CITY of CHARLOTTE
Pilot BMP Monitoring Program

Hal Marshall Bioretention
Final Monitoring Report

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Purpose

The purpose of this report is to document monitoring and data analysis activities undertaken by the City of Charlotte, NC, Mecklenburg County, and NC State University to determine the effectiveness and stormwater treatment capabilities of the Hal Marshall Bioretention area.

Executive Summary

Bioretention is a stormwater treatment practice that has gained popularity due to its aesthetics, potential to reduce flooding, and early documented improvements to stormwater quality. A bioretention cell in an urban setting was examined in Charlotte, NC, from 2004 to 2006. Flow-weighted, composite water quality samples were collected for 23 events and analyzed for TKN, NH_4-N, NO_{2-3}-N, TP, TSS , BOD-5, Cu, Zn, Fe and Pb. Grab samples were collected from 19 storms for fecal coliform and 14 events for *E. coli*. There were significant reductions ($p<0.05$) in the concentrations of TN, TKN, NH_4-N, BOD-5, Fecal Coliform, *E.Coli*, Cu, Zn, and Pb. Iron concentrations significantly increased ($p<0.05$). NO_{2-3}-N concentrations were essentially unchanged. Efficiency ratios for TN, TKN, NH_4-N, TP, and TSS were 0.32, 0.44, 0.73, 0.31, and 0.60, respectively. Fecal coliform and *Escherichia coli* (*E. coli)* efficiency ratios were 0.69 and 0.71, respectively. Efficiency ratios for Zn, Cu, and Pb were 0.77, 0.54, and 0.31, respectively. Concentrations of Fe increased by 330%,. The peak outflow of the bioretention cell for 16 storms with less than 42 mm of rainfall was at least 96.5% less than the peak inflow, with a mean peak flow reduction being 99%. These results indicated that in an urban environment, bioretention systems can reduce concentrations of most target pollutants, including pathogenic bacteria indicator species. Additionally, bioretention can effectively reduce peak runoff from small to mid-size storm events.

Introduction

Stormwater runoff is a primary factor in the degradation of many surface waters, including streams and other water bodies (USEPA 2000). The adverse impact of this and other sources of pollution include; closures of shellfish waters, fish kills, and aesthetic degradation. Consequently, there is a reduction in fishing and recreational value of downstream waters. Stormwater runoff contains high levels of nitrogen, phosphorus, and heavy metals (Bannerman et al. 1993, Pitt *et al*. 1995, Wu *et al*. 1998).

Bioretention (Coffman et al., 1993) is one of several practices used to mitigate stormwater runoff. Bioretention is an integral part of Low Impact Development (LID) (Hager 2003), as the practice has the potential to reduce runoff volumes, minimize peak flows, recharge ground water , increase evapotranspiration, and reduce the mass of pollutants entering surface and ground waters. Compared to other "ultra-urban" BMPs, bioretention is cost effective (Wossink and Hunt 2003).

Bioretention has been demonstrated to provide removal rates exceeding 98% for oil and grease (Hsieh and Davis 2005), copper, lead, and zinc (Davis et al. 2003, Hunt et al. 2006) both in column study experiments and in initial field tests. However, initial bioretention designs employed in the field did not substantially reduce the levels (concentration and mass) of nitrate-nitrogen (NO_3-N) (Davis *et al*. 2001, 2003, Hsieh and Davis 2005). Two recent studies (Hunt 2003, Kim *et al*. 2003) performed in a laboratory environment demonstrated how the addition of an internal saturation layer increased nitrate-nitrogen conversion to nitrogen gas. Hunt et al. (2006) and Hseih and Davis (2005) showed that adding a saturation zone at the bottom of field-implemented bioretention areas appeared to reduce effluent nutrient levels. Designed saturated zones in field studies examined by Dietz and Clausen (2006) showed significant reduction in total-N (TN).

No data have been reported in literature on bioretention's ability to remove pathogenic bacteria or its indicator species, Fecal coliform and *E. coli*. How

bioretention cells partition influent runoff among bypass, underdrain flow, evapotranspiration, and exfiltration has only been cursorily examined (Dietz and Clausen 2005, Hunt et al. 2006, Heasom et al. 2006), but is essential knowledge for integration into LID.

The goals of the field research presented herein were to (1) compare nutrient and metal removal rates reported earlier with a bioretention area treating an institutional parking in an ultra-urban environment, (2) research how well this cell reduced the concentrations of Fecal coliform and *E. coli*, (3) examine how much runoff (both peak and flow) was reduced by the cell, and (4) estimate the amount of inflow runoff that exited the system via either exfiltration or evapotranspiration.

Site Description

The Hal Marshal Bioretention Cell (HMBC) was a retrofit BMP constructed by Mecklenburg County treating runoff from an asphalt parking area adjacent to the Hal Marshall Municipal Services Building in the City of Charlotte, NC. The Hal Marshal Building houses the offices for Mecklenburg County Land Use and Environmental Services (LUESA). The drainage area was 0.37 ha (0.92 ac) of an aging asphalt parking lot which was last paved at least 15 years prior to the study. The parking area is primarily used by employees of and visitors to Mecklenburg County Social and Environmental Services. The traffic load on the watershed was a mix of private vehicles and service vehicles; during office hours, use of the parking spaces was observed to be near 100%. Watershed and bioretention cell characteristics are summarized in Table 1. Figure 1 depicts the cell 16 months after the study began.

The BMP was sited between the parking area and an abandoned railroad line. A steep slope leads from the bioretention area down to the railroad line approximately 6 m (20 ft) below the surface of the bioretention area. It is likely that the groundwater table is 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 LUESA. The design of the bioretention area followed the recommendations made by the state of North Carolina Division of Water Quality "Stormwater BMP Design Manual"(NCDENR, 1999). The runoff volume from a 2.54 cm (1-inch) rainfall event was stored between the soil surface and the overflow structure. The design ponding depth was approximately 13 mm (6 in.). The storage volume was 41 m^3 (1460 ft^3), not including water stored in the soil media. When inundated to the brink of overflow, the bioretention surface area was 229 m^2 (2480 ft^2). A forebay was located at the inlet to the bioretention cell and measured approximately 3m (10 ft) in diameter.

Table 1: Description of Hal Marshall Bioretention Cell (HMBC) and Watershed

Watershed Description	Municipal Parking Lot
Watershed Area	0.37 ha (0.92 ac)
Watershed CN	98
Bioretention Cell Surface Area	229 m^2 (2480ft^2)
Bioretention Cell Storage Volume (not including storage within soil)	41 m^3 (1460 ft^3)
Soil Media Depth	1.2 m (4 ft)
Underdrain System	1 - 0.15 m (6 in) corrugated plastic pipe
Soil Media Type[a]	Loamy Sand
Soil Media P-Index (May 2006)[a]	6 (Low)
Soil Media Silt and Clay Fraction[a]	5.7%
Soil Media Permeability[b]	0.0003 cm/sec (2.75 in/hr)
Soil Media CEC[a]	1.9
Vegetation Density	1100 stems/ha (2800 stems/ac)
Predominant Vegetation Types[c]	Blueflag Iris (*Iris virginica*), Cardinal flower (*Lobelia cardinalis*), Common rush (*Juncus effusus*), Hibiscus (*Hibiscus spp.*), Red Maple (*Acer rubrum*), Sweet Pepperbush (*Clethra alnifolia*), Virginia Sweetspire (*Itea virginica*), Wild Oat Grass (*Chamanthium latifolium*)

a – determined from soil samples collected on May 4, 2006
b – test conducted on May 4, 2006
c – a total of 17 species were observed in the cell on August 8, 2006.

Figure 1. Hal Marshall Bioretention Cell (HMBC) 16 months after the cell was revegetated and the study commenced.

The Bioretention cell's media depth was nominally 1.2 m (4 ft) and was drained by a conventional underdrain system consisting of one 0.15m (6 in.) flexible corrugated plastic pipe. Immediately before the commencement of monitoring in 2004, the fill soil was replaced and a single inlet "chute" with a 120° weir and forebay were installed. Mulch and vegetation was also replaced as part of the rehabilitation. The following species were a subset of what was planted in the HMBC: blue flag iris (Iris virginica), Hibiscus (*Hibiscus* sp.), Sweet Pepperbush (*Clethra alnifolia*), Virginia sweetspire (*Itea virginica*), and Wild Oat Grass (*Chasmanthium latifolium*). Several volunteer species were present by the study's end, including Asiatic wild rice (*Zizania latifolia*), bulrush (*Scirpus validus*), common reed (*Phragmites occidentalis*), and common rush (*Juncus effusus*). The stem count of the HMBC was 1100 stems/ha (2800 stems/ac), indicating a relatively well-shaded cell at maturity.

Charlotte's weather is on average warm and humid[1]. The annual mean temperature is 16.3°C (61.4°F), with the temperature of the coolest average month, January, being 5.4°C (41.7°F) and the highest monthly average being 26.8°C (80.3°F) in July. The average annual precipitation is 1108 mm (43.64 in.). The wettest month, on average, is March (112 mm or 4.39 in) and the driest month is April (75 mm or 2.95 in.). Monthly precipitation totals do not vary substantially (NC Climate Office 2006).

Monitoring Methods

A 120° weir was installed at the sole inlet to the bioretention to measure inflow (Figure 2). The sample collection strainer was placed just upstream of the invert of the weir, in a well-mixed area of the flow stream and at the approximate midpoint of the flow stream during low flow conditions.

Figure 2. 120° weir at the HMBC inlet.

[1] All historical averages are for 30 years and given for meteorological station number 311690, Charlotte Douglas Airport, administered by the National Weather Service.

HMBC outlet water quality samples were collected where the underdrain daylighted on the railroad embankment, approximately 10 m (30 ft) from the bioretention cell. No water was allowed to enter the underdrain other than the bioretention cell infiltrate. The underdrain discharged into a weir box with a baffle section and a 90° 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 coupled with ISCO model 6712 samplers to measure the stage of water at the inlet and underdrain outlet weirs and to facilitate flow-paced composite storm samples for the determination of Event Mean Concentrations (EMC's). An ISCO tipping bucket rain gauge was placed at a nominal height of 2 m and immediately adjacent to the bioretention area and connected to the outlet sampler for the recording of rainfall data.

Monitoring of storm events occurred from February 2004 to March 2006. Twenty-three complete (inflow and outflow) storm events were collected for the following pollutants: TN, $NO_{2\text{-}3}$-N, TKN, NH_4-N, TSS, Zn, Cu, and Pb. Twenty-two events were captured for TP; seventeen for iron.

Grab samples for Fecal Coliform and *E. coli* were collected. Samples were collected during storm events, and were immediately taken to the Mecklenburg County Analytical Laboratories. Fecal coliform was tested for 19 storms, and *E. coli* was analyzed for 14 events.

During several of the events for which grab samples were taken, composite samples were not. Of the 31 storm events from which data were collected, the mean storm size was 27.4 mm (1.08 in), the median storm size was 24.1 mm (0.95 in), and the event sizes ranged from 6.4 mm (0.25 in) to 80.8 mm (3.18 in) (Table A1 – in Appendix). Monthly temperatures during the study period were relatively near normal. Monthly precipitation was less than 50% of normal during the months of March 2004, April 2004, October 2004, January 2005, September 2005, February 2006, and March 2006. Precipitation was 50% greater than normal during the months of June 2004, August 2004, September 2004, June 2005, and December 2005 (NC Climate Office 2006). Total

precipitation for the 26-month period was approximately 11% less than normal, making the monitoring period slightly drier than normal.

Data Analysis Results

Nitrogen and Phosphorus.

Effluent concentrations of TN, TKN, and NH_4-N were 32.2%, 44.3%, and 72.3% lower, respectively, than influent concentrations. There was a slight increase in NO_{2-3}-N concentration (4.7%). Total nitrogen, TKN, and ammonium concentrations were significantly reduced ($p < 0.05$). The increase in NO_{2-3}-N concentration was not significant (Table 2).

Because this system did not employ a designed saturated zone, or internal water storage (IWS) zone, the lack of NO_{2-3}-N reduction is expected. Studies conducted by Hunt et al. (2006), Hsieh and Davis (2005), and Dietz and Clausen (2006) show that the presence of an internal water storage layer or "designed" saturation increases NO_{2-3}-N removal, sometimes significantly.

NH_4-N levels were reduced to and below the detection limit (0.1 mg/L) by this cell. Nearly all the NH_4-N appears to have been converted to NO_{2-3}-N in the purposefully aerobic environment of this bioretention cell. The conversion of NH_4-N to NO_{2-3}-N partially explains the concentration reduction of TKN and TN. As hypothesized at an earlier study in Greensoboro, NC, (Hunt et al. 2006) ammonification could have taken place converting organic nitrogen to NH_4-N, which was then converted to NO_{2-3}-N. Similar results were found by Dietz and Clausen (2006). Very little humic matter was found in the soil mix (0.13%), so the media proper was likely not a source of nitrogen. In soils with higher organic amounts, nitrogen concentrations had been shown to increase. The lack of organic matter in the soil did not appear to adversely impact vegetative growth, as plant density (1100 stems/ha) was high.

Total phosphorus effluent concentrations were 31.4% lower than those of the influent. The reduction, however, was not significant ($p \approx 0.08$). The effluent concentration was 0.13 mg/L, which, compared to other sites tested in North Carolina, was relatively low. Cells studied in Greensboro (Hunt *et al*. 2006) had

effluent TP concentrations of 0.56 mg/L and 3.0 mg/L. Another study, in Louisburg, showed average effluent TP concentrations of 0.16 mg/L and 0.18 mg/L for two cells (unpublished data). The effluent concentrations observed at the HMBC were 0.06 to 0.08 mg/L higher than those in Dietz and Clausen (2006).

Table 2: Influent and Effluent Mean Concentrations for select pollutants at HMBC.

Pollutant[a]	N	Analytical Method	RL[b]	Unit	Distrib.	Inflow	Under-drain	E.R.	Signif.
TN	23	n/a	0.35	mg/L	Log-normal	1.68	1.14	0.32	P < 0.001
TKN	23	EPA 351.2	0.25	mg/L	Log-normal	1.26	0.70	0.44	P < 0.001
NH_4-N	23	SM 4500-NH3H	0.10	mg/L	Log-normal	0.34	0.10	0.73	P < 0.0001
NO_{2-3}-N	23	EPA 353.2	0.05	mg/L	Log-normal	0.41	0.43	(0.05)	No
TP	22	SM 4500-P	0.01	mg/L	Log-normal	0.19	0.13	0.31	No
TSS	23	SM 2540D	5	mg/L	Log-normal	49.5	20.0	0.60	P < 001
BOD-5	23	SM 5210B	2	mg/L	Log-normal	8.54	4.18	0.63	P < 0.03
Fecal coliform	19	SM 9222D	100	CFU/ 100ml	Log-normal	14700	4500	0.69	P < 0.05
E. coli	14	SM 9223B	1	MPN/ 100ml	Log-normal	938	273	0.71	P < 0.01
Cu	23	EPA 200.8	2	g/L	Log-normal	12.8	5.9	0.54	P < 0.0001
Zn	23	EPA 200.7	10	g/L	Log-normal	72	17	0.77	P < 0.0001
Pb	23	EPA 200.8	5	g/L	Log-normal	4.85	3.33	0.31	P < 0.03
Fe	17	EPA 200.7	50	g/L	Log-normal	1110	4710	(3.30)	P < 0.01[c]

[a] – Mercury was also examined, concentrations never exceeded the RL of 0.2 g/L for either inflow or outflow
[b] – Reporting Limit. For statistical analyses, values less than the reporting limit were considered to be ½ RL.
[c] – Increase in concentration

The HMBC fill soil contained very little phosphorus. The North Carolina Department of Agricultural and Consumer Services (NCDACS) phosphorus

index, known as P-Index, was 6 (determined using Mehlich-3 measurement, Hardy et al. 2003), which is considered very low. While the soil's TP content was limited, the fill soil's capacity to capture influent phosphorus may be limited in the long term, as the soil CEC was 1.9 (Table 1). The HMBC was examined for the first two years immediately following installation of filter media, so performance should be re-examined at a later time to study the impact of pollutant accumulation within the fill soil.

Solids and Metals.

The HMBC effluent concentrations of Fe were 330% higher than influent concentrations. TSS, Zn, Cu, and Pb effluent concentrations were 59.5%, 77.0%, 54.0%, and 31.4% lower, respectively, than influent concentrations. Mean differences were statistically different at a =0.05 (Table 2). Percent reduction for Pb, may be misleadingly low, as 12 of the 23 influent-effluent pairs had concentrations below the reporting limit (RL). Other than the first four monitored events, every Pb effluent concentration was below the RL. The HMBC appeared to reduce Pb to the minimum measurable level. The pollutant removal data for Zn, Cu, and Pb were similar to those reported earlier by Davis et al. (2003) for field sites in Largo and Greenbelt, Maryland. Field removal rates tend to be somewhat lower than those reported in laboratory settings. The increased export of iron by the HMBC has been observed at other bioretention sites in the North Carolina piedmont, where the in situ soils are clayey with relatively high iron contents (Hunt et al. 2006). The concentration of TSS in the effluent is not particularly high and is probably a result of soil media loss from the cell (Hsieh and Davis 2005). At the end of the study period at HMBC, TSS effluent concentrations were not appreciably lower than those recorded at the study's beginning. While it has been hypothesized that the concentration of effluent solids would decrease with bioretention cell age as the fill media consolidates, this hypothesis was not observed to be true in the first two years at HMBC.

Fecal coliform and *E. coli*

Fecal coliform and *E. coli* effluent concentrations were 69%, and 71%, lower than inflow concentrations, respectively (Table 2). Statistically effluent concentrations were significantly less than influent concentrations for both these pollutants ($p<0.05$). This is the first study that has examined how well a bioretention cell impacted pathogenic bacteria indicator species' concentrations. Effluent concentrations of fecal coliform were at or below the state level of 200 col/ 100 mL for 14 of 19 samples collected. Fecal coliform influent concentrations were at or below the state of NC level for 3 of 19 samples collected. Similar numbers at or below the nationally-used E. coli standard of 136 MPN per 100 mL were 12 and 6 for 14 samples collected for outflow and effluent concentrations, respectively (USEPA, 2003).

A few studies which have been conducted on sand filters for stormwater treatment show similar removal. Barrett (2003) found that Austin sand filters examined in California reduced EMC's of fecal coliform by 65%. To kill bacteria, exposure to sunlight and dry conditions are needed. The pool volume of the HMBC drained relatively quickly (approximately 25 mm (1 in.) per hour); however, this cell was relatively densely vegetated (1100 stems/ha or 2400 stems/ac). The cell was therefore well shaded. This makes the effluent concentrations observed at HMBC even more promising. Lab studies conducted by Meschke and Sobsey (2003) on *E. coli* removal from waste water loaded columns found that removal rates increased with less permeable soils, suggesting that a bioretention fill soil containing some fine soil particles (clays and silts) may remove pathogenic bacteria more easily and at higher efficiencies than pure sand fill soil. The clay and silt content in the HMBC fill soil was approximately 6%.

Small to Medium Event Hydrology. Reduction in Peak Flows.

Peak inflow and outflow rates from 16 events ranging from 2.0 to 39.9 mm were collected (Table A2). The HMBC reduced outflow peaks by at least 96.5%. Per a paired t-test statistical analysis, the reduction in peak flow from outflow to

inflow was significant ($p<0.0003$). During the two smallest storms that were analyzed (under 3 mm), there was no outflow. An example inflow and outflow hydrograph from a 26.2 mm event on 13-14 January 2005 is shown in Figure A1. The event was likely near, but lower than the "capacity" event for the HMBC. The bioretention cell reduced peak flow for this storm by over 99%. Additionally, the peak flow was delayed by three hours. Outflow persisted for 40 hours at rates over 0.01 L/S, while the inflow duration was slightly less than 10 hours. This drawdown rate was near the intended design range, 24- 36 hours. The HMBC was only able to substantially reduce peak flows from small to medium-sized storm events. All events exceeding 40 mm overtopped the outlet weir. Events exceeding 42 mm were not reliably captured by HMBC, as several of those events likely overflowed the cell. Therefore, these larger storms were not analyzed for peak outflow reduction. Bioretention cells are able to mitigate peak flows because of their high surface infiltration rates, potential to store water in soil pores, and slow drawdown time. Compounding these factors at HMBC was a steep hydraulic gradient from the bottom of the bioretention cell to the nearby railroad line.

Summary and Recommendations

The following conclusions and recommendations may be made from the research at the HMBC.

1. Bioretention nutrient reduction in this urban environment was substantial. Concentration reduction of all nitrogen species and total nitrogen with the exception of $NO_{2\text{-}3}$-N was significant ($p<0.05$). Reductions in nitrogen concentration exceeded 32%. $NO_{2\text{-}3}$-N reductions were not observed, due to the aerobic nature of the bioretention cell. The $NO_{2\text{-}3}$-N reduction would probably be enhanced by including an internal water storage feature to facilitate the conversion of $NO_{2\text{-}3}$-N to nitrogen gas via denitrification (Dietz and Clausen 2006). Phosphorus reductions were substantial (31%), but not significant at the □=0.05 level. The reduction in phosphorus concentration is attributed to the low-phosphorus content fill media at the

site. Reductions in nutrient concentrations were higher than in previous field studies conducted in North Carolina (Hunt et al. 2006). The fill soil's low CEC, however, may hamper long term TP reductions at HMBC.

2. Metal and solids removal were comparable to many prior field studies, but were not as high as reported in several lab studies (Davis et al. 2001, Davis et al. 2003, Hsieh and Davis 2005). The bioretention fill media appeared to exit the cell via underdrains, albeit at a relatively low rate, but effluent EMCs for TSS were 60% lower than those of the influent.
3. Bioretention cells show promise in removing pathogenic bacteria. Fecal coliform and *E.Coli* levels were reduced by 71% and 69%, respectively, and both were significant ($p<0.05$) reductions. Moreover, the effluent concentrations of the indicator species were consistently lower than most state's standards. Because this is presumably the first cell studied for bacteria, it is important not to overstate a bioretention cell's ability to remove bacteria. However, these initial results are promising.
4. Peak flows from small to mid-sized precipitation events (those less than 42 mm) were mitigated by at least 96% by the HMBC. Similar results have been reported by Heasom et al. (2006). In highly urban environments where even small storms can produce intense local flooding, this observed flood reduction may support bioretention's widespread use. If bioretention is to be incorporated as part of LID, mitigation of peak flows from storm events is critical.
5. This often significant ($p<0.05$) concentration reduction (e.g., TN, TKN, NH4-N, Cu, Zn) highlighted previously was enhanced by the substantial volume reduction observed in the outflow hydrographs. This reduction from inflow volume to outflow volume may have been enhanced by the steep gradient between the cell and the underlying water table. In other locations, with tighter soils and higher water tables, a reduced or perhaps negligible volume reduction could be expected. Previous field studies in North Carolina (performed on unlined bioretention cells) (Hunt et al. 2006)

and in Pennsylvania (Heasom et al. 2006) indicate that a substantial reduction in outflow can often be achieved.

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APPENDIX A

Additional Graphs and Tables

Table A1. Event Date, Size, and types of samples collected

Event Date	Depth of Precip. mm (in.)	Composite samples[1]	Bacteria Grab Samples[2]
2/7/2004	35.8 (1.41)	X	
5/5/2004	24.1 (0.95)	X	
6/1/2004	8.9 (0.35)	X	
7/17/2004	61.7 (2.43)	X	
8/12/2004	80.8 (3.18)		X (FC only)
8/28/2004	24.9 (0.98)	X	X (FC only)
9/27/2004	61.7 (2.43)	X	X (FC only)
10/13/2004	11.4 (0.45)	X	X (FC only)
11/4/2004	20.8 (0.82)	X	X (FC only)
12/6/2004	11.2 (0.44)	X	X
1/14/2005	26.2 (1.03)	X	X
2/14/2005	7.1 (0.28)		X
2/22/2005	11.4 (0.45)	X	X
3/8/2005	16.5 (0.65)	X	X
4/7/2005			X
4/13/2005	42.7 (1.68)	X	X
5/13/2005	6.4 (0.25)	X	X
6/28/2005	31.8 (1.25)	X	X
7/8/2005	16.0 (0.63)	X	
9/19/2005	15.0 (0.59)	X (except TP)	
10/6/2005	52.8 (2.08)	X (except Fe)	X
12/5/2005	32.3 (1.27)	X (except Fe)	X
12/12/2005	10.9 (0.43)	X (except Fe)	
12/16/2005	42.7 (1.68)		X
12/29/2005	8.9 (0.35)	X (except Fe)	X
3/22/2006	24.1 (0.95)	X (except Fe)	X

[1] - BOD-5, TN, NO2-3-N, TKN, NH4-N, TP, Total Solids, Zn, Cu, Fe, Pb
[2] – Fecal Coliform (FC), E. coli

Table A2 – Reduction from Peak Inflow to Peak Outflow at HMBC.

Event Date	Rainfall Amount (mm)	Peak Inflow (L/s)	Peak Outflow (L/s)	Reduction in Peak (%)
2/7/04	35.6	25.6	0.06	99.8
4/26/04	2.8	14.5	0	100
6/1/04	8.9	18.8	0.25	98.7
10/13/04	10.2	14.1	0.09	99.4
12/6/04	10.9	23.3	0.06	99.8
1/14/05	26.2	73.5	0.14	99.8
2/14/05	6.9	6.8	0.03	99.6
2/22/05	7.1	4.1	0.08	98.0
3/8/05	16.5	22.3	0.11	99.5
4/7/05	2.0	3.7	0	100
4/13/05	39.9	14.5	0.11	99.2
5/13/05	6.4	50.8	0.08	99.8
6/28/05	17.8 [a]	32.9	0.06	99.8
12/5/05	32.5	13.6	0.48	96.5
12/12/05	10.9	13.0	0.20	98.5
12/29/05	9.1	20.1	0.31	98.5

a – data collected at municipal location within 0.3 km (0.2 mi) of HMBC
Note: Five additional storms exceeding 42 mm were monitored, but overtopped the bioretention cell.

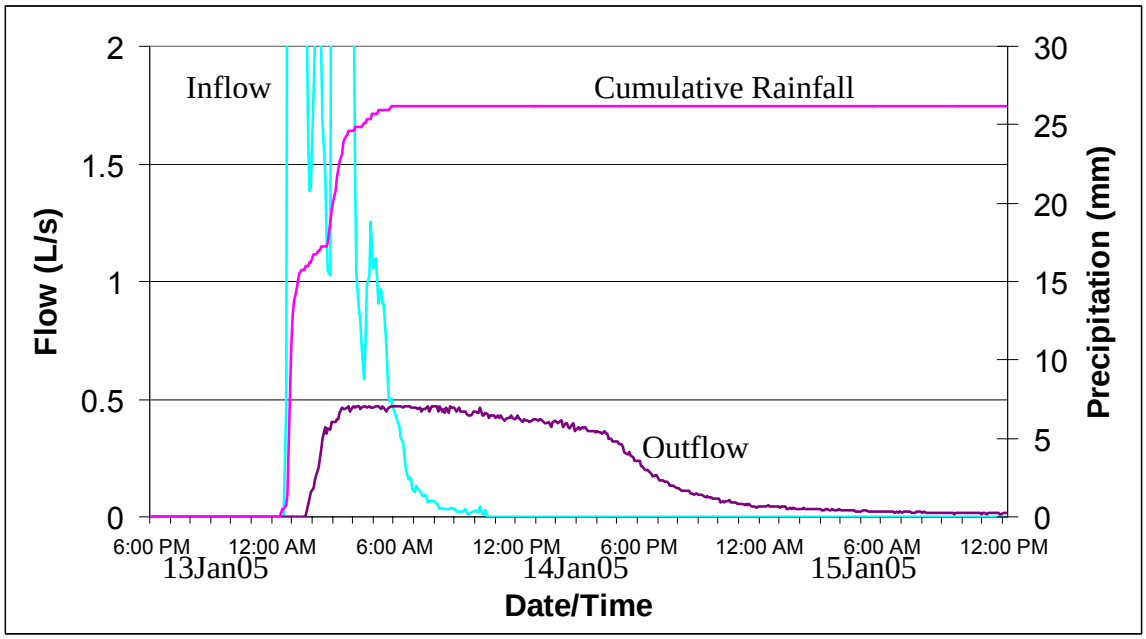

Figure A1. Inflow and Outflow Hydrographs for HMBC for 13-14 January 2005 rain event totaling 26.2 mm. Peak inflow for this event was 73.5 mm.

APPENDIX B

Monitoring Protocol

Stormwater BMP performance Monitoring Protocol for:

Hal Marshall Bioretention

Description of Site:

The Hal Marsh Bioretention area located at the Se corner of the municipal parking lot adjacent to the Hal Marsh building in Uptown Charlotte. The Bioretention area has recently been reinstalled due to clogging of the surface layer.

Watershed Characteristics

Area: .918 acres
Description Municipal parking area

Sampling equipment

A 120 degree v-notch weir has been installed to allow accurate measurement of flow at the inlet. A weir box with a 30 degree v-notch weir has been installed at the drawdown outlet. Bubblers will be used at both locations to determine flow rate.

Inlet Sampler
Primary device: 120 degree v-notch weir
Secondary Device: ISCO model 720 bubbler
Bottle Configuration 24 1000mL Propak containers

Outlet Sampler
Primary Device: 30 degree v-notch weir
Secondary Device: ISCO Model 720 Bubbler
Bottle Configuration 24 1000mL Propak containers
Rain gage ISCO model 673 tipping bucket

Sampler settings

Inlet Sampler
Sample Volume 200 mL
Distribution 5/bottle
Pacing 22 Cu Ft.
Set point enable None

Outlet Sampler	
Sample Volume	200mL
Distribution	5/bottle
Pacing	22 cu ft
Set point enable	none

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

Sample Collection and Analysis

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

General Monitoring Protocol

Introduction

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

Equipment Set-up

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

The use of ISCO refrigerated single bottle samplers may be used later in the study if future budgets allow. All samplers used for this study will be configured with 24 1000ml pro-pak containers. New pro-pak containers should

be used for each sampling event. Two different types of flow measurement modules will be used depending on the type of primary structure available for monitoring

Programming

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

Sample and data collection

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

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

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

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

Data Transfer

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