CITY of CHARLOTTE
Pilot BMP Monitoring Program

CATS - Bus Maintenance Operations Facility
Crystal Stream® Stormwater Treatment Structure

Final Monitoring Report

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Charlotte-Mecklenburg Storm Water Services

Purpose

The purpose of this report is to document monitoring and data analysis activities undertaken by the City of Charlotte, Mecklenburg County, and North Carolina State University to determine the effectiveness and stormwater treatment capabilities of a the Crystal Stream® stormwater treatment structure installed at the City of Charlotte-CATS-Bus Maintenance Operations Facility(BMOF).

Introduction

Hydrodynamic separators are a class of structural stormwater BMP that rely on the mechanisms of settling and separation to remove heavy particles (such as sediment) and floating particles (oil, grease, and gross solids) from a given watershed. Stormwater is routed into the flow-through system where the energy of the water carries it through the system in a particular flow path (typically a swirl action or through some filtration mechanism) where pollutants can be removed and stored in the system (EPA, 1999). Currently, there are a number of different models of hydrodynamic separators sold by private companies designed for use in stormwater treatment.

Hydrodynamic separators are designed primarily to remove sediment, oil, and grease from a given watershed. In addition, these systems have been shown to remove some nutrients and metals by various studies, primarily by slowing influent stormwater and allowing suspended particles to settle out. When flood control is a primary concern, hydrodynamic separators will not act to remediate the impact of imperious areas.

This report will focus on the effectiveness of the Crystal Stream®, a hydrodynamic separator produced by Crystal Stream Technologies Inc that was installed at the CATS BMOF site. This unit works byway of passing stormwater through a system of baffles and screens. Additional product information is available on the Crystal Stream Technologies website: http://www.crystalstream.com/.

Site Description

The Crystal Stream® model 1056 was installed at the Charlotte Area Transit System (CATS) Bus Maintenance and Operations Facility (BMOF). The drainage area for the system was approximately 0.69 acres and primarily consisted of concrete bus parking areas, driving lanes, fuel and wash areas, and metal roofs (Figure 1). Both the inlet and outlet for the system consisted of 15-inch reinforced concrete pipes.

Figure 1: Photo of watershed area draining to BMP

Monitoring Plan and Data Analysis

Inflow and outflow monitoring took place in the 15-inch reinforced concrete pipes located immediately upstream and downstream of the BMP, respectively. During some storm events, the inlet pipe had the potential for a slight tail water condition. Monitoring consisted of measuring stormwater flows utilizing an area-velocity flow meter in the inlet pipe and collecting flow-weighted composite samples using automated sampling equipment. Monitoring equipment was attached within the pipe system using expansion brackets as shown in Figure 2.

Figure 2: Typical installation of area-velocity probe (left) and sampler intake (right) with expansion bracket

The outlet of the system was not conducive to flow monitoring. To achieve a representative flow weighted sample, the inlet and outlet samplers were linked and a pulse was sent from the inlet sampler to the outlet sampler each time a flow paced aliquot was to be taken. Thus, flow measurements are based on the influent flow alone. The sample intake tubing was placed inside a reservoir installed where the effluent flow exited the system. Flow weighted samples were taken at both the inlet and outlet using this configuration.

Monitoring efforts were initiated in July 2005 and continued until March 2007, with 21 individual storm events being collected / measured approximately once per month. Additional inlet and outlet manual grab samples, from which levels of fecal coliform, *E. coli*, and oil & grease were measured, were collected for 7 of the 21 storm events (all 3 parameters were not analyzed in all 7 grab samples).

Average inflow and outflow event mean concentration (EMC) values for each pollutant were used to calculate a BMP efficiency ratio (ER):

$$ER = (EMC_{inflow} - EMC_{outflow}) / EMC_{inflow}$$

where EMC_{inflow} and $EMC_{outflow}$ represent the mean BMP inflow and outflow EMCs across all storm events. Removal rates were also calculated on a storm-by-storm basis. Some authors have suggested that reporting BMP effectiveness in terms of percent removal may not give a completely accurate picture of BMP performance in some situations (Urbonas, 2000; Winer, 2000; Strecker et al., 2001; US EPA, 2002). For example, if the influent concentration of a pollutant is extremely low, removal efficiencies will tend to be low due to the existence of an "irreducible concentration", lower than which no BMP can achieve (Schueler, 1996). For these relatively "clean" storms, low removal efficiencies may lead to the erroneous conclusion that the BMP is performing poorly, when in fact pollutant targets may be achieved. Caution should be used when interpreting BMP efficiency results that rely on a measure of percent or proportion of a pollutant removed.

Water quality data were compiled so paired events could be analyzed for significant changes in water quality from the inlet to the outlet. A student's t test is frequently used to test for statistical significance; however, this test relies on the assumption that the data set being analyzed is normally distributed. For data sets which contain less than 25 samples, it is difficult to determine how the data are distributed. Nevertheless, the data were checked for normality using the Kolmogorov-Smirnov (K-S) test. If the raw data were not normally distributed, a log transform of the data set was performed and it was once again tested for normality. In the case that the K-S test showed normal distribution for both the raw and log-transformed data, the log transform data were chosen for analysis.

Fortunately, there are tests that can show statistical significance regardless of distribution. A Wilcoxian Signed Rank (WSR) test is one example of a non-parametric statistical procedure (can show significance regardless of the distribution of a data set). This procedure was performed in addition to the Student's t test for all parameters. In the case that neither the raw data nor the log-transformed data could be verified as having a normal distribution, the outcome of the WSR was considered the only measure of statistical significance. If a particular data set had conflicting statistical results (Student's t test and WSR had two different results) the WSR was assumed correct. See Appendix A.

Data Analysis Results

Flow Results

The flow data collected at the site was obtained from the influent sampler. Thus, comparisons of influent and effluent flows can not be made. The influent volumes produced during each rain event are shown in figure 3. During some storm events, it is likely that backwater conditions were present in the system, which may have affected flow measurements; however, it is felt that the flow weighted samples collected were reasonable estimations of event mean pollutant concentrations produced. In addition, concentration data were analyzed as part of this study, which is the primary measurement factor being used to evaluate efficiency relationships between influent and effluent pollutants.

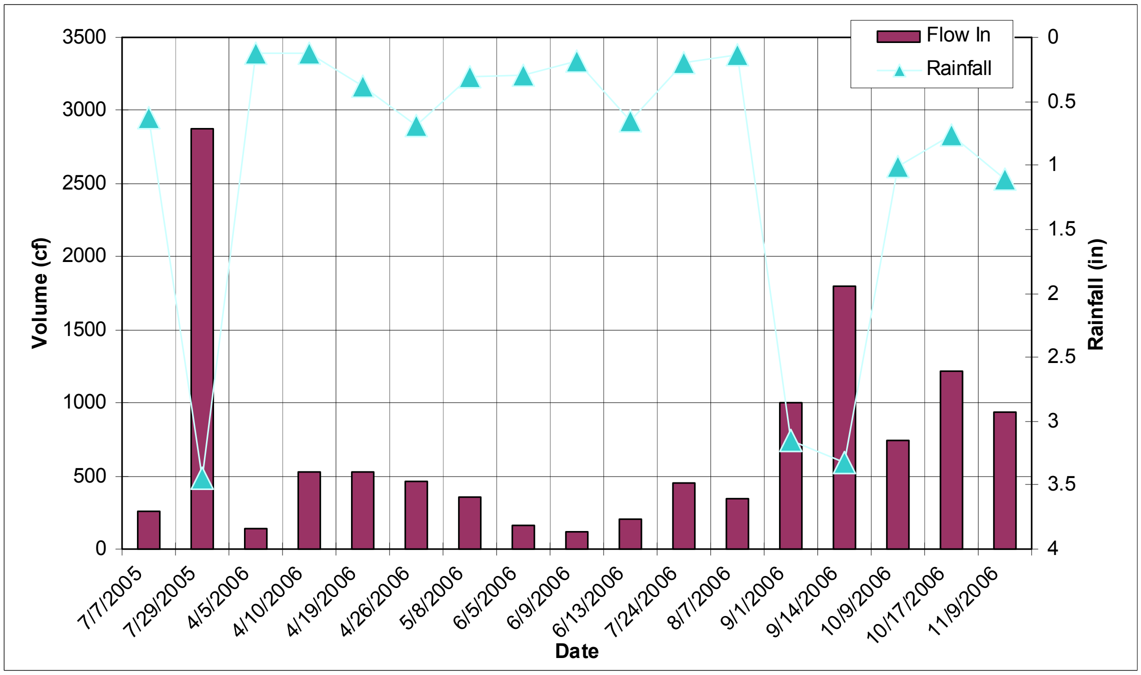

Figure 3: Influent volumes for various storm events

Water Quality Results

Figure 4 and Table 1 illustrate the performance of the CATS BMOF Crystal Stream® with regard to pollutant removal. The pollutant removal efficiency is described by the efficiency ratio (ER) which is discussed above. A positive ER indicates that the pollutant, which entered the BMP as stormwater runoff, was retained by the BMP. A negative ER represents a surplus of pollutant leaving the BMP, suggesting either internal production of pollutants, or more likely a loss of stored pollutants from previous storm events.

Negative ERs were calculated for BOD, COD, TKN, TR, Turbidity, and Zinc. None of these increases were statistically significant ($p<0.05$). There were positive ERs calculated for all other pollutants, with NOx, TSS, SSC, and lead being statistically significant reductions. The performance of this BMP varied from a water quality stand point. Changes in the ER were noted from storm to storm for many pollutants.

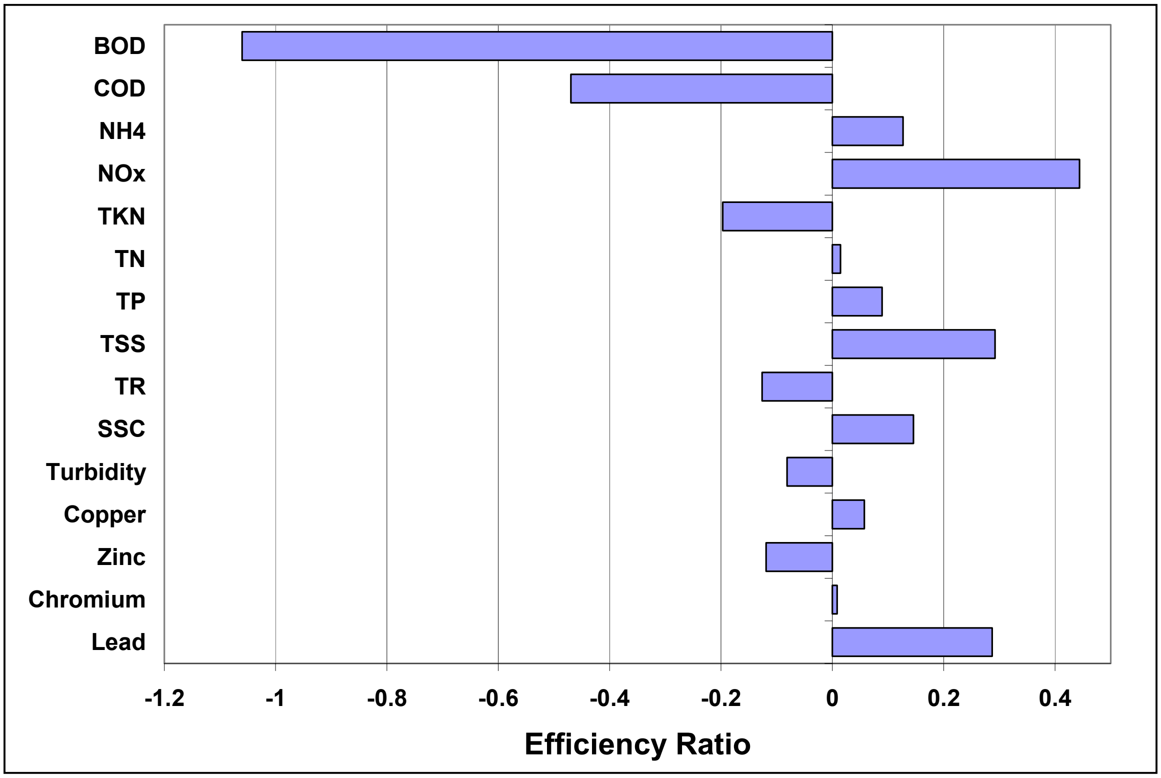

Figure 4: Efficiency ratios of selected pollutants based on pre- and post-BMP mean concentrations (EMCs) at the Crystal Stream®.

Efficiency ratio (ER) = $(EMC_{inflow} - EMC_{outflow}) / EMC_{inflow}$

Table 1: Summary of Water Quality Results

Parameter	Units	# of Samples	Influent EMC	Effluent EMC	ER	p-value	Significant ($p < 0.05$)
BOD	ppm	6	49.6	102.1	-106%	0.219	
COD	ppm	8	131.0	192.5	-47%	0.148	
NH4	ppm	20	0.2	0.2	13%	0.203	
NOx	ppm	20	0.4	0.2	44%	0.013	**Yes**
TKN	ppm	20	0.8	1.0	-20%	0.143	
TN	ppm	20	1.3	1.2	1%	0.956	
TP	ppm	20	0.2	0.1	9%	0.062	
TSS	ppm	20	34.0	24.0	29%	0.003	**Yes**
TR	ppm	9	147.8	166.4	-13%	0.250	
SSC	ppm	18	21.0	17.9	15%	0.026	**Yes**
Turbidity	NTU	21	18.1	19.6	-8%	0.742	
Copper	ppb	21	25.7	24.2	6%	0.431	
Zinc	ppb	21	149.2	167.0	-12%	0.496	
Chromium	ppb	21	5.6	5.6	1%	0.375	
Lead	ppb	21	10.0	7.1	29%	0.013	**Yes**

Sediment

The ER for TSS removal in the Crystal Stream® was 0.29 (significant at $\propto$=0.05). The storm to storm variability in TSS removal indicates that although there is some treatment for TSS occurring in the BMP, likely through sedimentation and filtration, there may also be some resuspension and passage of sediment during many storm events. Influent and effluent TSS concentrations substantially varied throughout the study (Appendix A – Figure A1).

In addition to the TSS samples taken at the site, 18 storm events were sampled for SSC as well. All SSC samples were taken after the system was serviced. SSC is considered by some to be a more accurate analysis of sediment concentration in a given sample (Glysson et al., 2000) as it more effectively takes large sediment particles into account. The ER for SSC removal in the Crystal Stream® was 15% (significant at $\propto$=0.05). SSC concentrations for each storm can be seen in Appendix A – Figure A2.

It should be noted that collecting samples from the bottom of the pipe (conventional method) could result in non-representative sediment samples during some storm events (Andoh et al., 2002 and Kayhanian et al., 2005). This is due to the orientation of sediment particles being conveyed during a storm event in a given pipe. Heavier particles tend to flow along the bottom of the pipe, while lighter particles flow along the water surface. It is desirable to collect a sample which is pulled from the entire flow stream, which may not have occurred during some larger storm events. However, this was not a feasible goal for the purpose of this study, as the Pilot BMP monitoring program has employed conventional monitoring protocols to analyze various types of BMPs.

A review of literature shows some studies have been performed specifically on the function of the Crystal Stream®, and it was tested as part of the Environmental Protection Agency (EPA) Environmental Technology Verification (ETV) Program. The study performed on the Crystal Stream® as part of the ETV program showed a TSS ER of 15%, reasonably close to that determined in the CATS-BMOF study. The removal efficiency of the BMP varied storm to storm in the ETV study. Removal efficiencies ranged from -120% to 68% for the 15 storms analyzed in the ETV study, while the removal efficiencies ranged from -100 to 81% during the CATS-BMOT study. Both studies indicate high storm to storm performance variability.

Particle size analyses were performed on samples as part of the ETV study. The sediment in the samples was divided into categories representing the percentage of the sediment particles that fell into a sand classification and the percentage that fell into a silt (or smaller) classification. These analyses showed that the effluent samples contained a higher percentage of silt particles than sand particles, commonly having a lower sand percentage than the influent samples. The sand / silt distribution in the influent samples varied substantially throughout the study performed as part of the ETV.

Sediment makeup can impact hydrodynamic separator function (Andoh et al. 2002 and Barbaro, 2005). Small sediment particles can be more difficult to remove from the flow stream and can be considered non-settleable suspended solids. The presence of settleable solids is important in the function of BMPs that rely on hydraulics instead of filtering to remove solids.

In addition to the documentation pertaining to the function of the Crystal Stream® with regard to pollutant removal efficiency, there have been hydrodynamic devices studied and input into the International Stormwater BMP Database (ISBD). Table 2 shows the median pollutant effluent concentration for Hydrodynamic devices in the International Stormwater BMP database (Geosyntec, 2006). The median effluent TSS concentration determined for the CATS-BMOF Crystal Stream® (16.5 mg/L) is lower than that reported by Geosyntec, 2006 (36 mg/L) in a report summarizing studies in the International Stormwater BMP Database. It should also be noted that the report by Geosyntec (2006) indicated a significant difference in the influent and effluent TSS EMC for hydrodynamic devices in the International Stormwater BMP Database, the CATS-BMOF study produced the same result for the Crystal Stream®.

Table 2: Comparison of Median Effluent Concentration for Various Hydrodynamic Devices

Parameter	**Crystal Stream at CATS - BMOF**		**International Stormwater BMP database (Geosyntec, 2006)**		
	Median of Effluent EMCs (mg/L)	Significant Difference between influent and effluent EMC ?	Median of Effluent EMCs (mg/L)	Significant Difference between influent and effluent EMC ?	Number of BMPs Studied
TSS	16.50	Yes	36	Yes	14
TN	0.85	No	2.16	No	2
TKN	0.65	No	1.31	No	4
NOx	0.14	Yes	0.25	No	4
TP	0.08	No	0.16	Yes	12
Zinc	110.00	No	100	Yes	11
Copper	15.00	No	15	No	9
Lead	5.00	Yes	6.7	Yes	8

Nutrients and Organic Material

Crystal Stream® removal rates for TN and TP are not readily documented by other studies; however, the median effluent concentrations can be compared to the International Stormwater BMP Database (Table 2). By comparison, this study showed effluent concentrations that were lower than other hydrodynamic separator studies. A major pollutant removal mechanism typical of hydrodynamic devices is sedimentation. Since many pollutants are associated with sediment, this pollutant removal mechanism can have a substantial impact (Vaze and

Chiew, 2004) on some nutrients. In this case, however, a low TSS removal efficiency may be tied to the low removal efficiency of other pollutants.

Oxygen Demand:

Biochemical oxygen demand (BOD_5) and COD are typical measurements of the amount of organic matter in stormwater runoff. Any process that contributes to the decomposition of organic matter will cause a reduction of BOD_5 and COD. Physically, this can occur by adsorption onto particles and subsequent filtration and sedimentation. The Crystal Stream® BOD removal efficiency was -106% and the COD removal efficiency was -47%. There was a lack of literature pertaining to the function of hydrodynamic devices in the removal of COD and BOD, so comparisons to national studies were not made.

Nitrogen:

Soluble pollutants can be removed by chemical adsorption to suspended particles followed by sedimentation of those particles, and by plant uptake and microbial transformations. In stormwater treatment practices (such as wet ponds and wetlands) which rely on biogeochemical reactions, a major removal mechanism of the various forms of nitrogen present in a natural system is bacterial transformation. Hydrodynamic devices are not considered nitrogen reducing BMPs and are not expected to employ the same mechanisms of pollutant removal as other BMPs (oxidation-reduction reactions, plant uptake, etc.). Thus, nutrient removal in hydrodynamic devices would presumably be low. TKN, NOx, NH_4, and TN removal in the CATS BMOF Crystal Stream® was -20%, 44%, 12%, and -1% respectively. The analysis showed the relationship for NOx to be statistically significant. The removal of NOx indicates some anaerobic conditions within the system, likely in the sediment stored within the device. The relatively high NOx and NH4 removal, and low TN removal (along with the high BOD and COD values) suggests that there is some organic matter being added to the flow stream as it passes through the system.

The effluent concentrations of these nitrogen species can be compared, to some degree, with other hydrodynamic devices in the International Stormwater BMP Database. Geosyntec (2006) reported the median effluent concentrations for TKN, NOx, and TN as 1.31 mg/L, 0.25 mg/L, and 2.16 mg/L, respectively. The monitoring study performed on the Crystal Stream® at the CATS BMOF showed median effluent concentrations of 0.65 mg/L, 0.14 mg/L, and 0.85 mg/L, respectively. Influent EMCs for TKN, NOx, and TN were relatively low, likely leading to lower removal efficiencies. In comparison with the ISBD, the median effluent concentrations for TKN, NOx, and TN were low. Median effluent Inflow and outflow TN concentrations for each storm can be seen in Appendix A – Figure A3.

Phosphorous:

TP removal in the CATS BMOF Crystal Stream® was 9%, a statistically insignificant relationship. Adsorption onto iron-oxide and aluminum-oxide surfaces and complexation with organic acids accounts for a large portion of phosphorus removal from the water column. In some natural systems, these particles can fall out of solution and be stored on the bottom of the treatment system. Under some conditions, phosphorous can be released from the sediment, adding to the effluent mass of TP. The removal of NOx would suggest some anoxic conditions occur in this device, the same conditions needed for phosphorous export; however, the relatively low TSS removal indicates that TP that is bound to sediment is not being removed from the system through sedimentation.

The median effluent concentration of TP was slightly lower than that determined for hydrodynamic devices in the ISBD. The median effluent concentration of TP determined for the Crystal Stream® (0.08 mg/L) is relatively close to that reported by Geosyntec (2006) (0.16 mg/L). Since the median influent concentration of TP calculated for the device was 0.012 mg/L, it is probable that this hydrodynamic separator receives stormwater with a TP concentration so close to an irreducible concentration, that a low removal efficiency results; additionally, sediment bound TP was not readily removed. Inflow and outflow TP concentrations for each storm can be seen in Appendix A – Figure A4.

Metals

As for most of the other pollutants discussed in this document, trace metals can be removed from the water column through physical filtering and settling/sedimentation. Additionally, trace metals readily form complexes with organic matter, which can then become attached to suspended particles. As with phosphorus, the storage of metals on sediments creates conditions under which the pollutant is susceptible to future loss/transformation if conditions are favorable, particularly if their storage zone becomes saturated.

The Crystal Stream® exhibited a metal removal efficiency that would be expected based on the TSS removal. Zinc, copper and lead removal in the system was -12%, 6% and 29%, respectively. The lead concentrations were consistently at or below the minimum detectable level (5 mg/L), thus, efficiency ratios and median effluent concentrations cannot be evaluated. Compared to other studies performed on hydrodynamic devices, the median effluent concentration of zinc (110 mg/L) was consistent with that reported in the ISBD (100 mg/L). The median effluent concentration of copper (15 mg/L) was the same as that reported in the ISBD (15 mg/L) (Table 2).

CONCLUSIONS

Based on the monitoring data collected and analyzed for this study at the CATS BMOF, the Crystal Stream® showed low performance when the site was evaluated byway of removal efficiency ratios and compared to the 85% removal efficiency criteria in the City's NPDES stormwater permit. The BMP was routinely maintained at semi-annual to annual intervals, and removal efficiencies were found to be positive in regards to TSS, TN, and TP. It is likely that the low influent concentration of pollutants entering this hydrodynamic BMP was a factor which impacted these findings. In addition, sampling at the invert of the stormwater pipes may also have been a factor for some storm events monitored. Effluent concentrations of TSS, TP, and TN were lower than those reported for hydrodynamic devices in the International Stormwater BMP database, indicating that although the efficiency ratios determined for various pollutants were less than the 85% removal efficiency desired by the City of Charlotte, the low influent concentrations may have played a role in the BMP performance.

Compared to the results of the analysis on the Crystal Stream® as part of the EPA - ETV program, the sediment removal at CATS BMOF was similar. Low influent sediment concentrations and the presumed fine sediment particles in the influent likely played a role in the relatively low TSS efficiency described in this report. As low concentrations of fine particles are hard to remove from the flow stream, the efficiency of the system would presumably (and understandably) be lower.

There is some debate among the water quality profession concerning the most appropriate methodology to quantify suspended sediment concentrations in surface water quality samples. While TSS is the most commonly evaluated parameter, suspended sediment concentration (SSC) is considered by some to be a more appropriate way to quantify this pollutant; however, it should be noted that the City of Charlotte's NPDES stormwater permit requires stormwater BMPs to be adequately designed to reduce TSS by 85% in stormwater runoff. Therefore, a TSS removal efficiency of 85% is the predominate indicator of BMP performance evaluation within the City's BMP monitoring program. For comparison purposes, both TSS and SSC samples were collected and analyzed for a number of storm events monitored at this BMP site. The TSS removal efficiency was 29%, while the SSC removal efficiency was 15% at the CATS BMOF site.

Other pollutants of concern such as TN, TP, and various metals were not efficiently removed by the BMP (Figure 4 and Table 1); however, the median effluent concentrations of TN and TP were lower than those reported by Geosyntec, 2006 in an analysis of hydrodynamic devices in the International

Stormwater BMP Database. Influent concentrations were potentially close enough to the irreducible concentration such that efficiency ratios indicate low performance. Median metal effluent concentrations were consistent with those reported by Geosyntec, 2006.

The storm by storm removal efficiencies seen in Appendix A (figures A1-A4) show the fluctuation in removal efficiency that occurred throughout the study. A similar pattern was noticed in the results of the ETV study and also reported by Andoh et al. (2002), who observed variable TSS removal performance yet relatively consistent effluent TSS concentrations. A similar consistent effluent TSS concentration was not observed in this study, possibly due to the low influent TSS concentration.

While the removal efficiencies reported for the Crystal Stream® BMP in this study were less than the 85% TSS removal efficiency criteria in the City's NPDES stormwater permit, the results apply to the BMP's performance within one specific land use type (that being impervious areas associated with commercial/municipal parking areas and roof tops). In addition, it should be noted that the influent EMCs reported at the CATS BMOF facility were comparable to influent EMCs reported for other conventional BMPs with similar land use types studied under the City's program.

REFERENCES

Andoh, Robert Y. G., S.P. Hides, and A.J. Saul. 2002. Improving Water Quality Using Hydrodynamic Vortex Separators and Screening Systems. 9th International Conference on Urban Drainage. September 8-13, 2002, Portland, Oregon.

Barbaro, Henry, and Clay Kurison. 2005. Evaluating Hydrodynamic Separators. Boston, Ma, Massachusetts Highway Department.

GeoSyntec Consultants. 2006. Analysis of treatment system performance. International Stormwater Best Management Practices (BMP) Database [1999-2005]. Water Environment Research Foundation. http://www.bmpdatabase.org/ [accessed May 1, 2006].

Glysson, G.D., J.R. Gray, and G.E. Schwartz. 2001. A Comparison of Load Estimates Using Total Suspended Solids and Suspended-Sediment Concentration Data. World Water and Environmental Resources Congress. May 20-24, 2001, Orlando, Florida.

Kayhanian, M., Thomas Young, and Michael Stenstrom. 2005. Limitations of Current Solids Measurements in Stormwater Runoff: A Discussion of Sampling, Classifying, and Quantifying Suspended Solids. Stormwater Magazine. July/August 2005.

Schueler, T. 1996. Irreducible pollutant concentrations discharged from stormwater practices. Technical Note 75. Watershed Protection Techniques. 2:369-372.

Strecker, E.W., M.M. Quigley, B.R. Urbonas, J.E. Jones, and J.K. Clary. 2001. Determining urban stormwater BMP effectiveness. J. Water Resources Planning and Management. 127:144-149.

U.S. Environmental Protection Agency. 2005. Environmental Technology Verification Report – Stormwater Source Area Treatment Device: Practical Best Management of Georgia, Inc. Crystal Stream™ Water Quality Vault Model 1056. EPA 600/R-05/085. National Risk Management Research Laboratory – Water Supply and Water Resources Division.

U.S. Environmental Protection Agency and Amer. Soc. Civil Engineers. 2002. Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater Database Requirements. U.S. EPA. EPA-821-B-02-001. Washington, DC.

Urbonas, B.R. 2000. Assessment of stormwater best management practice effectiveness (chapter 7). *In:* (eds). Heaney, J.P., R. Pitt, R. Field. Innovative

Urban Wet-Weather Flow Management Systems. EPA/600/R-99/029. Washington, DC.

Vaze, J. and F.H.S. Chiew. 2004. Nutrient loads associated with different sediment sizes in urban stormwater and surface pollution. J. Environmental Engineering. 130:391-396.

Winer, R. March 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices, 2nd Edition. Center for Watershed Protection. U.S. EPA Office of Science and Technology

Crystal Stream Technologies website: http://www.crystalstream.com/.

APPENDIX A

Additional Graphs and Tables

Table A1: Results of statistical between inlet and outlet BMP concentrations of selected pollutants at the CATS BMOF Crystal Stream®

Parameter	Assumed Distribution	Reject Based on KS Test	Paired *t*-Test	Wilcoxian Signed - Rank Test	Significant ?
			***p* - value**		
BOD	Log	No	0.2165	0.219	
COD	Log	No	0.1676	0.148	
NH4	Log	**Yes**	0.1949	0.203	
NOx	Log	**Yes**	0.0098	0.013	**Yes**
TKN	Log	No	0.1709	0.143	
TN	Log	No	0.9092	0.956	
TP	Log	No	0.0314	0.062	
TSS	Log	No	0.0028	0.003	**Yes**
TR	Log	No	0.1961	0.250	
SSC	Log	**Yes**	0.0925	0.026	**Yes**
Turbidity	Log	No	0.6082	0.742	
Copper	Log	No	0.4416	0.431	
Zinc	Log	No	0.6945	0.496	
Chromium	Log	**Yes**	0.2889	0.375	
Lead	Log	**Yes**	0.0460	0.013	**Yes**

1. Rejection (α=0.05) of Kolmogorov-Smirnov goodness-of-fit test statistic implies that the assumed distribution is not a good fit of these data.

2. Statistical tests were performed on log-transformed data except for copper, in which case raw data were used.

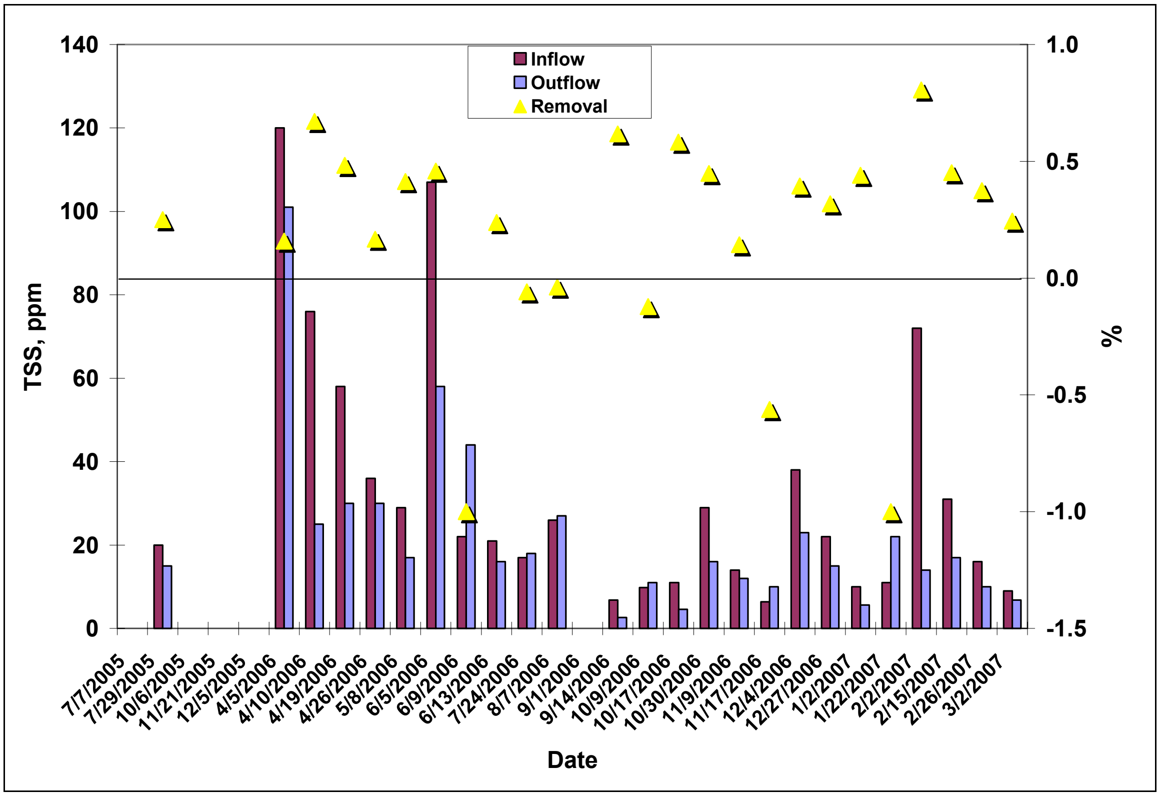

Figure A1: Change in TSS concentration due to BMP treatment by storm event.

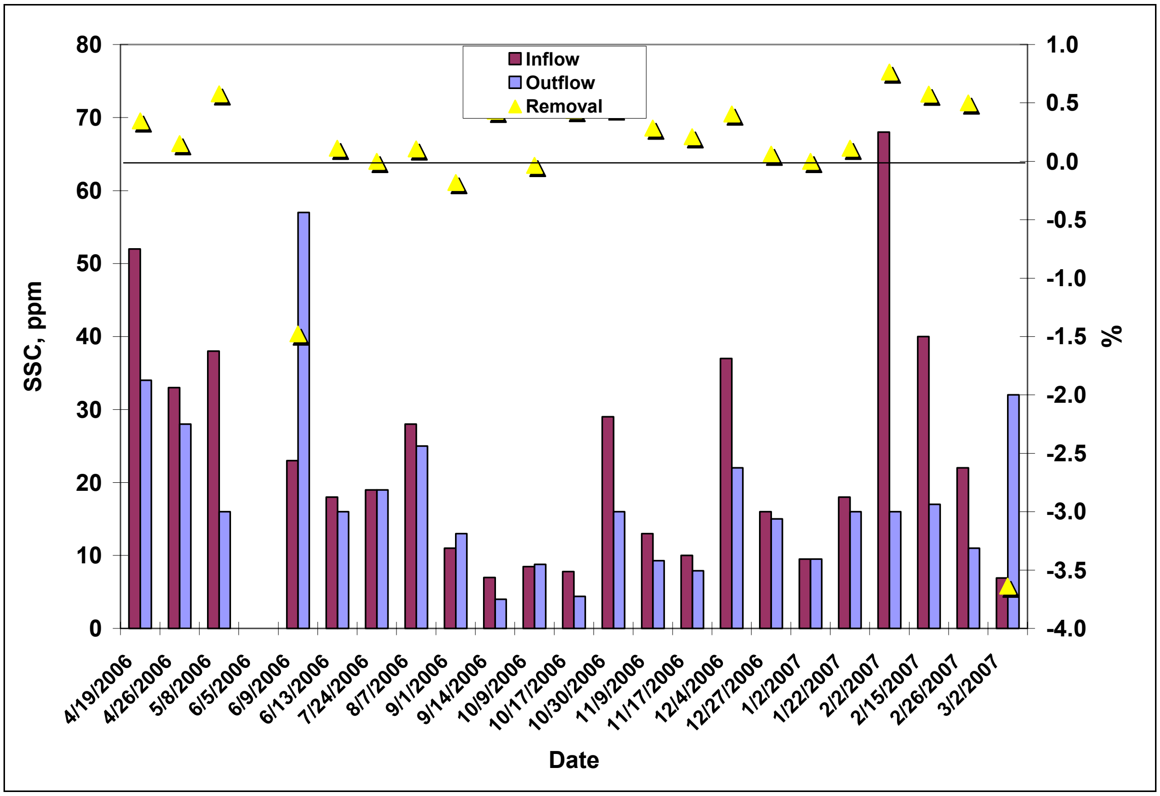

Figure A2: Change in SSC concentration due to BMP treatment by storm event.

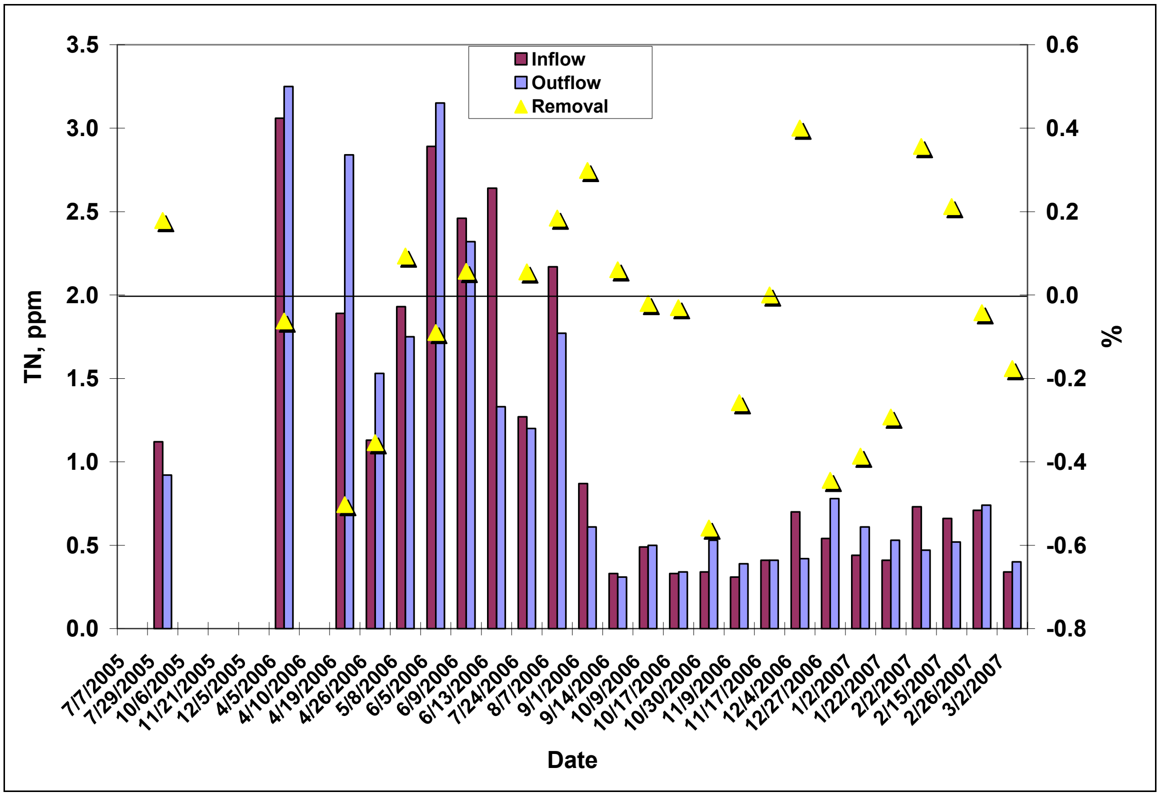

Figure A3: Change in TN concentration due to BMP treatment by storm event.

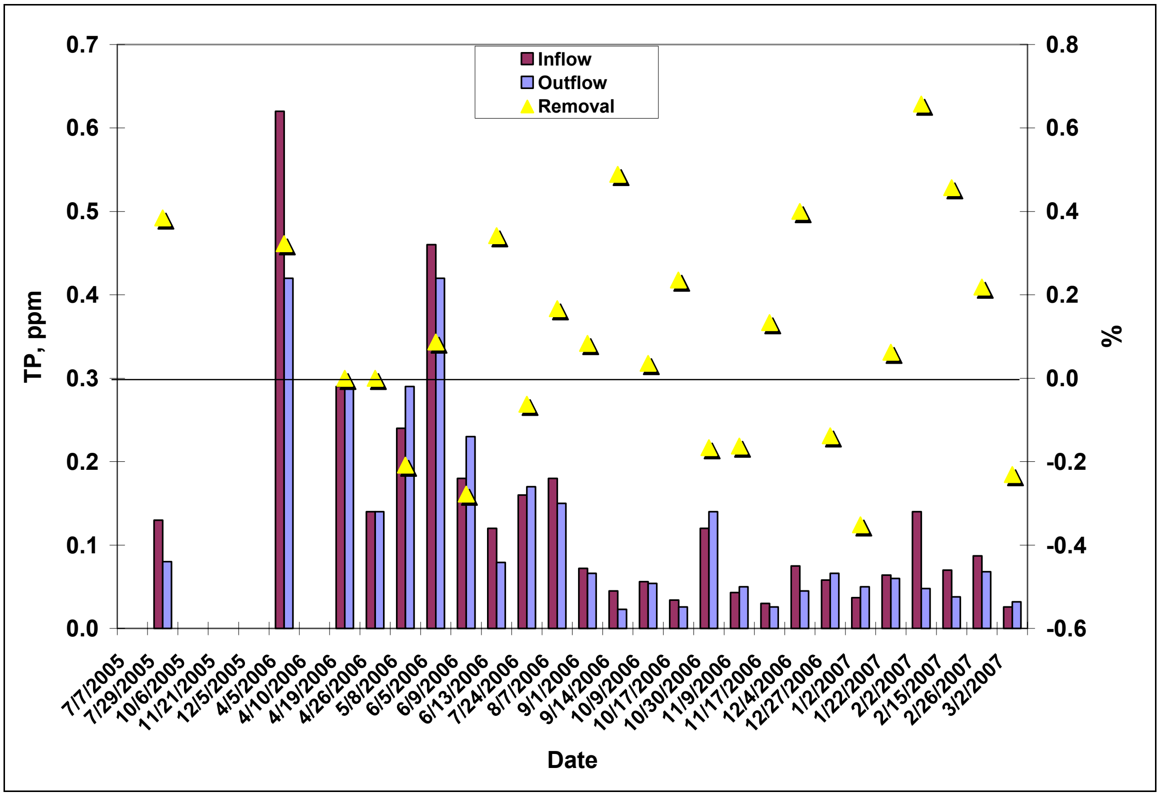

Figure A4: Change in TP concentration due to BMP treatment by storm event.

APPENDIX B

Monitoring Protocol

Stormwater BMP performance Monitoring Protocol for:

CATS Bus Maintenance and Operations Facility
Crystal Stream® BMP

Description of Site:

The CATS-BMOF Crystal Stream® BMP is a manufactured proprietary BMP serving a portion of the Bus Maintenance and Operations Facility for the City of Charlotte.

Watershed Characteristics (estimated)

Watershed served by Crystal Stream® BMP is approximately 0.69 acres and is 100% impervious concrete and metal roof surfaces. Primary use of the watershed is for bus parking and fuel and wash activities.

Sampling equipment

Monitoring will take place in the 15” RCP pipes at the sampling manholes located immediately upstream and downstream of the BMP. During storm events this pipe may experience a tail water condition. As a result it is necessary to utilize a low profile Area-Velocity meter at this location. The Area-Velocity meter should be positioned just upstream of the flared section of RCP and not further upstream to avoid any potential turbulence caused by upstream structures.

Inlet Sampler	
Primary device:	15” diameter RCP
Secondary Device:	ISCO model 750 area-velocity meter
Sampler	ISCO 3712 Avalanche
Bottle Configuration	four 1 gal polypropylene bottles

Outlet Sampler	
Primary Device:	N/A
Secondary Device:	N/A
Sampler	ISCO 3712 Avalanche
Bottle Configuration	four 1 gal polypropylene bottle
Rain gage	ISCO model 674 installed onsite

Sampler settings

Inlet Sampler

Sample Volume	200 mL
Pacing	32 Cu Ft.
Set point enable	None

Outlet Sampler

Sample Volume	200mL
Pacing	32 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 and analyzed in accordance with the *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.