318968	0	0	0	0	0	0
8	22815	17019	39834	7728	3036	1195929	17277	8096	25373	1373	5422	795155
9	7653	9655	17308	2838	1419	329430	0	0	0	0	0	0
10	27813	17680	45493	10960	4963	2791605	15952	6242	22195	2543	5626	539451
11	5845	3108	8952	3425	502	66118	0	0	0	0	0	0
16	35694	19043	54737	14167	8280	4047759	4533	6410	14569	4079	5828	777010
17	11541	12923	24464	5080	3100	747006	1860	3162	5234	717	1727	79709
18	10363	6932	17295	3216	2430	1107759	2378	1970	4755	815	2072	135868
23	10631	5581	16212	3601	2790	1060002	2018	1059	3078	684	530	201242
27	11742	12405	24147	5369	4066	411206	-	-	-	-	-	-

Table 20. Small bioretention basin pollutant loads by storm event.

	Small Bioretention Inlet (mg)						Small Bioretention Outlet (mg)					
Storm Event #	TKN	$NO_{2,3}$-N	TN	NH_4-N	TP	TSS	TKN	$NO_{2,3}$-N	TN	NH_4-N	TP	TSS
2	37831	32034	69865	5186	6712	915264	47557	11889	59446	2821	16121	1410577
4,5	16376	9773	26149	1486	2575	957463	4972	2788	7760	480	1053	232323
6	10832	9603	20435	2328	1908	452679	5528	4322	9850	285	1667	219367
8	24686	18415	43101	8361	3285	1294037	26847	16108	42955	3118	7015	1039231
9	11172	14095	25267	4143	2072	480924	5228	3147	8375	305	1218	152265
10	30098	19133	49231	11860	5371	3020994	26063	9569	35633	5057	8013	1478213
11	8915	4740	13655	5224	766	100853	1655	569	2223	306	379	80185
16	38622	20605	59227	15329	8959	4379819	10595	5931	16526	3532	4845	588614
17	16256	18203	34459	7155	4367	1052172	11973	9496	21468	4789	4005	577989
18	14749	9867	24616	4577	3458	1576652	8998	5004	14002	3906	3906	965650
23	10156	5331	15487	3440	2666	1012635	950	557	1507	368	276	41857
27	15639	16521	32161	7150	5416	547673	2431	4827	7257	484	1154	273033

Table 21. Metals concentration data (as reported by the North Carolina State University Environmental Analysis Lab).

			Total Concentration			Dissolved Concentration		
	All values in µg/L		DL[1] = 2	DL = 2	DL = 30	DL = 2	DL = 2	DL = 30
Storm Event #	Sample Date	Site Name	Cu	Zn	Pb	Cu	Zn	Pb
23	2/10/2010	MCBRLOUT	10	30	**0**[2]	-	-	-
		MCBRSIN	40	150	**0**	-	-	-
		MCBRSOUT	30	60	**0**	-	-	-
		MCSWIN	70	180	**0**	-	-	-
		MCSWOUT	40	110	**0**	-	-	-
26	2/23/2010	MCSWIN	**0**	270	**0**	**0**	20	**0**
		MCSWOUT	**0**	140	**10**	**0**	20	**0**
27	3/3/2010	MCBRSIN	**0**	40	**0**	**0**	**0**	**0**
		MCBRSOUT	**0**	20	**0**	**0**	**0**	**0**
		MCBRLOUT	**0**	**0**	**0**	**0**	**0**	**0**
		MCSWIN	**0**	100	**0**	**0**	**0**	**0**
		MCSWOUT	**0**	80	**0**	**0**	**0**	**0**
28,29	3/12/2010	MCSWIN	30	130	**0**	10	**0**	**0**
		MCSWOUT	0	40	**0**	**0**	**0**	**0**

			Total Concentration			Dissolved Concentration		
	All values in µg/L		DL[1] = 2	DL = 2	DL = 30	DL = 2	DL = 2	DL = 30
Storm Event #	**Sample Date**	**Site Name**	**Cu**	**Zn**	**Pb**	**Cu**	**Zn**	**Pb**
30,31	3/14/2010	MCBRSIN	20	170	40	**0**	20	**0**
		MCBRLOUT	**0**	40	**0**	**0**	20	**0**
		MCBRSOUT	**0**	30	**0**	**0**	20	**0**
		MCSWIN	**0**	100	**0**	**0**	**0**	**0**
		MCSWOUT	**0**	190	**0**	**0**	**0**	**0**
33	3/30/2010	MCBRSIN	30	**0**	**0**	20	**0**	**0**
		MCBRLOUT	30	**0**	**0**	20	**0**	**0**
		MCBRSOUT	20	**0**	**0**	20	**0**	**0**
		MCSWIN	30	**0**	**0**	30	**0**	**0**
		MCSWOUT	30	**0**	**0**	20	**0**	**0**
34	4/10/2010	MCBRSIN	40	80	**0**	20	**0**	**0**
		MCBRLOUT	30	40	**0**	20	**0**	**0**
		MCBRSOUT	40	80	**0**	30	**0**	**0**
		MCSWIN	30	50	**0**	20	**0**	**0**
		MCSWOUT	30	40	**0**	20	**0**	**0**

[1] DL = detectable limit

[2] Bold values are less than the detectable limit.

Table 22. Bioretention flow volumes.

Storm Event #	MCBRLIN	MCBRLOUT	MCBRSIN	MCBRSOUT
1	-[1]	50	-	-
2	5622	5875	7030	7116
3	-	-	-	-
4	178	0	447	0
5	414	0	683	547
6	720	0	1100	775
7	275	0	306	0
8	2640	2553	2351	3058
9	825	87	1272	597
10	2234	2721	2073	2747
11	424	0	691	257
12	2556	149	1240	639
13	1167	610	1059	722
14	473	0	555	120
15	130	0	207	149
16	2068	2286	2803	1599

Storm Event #	MCBRLIN	MCBRLOUT	MCBRSIN	MCBRSOUT
17	1157	938	1777	1458
18	1127	1199	1729	1550
19	-	-	-	-
20	105	-	-	-
21	116	59	-	218
22	2997	3691	-	2458
23	507	105	504	148
24	-	-	-	123
25	-	-	-	0
26	777	-	531	0
27	720	-	1031	311
28	113	-	327	0
29	57	-	401	0
30	1448[2]	-	437	404
31	235 [2]	-	254	27
32	939	-	423	87
33	4228	4361	1224	1200
34	3032	2903	877	587
35	836	-	737	0
36	820	-	709	-

[1] Missing data indicates poor/unreadable data due to physical or mechanical issues (e.g. debris in pipes, inaccurate level readings).
[2] Volume readings were recorded, but are likely to be too high due to heavy amounts of debris in pipe.

Table 23. Peak flow rates for the inlets and outlets of the large and small bioretention basins.

	Peak Flow Rates (cfs)			
Storm Event #	MCBRLIN	MCBRLOUT	MCBRSIN	MCBRSOUT
1	-	0.007	-	-
2	0.158	0.085	0.191	0.212
3	-	-		-
4	0.143	0		-
5	0.265	0	0.032	0.032
6	0.096	0	0.096	0.001
7	0.23	0	0.129	0
8	0.262	0.309	0.236	0.432
9	0.146	0.005	0.072	0.012
10	0.548	0.447	0.263	0.626
11	0.029	0	0.03	0.01
12	0.322	0.009	0.03	0.037

	Peak Flow Rates (cfs)			
Storm Event #	**MCBRLIN**	**MCBRLOUT**	**MCBRSIN**	**MCBRSOUT**
13	0.126	0.021	0.093	0.102
14	0.155	0	0.114	0.009
15	0.055	0	0.081	0.005
16	0.23	0.486	0.251	0.186
17	0.12	0.018	0.126	0.155
18	0.414	0.019	0.292	0.578
19	-	0	-	0
20	0.038	0	-	0
21	0.057	0.439	-	0.004
22	0.158	0.295	-	0.243
23	0.126	0.009	0.038	0.007
24	-	-	-	0.006
25	-	-	-	0
26	0.185	-	0.029	0
27	0.102	-	0.029	0.016
28	0.026	-	0.022	0
29	0.023	-	0.027	0
30	0.34	-	0.203	0.019
31	0.03	-	0.019	0.003
32	1.347	-	0.408	0.006
33	0.67	1.256	0.141	0.279
34	1.038	1.989	0.158	0.253
35	0.319	-	0.215	0
36	0.09	-	0.026	-

Table 24. Inflow volumes shown as the sum of direct rainfall and runoff volumes, reported with outflow volumes.

	Large Bioretention Basin		Small Bioretention Basin	
Storm Event #	**Reported Inlet Vol + Drct Rnfl (cf)**	**Flowlink reported Outflows (cf)**	**Reported Inlet Vol + Drct Rnfl (cf)**	**Flowlink reported Outflows (cf)**
1	-[1]	50	-	-
2	6329	5875	7381	7116
3	-	-	-	-
4	196	0	457	0
5	468	0	709	547
6	805	0	1142	775
7	304	0	320	0
8	2875	2553	2468	3058
9	895	87	1306	597

	Large Bioretention Basin		Small Bioretention Basin	
Storm Event #	Reported Inlet Vol + Drct Rnfl (cf)	Flowlink reported Outflows (cf)	Reported Inlet Vol + Drct Rnfl (cf)	Flowlink reported Outflows (cf)
10	2497	2721	2204	2747
11	467	0	712	257
12	2679	149	1301	639
13	1257	610	1104	722
14	528	0	582	120
15	146	0	215	149
16	2303	2286	2920	1599
17	1319	938	1858	1458
18	1262	1199	1796	1550
19	-	-	-	-
20	130	-	-	-
21	133	59	-	218
22	3295	3691	-	2458
23	550	105	526	148
24	-	-	-	123
25	-	-	-	0
26	815	-	550	0
27	807	-	1074	311
28	129	-	335	0
29	77	-	411	0
30	1528	-	477	404
31	252	-	262	27
32	1029	-	468	87
33	4547	4361	1383	1200
34	3267	2903	994	587
35	893	-	765	0
36	872	-	735	-

[1] Missing data indicates poor/unreadable data due to physical or mechanical issues (e.g. debris in pipes, inaccurate level readings).

Table 25. Swale pollutant loads by storm event.

	Pollutant Loads (mg)											
	Swale Inlet						Swale Outlet					
Storm Event #	TKN	NO2,3-N	TN	NH4-N	TP	TSS	TKN	NO2,3-N	TN	NH4-N	TP	TSS
16	68752	25640	94391	27729	20512	6837207	68942	41593	110535	25640	27919	2089147
17	22813	17878	40692	12291	6611	2048556	40878	22534	63412	12012	11546	1303626
18	36418	12619	49038	11734	11512	6309580	36271	16431	52702	10954	10437	2376748
23	11820	4282	16102	2743	5202	1928683	10811	5397	16208	2123	5167	1450936

	Pollutant Loads (mg)											
	Swale Inlet						Swale Outlet					
Storm Event #	TKN	NO2,3-N	TN	NH4-N	TP	TSS	TKN	NO2,3-N	TN	NH4-N	TP	TSS
26	34505	15979	50484	8576	16415	-	30552	17185	47737	6566	13333	-
27	24983	24924	49908	5322	9313	2217456	10752	12781	23534	2212	3946	563681

Table 26. Swale flow volumes.

Storm Event #	MCSWIN	MCSWOUT
1	-	36
2	19238	2994
3	-	--
4	473	135
5	1245	415
6	1924	698
7	534	159
8	5899	1183
9	1253	385
10	6032	1444
11	114	28
12	1726	3478
13	2659	3306
14	928	1217
15	299	445
16	6706	7551
17	3288	4700
18	3909	3649
19	5	-
20	69	-
21	131	-
22	4695	-
23	625	-
24	3	-
25	0	-
26	1183	-
27	1044	498
28	278	151
29	441	321
30	1866	2156
31	67	21
32	7114	1928

Storm Event #	MCSWIN	MCSWOUT
33	12338	7168
34	-	4936
35	3453	990
36	6075	1174

[1] Greyed boxes indicate that the weir box had not yet been installed at the end of the swale outlet pipe, therefore making the outflow data unreliable. Missing data indicates poor/unreadable data due to physical or mechanical issues (e.g. debris in pipes, inaccurate level readings).
[2] Volume reading was recorded, but is likely to be too high due to sand covering the bubbler in the pipe.

Table 27. Peak flow rates for swale.

Storm Event #	MCSWIN	MCSWOUT
1	-[1]	0.02
2	0.678	0.154
3	-	-
4	0.252	0.042
5	0.888	0.265
6	0.238	0.044
7	0.353	0.06
8	0.833	0.245
9	0.154	0.024
10	2.099	0.717
11	0.034	0.006
12	0.144	0.294
13	0.279	0.33
14	0.245	0.308
15	0.135	0.178
16	0.855	0.877
17	0.308	0.346
18	1.423	0.942
19	0.008	-
20	0.019	-
21	0.088	-
22	0.394	-
23	0.17	-
24	0.001	-
25	0	-
26	0.232	-
27	0.206	0.06

Storm Event #	MCSWIN	MCSWOUT
28	0.052	0.032
29	0.149	0.107
30	0.727	0.629
31	0.012	0.003
32	2.961	2.918
33	2.364	1.211
34	-	1.581
35	1.947	0.571
36	0.721	0.135

[1] Grey boxes indicate that the weir box had not yet been installed at the end of the swale outlet pipe, therefore making the outflow data unreliable.

Appendix B

Example of initial abstraction calculation.

CN for highway= 98
S= 1000/CN-10=0.20408 in
IA = 0.2*S= 0.0408
P= 1.41 in
P-IA= 1.369 in
Drainage area = 56192.4 ft^2
Runoff total to both basins= (P-IA ft)(Drainage Area ft^2)
Runoff total to both basins= 6411.48 cf
Direct rainfall onto large basin= 235.00 cf
Direct rainfall onto small basin= 116.80 cf
Avg. ratio of runoff to large basin= 0.47
Avg. ratio of runoff to small basin= 0.53
Predicted inflow to basin=(total runoff volume*ratio)+direct rainfall
Predicted inflow to large basin= 3248.39 cf
Predicted inflow to small basin= 3514.88 cf

Appendix C

Percent Concentration Reductions

Bioretention Basins

Percent removals based on average pollutant concentrations are shown in Table 28 and were calculated using Equation 4.

$$\frac{(C_{in} - C_{out})}{C_{in}} * 100 \qquad (4)$$

Where,

C_{in} = EMC of pollutant at the SCM inlet (mg/L)
C_{out} = EMC of the pollutant at the SCM outlet (mg/L)

For all nutrient forms and TSS, influent concentrations were reduced by both the large and small bioretention basins, except for TP. This may have been due to the near-irreducible influent concentration of TP (mean of 0.08 mg/L).

Table 28. Percent concentration reductions for the bioretention basins at Mango Creek.

	Percent Concentration Reduction (%)	
	Small Basin	**Large Basin**
# of storms sampled	n= 13 inlet, n= 12 outlet	n=13 inlet, n=9 outlet[1]
TKN	39	52
$NO_{2,3}$-N	34	56
TN	37	54
NH_4-N	57	65
TP	-6	19
TSS	39	63

[1] Not every storm produced outflow from the large bioretention basin.

Swale

Percent removals based on average pollutant concentrations are shown in Table 29. The negative percent reductions indicate an increase in nutrient concentrations through the swale.

Table 29. Percent concentration reductions for the swale at Mango Creek.

	Percent Concentration Reduction (%)
# of storms sampled	n=12, inlet & outlet (11 TSS)
TKN	-4
$NO_{2,3}$-N	-9
TN	-6
NH_4-N	29
TP	-5
TSS	22

The swale at Mango Creek did not reduce the concentrations of TN or TP derived from the bridge deck stormwater. Ammonium nitrate concentrations were reduced by 29% and TSS concentrations were reduced by 22%. The relatively low percent reduction for nitrogen and phosphorus species may have been due to the low influent concentrations, similar to what was observed in the bioretention basins.