

# CITY of CHARLOTTE Pilot BMP Monitoring Program

## CATS - Bus Maintenance Operations Facility CDS<sup>®</sup> Stormwater Treatment Structure 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, Mecklenburg County, and North Carolina State University to determine the effectiveness and stormwater treatment capabilities of the CDS<sup>®</sup> Technologies 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 CDS<sup>®</sup>, a hydrodynamic separator produced by CDS Technologies Inc. that was installed at the CATS BMOF site. This unit works byway of a swirl action produced in the system and also by indirect screening. Additional product information is available on the CDS Technologies website: <http://www.cdstech.com/>.

## Site Description

The CDS<sup>®</sup> Model PMSU 40\_30 was installed at the Charlotte Area Transit System (CATS) Bus Maintenance and Operations Facility (BMOF). The drainage area for the system was approximately 2.19 acres and primarily consisted of concrete bus parking areas, driving lanes, and metal roofs (Figure 1). Both the inlet and outlet for the system consisted of 24-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 24-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 area-velocity flow meters 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**

Monitoring efforts were initiated in July 2005 and continued until March 2007, with 27 individual storm events being collected / measured approximately once per month. Additional manual grab samples, from which levels of fecal coliform, *E. coli*, and oil & grease were measured, were collected for 7 of the 25 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.

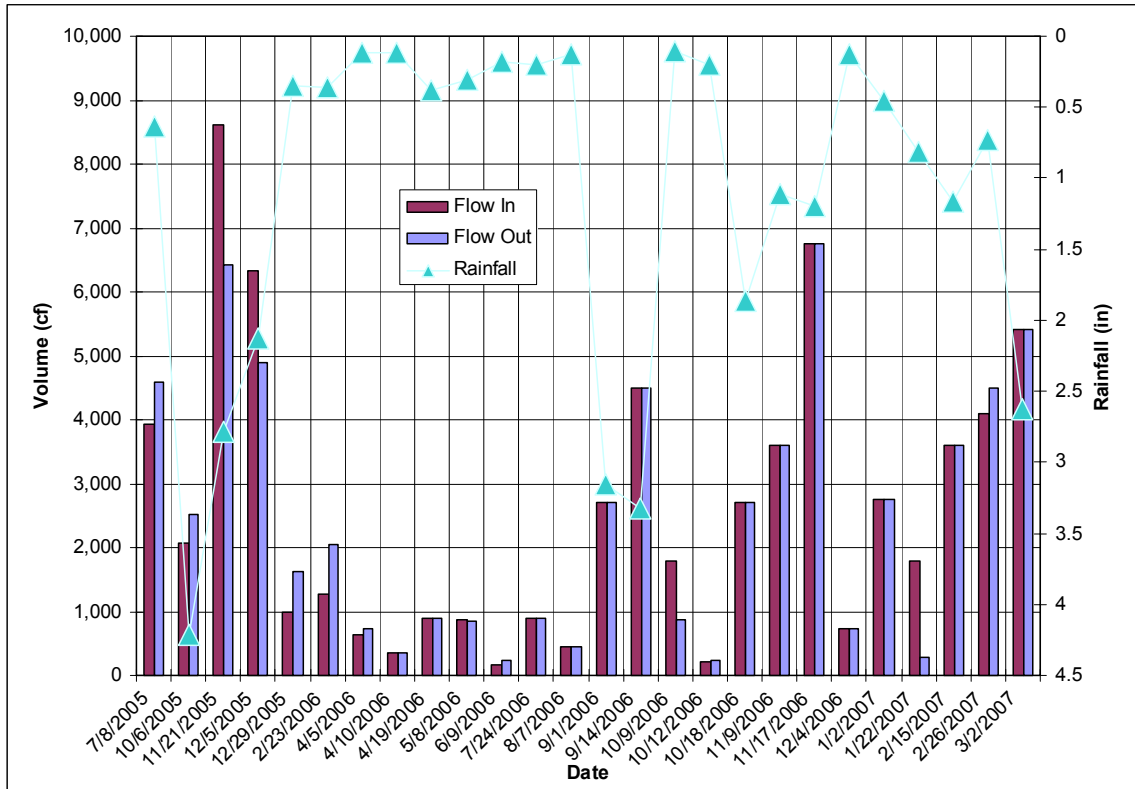
Fortunately, there are tests that can show statistical significance regardless of distribution. A Wilcoxon Signed Rank (WSR) test is one example of a non-parametric statistical procedure (can show significance regardless of the distribution of a data set). This procedure was performed in addition to 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 somewhat inconsistent with what would be expected. This BMP is not intended to be a detention system; thus, the flow that enters should be equal to the flow that exits during a given rain event. The area velocity meters used for monitoring the CATS BMOF CDS<sup>®</sup> produced different flow values at the inlet and outlet during many storm events (Figure 3), with either the inlet or outlet being higher for a given storm event. This is likely

due to the wide variability of factors that can affect area velocity flow measurement in smaller pipe systems for any given storm event. In addition, during some storm events, backwater conditions were present in the system, which may also have contributed to the variability of flow measurements. Although inflow and outflow flow measurements did not match as expected, 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.



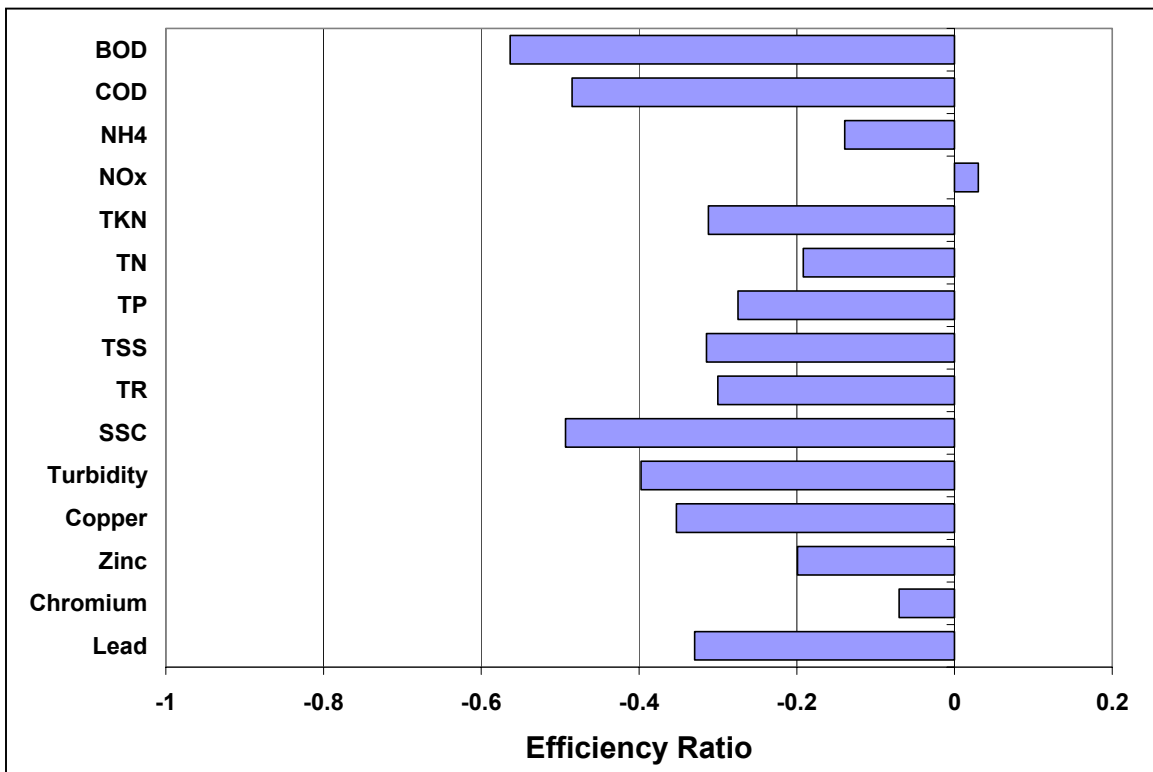
**Figure 3: Influent and effluent volumes for various storm events**

### **Water Quality Results**

Figure 4 and Table 1 illustrate the performance of the CATS BMOF CDS<sup>®</sup> 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 all pollutants other than NO<sub>x</sub>; however, the increases in BOD, NH<sub>4</sub>, and chromium were not statistically significant ( $p < 0.05$ ). The decrease in NO<sub>x</sub> was also not statistically significant. The performance of this BMP varied from a water quality standpoint. Changes in the ER were noted from storm to storm for many pollutants. According to statistical tests performed on the data set collected from the site, the CATS BMOF CDS<sup>®</sup> did not significantly ( $p < 0.05$ ) reduce any pollutants (Figure 4 and Table 1).



**Figure 4: Efficiency ratios of selected pollutants based on pre- and post-BMP mean concentrations (EMCs) at the CDS<sup>®</sup>.**

$$\text{Efficiency ratio (ER)} = (\text{EMC}_{\text{inflow}} - \text{EMC}_{\text{outflow}}) / \text{EMC}_{\text{inflow}}$$

**Table 1: Summary of Water Quality Results**

Parameter	Units	# of Samples	Influent EMC	Effluent EMC	ER	p-value	Significant (p < 0.05)
<b>BOD</b>	ppm	<b>9</b>	18.9	23.6	-0.56	0.078	No
<b>COD</b>	ppm	<b>11</b>	60.0	87.2	-0.48	0.005	<b>Yes</b>
<b>NH<sub>4</sub></b>	ppm	<b>27</b>	0.1	0.1	-0.14	0.637	No
<b>NOx</b>	ppm	<b>27</b>	0.4	0.4	0.03	0.815	No
<b>TKN</b>	ppm	<b>27</b>	0.6	0.7	-0.31	0.012	<b>Yes</b>
<b>TN</b>	ppm	<b>27</b>	1.0	1.0	-0.19	0.030	<b>Yes</b>
<b>TP</b>	ppm	<b>27</b>	0.1	0.1	-0.27	<0.0001	<b>Yes</b>
<b>TSS</b>	ppm	<b>27</b>	23.0	30.0	-0.31	0.001	<b>Yes</b>
<b>TR</b>	ppm	<b>11</b>	75.0	98.0	-0.30	0.012	<b>Yes</b>
<b>SSC</b>	ppm	<b>20</b>	20.0	29.0	-0.49	0.001	<b>Yes</b>
<b>Turbidity</b>	NTU	<b>27</b>	13.0	14.0	-0.40	0.000	<b>Yes</b>
<b>Copper</b>	ppb	<b>27</b>	14.0	19.0	-0.35	<0.0001	<b>Yes</b>
<b>Zinc</b>	ppb	<b>27</b>	120.0	150.0	-0.20	0.013	<b>Yes</b>
<b>Chromium</b>	ppb	<b>27</b>	5.0	5.0	-0.07	0.090	No
<b>Lead</b>	ppb	<b>27</b>	5.0	6.4	-0.33	0.001	<b>Yes</b>

## Sediment

The ER for TSS removal in the CDS<sup>®</sup> was -0.31 (significant at  $\alpha=0.05$ ). The storm to storm variability in TSS removal indicates that although there may be some treatment for TSS is 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, and statistically significant relationships were not found (Appendix A – Figure A1). The BMP was cleaned in early 2005 as part of the site construction close out and then again in March 2006, September 2006, and March 2007. Because only individual storm events were monitored, on a monthly basis, and not all storm events were captured, performing a mass balance was not feasible; therefore, it is possible for the BMP to show a negative pollutant removal (conservation of mass can not be applied).

In addition to the TSS samples taken at the site, 20 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). The ER for SSC removal





in the CDS<sup>®</sup> was -49% (significant at  $\alpha=0.05$ ). SSC concentrations for each storm can be seen in Appendix A – Figure A2.

It should be noted that there was a substantially lower number of samples analyzed for SSC than TSS (Table 1) and that collecting samples from the bottom of the pipe (conventional method) could result in non-representative 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 CDS<sup>®</sup>, and it was tested as part of the New Jersey Corporation for Advanced Technology (NJCAT) Program. In the study, the manufacturer's claims regarding solids mass removal efficiency (which vary depending on model size and operating flow) were verified per the New Jersey Department of Environmental Protection (NJDEP) treatment efficiency calculation methodology. Observation of the laboratory testing method; however, showed that the test was performed multiple times using either fine sand (or coarser sand). An average  $d_{50}$  was not given and the sediment addition was described in terms of a mass instead of a concentration, making comparisons to field testing difficult.

The conditions under which the system was tested in the laboratory (as discussed in the NJCAT report) likely differ from those experienced during the Charlotte pilot BMP monitoring program. Although no particle size analysis was performed on the influent or effluent sediment from the BMP, a brief study of the soils in Mecklenburg County shows that the dominant soils types in the area are loam, sandy loam, and sandy clay loam. The estimated  $d_{50}$  for these soils ranges between 98 and 35 (Munoz-Carpena and Parsons, 2005), which suggests the



potential presence of smaller soil particles than those described in the NJCAT study (fine sand). This can not be verified due to the lack of a particle size analysis but is inferred from the soils present in the surrounding areas. In addition, other sources of suspended sediment may occur in urban stormwater runoff based on watershed characteristics. 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.

Some case studies of CDS<sup>®</sup> performance are described in the NJCAT report. The case studies indicated various levels of performance. One such study performed in Brevard County, Florida, showed an average TSS removal efficiency of 55%. However, a study from Issaquah, Washington, showed higher concentrations of TSS in the system's effluent for 68% of the sample pairs evaluated in the study. A sieve analysis performed on samples collected during one storm event showed that 60% of the solids in the influent sample were smaller than 63 micron. Another study performed in Melbourne, Australia showed that TSS removal in the CDS system being studied was erratic at concentrations lower than 75 mg/L. These studies seem to indicate, as mentioned above, that particle size and influent sediment concentration plays a major role in hydrodynamic system function. Small particles in low concentrations are difficult to remove from stormwater flows. This was likely the scenario at the CATS-BMOF site, where median influent concentrations were approximately 30 mg/L.

In addition to the documentation pertaining to the function of the CDS<sup>®</sup> 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 CDS<sup>®</sup> (30 mg/L) is relatively close to that reported by Geosyntec,



2006 (36 mg/L) in a report summarizing studies in the International Stormwater BMP Database. Low inflow concentrations likely contributed to the low TSS ER reported for the CDS<sup>®</sup> in this study. This indicates that the influent TSS concentration may have been at or below the irreducible concentration for hydrodynamic devices. It should be noted that the report by Geosyntec (2006) indicated a significant difference in the influent and effluent EMC for hydrodynamic devices in the International Stormwater BMP Database; however, the composition of the influent sediment and the influent concentrations are not reported.

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

Parameter	CDS <sup>®</sup> 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
<b>TSS</b>	30	Yes (negative)	36	Yes	14
<b>TN</b>	1.04	Yes (negative)	2.16	No	2
<b>TKN</b>	0.69	Yes (negative)	1.31	No	4
<b>NOx</b>	0.35	No	0.25	No	4
<b>TP</b>	0.1	Yes (negative)	0.16	Yes	12
<b>Zinc</b>	150	Yes (negative)	100	Yes	11
<b>Copper</b>	19	Yes (negative)	15	No	9
<b>Lead</b>	6.4	Yes (negative)	6.7	Yes	8

### Nutrients and Organic Material

CDS<sup>®</sup> 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<sub>5</sub>) 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<sub>5</sub> and COD. Physically, this can occur by adsorption onto particles and subsequent filtration and sedimentation. The CDS<sup>®</sup> BOD removal efficiency was -56% and the COD removal efficiency was -48%. This is likely tied to the low TSS removal efficiency determined for the device.

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, NO<sub>x</sub>, NH<sub>4</sub>, and TN removal in the CATS BMOF CDS<sup>®</sup> was -31%, 3%, -14%, and -19% respectively. The analysis showed the relationships for TKN and TN to be statistically significant. The removal of NO<sub>x</sub> indicates some anaerobic conditions within the system, likely in the sediment stored within the device.

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, NO<sub>x</sub>, and TN as 1.31 mg/L, 0.25 mg/L, and 2.16 mg/L, respectively. The monitoring study performed on the CDS<sup>®</sup> at the CATS BMOF showed median effluent concentrations of 0.69 mg/L, 0.35 mg/L, and 1.04 mg/L, respectively. Influent EMCs for TKN and TN were low, likely leading to low removal efficiencies. In comparison with the ISBD, the median effluent concentrations for TKN and TN were low. Median effluent NO<sub>x</sub> concentrations were comparable to those reported in the ISBD. Inflow and outflow TN concentrations for each storm can be seen in Appendix A – Figure A3.

*Phosphorous:*

TP removal in the CATS BMOF CDS<sup>®</sup> was -27%, a statistically significant 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 NO<sub>x</sub> would suggest some anoxic conditions occur in this device, the same conditions needed for phosphorous export; however, the 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 relatively the same for the CATS BMOF data and for hydrodynamic devices in the ISBD. The median effluent concentration of TP determined for the CDS<sup>®</sup> (0.10 mg/L) is essentially the same as that reported by Geosyntec (2006) (0.16 mg/L). Since the median influent concentration of TP calculated for the device was 0.09 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 CDS<sup>®</sup> exhibited a metal removal efficiency that would be expected based on the low TSS removal. Zinc, copper and lead removal in the system was -20%, -35% and -33%, 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 (150 mg/L) was higher than that reported in the ISBD (100 mg/L). The median effluent concentration of copper (19 mg/L) was comparable to that reported in the ISBD (15 mg/L) (Table 2). Again, this low removal efficiency is likely related to the low TSS removal that was shown. Due to metals binding to sediment, the relationship between TSS removal and metals removal is likely.

## **CONCLUSIONS**

Based on the monitoring data collected and analyzed for this study at the CATS BMOF, the CDS<sup>®</sup> did not significantly reduce the majority of the measured stormwater pollutants at the site. Although the BMP was routinely maintained at semi-annual to annual intervals, removal efficiencies were found to be negative in regards to TSS, TN, and TP, likely due to resuspension of previously stored pollutants. It also 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 comparable to or 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 likely played a role in the BMP performance.

Compared to the results of the analysis on the CDS<sup>®</sup> as part of the NJCAT program, the sediment removal efficiency at the CATS BMOF site was low. It should be noted, however, that the sediment entering the CATS BMOF CDS<sup>®</sup> was presumably much different than that used in the laboratory described in the NJCAT report. Additionally, a number of field studies which were performed on CDS<sup>®</sup> systems were detailed in the NJCAT report. Some of these studies also showed effluent TSS concentrations higher than influent TSS concentrations during some storm events. Low influent sediment concentrations and the presumed fine sediment particles in the influent likely played a role in the 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 -31%, while the SSC removal efficiency was -49% at the CATS BMOF site.



Other pollutants of concern such as TN, TP, and various metals were removed by the system with a low efficiency (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 somewhat higher than those reported by Geosyntec, 2006.

A number of the analyses produced statistically significant results regarding the difference in influent and effluent pollutant concentration (Table 2). The storm by storm removal efficiencies seen in Appendix A (figures A1-A4) show the fluctuation in removal efficiency that occurred throughout the study; however, these removal efficiencies were consistently less than 0%. Similar fluctuations were 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 CDS<sup>®</sup> 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.





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CDS Technologies website: <http://www.cdstech.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 CDS®**

Parameter	Assumed Distribution	Reject Based on K-S Test <sup>1</sup>	Paired t-Test	Wilcoxon Signed - Rank Test	Significant ?
			p-value		
BOD	Log	No	0.0881	0.0781	No
COD	Log	No	<b>0.0064</b>	<b>0.0049</b>	<b>Yes</b>
NH4	Log	<b>Yes</b>	0.5851	0.6367	No
NOx	Log	<b>Yes</b>	0.3659	0.8146	No
TKN	Log	No	<b>0.0083</b>	<b>0.0123</b>	<b>Yes</b>
TN	Log	<b>Yes</b>	0.1299	<b>0.0296</b>	<b>Yes</b>
TP	Log	<b>Yes</b>	<b>0.0004</b>	<b>&lt;0.0001</b>	<b>Yes</b>
TSS	Log	No	<b>0.0021</b>	<b>0.001</b>	<b>Yes</b>
TR	Log	No	<b>0.0095</b>	<b>0.0117</b>	<b>Yes</b>
SSC	Log	No	<b>0.0002</b>	<b>0.0005</b>	<b>Yes</b>
Turbidity	Log	<b>Yes</b>	<b>0.002</b>	<b>0.0001</b>	<b>Yes</b>
Copper	Log	No	<b>0.0002</b>	<b>&lt;0.0001</b>	<b>Yes</b>
Zinc	Log	No	<b>0.0218</b>	<b>0.0127</b>	<b>Yes</b>
Chromium	Log	<b>Yes</b>	0.0972	0.0898	No
Lead	Log	<b>Yes</b>	<b>0.0009</b>	<b>0.0008</b>	<b>Yes</b>

1. Rejection ( $\alpha=0.05$ ) 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.

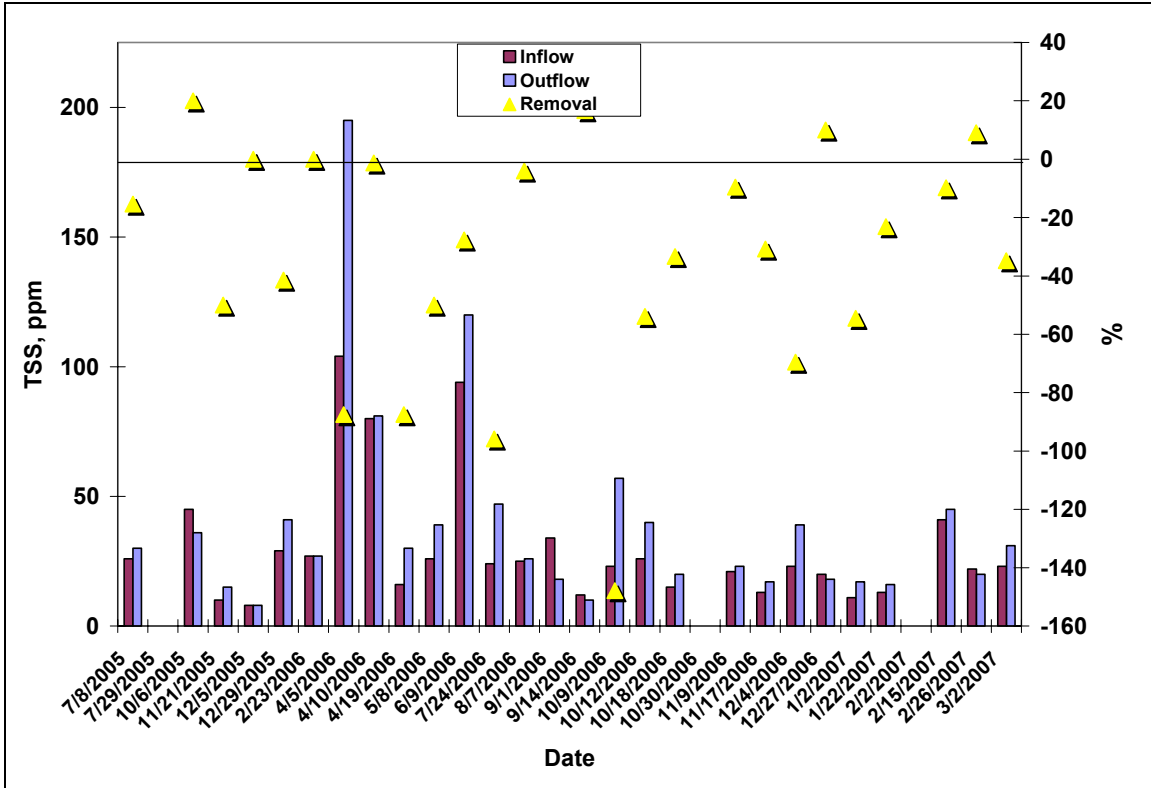


Figure A1: Change in TSS concentration due to BMP treatment by storm event.

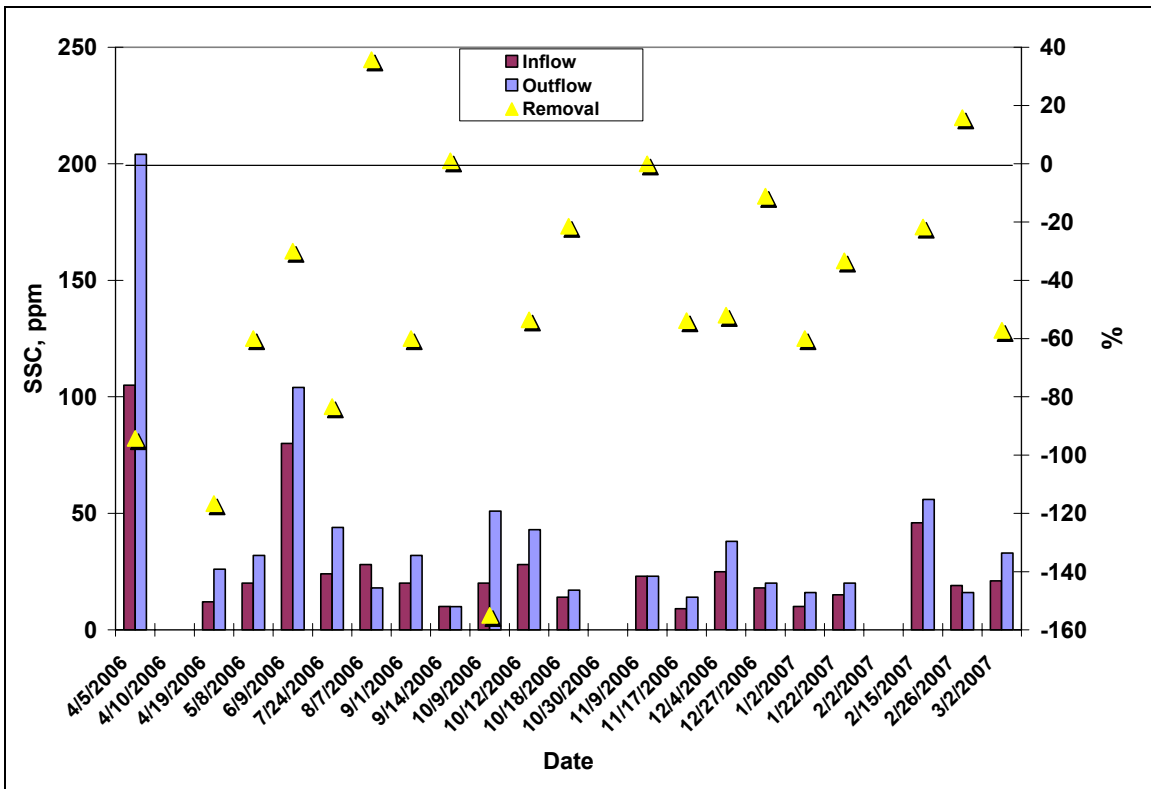


Figure A2: Change in SSC concentration due to BMP treatment by storm event.

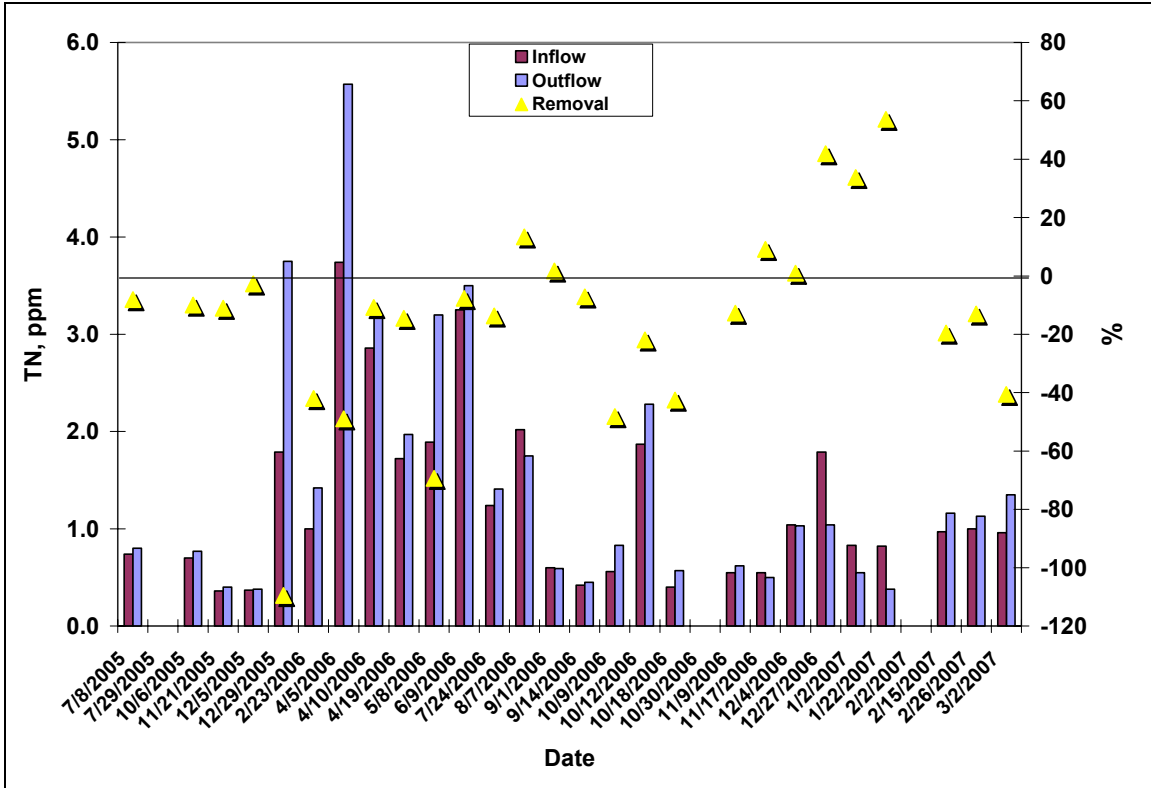


Figure A3: Change in TN concentration due to BMP treatment by storm event.

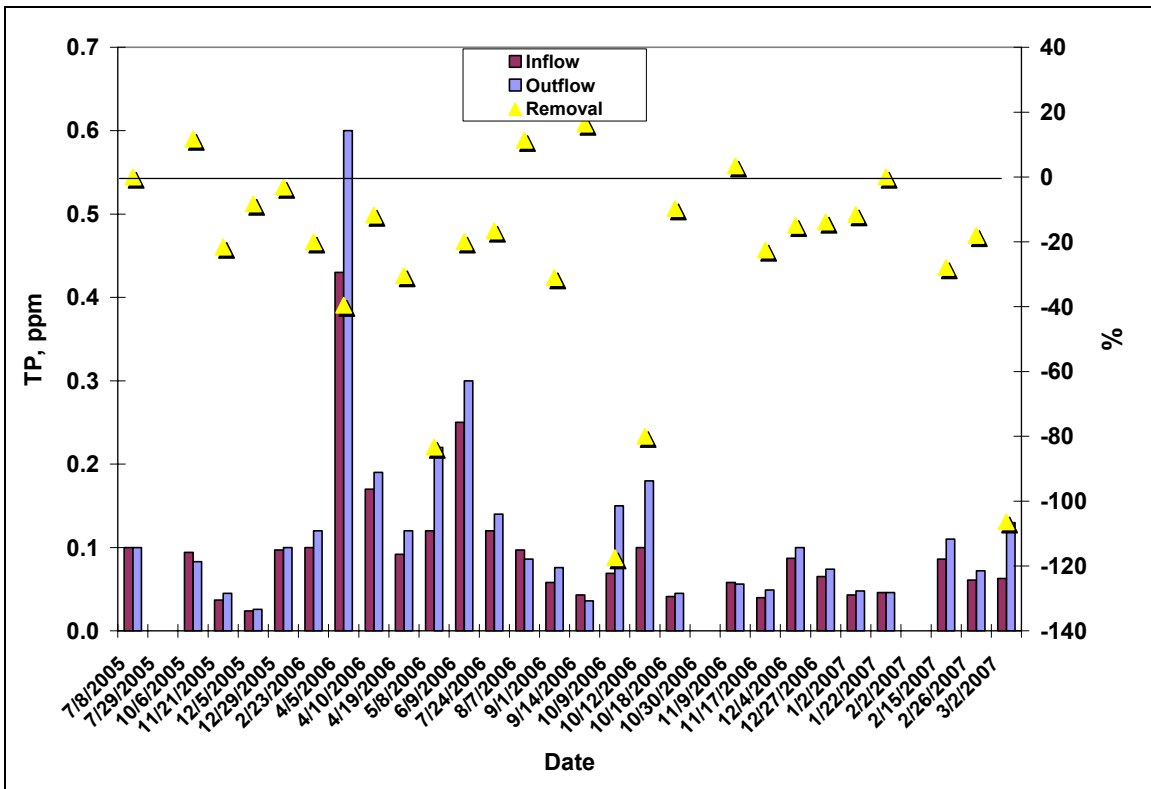


Figure A4: Change in TP concentration due to BMP treatment by storm event.



## APPENDIX B

### *Monitoring Protocol*

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## **Stormwater BMP performance Monitoring Protocol for:**

CATS Bus Maintenance and Operations Facility  
CDS<sup>®</sup> BMP

### **Description of Site:**

The CATS-BMOF CDS<sup>®</sup> 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 the CDS<sup>®</sup> BMP is approximately 2.19 acres and is 100% impervious concrete and metal roof surfaces. Primary use of the watershed is for bus parking.

### **Sampling equipment**

Monitoring will take place in the 24" 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: 24" 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: 24" diameter RCP  
Secondary Device: ISCO Model 750 area- velocity meter  
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	109 Cu Ft.
Set point enable	None

### Outlet Sampler

Sample Volume	200mL
Pacing	109 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.