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MONITORING STUDY OF THE PERFORMANCE OF STORMWATER BEST MANAGEMENT PRACTICES IN THE CITY OF CHARLOTTE

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Table of Contents

List of Figures

List of Tables

Executive Summary

Twelve Stormwater Best Management Practices (BMP's) have been selected for monitoring to determine their ability to remove selected pollutants from urban runoff in Charlotte, North Carolina. Selected BMPs are Dry Detention Basins, Stormwater Wetlands, Urban Ponds, a Bioretention area, a Level Spreader, and manufactured devices including hydrodynamic separators and filters. These BMPs are representative of the BMPs commonly found in the city.

Automatic samplers fitted with flow metering devices were installed at the inlet(s) and outlet(s) of each BMP. Samplers were programmed to collect a flow weighted sample for each precipitation event such that individual "Event Mean Concentrations" could be determined for a number of common pollutants for each monitored storm. Substantial monitoring data from seven of the sites was available at the writing of this report and are included herein. A total of 89 storm events collected at the 7 sites were monitored during the study period. Sampling events at individual BMPs ranged from 6-18 storm events depending when sampling for a given site began.

Of the seven BMPs presented herein, a sufficient number of events were monitored at four to draw initial conclusions as to the pollutant removal performance of the BMPs. Only general observations may be made at this time as to the performance of the three remaining sites. The Efficiency Ratios (by concentration) for these four BMPs are shown in Table 1

Table 1 Efficiency Ratio (by concentration) of Selected Pollutants

Practice	Hal Marshall Bioretention	Shade Valley Wet Pond	Pierson Wet Pond	Edwards Branch S/W Wetland
TN	46%	19%	21%	45%
TP	45%	16%	41%	45%
TSS	63%	63%	56%	15%
Fecal Coliform	69%	n/a	57%	99%
Copper	60%	71%	40%	57%

As expected, the practices which rely on biological activity for their performance (Hal Marshall and Edwards Branch) both recorded the best Total Nitrogen (TN) removal rates. Total Phosphorous (TP) was also substantially reduced by both of these practices, as well as the Pierson Wet Pond.Total Suspended Solids (TSS) removal was substantail for the bioretention area and the two wet ponds, but lower for Edwards Branch. The practices from which fecal coliform data were collected all showed substantial reductions from inlet to outlet as was also the case for copper removal.

To aid in future BMP selection, "complete" monitoring data will be required from more than just these four BMPs. In a few months, the other three practices described at length herein will also be able to be fully analyzed. Additionally, many other BMPs are being studied within the City, and each BMP's performance data will be added to this local database to help aid in future BMP selection and design.

These four practices that have been monitored do provide a useful benchmark. If nutrient removal is a target, it appears that vegetated practices with engineered soil media may emerge as the practices of choice. The Hal Marshall Bioretention area, the Edwards Branch stormwater wetland, and the Bruns Avenue stormwater wetland (the latter albeit

with fewer events to analyze) each showed the highest TN and TP removal. The Hal Marshall bioretention area probably performed the best of all the practices studied with respect to nutrient *load* removal.
If TSS is the target pollutant, any of the practices tested, including the dry detention basins, appear to be sufficient. Nearly all the practices tested removed TSS relatively well. For fecal coliform reduction, the data are still nascent, but the Hal Marshall bioretention cell certainly shows promise.
In summary, the authors believe this monitoring effort is beginning to yield data that will effect decisions among the City's staff with respect to the type of practice that is appropriate per a given situation (watershed size, target pollutant, liability/safety requirements, etc). With the continued monitoring and analysis effort, more complete recommendations regarding BMP function may to be made. Finally, City leaders should be pleased that all the BMPs presented herein reduced at least some pollutants substantially.

Introduction

Since July 2003, faculty of the Biological and Agricultural Engineering Department at N.C. State University have conducted a monitoring study with the City of Charlotte and Mecklenburg County. The goal of the study continues to be the hydrologic and water quality evaluation of stormwater practices located within the City. While 12 stormwater practices are currently being monitored, enough data has been collected on seven of them for an informed evaluation to be made regarding each practice's function. The practices that have been studied and included in this report include one bioretention area, Hal Marshall Parking Lot; two wet ponds, Shade Valley and Pierson; two stormwater wetlands, Bruns Avenue and Edwards Branch; and two dry detention cells, Morehead and University Park. Enough data has been collect on the first five listed above for statistically significant analyses to be performed for nearly all pollutants. The two dry detention areas have enough data to detect trends, but many analyses were invalid due to a lack of data.

The purpose of this study is to identify practices that the City of Charlotte may look to promote and utilize in the future. Because of intense urban development, the City is faced with the need to efficiently treat stormwater runoff before it reaches waters such as Mountain Island Lake and Lake Wylie. As data continues to be collected, NCSU will provide recommendations regarding the future use of multiple practices (e.g. whether to use bioretention, dry detention, etc). At this time, the authors do not believe any definitive comparisons can be made based upon the data collected on these seven BMPs. However, much of the information presented herein does support the use of stormwater practices for pollutant reduction and mitigation of hydrologic changes.

Methods

The US-EPA/ASCE International Stormwater BMP Performance Database monitoring and reporting guidelines were observed while monitoring these BMPs(EPA, 2002). A project-specific monitoring plan and manual were developed and provided to monitoring personnel. BMPs were selected which represent those types of BMPs which are most likely to be installed in the City and the greater Charlotte region. Specific BMPs targeted were: wetlands, bioretention areas, innovative or improved ponds, dry detention basins, and manufactured devices.

Selected BMPs were instrumented with portable automatic samplers equipped with flow meters. The samplers utilized were ISCO Avalanche samplers. These samplers were powered with 12 volt batteries and were housed in steel housing units for protection from weather and vandalism. The samplers were capable of collecting a variable number of flow paced sample aliquots depending on the sampling program written to the sampler controller. Flow paced samples are individual aliquots which are taken as a result of a known volume of flow passing the sampling location. These aliquots were collected in multiple bottles contained within the refrigeration unit. Multiple bottles were used in order to maximize the volume available for sample storage. Upon sample collection and transfer to the laboratory for analysis, the multiple samples were transferred to a large single bottle. The resulting single sample is referred to as a flow weighted sample. The advantage of a flow weighted sample over a discrete or "moment in time" sample is that a flow weighted sample best represents the average condition of water which passes by the flow measurement point. Collection of flow weighted samples allows for the determination of Event Mean Concentrations (EMC's). EMC's represent the mean or average concentration of pollutant that passes a sampling point during a storm event.

Measurement of flow was conducted using one of two ISCO Flow modules which were connected to the samplers and enable the measurement and logging of flow at the sample point. The two types of flow meters used were ISCO 730 bubblers and 750 area-velocity meters. Bubblers are stage measurement devices which use an existing in-stream structure and pre-programmed or user defined stage discharge relationships to calculate flow based on water level. Area-velocity meters utilize ultrasonic sensors which are put at the bottom of a cross section or pipe of known dimensions and measure the velocity and depth of the water column over it.

In addition to flow weighted composite sample collection, manually collected "grab" samples were taken at the sampling locations when possible. Taking grab samples is necessary for some pollutants, such pollutants can only be stored for a short amount of time before they are transported to a laboratory for analysis. When possible, sample collection personnel collected grab samples at the midpoint of the expected inflow and outflow hydrographs. Due to the high labor requirement for grab sample collection, fewer storm events were monitored using this method than those sampled using the automatic samplers.

Individual Site Monitoring Reports

Individual site monitoring reports have been prepared for seven of the sites in which monitoring efforts are taking place. Insufficient data exists from the others to provide monitoring reports at this time. These reports provide a broad overview of the results of the water quality analysis. The analysis focused on a select group of pollutants generally considered most important in stormwater management. Results of other pollutants though analyzed are not included in these reports. In particular, analytical results from several metals were not found in detectible levels in the majority of the samples. As a result, analysis of water quality samples for these constituents has been halted. In addition, general water chemistry analyses such as pH and conductivity are not reported as part of this study since they are not generally investigated as part of a BMP performance study. The pollutants which were included in these reports are listed in Table 2

Table 2 Sample Constituents Included in Monitoring Reports

Pollutant	units	Sample Type
Fecal C.	col/ 100mL	Grab
NH4-N	ppm	Composite
NO3-N	ppm	Composite
TKN-N	ppm	Composite
Total N	ppm	Composite
Total P	ppm	Composite
TSS	ppm	Composite
Turb	NTU	Composite
Copper	ppb	Composite
Zinc	ppb	Composite

Determination of performance was conducted using one of two methods. The primary method utilized to determined performance was the Efficiency Ratio (ER). The Efficiency ratio computes a mean concentration reduction by comparing the mean inlet EMC and the mean outlet EMC. The ER is most suitable for BMPs in which inflow volumes are very near to outflow volumes for a given storm event. Where accurate inflow and outflow records were available, the Summation of Loads (SOL) computation was also conducted. The SOL method takes into account the impact of any unequal water balance data to adjust the concentration reduction measures (such as ER) to represent the actual load reduction. The SOL method is most applicable where differences exist between inflow and outflow volumes, such as with bioretention areas or green roofs.

Statistical analysis was conducted using Excel spreadsheet models or SAS statistical software. Several parameters were shown to have non-normal distributions. In this case, Log transforms were applied for the purpose of parametric statistical analysis. Differences in the mean inlet and outlet EMC were tested for significance using a paired t-test with $\alpha=0.05$.

Hal Marshal Parking Lot Bioretention Area

Site Description

Hal Marshal Bioretention area is a retrofit bioretention area providing stormwater runoff treatment for an asphalt parking area adjacent to the Hal Marshall Municipal Services Building. The Hal Marshal Building houses the offices for the Mecklenburg County Land use and Environmental Services (MCLES). As a result, the location of the bioretention area is ideal for water quality monitoring activities.

The BMP is sited between the parking area and an abandoned railroad line. A steep slope leads from the bioretention area down to the railroad line approximately 20 feet below the surface of the bioretention area. It is likely that groundwater levels are very deep at this location providing a steep hydraulic gradient between the water stored within the bioretention area and the groundwater. The bioretention area was constructed in the winter of 2003 by the City of Charlotte Stormwater Services and MCLES. The design of the bioretention area follows the design recommended by the state of North Carolina Division of Water Quality "Stormwater BMP design Manual"(NCDENR, 1999). The design recommendations call for a water quality storage volume equivalent to the volume resulting from a 1 inch rainfall event in the watershed. In addition, the design ponding depth of the bioretention area does not exceed 9 in. in depth. This design resulted in a bioretention area of approximately 1500 sq ft. The 4 ft deep fill media consisted of loamy sand. An underdrain system below the fill media provided drainage of water via a 6 in. flexible corrugated plastic pipe. The watershed draining the area was 0.92 acres of an aging asphalt parking lot. The parking area is primarily used by employees of Mecklenburg County and office visitors. The traffic load on the watershed is a mix of private vehicles and service vehicles. During office hours use of the parking spaces was observed to be near 100%. Prior to monitoring efforts the inlet to the bioretention area was a 6 in. PVC pipe installed through the existing concrete curb. This inlet was frequently overloaded with trash, debris and water causing shallow flooding of a portion of the parking area. As the monitoring plan was being developed, it became apparent that the bioretention area was clogged. This was evident due to the extremely long drawdown time of the water in the storage zone after storm events, as well as mortality of the plant species planted within the bioretention area. Although the exact cause of the clogging was not determined, it was believed that clogging was a result of either an insufficient drainage rate within the fill soil or improper mulch media causing clogging at the surface. In the spring of 2004, a full rehabilitation of the BMP was conducted including replacement of the fill soil, and the installation of a single inlet "chute" with a 120 degree inflow weir and forebay to localize sediment deposition. Mulch and vegetation replacement was also done as part of the rehabilitation.

Monitoring Plan

The previously mentioned 120 degree weir was installed at the inlet to the bioretention to measure inflow to the BMP. It is typically recommended that bioretention areas be constructed such that sheet flow of runoff occurs into the storage area. However for this design that was not practical due to the slope of the parking area. Additionally, the design of a weir at the inlet allows a water balance to be conducted (inflow, under drain flow, overflow, and evapotranspiration-exfiltration loss) during storm events, of which little is known for this type of BMP. The sample collection strainer was placed just upstream of the invert of the weir at the approximate midpoint of the flow stream during low flow conditions.

BMP outlet water quality samples were collected downstream of the under drain of the bioretention in a weir box constructed for flow monitoring. The weir box was constructed of cold rolled sheet steel with a baffle section and a 90 degree V- notch weir. No weir was installed at the overflow device, a concrete berm, due to its cost and the relatively infrequent nature of overflow events. ISCO model 730 bubblers were used to measure the stage of water at the inlet and underdrain outlet weirs and to trigger flow paced composite storm samples for the determination of EMC's. An ISCO tipping bucket rain gage was placed adjacent to the bioretention area and connected to the outlet sampler for the recording of rainfall data.

Monitoring of storm events began at the site in winter of 2004 and continues to the present. Twenty-two individual storm events have been monitored and are included in this report. Eighteen events have produced paired inflow and effluent samples for analysis of composite flow samples. Grab samples were collected at the inlet and outlet for 14 storms. These samples were analyzed for Fecal Coli form concentrations

Hydrologic results

Recording stage at the V- notch weirs at the inflow and outflow locations allowed direct measurement of flow rates during storm events. A typical hydrograph is shown in

Figure 1. Total rainfall for the event shown was just over 1.04 inches in depth. The event can be considered to be near, but less than the "capacity" event for the device. Flow rate at the outlet was not observed to exceed 0.2 cfs for any of the storm events monitored and may be considered the maximum underdrain outflow of the BMP. Additionally, outflow was observed to decrease considerably 12 hours after precipitation ceased and approached zero at 24 hours after the end of the rainfall event. This drawdown pattern was observed for all events sampled. As a result, the drawdown period for the BMP is considered to be 12- 36 hours for most events.

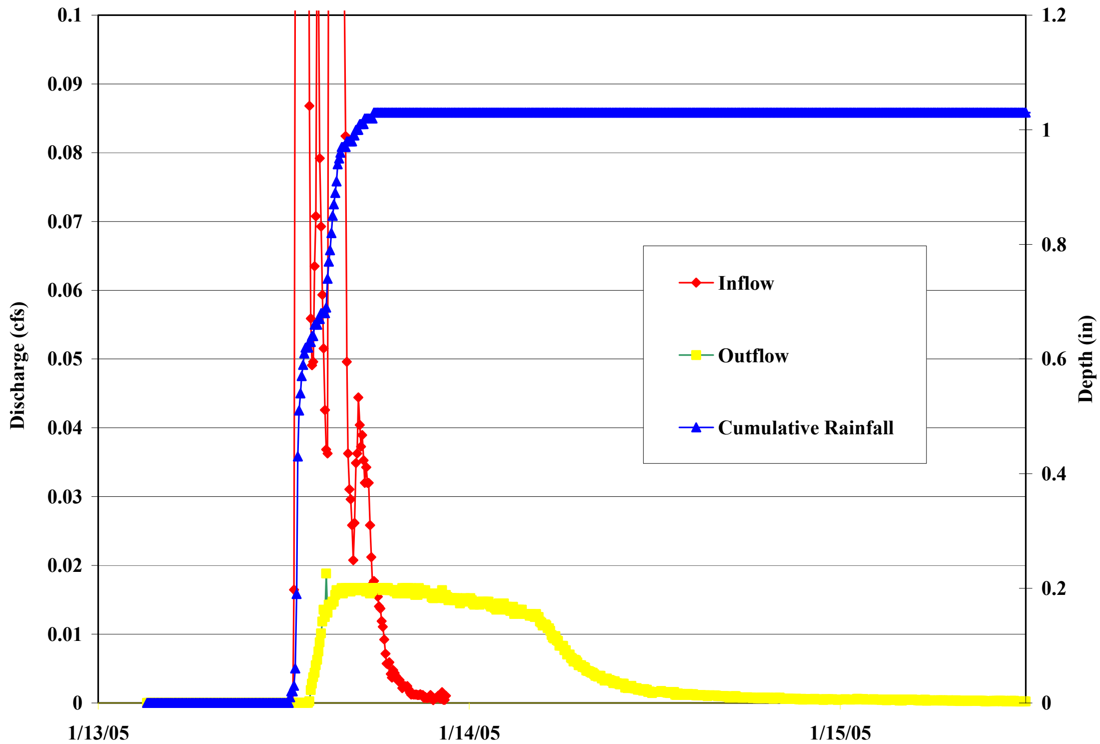

Figure 1 Rainfall and Hydrograph from Typical Storm

By using the known drainage area of the parking lot, the volume of inflow and outflow can be represented in inches of water and compared to rainfall. Results from all monitored storms are shown in Table 3.

Table 3 Flow Volumes for Monitored Storms

Date	Rainfall (in)	Inflow (in)	Outflow in (drainage only)	Comments
2/7/2004	1.34	1.37	0.59	
4/26/2004	0.11	0.70	0.03	Erroneous rainfall or inflow
4/30/2004	0.95	3.93	0.87	Erroneous inflow measurement
5/31/2004	0.35	0.36	0.28	
7/17/2004	2.43	2.13	1.15	Exceeded capacity of BMP
8/12/2004	3.18	N/A	2.84	Exceeded capacity of BMP
8/28/2004	0.54	N/A	0.29	
9/27/2004	2.26	2.04	0.86	Exceeded capacity of BMP
10/13/2004	0.4	0.14	0.15	
11/4/2004	N/A	0.76	N/A	Missing rainfall/ outflow data
12/6/2004	0.44	0.31	0.14	
1/14/2005	1.03	1.17	0.30	
2/14/2005	0.32	0.27	0.05	
2/22/2005	0.28	0.33	0.27	
3/8/2005	0.65	0.57	0.45	
4/12/2005	1.57	1.21	0.59	Exceeded capacity of BMP
5/12/2005	0.31	0.53	0.24	
6/27/2005	N/A	0.97	0.08	Missing rainfall data
7/8/2005	N/A	0.58	0.94	Missing rainfall data

These measurements allow a water balance to be computed for the monitored storms. Storms larger than 1 inch in depth may have resulted in bypass of the bioretention area, which was not measured. Therefore, flow results for larger storms were not included in this water balance. In addition, equipment malfunction resulted in a lack of data for some storms. Other malfunctions lead to obviously erroneous data. For instance, the storms of April 26th and 30th, 2004 resulted in an inflow volume measurement much larger than measured rainfall indicating a possible problem with the inflow stage measurement equipment. Results from this storm and others with questionable data were not included in the final analysis. Figure 2 shows the volume of inflow and outflow for each storm where appropriate data were collected. Although two storms had rainfall depths greater than 1 inch, which could possibly lead to bypass scenarios, these events were spread over long time periods making it unlikely that bypass occurred. As more storms are monitored additional data will strengthen this relationship.

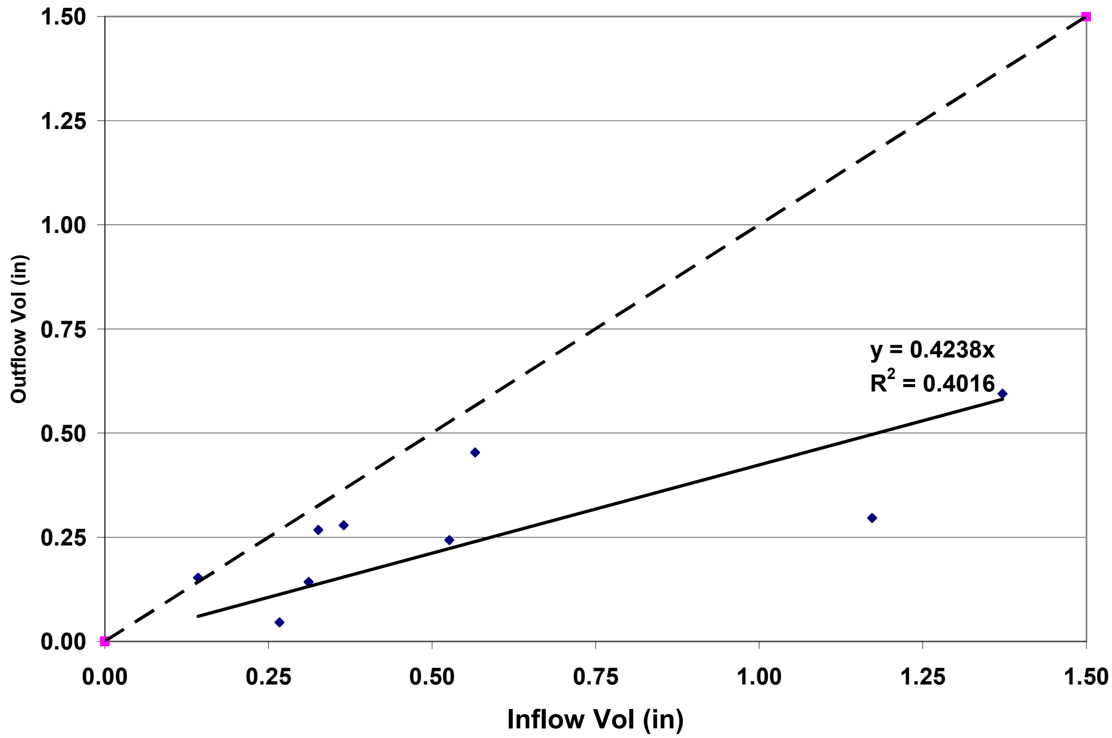

Figure 2 Measured Outflow Volume vs. Inflow Volume Hal Marshal Bioretention Area

The dashed line represents the zero slope, or the line of no runoff reduction, for comparison. As the regression line shows, a reduction in flow volume was observed of nearly 52 % (1-β). This high volume reduction may be partially a result of the siting of the BMP at the verge of a steep slope. It is unlikely that this reduction would be observed for larger storms if bypass measurements were available. However recent research of long term local rainfall records indicate that less than 20% of rainfall volume is represented in storm events exceeding 1 inch in depth (Bean, 2005).

Water Quality Results

A summary of the data analysis conducted on the inlet and outlet concentrations is shown in Table 4. All of the constituents detailed above were skewed positively and required a Logarithmic transformation to provide normal distribution of data for analysis. A paired t-test of the logarithmically transformed EMCs was performed for each storm (α= 0.05). For each analysis shown there was a significant difference between the inlet EMC and the outlet EMC ($\alpha = 0.05$). The only exception was Nitrate-Nitrogen for which the inlet and outlet EMCs had the same mean value. With the exception of turbidity, each of the pollutants showed a reduction in concentration. Previous research has shown that turbidity typically increases in bioretention areas(Hunt et al., 2006). The removal efficiencies shown in Table 4 represent the concentration removal only. A similar efficiency can be computed using a Sum of Loads method (SOL) which computed the actual removal of pollutant loads for the monitored storms. Due to the high volume reduction observed, SOL removal results are much higher than ER. A comparison of the removal results is shown in Table 4. If storms that produced bypass were factored into this analysis the SOL's would not be as high, but would still be greater than the comparison of concentrations.

Table 4 Summary of Pollutant Concentration Results

Pollutant	n	units	Inlet EMC	Outlet EMC	Efficiency Ratio	Distribution	P Value	Significant
Fecal C.	14	col/ 100mL	19,000	6,100	0.69	Log	0.000600	Yes
NH4-N	18	ppm	0.36	0.12	0.66	Log	0.0000247	Yes
NO3-N	18	ppm	0.45	0.45	0.00	Log	0.670	No
TKN-N	18	ppm	1.42	0.72	0.49	Log	0.0000113	Yes
Total N	18	ppm	1.87	1.02	0.46	Log	0.00908	Yes
Total P	18	ppm	0.22	0.12	0.45	Log	0.000356	Yes
TSS	18	ppm	55.8	20.4	0.63	Log	0.000178	Yes
Turb	18	NTU	18	61	-2.43	Log	0.000101	(Yes)
Copper	18	ppb	14.1	5.7	0.60	Log	0.0000004	Yes
Zinc	18	ppb	78.7	20.9	0.73	Log	0.0000002	Yes

TN removals rates were quite high (46%). This is higher than the removal percentage the North Carolina Department of Environment and Natural Resources Neuse River and Tar River Nutrient reduction program recognizes for bioretention areas. The TN load reduction of this bioretention cell is even higher (46%-73%) as a result of the volume reduction. This level of performance can be considered one of the highest for bioretention cells within the state of North Carolina. Because no anaerobic zone was designed into the bioretention cell, and due to the rapid drainage shown earlier in the hydrologic analysis, it is likely that much of the soil column remained aerobic. As a result, this bioretention area was not expected to lower the concentrations of Nitrate-N (which needs anaerobic conditions to be reduced). The Hal Marshal bioretention area did not impact NO_3-N concentrations as the 0.45 ppm influet concentrations were matched by 0.45 ppm effluent concentrations. Any reduction of NO_3-N occurred due to the hydraulic load reduction, which in this case was near 50%.

Table 5 Comparison of Pollutant Removal Computations

Pollutant	Efficiency Ratio (ER)	Sum of Loads (SOL)
Fecal C.	0.69	0.85
NH4-N	0.66	0.83
NO3-N	0.00	0.51
TKN-N	0.49	0.75
Total N	0.46	0.73
Total P	0.45	0.73
TSS	0.63	0.82
Turb	-2.43	-0.68
Copper	0.60	0.80
Zinc	0.73	0.87

Total Phosphorous (TP) load reduction is better than North Carolina's Tar-Pam standard (45%). The fact that concentrations were reduced by 45% and that the effluent concentration was 0.12 mg/L indicates a media designed for P-removal was utilized. As expected, the P-index of this media was in the low range (7-14) meaning the fill media did not have much Phosphorous in it. This finding echoes those of earlier studies (Hunt et al 2006).

This is the first known study of *Fecal Coliform* removal in a bioretention area in the United States, and the results are promising. Direct sunlight and drying are thought to be the best ways to reduce pathogens. The Hal Marshal bioretention area was not overgrown with vegetation, allowing direct sunlight / ultra-violet light exposure. Additionally, the rapid drainage allowed the surface of the bioretention bed to dry out. This can be considered a near perfect design for *Fecal Coliform* removal. Adding weight to this study is the fact that 14 paired samples were collected. The Hal Marshal bioretention area will serve as a benchmark for pathogen removal.

Conclusions

Pollutant removal by the Hal Marshal Bioretention area was observed to be very good. Pollutant removal was higher than in many other installations monitored in previous studies (Hunt et al., 2006). This high pollutant removal was enhanced by the significant volume reduction observed in the outflow hydrographs. This reduction from inflow volume to outflow volume may have resulted from the proximity of the bioretention area to a steep gradient which ensured a low surface water table. In other locations with tighter soils and higher water tables, a reduced or even negligible volume reduction could be expected. However, concentration reduction of all pollutants with the exception of nitrate was significant($p<0.05$). Also of interest is the high phosphorous reduction observed (45% and 73%) for concentration and load basis, respectively. Previous research has indicated that the use of a low P-index soil type correlates with high phosphorous reduction. Observed removal of Fecal Coliform concentrations was very encouraging. Significant ($p<0.05$) reductions were observed in grab samples collected at the outlet during storm events when compared to inlet concentrations.

Shade Valley Pond

Authors note: The report provided below for Shade Valley pond was included in the Proc. 2005 World Water and Environmental Resources Congress. Anchorage, AK. May 2005. As a result the format and some of the analysis does not match the other reports on individual practices in this document.

An aging urban pond in Charlotte, North Carolina was monitored for a period of one year prior to a water quality enhancement project for the pond and nearby drainage network. The 11 ha (27 ac) watershed for the 0.24 (ha (0.6 ac) pond consisted of mixed residential and commercial uses. Inflow and outflow composite samples were collected from August 2003 through July 2004. Samples from 17 storms were analyzed for a suite of pollutants and event mean concentrations (EMC's) were determined for each storm. The pond was enhanced by the addition of a forebay, a detention component and a littoral shelf around its edge. In addition, a number of drainage improvements were made within the watershed to remove failing conveyances. The detention component of the pond was designed to store and hold the runoff associated with a rainfall of 2.54 cm (1 in) for a period of up to 24 hours. Water Quality results for the post construction period were not available at the time of this writing.

During the pre-construction monitoring period, mean Total Kjeldahl Nitrogen (TKN) and Ammonium-Nitrogen (NH_4-N) EMCs at the outlet were 32% and 19% higher than the inlet concentrations respectively. Mean Nitrate Nitrogen (NO_3-N) and Total Nitrogen (TN) concentrations were shown to be 77% and 20% lower at the outlet. 16% and 63% reductions in Total Phosphorous (TP) and Total Suspended Sediments (TSS) concentrations respectively were observed from the inlet to the outlet. Copper, Lead and Zinc concentrations were reduced by 71%, 39% and 49% respectively. Statistically significant differences between the observed inlet and outlet mean concentrations was observed for all pollutants excepting TP and NH_4-N.

Introduction

Small ponds are a common feature in many urbanized areas. Such ponds may exist for a number of reasons. Often they are rural ponds which are left during development of nearby areas or newly constructed ponds which are installed as water features. Where stormwater regulations require control of sediment, wet ponds are often constructed. Previous studies have shown that wet ponds constructed for pollutant removal effectively remove pollutants in both particulate and soluble form (Schueler, 1987). Performance of these wet ponds is related to pond size relative to watershed area (EPA, 1983). In North Carolina, properly designed wet ponds are an accepted BMP for the removal of sediment It is assumed that these BMPs remove 85% of TSS (NCDENR, 1999). The primary pollutant removal mechanism for ponds is settling and adherence of pollutants to pond bottom sediments. However, sediment accumulation within the pond bottom may reduce the capacity of the pond. Drainage systems may fail structurally Resulting in increased bank erosion and downstream sediment load. Small urban ponds show much promise for stormwater BMP retrofit sites. Many improvements can be implemented on a pond which may improve its pollutant removal efficiency. The addition of forebays, littoral shelves, and detention may enhance several mechanisms of pollutant reduction. Such features are well accepted components of recently developed BMPs such as wetlands and extended wet detention.

This study investigates the performance of an existing poorly maintained urban pond and the effect of an extensive water quality improvement project on the ponds performance. The pond was monitored for inclusion in the ASCE Urban Stormwater BMP database (EPA, 2002).

Study Site

This research was conducted at Shade Valley pond, an urban pond located in a fully developed watershed. Constructed during the 1950's as a water feature for a nearby multi-family housing development, Shade Valley pond sits just upstream of Shade Valley Road. The area immediately surrounding the pond consists of an apartment complex and its associated parking areas. Additionally an 27.3 ac watershed consisting of a mix of commercial, residential and transportation areas feeds the pond via a small, perennial stream. Impervious area within the watershed is nearly 86%. Much of the watershed consists of connected impervious areas which quickly route runoff into conveyance structures. Prior to the summer of 2004 the condition of the pond was very poor. Due to mowing of the vegetated border of the pond and intense waterfowl activity, the banks of the pond were rapidly eroding. Conveyance structures at the pond edge had collapsed resulting in erosion of the adjacent areas. Sediment deposition at the main inlet of the pond had created an exposed sand bar which nearly encircled the inlet. Fecal matter and feathers were prevalent on the banks of the pond and in the pond itself. Conditions during this time are shown in Figure 3a and 3b

Figure 3. a and 3.b Condition of Pond during Pre- Construction Monitoring Period

Runoff entered the pond by way of numerous poorly maintained conveyances such as culverts and concrete channel conveyances. Approximately 78% of the contributing watershed entered the pond through three existing culverts which discharged into a scour pool on the opposite side of the pond from the outlet. Shade valley pond was approximately 0.6 ac in area with an average depth of 3 ft. The banks of the pond were severely eroded due to the intense waterfowl activity in the area. The outlet of the pond consisted of an undersized 30 in Reinforced Concrete Pipe (RCP) which went under shade valley road and discharged into a nearby perennial stream. A 6 ft wooden weir maintained the level of water within the pond.

The City of Charlotte began a construction project in the summer of 2004 to modify the existing pond with the purpose of providing improved water quality downstream. The pond was drained and dredged to remove sediments and increase average pond depth. The undersized outlet was replaced. The inlets were combined, where possible, and the failed conveyances were replaced. In addition to the drainage system improvements, several design features were incorporated into the new pond. These features included a forebay, a littoral shelf, and a detention function in the new outlet.

The forebay was constructed at the inlet to provide for storage of heavy sediments deposited in the pond and to facilitate the removal of such sediment during maintenance operations. In addition, a littoral shelf was constructed along the edge of the pond and in the area between the forebay and main pond body.

The littoral shelf was designed so that during periods of normal pool the water level at the shelf would be from 1-1 ft deep. Emergent aquatic vegetation was planted in the shelf. The littoral shelf of the new pond composed nearly 30 % of the surface area of the pond. The banks of the pond were planted with brushy vegetation. The pond outlet was replaced as a result of the drainage improvements which required replacement of the 30 in RCP under Shade Valley road. A cast in place riser was constructed to act as the principle and overflow riser. An orifice was utilized as the low flow and drawdow control device. An overflow weir was constructed approximately 18 in above the orifice so that the new pond would provide detention for the runoff associated with the first 1 in. of any rainfall event. The orifice was sized so that the water level within the pond would return to pre event level within 24 hours of the end of the runoff event. Construction activities were completed in the late winter of 2005. Vegetation was planted and goose control installed spring/summer 2005.

Material and Methods

Beginning in August 2003, event based flow composite water quality samples were collected at the inflow and outflow of Shade Valley pond. This monitoring was conducted in order to characterize the pre-existing performance of the pond. The existing 6 ft rectangular weir did not facilitate an measurement of the flow at the outlet. Consequently, a 120° sharp crested V-notch weir was attached to the existing wooden outlet weir. The invert of the V-notch was installed at the pre-existing normal pool depth so that no alteration of pond level occurred.

Figure 4.a and 4.b Locations of Inlet and Outlet Sample Collection

Any detention which occurred within the pond during storm events was determined to be minor compared to the overall runoff from the event. Inlet and outlet sampling locations were outfitted with ISCO 6712 samplers for flow monitoring and sample collection. Location of inlet and outlet sample collection is shown in **Error! Reference source not found.**5. An ISCO model 750 bubbler module was outfitted to the outlet sampler for flow monitoring purposes. In addition, an ISCO tipping bucket rain gage was installed on the outlet sampler to provide continuous measurement of rainfall depth and intensity during sampling events.

The intake for the inlet sampler was installed immediately downstream of the convergence of the three major RCP culverts in an area of well-mixed flow. Accurate direct measurement of inflow was not possible due to multiple inlets entering the pond and submerged conditions at those inlets. Since the pond had no appreciable detention component to its operation, it was considered a flow through device. As a result, it was assumed that hydrologically the inflow matched the outflow. A system of sample collection was implemented using a wireless transmitter and receiver. The wireless system consisted of a transmitter which was fitted to the outlet sampler. The transmitter monitored the sampler communication port for an output signal. This signal was sent when the sampler initiated sample aliquot collection. Upon receiving the signal the transmitter sent a wireless signal to the receiver unit which was fitted to the inlet sampler. The receiving unit signaled the inlet sampler to collect an individual aliquot. Using this wireless system the inlet sampler collected a sample at the same time that the outlet sample was being taken. The wireless system was constructed and installed by Custom Controls, Inc.

Each sampler was outfitted with an array of 24 1L bottles, which corresponded to a total sample volume of 24L. The outlet sampler was programmed to collect an individual aliquot of 200ml for each 1000L of outflow from the pond. Each sampler could accommodate up to 120 aliquots during a runoff event. Typical sample aliquot distribution throughout an example storm hydrograph is shown in Figure 5.

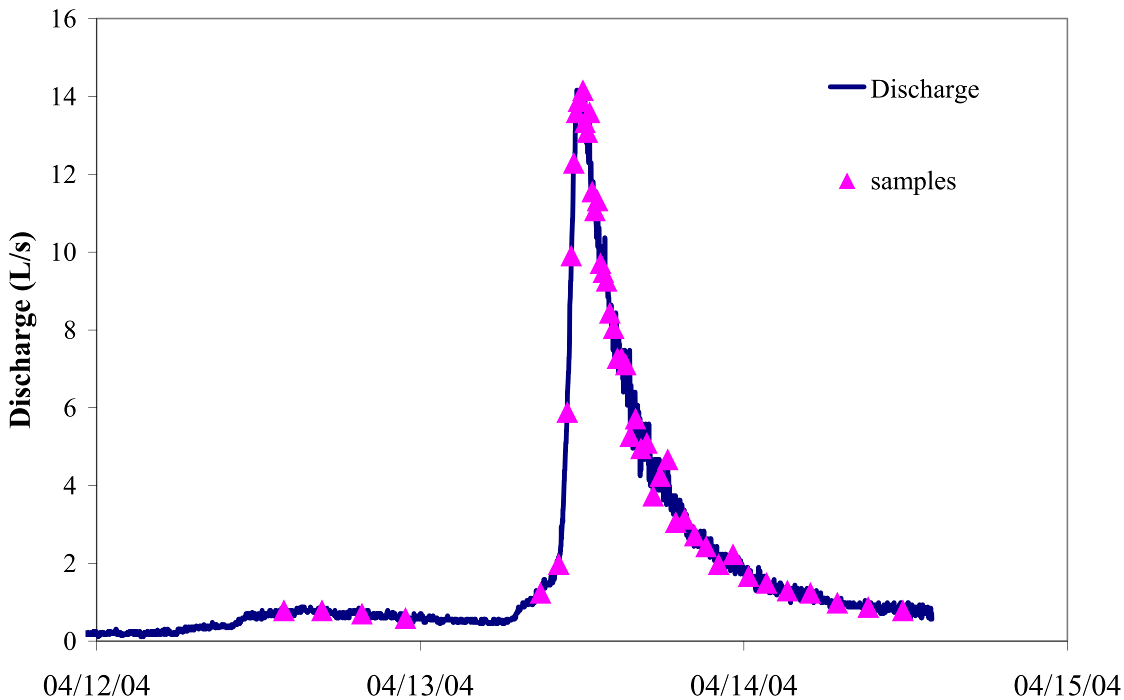

Figure 5 Typical Hydrograph at Shade Valley Pond for a 0.7 in Rainfall Event

Water samples were collected from each sampler within 48 hours of the end of a runoff event and delivered to the laboratory for chemical analysis. All samples were analyzed by the Mecklenburg County Water Quality Program Analysis laboratory. Samples were analyzed for a series of pollutants including nutrients, heavy metals, and sediments. Using the data from these analyses an Event Mean Concentration (EMC) for each pollutant was computed for the inflow and outflow of each event. In addition, continuous flow data was collected by the sampling equipment so that storm hydrographs of the outlet could be produced.

Results

From August 2003 to July 2004, 17 rainfall events producing runoff were monitored. This period represents the pre-construction period on Shade Valley pond. Event depth ranged from 0.09 in to 2.7 in. The sampling events were distributed throughout the year. One to two runoff events were monitored in every calendar month of the year. Figure 6 shows the distribution of sampled events throughout the year and their associated rainfall depths.

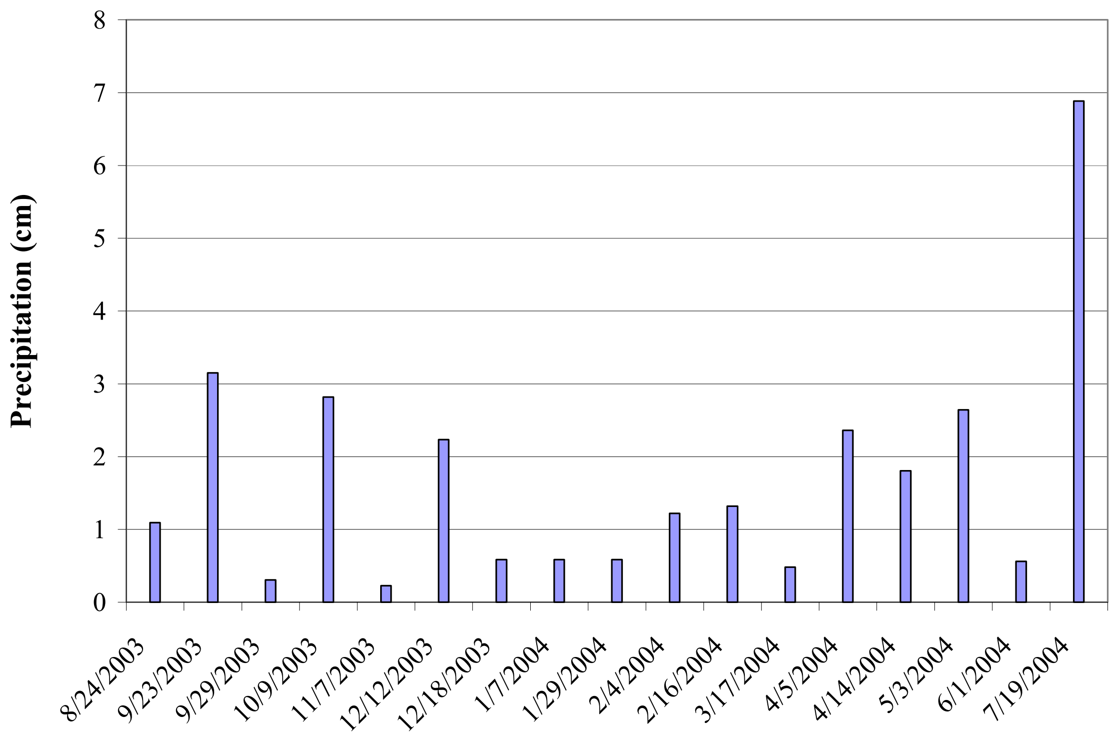

Figure 6 Distribution of Monitored Events

Efficiency ratios for the pond were computed from the mean EMC's (EPA 2002). Statistical significance of the differences in inlet and outlet mean concentrations were determined using a paired t-test (SAS, 2003). Results of these tests performed on Nitrogen constituents are shown in Table 6. Concentrations of TN for the period of monitoring were slightly lower at the outlet than the inlet. NH_4-N

Table 6 :Mean EMCs and Statistical Significance of Nitrogen Pollutants

Pollutant	Inflow (ppm)	Outflow (ppm)	% reduction	p-value	Significant
TKN	1.54	2.03	-31.82	.0262	Yes (increase)
NH_4-N	0.27	0.22	-18.52	.2992	no
NO_3-N	1.37	0.32	76.64	<.0001	yes
TN	2.98	2.40	19.46	.0414	yes

Mean concentrations of TKN and NH_4-N both had a net increase between the inflow and outflow for the monitoring period. NO_3-N showed a substantial decrease in mean concentration. Observed reduction in NO_3-N concentration for each storm exceeded 60%. Total Nitrogen was shown to be reduced by a mean of 15%.

Table 7 shows the results of the analysis test performed on TP, TSS, Cu, Pb, and Zn.

Table 7. Mean EMC and Statistical Significance for TP, TSS and Metals

Pollutant	Inflow (ppm)	Outflow (ppm)	% reduction	p-value	significant
TP	0.19	0.16	15.79	.1159	no
TSS	109.18	40.29	63.10	.0188	yes
Cu	13.17	3.76	71.45	.0131	yes
Pb	5.08	3.12	38.58	.0207	yes
Zn	70.35	35.59	49.41	.0070	yes

Analysis showed many samples did not meet the minimum detectable limit (MDL) for metals analysis. In particular, Pb and Zn concentrations in outflow event samples were consistently below the detection limit. When this occurred, the concentration was set to ½ the value of the MDL for calculation purposes. Reduction in mean TSS concentrations was shown to be 63%, which agrees well with published removal efficiencies for wet ponds designed for sediment removal.

Discussion

Reduction of pollutant concentrations in the Shade Valley pond prior to the water quality improvement project indicated that the existing pond does have a net positive impact on stormwater runoff originating in the watershed. However, increased concentrations of TKN and NH_4-N indicate that the degraded state of the pond may have a negative impact on the downstream water quality for those pollutants in particular. Considering the age of the pond, it is likely that binding sites for phosphorous within the underlying soils of the pond have been filled. During storm events phosphorous may be re-suspended and discharged through the outlet. Alternatively, the existence of a resident population of waterfowl may provide a source of organic-N, NH_4-N and Phosphorous which may be entering the pond through fecal deposition rather than stormwater runoff.

Future study of the performance of the improved pond will allow better conclusions to be drawn on the data collected during this study.

Bruns Avenue Stormwater Wetland

Overview

The Bruns Avenue Stormwater Wetland is a retrofit wetland adjacent to the Bruns Avenue Elementary School. The 15.8 acre watershed draining to the wetland consists of a residential development and school property. Monitoring activities were begun in September 2004 and have continued to the present. However, only analysis thru April 2005 are included in this report due to results not being complete for the summer of 2005 and the subsequent drought of the fall of 2005. Composite and grab samples were taken at two inlets and the single outlet of the wetland. The inlet concentrations were flow-weighted to determine the overall inlet concentrations. Samples from nine storms were analyzed for a variety of pollutants and event mean concentrations (EMC's) were determined for each storm.

All nutrient pollutants, including Total Nitrogen (TN), Total Kjeldahl Nitrogen (TKN) and Total Phosphorus (TP), were significantly reduced during the monitoring period. Mean concentrations of total suspended solids (TSS), copper, iron, lead, and zinc were also significantly reduced. This study provided valuable information about wetland removal performance in winter months.

Introduction

Stormwater wetlands are constructed wetland systems that mimic the functions of natural wetlands and are designed to mitigate the impacts of urbanization on stormwater quality and quantity. These BMPs provide an efficient method for removing a wide variety of pollutants, such as suspended solids, nutrients, and heavy metals. Properly designed wetlands can also be used to reduce pollution associated with high levels of *fecal coliform* contamination.

Stormwater wetlands are designed with four treatment areas: deep pools, shallow water, shallow land and upland. Vegetation throughout the wetland aids in filtering sediment and debris from the water and provides some uptake of nutrients.

This study investigates the pollutant removal performance of a two-year-old constructed stormwater wetland in Charlotte, NC.

Site Overview

The project site is located at the Bruns Avenue Elementary School in Charlotte, NC. A stormwater wetland was constructed in 2002 using City funds. The 15.8-acre watershed consists of vacant, wooded and impervious areas of the school grounds, as well as portions of single- and multi-family residential areas. Impervious area within the watershed totals 60% of the total area. The watershed was divided into six sub-watersheds based on the original topographic data for the site. Table 8 outlines the watershed characteristics for the three contributing sub-watersheds.

Table 8. Bruns Ave Wetland Contributing Watershed Characteristics

Watershed	Area (acres)	Curve Number
Primary Inlet	4.85	74
Secondary Inlet	4.72	81
Local Contribution	6.22	77
Total	15.79	77

Methods

Beginning in September 2004, grab samples and event based flow composite water quality samples were collected at the primary and secondary inlets and outlet of the Bruns Ave wetland. Influent and effluent runoff levels were measured using v-notch weirs and stage recorders. Rainfall and inlet and outlet flows were quantified using ISCO Flowlink 4.15.

The water quality data and storm flow volumes were compiled to compute event mean concentrations (EMCs) and determine the efficiency ratio for each pollutant. Statistical significance of pollutant reduction was tested using a one-way analysis of variance (ANOVA) in the form of a paired two-sample t-test for means.

Results

Between September 1, 2004 and April 30, 2005, nine runoff-producing events were monitored. The events produced an average of 1.3 in. of rain and occurred approximately once per month. Figure 8 illustrates the dates and amounts of each precipitation event.

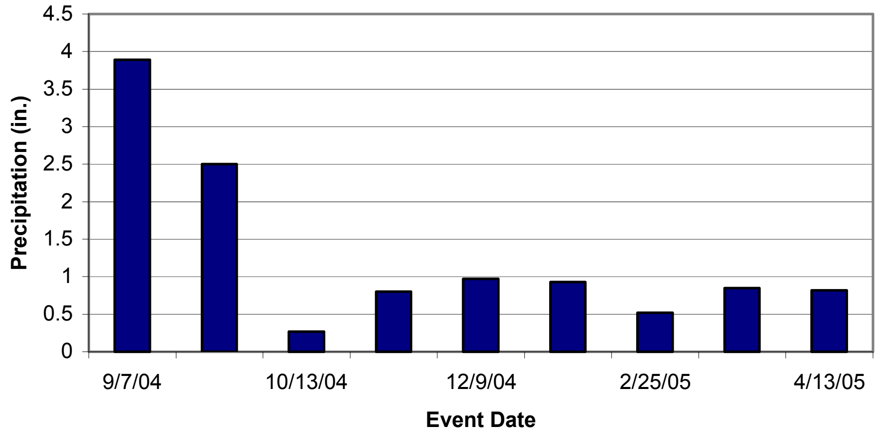

Figure 7 Storm Event Totals for Bruns Avenue Wetland

Using Flowlink software, the influent and effluent flow levels were converted to storm volumes. The hydrograph for the September 7, 2004 event illustrates the change in volume as it relates to time (Figure 8). Although Influent 1 is labeled as the primary inlet, the total runoff from the contributing watershed was smaller than that of the secondary inlet. This can be attributed to the higher curve number for the secondary inlet.

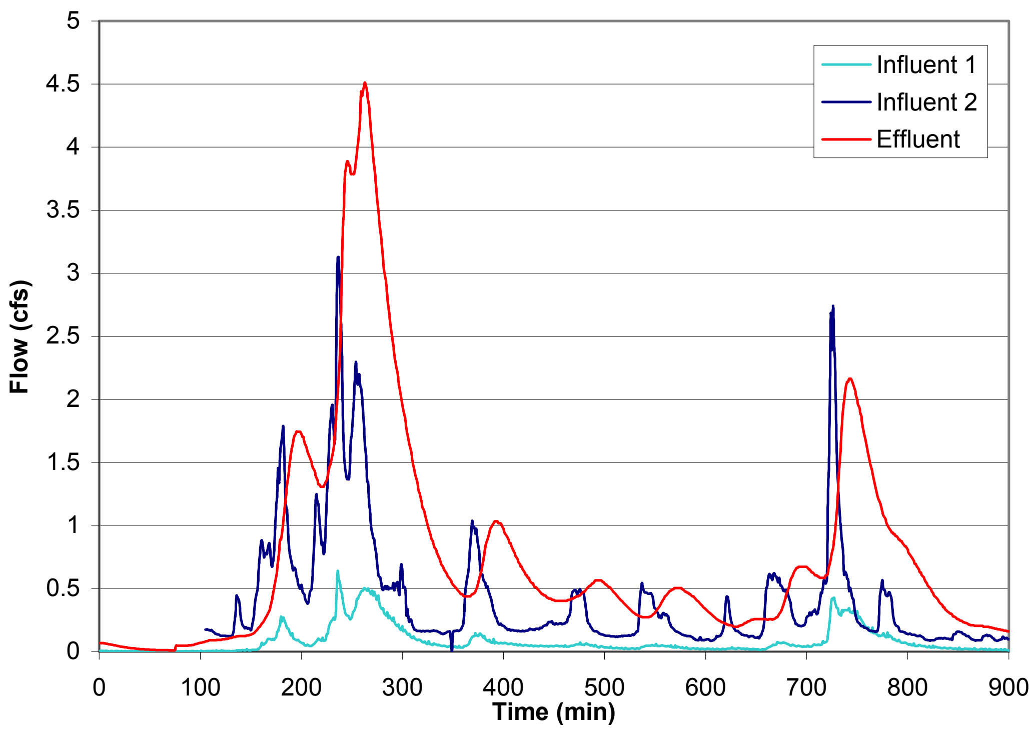

Figure 8 Hydrograph for 9/7/04 Storm at Bruns Ave Wetland

The total influent and effluent storm volumes for all nine storms are shown in Figure 9. For a majority of the storms the effluent volume was greater than the total influent volume, although the difference was not statistically significant. The higher outflow is the result of the 6.22-acre local watershed, which does not enter through either inlet. There is no way, however, to measure inflow from this local watershed.

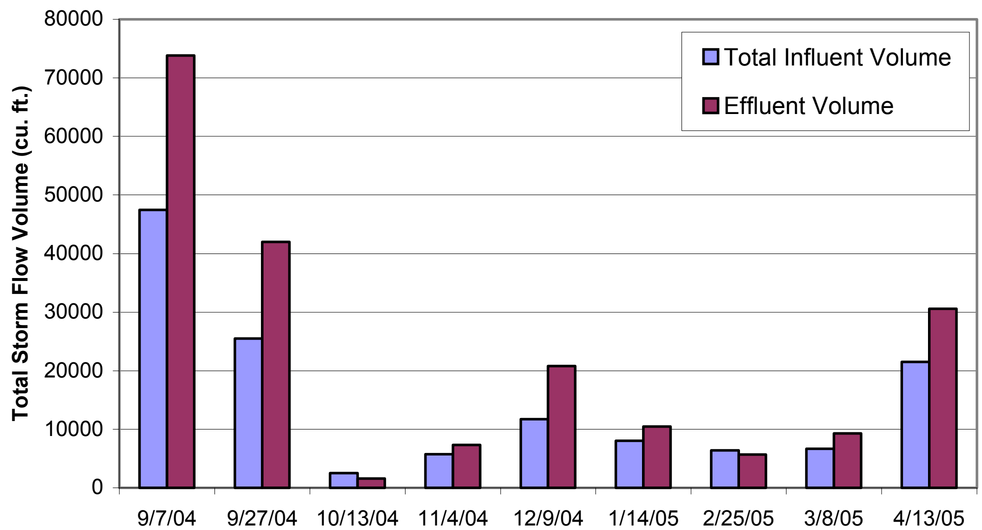

Figure 9 Storm Event Volume Measured at Bruns Ave Wetland

EMCs were calculated to determine the efficiency ratio of each pollutant. Statistical significance of pollutant reductions was analyzed using a paired t-test for means. Table 9 outlines the monitoring results.

All nitrogen pollutants, including Ammonia, Nitrate-Nitrite, TKN and TN were significantly lower exiting the wetland than at the two monitored inlets. The influent ammonia EMC was reduced by over 80%. During the monitored events TP levels were 60% lower at the outlet than at the inlets. Although Total Solids was only slightly reduced, total suspended solids concentrations and turbidity levels were significantly lower at the outlet. Fecal Coliform levels decreased by 83%; however, this was not determined to be significant.

All metal EMCs, with the exception of Manganese, were significantly lower at the outlet during the monitoring period. Many of the lead samples were identified as being below the minimum detectable limit (MDL). When this occurred, the concentration was set to be half of the MDL

.

Table 9 Summary Statistics at Bruns Ave Wetland

Pollutant	N	units	Influent EMC	Effluent EMC	Efficiency Ratio	Distrib	P value	Significant
Fecal C	9	col/ 100ml	47349	8013	0.83	Log	0.06	No
NH4-N	9	ppm	0.431	0.083	0.81	Log	< 0.01	Yes
NO3-N	9	ppm	0.983	0.544	0.45	Log	0.01	Yes
TKN-N	9	ppm	1.896	0.907	0.52	Log	< 0.01	Yes
Total N	9	ppm	2.877	1.451	0.50	Log	< 0.01	Yes
Total P	9	ppm	0.582	0.221	0.62	Log	< 0.01	Yes
TSS	9	ppm	91.280	30.857	0.66	Log	< 0.01	Yes
Turbidity	9	NTU	70.950	47.220	0.33	Normal	< 0.01	Yes
Copper	9	ppb	8.750	6.600	0.25	Log	0.02	Yes
Zinc	9	ppb	53.413	21.429	0.60	Normal	< 0.01	Yes

Discussion

The Bruns Avenue stormwater wetland appears to be effective in removing multiple nutrient, sediment and metal pollutants. With the exception of fecal coliform, total solids and manganese, all monitored pollutants were significantly reduced by the wetland system between September 2004 and April 2005. Because such a large fraction of the watershed – almost 40% - was not able to be monitored, statistical analysis only indicate that the outlet concentrations were lower than the weighted inlet concentrations. It is probable that non-captured portion of the watershed has similar pollutant loads to the two portions that were monitored, but at this point in the analysis, it is not yet reasonable to make this assumption.

This collection of data demonstrates wetland performance during winter months. Although data collected during the growing season will extend the understanding of these findings, the wetland's outlet has been significantly lower pollutant concentrations than the two measured inlets. This study provides evidence that even when biological activity is reduced, during colder months, the wetland is still an active system and has pollutant removal capabilities.

Edwards Branch Stormwater Practice

Site Description

Edwards Branch Wetland is an offline stormwater wetland installed in the Edwards Branch watershed. The wetland was constructed in 2001 in conjunction with a natural channel stream restoration of Edwards Branch. An elevated walkway over the wetland provides citizen access to Sheffield Park which is adjacent. Nestled between the restored stream reach and the park, the wetland is approximately ½ acre in size with average depth of approximately 1.5 ft (18 in). Although the topography of the wetland is typical of such BMPs the vegetation level is more representative of an innovative wetpond. The watershed, consisting of primarily single family residences on ¼ to ½ acre lots, is located on the opposite side of Edwards Branch from the wetland. Sizing and features of the wetland were selected to comply with state guidelines for wetland design (NCDENR, 1996).

Stormwater runoff originating in the watershed is conveyed from the watershed drainage culvert to the wetland through an inverted 8 in. ductile iron pipe running under Edwards Branch. Flows exceeding capacity of the 8 in. pipe section discharge directly into Edwards Branch. Because the system was offline, only a portion of stormwater runoff originating within the watershed is routed through the wetland system. Additionally, the hydraulics of the inlet system ensures that the capacity of the wetland is not exceeded and overflow of the wetlands outlet does not occur.

The wetland outlet is a 10 ft. X 10 ft. square cast in place concrete riser with a 24 in. diameter RCP barrel discharging to Edwards Branch. A 12 in. diameter orifice cut in the face of the riser provides the outlet for the wetland. A ¼ in. aluminum plate with a 2 in. diameter torch cut orifice bolted to the face of the riser governed the outflow rate. Placement and sizing of the orifice plate determined the storage depth and drawdown rate of the water quality volume of the wetland. Adjustment of the drawdown orifice elevation required complete replacement of the orifice plate and was only adjustable within the larger 12 in. orifice.

Monitoring Plan

Due to the unique inlet configuration, monitoring of flow at the inlet proved to be very difficult. An ISCO low profile area velocity probe was installed in the 8 in. pipe conveying water from the drainage network to the wetland inlet. During normal pool conditions, water within the wetland cell backed into the inlet pipe. During storm events the water level over the probe rose and then lowered slowly during the subsequent drawdown period. As a result of this condition, the area-velocity probe was submerged in slowly moving or static water during much of its operational time. Such conditions are less than ideal for these measurement devices.

The existing ¼ in. aluminum orifice plate on the wetland outlet was determined insufficient for monitoring due to the ragged edge of the orifice opening. In addition it was determined that the drawdown time for the wetland exceeded 48 hours and was having a negative effect on wetland plants. Water depth within the wetland exceeded what was typically accepted as ideal for plant establishment. As a result of these observations a new orifice plate was installed with two 1.75 in. circular orifices. The orifice plate was constructed of 12 gauge stainless steel. The orifice plate was precision made to ensure accurate application of a stage discharge curve developed using standard orifice equations. An ISCO 730 bubbler flow module was utilized with an ISCO Avalanche sampler to collect flow weighted outflow samples. The bubbler was welded to the orifice plate to ensure its stability. A debris screen was installed around the orifice outlet to keep dead vegetation and trash away from the orifice and to protect the sampler intake and bubbler.

Results

Monitoring efforts were initiated in October 2003 and continued to June 2005. Twenty-three storm events were monitored during the monitoring period. However, due to frequent failure of the inflow measurement system as well as other collection failures only 16 of these storms provided sufficient inflow and outflow samples for analysis. In addition to the automatically collected flow composites, manual grab samples were collected during 9 of the previously mentioned 23 storms. Summary analytical results from these storms are shown in Table 10.

Table 10 Summary Statistics for Edwards Branch Wetland

Pollutant	n	units	Inlet EMC	Outlet EMC	Efficiency Ratio	Distribution	P Value	Significant
Fecal C.	9	col/ 100mL	21,000	210	0.99	Log	0.000105	Yes
NH4-N	16	ppm	0.35	0.14	0.62	Log	0.0177	Yes
NO3-N	16	ppm	0.46	0.17	0.62	Log	0.00136	Yes
TKN-N	16	ppm	1.58	0.94	0.41	Log	0.00886	Yes
Total N	16	ppm	2.04	1.11	0.45	Log	0.00121	Yes
Total P	16	ppm	0.22	0.12	0.45	Log	0.000956	Yes
TSS	16	ppm	29.4	25.1	0.15	Log	0.133	No
Turb	15	NTU	28.73	45.00	-0.57	Log	0.284	No
Copper	16	ppb	13.6	5.8	0.57	Log	0.00195	Yes
Zinc	16	ppb	92.8	26.7	0.71	Log	1.67E-05	Yes

Mean TSS concentrations were reduced by 15% in the wetland. This removal efficiency is lower than is typically associated with storm water wetland systems. Inlet concentrations of TSS were very low (29.4 ppm). Lower, in fact than the concentrations usually observed at stormwater wetland outlets in previous studies (Scheuler, 2002). BMP performance is often very closely related to inlet pollutant concentrations. As pollutant concentrations drop, the removal mechanisms inherent to BMPs are less effective and removal drops.

Nitrogen and Phosphorous were removed at a rate of 45%, this correlates to pollutant removal guidance for stormwater wetlands in the North Carolina Department of Environment and Natural Resources Neuse and Tar River Nutrient Reduction programs.

Computed removal efficiency for Fecal coliform was very high (99%) for the 9 storms in which grab samples were collected. This reduction serves as a good indicator but more storm data is needed for a confident assessment of the degree of removal (Figure 11).

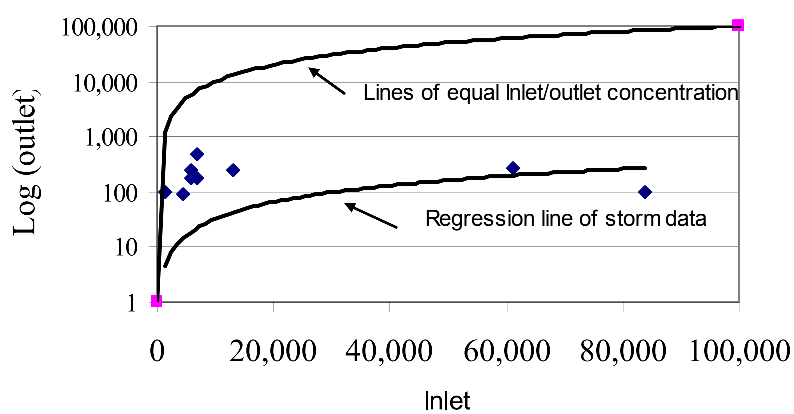

Figure 10 Outlet vs Inlet Fecal Coliform Edwards Branch Wetland

During the monitoring period a number of anecdotal problems were observed with the wetland. The aquatic and near bank vegetation establishment was very poor and declined during the monitoring period. Two possible explanations for this were noted: (1) the frequent use by waterfowl may indicate consumption of vegation by these species (as well as muskrats which were not directly seen), and (2) soils which were used during construction of the BMP may not have the necessary attributes for plant growth. The soil which was observed on the wetland bottom appeared to have a high clay content and showed little organic material. Water in the wetland was visually turbid. This observation was supported by analytical results which showed a 57% increase in turbidity in the wetland; however, this reduction was not shown to be statistically significant. Due to the fixed and un-adjustable nature of the wetland outlet orifice, management of the normal pool elevation was not feasible. An adjustable wetland outlet would allow management of the water level, possibly improving the growth of wetland vegetation.

Conclusions

Pollutant removal of most constituents measured was similar to other stormwater wetlands for which monitoring data is available. Efficiency removals did not account for flows which were bypassed. The complicated nature of the inlet makes estimating bypass problematic. Several general design considerations would enhance the pollutant removal capabilities of this BMP. Inclusion of a more easily adjustable outlet orifice would allow finer adjustment of normal pool and ensure that water levels could be controlled to maximize plant survivability. The elevation of the existing orifice plate is likely ~6 in. higher than what is optimum for wetland plant growth. Replacement or supplementation of the soil within the wetland with topsoil or other soil additive would likely improve plant growth as well. Despite some deficiencies in the practice, it should be once again noted that the wetland's performance is consistent with data from other stormwater wetlands.

Pierson Pond

Site Description

Pierson Pond is an urban pond of unknown age in a neighborhood of single family residences. The original purpose of the pond is unknown, but likely it was constructed for either agricultural purposes, recreation, or aesthetic reasons. The pond is fed by a small blue line stream exhibiting typical characteristics of urban impacted streams. The watershed draining into Pierson Pond is approximately 120 acres of mixed commercial and residential development with the majority of the watershed being single family residences on approximately ¼ to ½ acre lots.

Data on the pond dimensions have not yet been provided. Pond size is estimated to be less than 1 acre in size with no detention component. It is estimated from the local topography that pond depth does not exceed 8 ft. and average depth is likely to be 3-6 ft. The pond banks are fairly stable having been improved by a pond retrofit in the late 1990's. During the pond improvement activities, the pond outlet was improved and a littoral shelf was constructed at the water/bank interface. The area immediately surrounding the pond is primarily wooded hardwood and coniferous trees and shrubs. Local resident wildfowl species such as mallard ducks and Canadian geese are usually seen on the pond during site visits. No emergent aquatic vegetation was observed in the littoral shelf area during the monitoring period. It is suspected that unsuitable soil conditions and waterfowl browsing have limited growth of aquatic plants in the littoral shelf.

Monitoring Plan

The inlet to the pond consisted of two 48 inch reinforced concrete pipes. The inlet pipes were partially submerged during normal non-storm event periods. A rip rap apron at the downstream edge of the culverts provides erosion control for inflows. As a result of the "double barrel" inlet condition, measurement of inflow rate by direct means was not practicable. The outlet to the pond consisted of a large concrete riser over which the discharge poured into a 72 in. diameter reinforced concrete pipe "barrel". This single large culvert provided the only suitable location to measure flow rates on the pond system.

An ISCO low profile area velocity meter module was utilized in union with an ISCO Avalanche portable refrigerated sampler to collect flow weighted composite samples at the outflow point. An ISCO tipping bucket rain gage was installed near the pond outlet to provide rainfall records for all monitoring events. As a result of the flow-through nature of the pond (no detention component of the riser system), the inflow rate can be assumed nearly equivalent to the outflow rate. In order to utilize automatic sampling techniques at the inlet sampling location a wireless communication system (developed by CCU, Inc.) was utilized which would signal the inlet sampler each time the outlet sampler collected an outflow sample aliquot. Once this signal was received the inlet sampler would collect an inflow sample aliquot and await further signals from the wireless device (Figure 12). In this manner equivalent inflow and outflow flow paced composite samples were collected.

Figure 11 a and b Low profile Area-Velocity probe at Outlet and Wireless Sampler Triggering Device at Pierson Pond.

Results

Monitoring of storm events began in March 2004 and continued until May 2005. Monitoring efforts ceased due to a planed enhancement of the littoral shelf areas of the pond. Summary statistics including calculated efficiency ratio (ER) are shown in Table 11.

Table 11 Summary of Water Quality Sample Analysis and Statistics for Pierson Pond

Pollutant	n	units	Inlet EMC	Outlet EMC	Efficiency Ratio	Distrib.	P Value	Significant
Fecal C.	12	col/ 100mL	25,000	11,000	0.57	Log	0.091098	No
NH4-N	15	ppm	0.34	0.24	0.28	Log	0.28476	No
NO3-N	15	ppm	0.60	0.33	0.45	Log	0.008494	Yes
TKN-N	15	ppm	1.80	1.52	0.15	Log	0.13773	No
Total N	15	ppm	2.40	1.89	0.21	Log	0.076255	No
Total P	15	ppm	0.30	0.17	0.41	Log	0.000661	Yes
TSS	15	ppm	127.0	56.1	0.56	Log	0.001092	Yes
Turb	15	NTU	110.95	61.63	0.44	Log	0.001395	Yes
Copper	15	ppb	13.5	8.1	0.40	Log	0.000216	Yes
Zinc	15	ppb	80.3	40.8	0.49	Log	0.002418	Yes

Conclusions

Observed pollutant removals at Pierson pond were consistent with previous monitoring studies on the effect of ponds on stormwater event water quality. Statistically significant reductions were observed for NO_3-N, TP, TSS, Turbidity, Copper and Zinc. The significance of the observed difference was very strong (P value <0 .01 for all cases). Concentration reductions for all of the other primary pollutants were observed, but these results lacked statistical significance. It is possible that significance would be reached with inclusion of additional monitoring events within the data set. Overall the reduction of mean EMCs was surprising considering the small size of the pond relative to its watershed. Of particular note is the high reduction of Phosphorous (ER= 0.41). Assuming the pond had not recently been dredged, it would be expected that due to the apparent age of the pond, many of the available sites to which phosphorus could bind would no longer be available. That is, available soil bonding sites would already be filled, creating a phosphorus flow-through situation. However, this was apparently not the case. It should also be noted that the observed nitrogen (21%) and phosphorus (41%) removal rates were similar to those assigned to wet ponds in the Tar-Pamlico Stormwater guidance, 25% and 45%, respectively.

Morehead Dry Detention

Site Description

The Morehead Dry Detention basin treats a commercial office park and associated parking areas as well as some landscaped areas. The detention basin is fully vegetated with grass which appears to be well maintained and frequently mowed. Some erosion as well as sediment deposition has occurred within the detention bottom. The age of the basin is unknown at this time, but appears to be 15 to 20 years old. The outlet utilized a 4 inch rectangular hole to allow drawdown of stormwater. The orifice is on the side of a fabricated masonry riser approximately 4 feet high. The top of the riser serves as the emergency overflow.

The watershed draining to the basin is roughly 3.8 acres with approximately 70% of the watershed being impervious surfaces. It is typical of commercial office parks with well managed landscaping and facilities.

The detention facility was designed and constructed to satisfy the City of Charlotte’s post construction ordinance requiring that post development peak discharge of the 2 yr.- 24 hr. and 10 yr.- 24 hr. design storm be held to pre development levels. Generally speaking, dry detention basins are not designed to provide significant water quality improvement other than the reduced stream bank erosion potential which results from their detention functions.

Monitoring Plan

In order to facilitate accurate monitoring of outflow from the detention basin, a 12 gauge stainless steel circular orifice plate was installed at the outlet opening. The orifice installed had a diameter of 3.5 in. An ISCO 730 bubbler module was fitted to an ISCO Avalanche composite sampler to enable flow paced collection of outlet samplers. The inlet culvert showed signs of occasional submergence during high flow events. As a result, an ISCO low profile area velocity meter was installed in the invert of the inlet culvert for measurement of inflow rate.

Results

Monitoring of the site was initiated in December of 2004. Monthly storm event samples were collected through October of 2005. No storm event was monitored during the month of September as no stormwater runoff occurred during this period due to the drought in the region. As a result of the limited data collection period monitoring data may not be representative of any seasonal effects. A total of 8 storms were monitored during this period. Of the 8 storms monitored three resulted from precipitation events larger than 1 inch in depth. Such representation by large events is not representative of long term rainfall distributions. It is expected that further monitoring efforts will better reflect the mean storm size distribution. For the storms smaller than 1 in., no significant modification to hydrograph shape was observed. The area-velocity meters employed to measure inflow rates often give unsatisfactory results for smaller storms with lower flow rates and when submerged conditions allow debris or a "biofilm" to build up on the sensor face. A loss of flow measurement accuracy was observed for several storms during the monitoring period.

An example of this is shown in Figure 12 for a 0.42 in. storm of 12/23/05. The outflow hydrograph follows the same general shape of the inflow hydrograph, this would be expected for small storms in which the detention function of the basin is not utilized. Inaccuracies in the flow measurement system at the inflow cause spikes and negative values in the flow data which are obvious errors. Although the severity of these errors make total flow volume determination and precise peak flow calculations difficult, they are not substantial enough to affect the ability of the flow meter/sampler combination to collect acceptable flow weighted samples for water quality analysis. It is recommended that future monitoring activities include frequent cleaning of the sensor surface of area – velocity meters

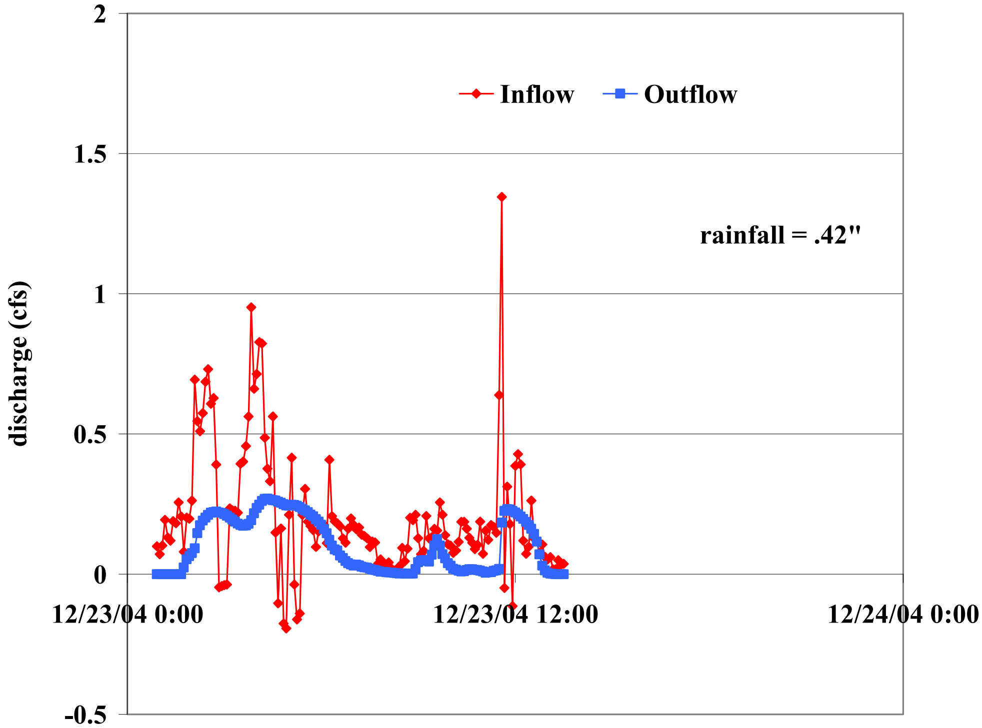

Figure 12 Morehead Dry Detention Inflow and Outflow Hydrographs for Small Storm of 12/22/2004

For larger storms, the detention feature of the BMP was evident in the resulting hydrographs. Figure 13 shows the impact of the BMP on the outflow hydrograph from a 2.36 in. storm event. Similar reductions in peak discharge were observed in other storms of similar size. This reduction is expected for storm intensities exceeding the design storm intensity for the 2- yr 24 hr storm. Both composite and grab samples were collected for analysis. A summary of the results of these 8 storms is provided in Table 10.

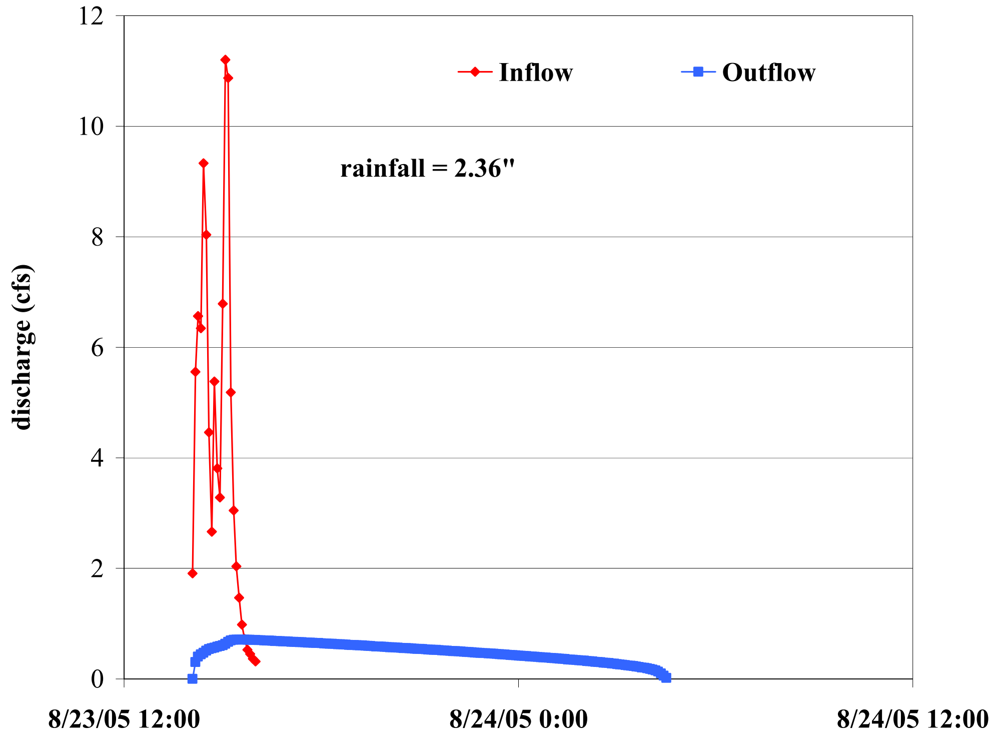

Figure 13 Morehead Dry Detention Facility Inflow and Outflow Hydrographs for Storm Event of 8-23-2005

Table 12 Summary Statistics for Morehead Dry Detention

Pollutant	N	units	Inlet EMC	Outlet EMC	Efficiency Ratio	Distribution	P Value	Significant
Fecal C.	8	col/ 100mL	5,000	6,000	-0.21	Log	0.430	No
NH4-N	8	ppm	0.30	0.24	0.20	Normal	0.141	No
NO3-N	8	ppm	0.55	0.50	0.08	Log	0.508	No
TKN-N	8	ppm	1.18	0.81	0.31	Normal	0.0410	Yes
Total N	8	ppm	1.72	1.31	0.24	Normal	0.0403	Yes
Total P	8	ppm	0.16	0.15	0.11	Log	0.447	No
TSS	8	ppm	19.1	5.5	0.71	Normal	0.00238	Yes
Turb	8	NTU	10	5	0.45	Log	0.00357	Yes
Copper	8	ppb	8.2	6.0	0.27	Log	0.00350	Yes
Zinc	8	ppb	106.9	66.8	0.38	Normal	0.00191	Yes

The limited numbers of storms for which monitoring results are available make conclusions as to the performance of the BMP difficult to make. Statistically significant differences in the means of the inlet and outlet EMC were observed for several constituents despite the limited sample size. TSS reductions were very high (71%) and statistically significant. Total Phosphorous, on the other hand, essentially had no reduction. It is likely that the majority of the phosphorous collected at this facility was in the dissolved state. Had much of the phosphorus been associated with soil, a higher removal rate would be expected.

Fecal coliform levels increased from influent to effluent (Figure 13). This may be due to this basin being attractive to animals. Also, the fact that dry detention areas are often flow-through devices during small to medium-sized storm events may mean that the there was little fecal coliform removal, particularly if the fecal coliform was associated with very small soil particles. Any conclusions associated with this basin should be tempered by the still limited number of storms collected.

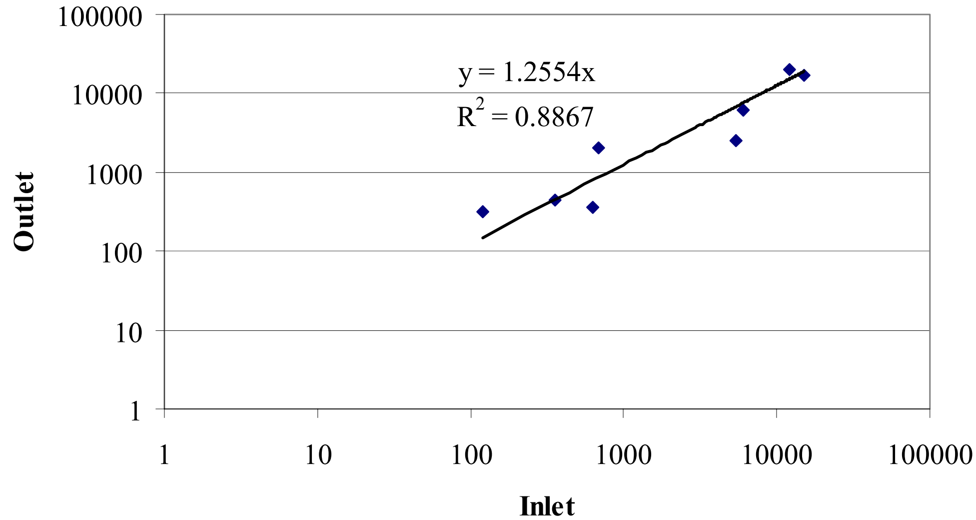

Figure 14 Fecal Coliform Concentrations at Morehead Dry Detention

Conclusions

Please see the conclusions at the end of the University Park Dry Detention monitoring report.

University Park Dry Detention

Site Description

The University Executive Park Dry Detention is an extended dry detention basin treating a commercial office park and associated parking areas as well as some landscaped area. The watershed draining to the detention area is approximately 5.9 acres with approximately 70% of the watershed being impervious surfaces. The detention basin is fully vegetated with grass which appears to be well maintained and frequently mowed. Some erosion as well as sediment deposition has occurred within the detention bottom. The age of the basin is unknown at this time. Although the inlet to the detention basin is near the outlet, topography of the detention bottom causes low flows to follow a circuitous flow path such that contact time within the basin is not short circuited. A 24 in. RCP with a flared section acts as the dry detention inlet. The invert of the inlet pipe is approximately 6 in. higher than the average elevation of the detention bottom. The outlet utilizes a 14 in. circular orifice to allow for drawdown of stormwater detained within. The orifice is on the side of a fabricated concrete headwall attached to a 15 in. RCP. A cast in place concrete emergency spillway is installed over the detention berm. It is unlikely that the emergency spillway was utilized during any monitoring events.

Monitoring Plan

Inlet monitoring took place in the 24 in. RCP pipe at the south end of the detention basin. During most storm events this pipe experienced a slight tail water condition. As a result, it was necessary to utilize an area-velocity meter at this location. The area-velocity meter probe was installed with the use of an expansion bracket with the probe situated in the bottom of the culvert pointing upstream. The strainer was installed in the invert of the culvert approximately 24 in. downstream of the area velocity probe which was installed 3 ft. upstream of the flared culvert section. Outlet detention was controlled by a 14 in. circular orifice. A model 750 bubbler was used in conjunction with a stage-discharge relationship for determination of flow through the outlet. The state-discharge relationship for the orifice/bubbler combination was determined using an Excel spreadsheet model utilizing common orifice discharge equations. The bubbler was attached to a solid concrete block and situated 12 in. upstream and 12 in. to the side of the center of the orifice plate. Bubbler elevation was set so that it was level with the invert of the orifice plate.

Monitoring was initiated in February 2005 and continued until October 2005. Storm events were monitored on a monthly basis with the exception of September when drought conditions in the area resulted in no storms of sufficient size for sample collection occurring.

Hydrologic Results

Results for 6 storms monitored during the study period were available for analysis at the time of this writing. Although such a small number of sample events can not be reliably used for conclusions, some general observations can be made. Hydrologic results from the University Dry Detention basin were generally similar to results from the Morehead Dry Detention. Submerged conditions at the inlet were believed to have caused in accuracies with the flow measuring capabilities of the area velocity meters at those locations. This effect was observed for several storms during the monitoring period. Two storms monitored during the study period consisted of rainfall events of larger than 1 in. Results from a large storm (2.09 in.) are shown in Figure 15. As can be seen, no significant reduction in peak discharges for this storm were observed. This is in contrast with the storm shown in Figure 13 in which a reduction of peak discharge was observed for a storm of similar size at the Morehead Dry Detention. No peak reduction in flows was observed during either of the large events which occurred during the monitoring period. The cause for this observed difference in hydrologic function is not known. It may be that the outlet of one of the basins is incorrectly designed or constructed or it may be a result of differences in the rainfall intensities of the monitored events.

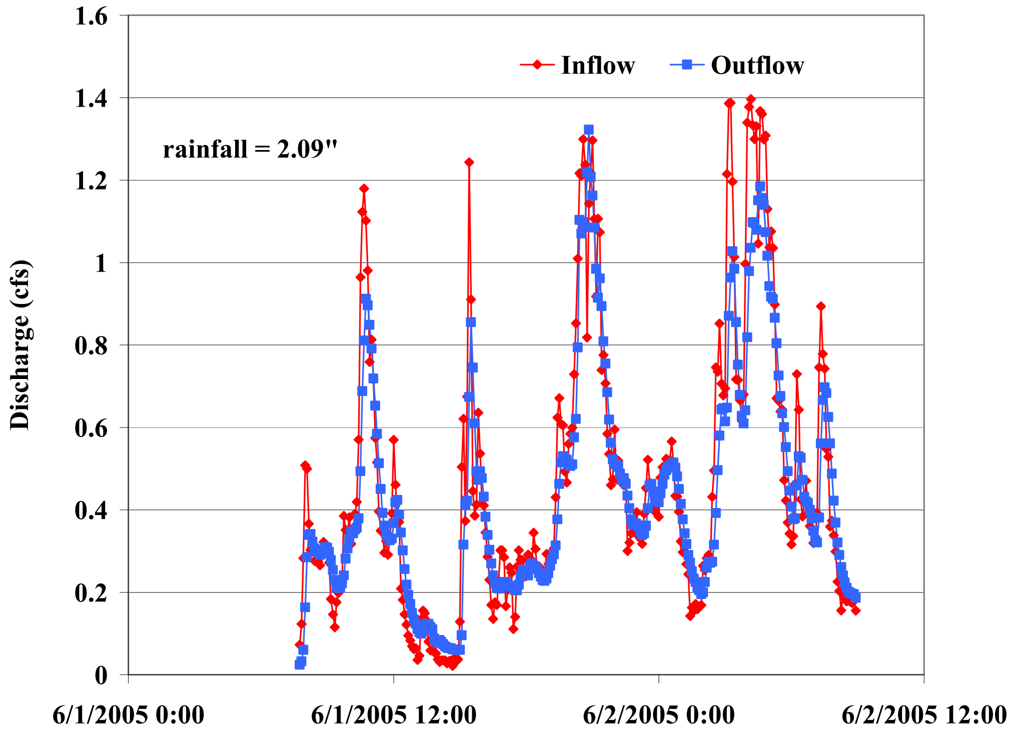

Figure 15 University Dry Detnetion Inflow and Outflow Hydrographs for 6/1/2005 Storm Event

Water Quality Results

Due to the short time period for monitoring and small number of storm EMCs available for analysis at this time, no statistically significant conclusions can be drawn from the monitoring results. However, some general trends have been noticed and with further data collection perhaps performance determinations can be made in the future. Concentrations of the pollutants observed at the basin inlet were among the lowest observed in the entire study. It is possible that the relatively recent development within the watershed and the degree of maintenance and use of the areas within the watershed restrict pollutant sources. For instance, observed metal concentrations were very low. Previous studies have linked metal concentration to traffic load and vehicle wash off. During monitoring activities data collection personnel noticed a low density of vehicles in the parking areas of the watershed. It is theorized that the low concentration of vehicles in these parking areas is a causative factor for the low metals concentrations.

Table 13 Summary Statistics for University Dry Detention

Pollutant	N	units	Inlet EMC	Outlet EMC	Efficiency Ratio	Distribution	P Value	Significant
Fecal C.	6	col/ 100mL	12,000	16,000	-0.30	Log	0.132	No
NH4-N	6	ppm	0.36	0.22	0.37	Log	0.155	No
NO3-N	6	ppm	0.73	0.42	0.43	Log	0.161	No
TKN-N	6	ppm	1.40	1.12	0.20	Log	0.441	No
Total N	6	ppm	2.13	1.54	0.28	Log	0.227	No
Total P	6	ppm	0.27	0.25	0.08	Log	0.933	No
TSS	6	ppm	20.1	7.4	0.63	Log	0.0716	No
Turb	6	NTU	13	6	0.51	Log	0.111	No
Copper	6	ppb	4.7	4.8	-0.03	Normal	0.404	No
Zinc	6	ppb	68.1	51.9	0.24	Log	0.0970	No

One specifically interesting trend observed is the slight increase in fecal coliform concentrations in the outlet grab sample. At this time it is unknown whether this increase is a result of normal data scatter or growth of fecal colonies within the basin during storm events. However as can be see in Figure 16 the relationship between inlet and outlet concentrations is quiet striking and shows a slight increase. Given the very low numbers of data points for analysis and short period of record, little conclusions can be drawn from these observations at this time.

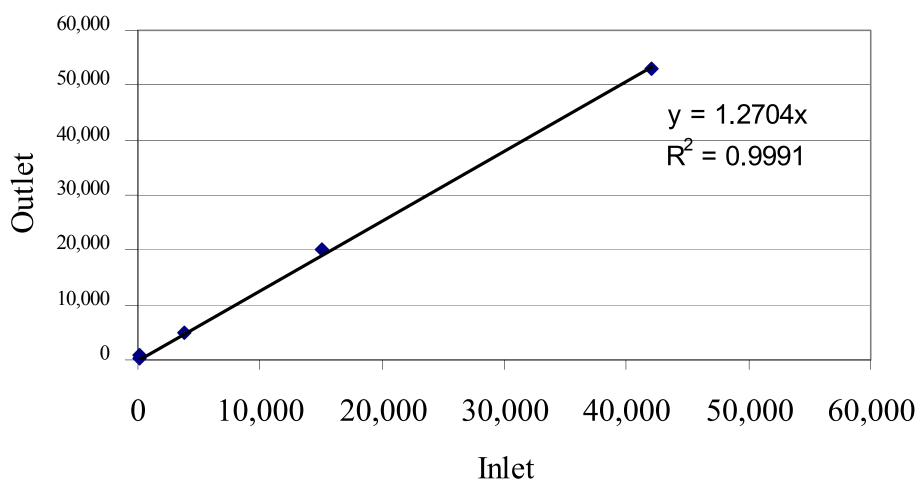

Figure 16 Fecal Coliform Concentrations at University Dry Detention

Conclusions for Morehead and University Park Dry Detention Basins

Neither site has been examined for an entire year. Moreover, the University Park dry detention area has only had 6 storms monitored. Because of this, any claims of performance need to be tempered. Initial observations show a surprisingly good TN removal rate from both sites (21% and 28%), which is similar to those of wet ponds. Similarly, TSS removal rates are similar to those associated with stormwater wetlands and wet ponds. However, neither device seemed to impact TP concentrations, while both cells showed an increase in fecal coliform counts from inflow to outflow. Because these dry detention devices do show promise with respect to certain pollutants, NCSU recommends continued study on both of these sites. Current nutrient reduction rules and guidelines in North Carolina (Neuse / Tar-Pam rules) do not recognize pollutant removal capabilities of dry detention basins. If the results observed in these limited samples – particularly for TN removal – are supported by future data and studies, TN reduction associated with dry detention basins should be considered.

Project Summary and Conclusions

Monitoring of selected BMPs was initiated in August of 2003. Thus far, seven BMPs have been monitored for a sufficient time period to begin data analysis. Relative to national studies, a substantial amount of data has been collected for the Hal Marshall Bioretention cell. Two wet ponds (Shade Valley and Pierson) and one stormwater wetland (Edwards Branch) have had a sizable number of storms collected and analyzed. Three other practices, one stormwater wetland (Bruns Avenue) and two dry detention basins (Morehead and University Park) have had some data collected, but as of yet have not been monitored for a full year. All seven of the practices do show promise, each able to remove at least some types of pollutants. The data collected from the first four stormwater practices (Hal Marshall, Shade Valley, Pierson, and Edwards Branch) are representative enough to indicate each practice's performance. A summary for select pollutants is found in Table 14 below.

Table 14 Efficiency Ratio (by concentration) of Select Pollutants for Four Stormwater BMPs

Practice	Hal Marshall Bioretention	Shade Valley Wet Pond	Pierson Wet Pond	Edwards Branch S/W. Wetland
TN	46%	19%	21%	45%
TP	45%	16%	41%	45%
TSS	63%	63%	56%	15%
Fecal Coliform	69%	n/a	57%	99%
Copper	60%	71%	40%	57%

As expected, the practices which rely on biological activity for their performance (Hal Marshall and Edwards Branch) both recorded the best TN removal rates. TP was also substantially reduced by both of these practices, as well as the Pierson Wet Pond. TSS removal was normal for the bioretention area and the two wet ponds, but lower for Edwards Branch. The practices from which fecal coliform data were collected all showed substantial reductions from inlet to outlet as was also the case for copper removal.

To aid in future BMP selection, "complete" monitoring data will be required from more than just these four BMPs. In a few months, the other three practices described at length herein will also be able to be fully analyzed. Additionally, many other BMPs are being studied within the City, and each BMP's performance data will be added to this local database to help aid in future BMP selection and design.

However, these four practices do provide a useful benchmark. If nutrient removal is a target, it appears that vegetated practices with engineered soil media may emerge as the practices of choice. The Hal Marshall Bioretention area, the Edwards Branch stormwater wetland, and the Bruns Avenue stormwater wetland (the latter albeit with fewer events to analyze) each showed the highest TN and TP removal. The Hal Marshall bioretention area probably performed the best of all the practices studied with respect to nutrient load removal.

If TSS is the target pollutant, any of the practices tested, including the dry detention basins, appear to be sufficient. Nearly all the practices tested removed TSS relatively well. For fecal coliform reduction, the data are still nascent, but the Hal Marshall bioretention cell certainly shows promise.

In summary, the authors believe this monitoring effort is beginning to yield data that will effect decisions among the City's staff with respect to the type of practice to install per a given situation (watershed size, target pollutant, liability/safety requirements, etc.) With the continued monitoring effort and analysis, more complete recommendations regarding BMP function will be able to be made. Finally, City leaders should be pleased that all the BMPs presented herein did reduce at least some pollutants substantially.

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