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EVALUATING BMPs FOR TREATING STORMWATER AND WASTEWATER FROM NCDOT's HIGHWAYS, INDUSTRIAL FACILITIES, AND BORROW PITS

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Prepared By

Daniel E. Line, P.E.

NC State University
Biological and Agricultural Engineering Dept.
Box 7637, 909 Capability Dr., Suite 3200
Raleigh, NC 27695

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16. Abstract

This report includes the results of monitoring runoff and best management practice (BMP) efficiencies on 3 industrial sites (the Wilson, Orange, and Alexander county maintenance yards) and a borrow pit. Monitoring included characterizing runoff from a steam cleaning operation, a salt storage area, a soil storage area, a gravel truck wash pad, and the general maintenance yard while the BMPs included a wetland, level spreader, and extended detention pond. The monitoring protocol for the BMPs consisted of monitoring inflow, outflow, on-site rainfall, and collecting flow-proportional samples for at least 12 storm events.

Monitoring results documented that a large sediment trap reduced sediment load and turbidity in effluent from a borrow pit by 63 and 48%, respectively. Inflow and outflow monitoring for the wetland and extended detention pond indicated relatively poor removal efficiencies for most constituents; however, the lack of vegetation and poor configuration of the wetland made it function more like a detention pond than a wetland. Limited monitoring results suggest that the effectiveness of the extended detention pond was improved by adding a rock baffle and a floating effluent drain. The effectiveness of the level spreader could not be accurately determined due to maintenance problems.

Monitoring of effluent from steam cleaning 10 vehicles documented relatively high concentrations of metals, oil and grease, many inorganic nonmetals. Monitoring of effluent and runoff from a gravel washpad where trucks are washed had slightly elevated levels of sediment and chloride, but other pollutants were similar to urban stormwater. Runoff from a salt storage area had elevated levels of chloride indicating the need for improved containment of salt.

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DISCLAIMER

The contents of this report reflect the views of the authors and not necessarily the opinions/views of NC State University. The authors are responsible for the accuracy of the data and observations presented herein. Further, the contents do not necessarily reflect the official views or policies of the Center for Transportation and the Environment, the North Carolina Department of Transportation, or the Federal Highway Administration at the time of publication. This report does not constitute a standard, specification, or regulation.

SECTION I

INUSTRIAL SITES

SUMMARY

In June, 1998 an NPDES stormwater permit was issued to the NC Department of Transportation (NC DOT). As part of the permit, the NC DOT committed to a program of research and best management practice (BMP) implementation on its industrial and highway facilities. Part of the research program included monitoring stormwater runoff and BMP effectiveness implemented on industrial facilities. The objective of this part of the project was to characterize runoff from DOT industrial sites and to document the efficiency of BMPs on selected sites. This report presents the results from monitoring a sediment basin/trap at a borrow pit and a maintenance yard, a stormwater wetland, an extended detention pond, and a level spreader. The report also includes monitoring data documenting the quality of washwater from a gravel wash pad and pressure wash operation. The sediment basin received pumped drainage water from large borrow pit in Wilson County, while the sediment trap received runoff from a soil storage area on the Orange County maintenance yard. The stormwater wetland received runoff from a section of an area maintenance facility located in Wilson, NC. The extended detention pond received runoff from a section of the Alexander county maintenance yard. The level spreader was installed in an area of the Orange county maintenance yard where roadsalt and roadsalt spreaders were stored. The spreader distributed runoff over a grassed slope upstream of a continuous monitoring station.

The monitoring plan for the sediment basin, wetland, and extended storage pond was to monitoring inflow and outflow. The plan for the pressure wash operation and the gravel wash pad, sediment trap, and level spreader at Orange County was to monitor downstream only, since there was no well-defined upstream location. Flow-proportional samples of discharge were collected at each monitoring site via automated samplers, except for the pressure wash operation for which grab samples were collected. Samples at the borrow pit were collected continuously and composited over a 2-week period and analyzed for TSS, turbidity, and nitrate+nitrite (NO_{3+2}). For the other sites, storm event composite samples were collected and analyzed for metals, inorganic nonmetals, aggregate organics, and a list of 67 semi-volatile organics including many polycyclic aromatic hydrocarbons. Rainfall was continuously monitored at each site and several bulk rainfall samples were collected and analyzed for nitrogen species. Discharge was monitored using open channel flow devices such as weirs and culverts.

Results of a year of monitoring at the borrow pit documented the efficiency of the sediment trap in reducing incoming suspended sediment load and turbidity levels was 63 and 48%, respectively. However, the mean turbidity in the effluent from the trap was still 122 ntu, which suggested the need for additional treatment of effluent. At the Wilson County vehicle maintenance yard, inflow and outflow from the wetland for 13 storm events documented that the efficiency of the wetland at reducing concentrations and loads of incoming runoff was poor or negative for most contaminants; however, the vegetation and configuration of the wetland made it functionally more like a pond than a wetland thereby contributing to the poor efficiency results. Samples of effluent from pressure washing each of 10 vehicles on the site documented high concentrations of most all contaminants indicating that this effluent needed more rigorous treatment than stormwater runoff. At the Orange county maintenance yard, monitoring results showed that the runoff from the salt and soil storage areas were similar to or less polluted than urban runoff, except for suspended sediment and turbidity levels, which indicate the need for sediment control practices. The salt storage area also had elevated levels of chloride, which

indicates the need for improved salt storage and containment practices. The sediment trap and level spreaders installed in the soil and salt storage areas reduced sediment export from the sites, but the reductions were not statistically significant. Monitoring of washwater and stormwater outflow from a gravel washpad area indicated that levels of sediment and chloride in effluent were elevated, but given the low volume of washwater could be contained in a small detention area until being diluted by storm runoff. At the Alexander county yard, results showed that concentrations of the metals, aggregate organics, semi-volatile organics, and most inorganic nonmetals analyzed for were less than state standards or industrial or general urban stormwater monitored from other sites. Also, the extended detention pond was ineffective at reducing the export of sediment or other pollutants from the site. Limited results indicate that modifications to the pond such as a baffle and floating drain, may improve the effectiveness of the pond.

In summary, the following general conclusions and recommendations can be drawn from the monitoring data, while more specific ones are included in the individual BMP sections:

- The sediment trap in this study, like those on monitored residential construction sites, removed about 60% of the sediment from borrow pit effluent and reduced turbidity significantly, although outflow from the trap still had an average turbidity of 122 ntu. Thus, additional treatment is required to reduce the turbidity to the receiving water standard of 50 ntu.
- The concentrations of metals, nitrogen, phosphorus, aggregate organics, and sediment in runoff from the Wilson CMY, Alexander CMY, and Orange CMY’s salt storage area were, with a few exceptions, similar or less than those in runoff from urban and industrial areas of NC.
- The efficiency of the extended detention pond was poor, while the efficiencies of the constructed wetland, the level spreader, and the sediment trap at the Orange CMY could not be determined due to site-specific difficulties. The constructed wetland had too much deep water, too few plants, and little to no extended storage volume. The level spreader sustained damage from being driven over and had several significant changes to the drainage area during the monitoring period. Harvesting of trees and the creation of a large berm in the soil storage area, which drained to the sediment trap at the Orange CMY, during the monitoring introduced too much random variability into the runoff for a definitive evaluation of the efficiency of the sediment trap.
- Effluent from steam pressure-washing of vehicles at the Wilson CMY had very high levels of many pollutants. Because the volume of effluent was quite small, the actual mass loading of pollutants was not great; however, isolation and treatment of this effluent will likely dramatically reduce pollutants in stormwater runoff from the site.
- Concentrations of pollutants, with the exception of chloride which was high in several samples collected during the winter, in effluent from a gravel washpad at the Orange CMY were generally similar to or less than runoff from monitored NC industrial and comparable urban areas.

The following are some general recommendations based on the data collected and observations at the sites:

- In general it appears that the runoff from the three NC DOT industrial sites in this study was, with a few exceptions, of similar or better quality than that from NC industrial or urban areas. Thus, the focus of stormwater mitigation efforts should be on “hot spots” such as pressure wash operations and areas of a lot of road salt storage and/or handling activity.

- Maintaining good quality stormwater requires that pollutant sources such as oil spills/leaks, road salt, unnecessary materials, and exposed soil be minimized on-site. Hence, education for all employees regarding dealing with these issues is needed.
- Evaluating the efficiency of practices such as level spreaders using a single downstream monitoring station before-after BMP implementation approach requires that the drainage area remain as stable or as consistent as possible apart from the implementation of the BMP. Hence, selecting sites where no changes in the drainage area are expected for at least a 2-year period is essential.
- Extended detention ponds, like the one at the Alexander CMY, are an ineffective BMP for reduction of pollutant export; therefore, they should only be implemented in the basic configuration for peak discharge reduction. If modified to reduce flow through and to dewater from the top of the water column, the pond may be effective; however, this modified pond still should be evaluated.
- Most county maintenance yards, such as the Orange and Alexander CMYs, runoff from areas excluding wash pads had little to no oil and grease, surfactant, or semi-volatile organic compounds; therefore, these could be eliminated from future monitoring. Also, for sites with relatively little storage of exposed metal, sample analysis for metals could be eliminated.

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INTRODUCTION

The quality of runoff from urban and industrial land use areas is of increasing concern in the U.S. In the National Water Quality Inventory, 1990 Report to Congress, the 50 states estimated that roughly 30 percent of identified cases of water quality impairment are attributable to storm water discharges from urban/industrial areas (U.S. EPA, 1992). This assessment has prompted an effort, conducted through the National Pollutant Discharge Elimination System (NPDES) storm water permitting program, to characterize storm water discharges and develop pollution prevention plans and BMPs to control this runoff/discharge. Many individual industries, municipalities, and transportation facilities are now required to obtain NPDES permits for their stormwater discharges.

The NC Division of Water Quality (NC DWQ) has issued an NPDES stormwater permit to the NC Division of Transportation (DOT). As part of the permit process, the NC DOT has initiated a program to monitor the stormwater runoff and BMP effectiveness from industrial facilities, borrow pits, and highway facilities.

Determining which constituents to analyze urban and industrial runoff for is also an important decision when developing a monitoring program. While the concentration and list of contaminants in urban and industrial runoff varies with many site-specific factors, a general minimum list of contaminants may be developed from past studies. At ferry and DOT industrial facilities a considerable amount of vehicle maintenance type activities occur; thus, a set of contaminants similar to those of vehicle maintenance facilities may be expected. Line et al. (1996 and 1997) monitored two vehicle maintenance facilities in North Carolina and found the metals cadmium, chromium, copper, lead, nickel, and zinc along with the pesticide endrin present at detectable levels in the runoff. CALTRANS (2000) also lists these heavy metals as originating from vehicle maintenance facilities. Hydrocarbons are present in fuels and lubricants while metals are found in fuels (lead), brake linings (copper), and tires (copper and cadmium); therefore, these constituents were included in the analysis of selected samples (Cole et al., 1984). Additionally, conventional contaminants such as nutrients (may be present due to atmospheric deposition or fertilizer application), sediment, oil and grease, and aggregate organics have been found at relatively high concentrations in urban runoff (Bales et al., 1999; U.S. EPA, 1983) and hence were also included in the sample analysis.

Runoff data from the industrial sites in this study was be compared to urban runoff throughout this report to assess its severity. Much of the urban data used for comparisons was from Bales et al. (1999) who reported on runoff monitoring from 9 sites in the City of Charlotte and Mecklenburg County, NC during 1993-1997. The drainage areas to 6 of the sites were relatively homogeneous. Runoff data from the sites in this study was also compared to a much broader study of urban runoff conducted during the National Urban Runoff Program (NURP), which included sites in 19 cities across the U.S. (EPA, 1983). Results were also compared to runoff data from 4 storm events on each of 10 selected industrial sites in NC (Line et al., 1996). Results from these studies and the NC standards for class C receiving waters provide the basis for assessing runoff from these sites.

OBJECTIVES

The primary objective of this project was to document, through water quality monitoring, the effectiveness of stormwater BMPs implemented on NC DOT's industrial facilities and borrow pits. A secondary goal was to quantify pollutant export from NC DOT's industrial facilities.

METHODOLOGY AND PROCEDURES

With more than 100 DOT industrial facilities spread across the state, selecting the sites to monitor was a challenging task. The original goal of the project was to monitor a ferry facility, 3 vehicle maintenance facilities, and a borrow pit during the first phase of the project. However, after visiting and assessing ferry facilities in Minnesott Beach and Cedar Island, DOT and NCSU personnel determined that these sites had very little outdoor activities or materials storage and thus would provide little information. The sites were like a commercial business with a building and parking lot. Thus, monitoring of a ferry facility was dropped.

After visiting and reviewing maps of many maintenance facilities, the Wilson, Orange, and Alexander county facilities were chosen for inclusion in the study (figure 1). These maintenance yards were chosen for a variety of reasons including their being located in the 3 physiographic regions of the states, the range of activities on the sites, the presence of salt storage at 2 of the sites, the potential for installing BMPs, ease or appropriateness for runoff monitoring, and accessibility.

In addition to site selection, determining which storm events to monitor was also necessary. The NPDES storm water discharge monitoring guidance for characterizing runoff recommends that only storms of at least 0.1 inch accumulation following a period of 72 hours of dry weather be monitored (US EPA, 1992). For this project, data from storms of at least 0.2 inches accumulation following a 72-hour period of insignificant runoff were included.

<u>Monitoring Methods</u>: While the method of discharge monitoring varied by site and will be described below, sample collection and handling was similar for each site, except for the borrow pit, which will be described in the borrow pit section below. At the maintenance facilities, flow-proportional samples were collected at each monitoring station. Except for the Orange CMY soil storage area where plastic sample containers were used, the samples were stored glass jars in a refrigerator (<4 deg C) for 4-48 hours until they were recovered, transferred to appropriate laboratory-supplied containers, and shipped overnight on ice to the laboratory for analysis. Glass jars were used as required for oil and grease analysis (US EPA, 1992; APHA et al., 1998). Refrigerated samplers were used because immediate storage at <4 deg C is required for almost all of the parameters analyzed for (APHA et al., 1998) and is also recommended in the NPDES stormwater sampling guidance (US EPA, 1992) for composite samples collected by automated samplers. Laboratory-supplied containers were pre-acidified with the appropriate acid as shown in Table 1. The method detection limits (MDLs) and methods of analyses are also included in Table 1. The MDLs for some constituents varied slightly depending on the pollutant levels of the sample, especially for the pressure wash samples, for which the high levels of solids made analysis of semi-volatile organics difficult. The state certified lab used appropriate quality control procedures to produce accurate reliable data. Additionally, turbidity and pH

measurements were conducted on nonacidified samples at the NCSU Water Quality Group within 2-3 hr. of recovery from the sampler. The effect of the relatively long holding time for turbidity and pH was minimized by refrigeration which reduced microbial activity samples. Also, because the samples were stored in the dark, growth of algae and other similar organisms should be insignificant. A chain-of-custody form accompanied the sample from the time of recovery from the sampler through laboratory analysis to track its handling.

Table 1. Storage, Preservation, and Analysis Methods.

	Units	Container	Preservation	MDL	Method
Metals					
Cadmium	ug/L	P or G[1]	HNO_3 to pH<2	2	3113B[2]
Chromium	ug/L	P or G[1]	HNO_3 to pH<2	5	3113B[2]
Copper	ug/L	P or G[1]	HNO_3 to pH<2	50	3113B[2]
Lead	ug/L	P or G[1]	HNO_3 to pH<2	5	3113B[2]
Nickel	ug/L	P or G[1]	HNO_3 to pH<2	10	3113B[2]
Zinc	ug/L	P or G[1]	HNO_3 to pH<2	10	3113B[2]
Inorganic Non Metals					
Chloride	mg/L	P or G[1]	< 4 C	2	325.2[3]
Nitrogen, Ammonia	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.04	4500-NH_3H[2]
Nitrogen, Nitrate+Nitrite	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.05	353.2[3]
Nitrogen, TKN	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.15	351.2[3]
Nitrogen, Total	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.19	
Phosphorus, Dissolved	mg/L	P or G[1]	<4 C	0.05	365.1[3]
Phosphorus, Total	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.05	365.4[3]
Residue, Suspended	mg/L	P or G[1]	<4 C	1	2540D[4]
Residue,Total	mg/L	P or G[1]	<4 C	1	2540B[4]
Aggregate Organics					
COD	mg/L	P or G[1]	H_2SO_4, <4 C	5	410.4[3]
Oil and Grease	mg/L	G	HCL to pH<2, <4 C	5	1664[5]
Surfactant	mg/L	P or G[1]	<4 C	0.05	425.1[3]

[1] G=glass with Teflon lined cap, P=plastic, <4 C means cool to less than 4 degrees Celsius.

[2] 18th Edition Standard Methods for the Examination of Water and Waste Water.

[3] Chemical Analysis of Water and Wastes (U.S. EPA, 1983).

[4] 17th Edition Standard Methods for the Examination of Water and Waste Water.

[5] U.S. EPA, EPA-821-B-94-004b.

<u>BMP Efficiency Calculations</u>: Inflow and outflow pollutant loads were computed for each storm event as shown in the following equation:

Event Load= (flow proportional concentration) x (runoff volume)

In most cases the runoff volume was the volume of runoff for the whole storm hydrograph, except for some storms at the wetland which had an extended (> 1 day) drawdown. In this case it was impossible to determine where the outflow resulting from surface runoff ended and where the outflow from groundwater influx took over.

Pollutant reduction efficiencies were computed from both the concentration and load data. The concentration efficiency for each storm was computed using the following equation:

$$\text{Concentration Efficiency} = \frac{(\text{inflow} - \text{outflow})}{\text{inflow}} \times 100$$

where inflow and outflow are the inflow and outflow flow proportional concentrations for the storm event. There are several possible ways to compute the overall efficiency for load reductions including computing the efficiency for each event and taking the average of all and summing the loads from each event and then computing the efficiency. The first method weights each storm equally, which is often not the reality. The second method was reported as a more appropriate method (Strecker et al., 2001) and is depicted in the following equation:

$$\text{Load Efficiency} = \frac{(\Sigma\ \text{inflow load} - \Sigma\ \text{outflow load})}{\Sigma \text{inflow load}} \times 100$$

where the inflow and outflow loads are the inflow and outflow load for each storm event.

Statistical Analysis: While the computed efficiency is an appropriate measure of the effectiveness of the device it does not take into account the variability of the data. For this reason statistical analyses of the data were performed to further support the pollutant reduction efficiency numbers. For the sites where inflow and outflow data were paired, meaning they occurred for the same event and were not randomly selected among all events, a paired t test was an appropriate test for comparing inflow and outflow data (Ott, 1984). This method takes into account the often large differences between storm event pairs. Also, since some of the storm event data were not normally distributed log transformations of the data were performed. Strecker et al. (2001) reported that lognormal distributions were a valid approximation of the storm event water quality data they examined. For the Orange CMY salt and soil storage areas where it was no possible to collect inflow data, analysis of covariance was used to compare pre-BMP relationships with post-BMP relationships to assess BMP efficiency.

SITE DESCRIPTIONS AND RESULTS

Descriptions of sites and monitoring results are presented by site in the following section. Summaries of the data are included in the text while the data for individual storms are presented in the appendix. When the concentration of an analyte in a sample was less than the MDL, half of the MDL was reported (bold typeface in tables) and used in the computation of loads and summary statistics. However, when all of the samples had concentrations less then the MDL for an analyte, a ‘ND’ was reported in the summary statistics. Also, when both inflow and outflow concentrations for a particular storm were less than the MDL, the values were excluded from the analysis comparing inflow to outflow loads. Thus, half the MDL was used only when either the inflow or outflow concentration was greater than the MDL.

Storm event loads were computed by multiplying the concentration of the contaminant in the composite sample by the volume of runoff for the event or the period. The load reduction efficiency is then the total outflow load subtracted from the total inflow load divided by the inflow load. In contrast to averaging the efficiency from each storm, this method weights storms with higher discharges or contaminant concentrations greater than those with lower or less. This may underestimate the efficiency since one or two large storms, which often overwhelm the BMP, could decrease the efficiency considerably. This possibility will be discussed for individual sites in the following sections.

Baker Borrow Pit

Description of Site: The Baker Borrow pit is located near the city of Wilson in Wilson County (N35’ 40”; W77’ 54”). Soils around the pit were primarily the Altavista fine sandy loam and the State loamy sand. The Baker pit is several acres (5-10 acres) in surface area and appeared to be 10-20 ft deep. Prior to the start of monitoring on November 21, 2000, the drainage ditch for the pit had been cut and about a 30 ft wide strip of material had been removed. Monitoring continued until November 21, 2001 when all the soil material was exhausted and the pit banks were stabilized with vegetation (figure 2). Therefore, the monitoring period included nearly all of the active life of the pit. Digging and soil material removal activity in the pit during the period of monitoring was highly variable as shown in Table 2 (column 3).

In order to facilitate soil removal, ground water seepage into the pit was pumped out of the pit into a large sediment trap/stilling basin before being discharge via a rock-lined channel to the riparian area along Contentnea Creek. The sediment trap was approximately 200 ft long and 64 ft wide with an upper section of 140 ft delineated by a rip-rap baffle and a lower section 60 ft (figure 3). Water in the basin was generally 4-6 ft deep. From the inlet pipe, which was 6 inches in diameter and 3-4 ft above the water surface, water flowed about 140 ft before passing through a rip-rap baffle and then another 60 ft before passing through a rip-rap and wash stone outlet structure (figure 4). A rock-lined channel conveyed the discharge to a riparian buffer along Contentnea Creek.

Description of Monitoring: A 90 deg. V-notch weir was installed in the rock-lined channel draining water from the about 75 ft downstream of the outlet of the sediment trap (figure 4). Ideally the weir would have been installed closer to the basin outlet; however, the flow of water down the channel was controlled by a slightly elevated section near the edge of the wooded riparian area. Because this section tended to create backwater effects, which could submerge the weir, the weir and sampling station were installed at the edge of the wooded riparian area to provide the best drainage away from the measurement area. Observation during the course of monitoring confirmed little evidence of backwater effects on weir flow and because the channel was stabilized with rip-rap and filter fabric erosion in the channel upstream of the weir was insignificant.

Because the weir and wingwalls had to be installed during a time when outflow was occurring, their installation was difficult and not as robust as usual. Installation during no-flow periods facilitates packing of soil along the plywood wingwalls, which prevent water from going around the weir, and the application of concrete under and around the weir itself to prevent water from going under the weir. As a result, two breaches in the weir structure occurred during monitoring as noted in the following results section.

An automated sampler with a flowmeter was installed near the weir. The flowmeter used the bubbler method to continuously measure water depth at a point approximately 1.5 ft upstream of the weir crest. This upstream location was chosen to avoid measuring water depth in the drawdown of the weir, which could provide erroneous results. The flowmeter measured depth of water over the weir and continuously converted the depth to discharge using the standard weir equation. The flowmeter was used to control sample collection such that flow-proportional samples were collected by the automated sampler. At the usual discharge rate of about 100 gpm, samples were collected nearly every 12 hours. The flow rate varied considerably during the monitoring period ranging up to about 600 gpm during the June 20 to July 6, 2001 period. This variability resulted in changes in sampling frequency with higher discharge rates resulting in more frequent sample collection. The sampler intake was connected to a float so that sample water was drawn from nearly the vertical midpoint of the water column during usual discharge conditions. Individual samples were composited for a two-week period and sent to the certified laboratory for analysis.

The flowmeter at the outlet was also connected to the inlet sampler via a long cable. This cable facilitated simultaneous collection of samples at the inlet and outlet. It was assumed that the flow was generally at equilibrium over the relatively long duration of monitoring and that levels of measured parameters did not change appreciably over relatively short periods of time so that sampling at the same time should not significantly affect the results. The sampler intake for the inflow to the trap was fastened to the inside bottom of the PVC pipe, which carried water from the pump to the trap. Because water was well-mixed and moved rapidly through the pipe, fastening of the sampler intake to the bottom of the pipe should not have biased the results. Often when sediment is sampled, sediment concentrations tend to be greater near the bottom of the water column due to settling of larger, heavier sediment during transport; however, this should not occur in this case because sediment and water were well mixed in the pump and the velocity of water in the PVC pipe was high. Also, much of the larger, heavier sediment should have settled out of the water before entering the pump; hence, generally only finer sediment was in the inflow pipe.

Samplers were programmed to collect duplicate 250-ml samples and place in separate paired sampler bottles during each sampling event. The odd numbered sampler bottles contained sulfuric acid to immediately reduce the pH of the sample to less than 2, while the even numbered bottles contained no preservative. Once every 2 weeks, equal volume aliquots from each sampler bottle were composited into a single sample for analysis. Composite samples from the odd numbered sampler bottles were analyzed for NO_3+NO_2 –N while those from the even numbered bottles were analyzed for turbidity, total suspended solids or residue (TSS), and pH. From 6 to 24 individual samples were composited into one sample for analysis depending on the amount of discharge occurring during the 2-week monitoring period. The composite sample for NO_3+NO_2-N analysis was frozen to preserve until laboratory analysis while the sample for TSS was refrigerated until analyzed. The turbidity and pH measurements were conducted within 2 hr. of recovering the sample from the sampler.

Results of Monitoring: Because samples were composited over a 2-week period, the results are presented for 2-week periods for the year of monitoring beginning on November 21, 2000 (Table 2). The samplers were taken out of service on January 4, 2001 due to an extended period of no pumping and restarted on April 26, 2001. Additionally, no samples of influent were collected during the May 9 to May 23, 2001 period due to equipment problems and during the June 6 to June 20, 2001 period due to a break in pumping. Inflow sampling was also missed during the Sept. 10 to Sept 24, 2001 and Oct 8 to Oct. 22, 2001 periods due to equipment and weir failure. Samples of outflow were collected for all 17, 2-week monitoring periods.

Table 2. Sample Analysis Data for Baker Borrow Pit.

Begin	End	Activity	pH		Turbidity		TSS		NO_2+NO_3	
			in	out	in	Out	in	out	in	out
			pH	pH	ntu	Ntu	mg/L		mg/L	
21-Nov	06-Dec	Some	6.24	6.26	552	294	507	108	0.33	0.93
06-Dec	20-Dec	Some	7.32	6.48	46	37	47	15	0.31	0.43
20-Dec	04-Jan	None	No pumping							
04-Jan	26-Apr		Unknown							
26-Apr	09-May	Some	6.83	5.87	267	143	240	58	0.42	0.46
09-May	23-May	None				190		88		0.63
23-May	06-Jun	None	6.51	6.51	587	423	443	226	0.47	0.28
06-Jun	20-Jun	None		6.69		161		79		0.26
20-Jun	06-Jul	None		6.78	88	119	98	57	0.03	0.03
06-Jul	16-Jul	None	6.69	5.74	206	78	225	44	0.22	0.16
16-Jul	30-Jul	None	5.94		185	85	209	71	0.37	0.25
30-Jul	13-Aug	None			102	89	104	68	0.08	0.15
13-Aug	27-Aug	None	5.17	5.32	118	16	22	48	0.16	0.13
27-Aug	10-Sep	Some	6.06	6.33	139	35	146	24	0.11	0.08
10-Sep	24-Sep	Some						20		0.08
24-Sep	08-Oct	Active	5.50	6.29	49	25	34	17	0.09	0.08
08-Oct	22-Oct	Active		6.46		25		26		0.05
22-Oct	07-Nov	Active	6.88	7.06	243	192	225	127	0.10	0.11
07-Nov	21-Nov	Done	5.89	6.90	461	42	447	25	0.17	0.18
Mean			6.28	6.36	234	122	211	65	0.22	0.25
Median			6.24	6.46	185	87	209	57	0.17	0.16
St. dev.			0.64	0.48	178	108	157	51	0.14	0.23
Max.			7.32	7.06	587	423	507	226	0.47	0.93

Observations of digging and soil material removal from the Baker borrow pit are shown in column 3 of Table 2. At the start of monitoring only a 20-30 ft wide trench of material had been removed from the pit. During the first two months (Nov and Dec, 2000) soil material was removed, at a relatively slow pace, from the area of the pit farthest away from the sediment trap. Very little soil removing activity appeared to take place from January to August, 2001. From August to November, 2001 the pace of soil removal appeared to increase with more than half of the material in the pit being removed during this period.

Pollutant Reduction Efficiency: The pH of the inflow of the sediment trap ranged from 5.17 to 7.32 with a mean of 6.28 while the outflow ranged from 5.32 to 7.06 with a mean of 6.36 (Table 2). A paired t test of the data suggested that the pH of the inflow was not significantly different (P=0.411) than that of the outflow indicating that the sediment trap had no effect on the pH of the pit effluent. The average pH of 38 grab samples collected from the outflow of 6 borrow pits across eastern NC was 7.09, which was slightly higher than the Baker Pit. A simple t test was used to show that the grab sample data was significantly (0.05 level) different from the Baker pit data. This difference may have been caused by variability in groundwater, soils, or measurement techniques. The close proximity of the Baker pit to Contentnea Creek (<200 ft) likely influences the water entering the pit, which could make this site different from most others.

The turbidity of the inflow and outflow from the pit varied considerably during the monitoring period; however, outflow turbidity was less than inflow in all but one composite sample (Table 2). To assess the variability between individual samples collected within the 2 week period of the composite sample, the turbidity of several individual samples collected during the 11/21 to 12/6 and 12/6 to 12/20 periods were analyzed. Analysis results showed that the turbidities within the two, 2-week periods were relatively constant.

For all of the 2-week composite sample data, the average of the outflow (122 ntu) was 48% less than the average of the inflow (234 ntu) indicating that the sediment trap improved the clarity of the effluent water. Statistical analysis of the data using a paired t test confirmed that the turbidity of the inflow was significantly (P=0.003) greater than that of the outflow indicating that the trap was effective at reducing the turbidity of the effluent. However, the overall mean and turbidities of 10 of the 16 composite outflow samples still exceeded the 50 ntu NC standard for receiving waters. This indicates that to achieve this standard in all samples, additional measures such as chemical flocculation or vegetative filtration appear to be necessary. For this site the effluent must pass through a wooded riparian buffer before entering Contentnea Creek, which likely further reduced the turbidity of the water.

The average turbidity of the 38 grab samples collected by DOT at other borrow pits was 54 ntu, which was considerably less than the mean from the outflow from the Baker pit sediment trap (122 ntu). A simple t test confirmed that the grab sample and Baker data were significantly (P=0.004) different. The difference could be a result of differences in soils, trap configuration, degree of disturbance in pit, or discharge rates. In addition, the samples from the Baker pit included samples from periods of rainfall, which likely were not included in the grab samples collected by DOT personnel. Erosion of the banks and active areas of the borrow pits and disturbance of raindrops falling in effluent water combine to raise the turbidity of effluent and reduce the settling effectiveness of sediment traps during storms. This combined effect would tend to elevate the turbidity of samples from the Baker pit. Although difficult, it would be advisable for at least 30% of grab samples be collected during or shortly after a storm event. In any case, it would be helpful to know the number of days prior to collecting the grab sample that a significant rainfall event occurred.

The TSS concentrations in the inflow averaged 211 mg/L while in the outflow they averaged 65 mg/L. Other than the fact that the inflow TSS concentration was almost always greater than the outflow, the TSS concentrations seemed to vary without regard to rainfall or discharge. Statistical analysis of the data using a paired t test suggested that the inflow and outflow TSS concentrations were significantly (P=0.002) different indicating that the sediment trap significantly reduced TSS concentrations in the pit effluent. The average TSS concentration for the grab samples collected from the 6 borrow pits was 56 mg/L just slightly less than the average from the outflow of the Baker pit. The TSS concentrations from the DOT grab sampling of outflow from 6 borrow pits and the Baker pit were not significantly different (P=0.625) using a simple t test.

The evaluation of the effectiveness or efficiency of almost any practice should be based on loads; however, for the stilling basin/sediment trap inflow and outflow discharge were the same; therefore, the statistical analysis of loads is the same as that of concentrations. The TSS load for each period was computed by multiplying the concentration by the discharge (Table 3). Due to

Table 3. Discharge, Load Data, and Pollutant Reduction Efficiency for Borrow Pit.

Begin	End	Rain	Discharge	TSS		NO_2+NO_3-N		Trap Eff.	
				in	Out	in	out	TSS	NO_3
		in	gal	lb	Lb	lb	lb	%	%
21-Nov	06-Dec	1.06	2,169,930	9180	1956	6.0	16.8	79	-182
06-Dec	20-Dec	0.92	1,486,123	583	186	3.8	5.3	68	-39
20-Dec	04-Jan			No pumping					
04-Jan	26-Apr			Unknown					
26-Apr	09-May	0.00	1,846,900	3699	894	6.5	7.1	76	-10
09-May	23-May	0.07	1,528,220	3005*	1122	4.7*	8.0	63	-73
23-May	06-Jun	3.45	1,776,290	6566	3350	7.0	4.2	49	40
06-Jun	20-Jun	3.49	2,190,814	5288*	1444	5.7*	4.8	73	16
20-Jun	06-Jul	1.68	12,338,620	10090	5869	2.6	2.6	42	0
06-Jul	16-Jul	0.14	4,147,660	7787	1523	7.6	5.5	80	27
16-Jul	30-Jul	2.91	3,019,643	5266	1789	9.3	6.3	66	32
30-Jul	13-Aug	3.10	4,155,315	3606	2358	2.8	5.2	35	-88
13-Aug	27-Aug	3.09	4,968,515	912	1990	6.6	5.4	-118	19
27-Aug	10-Sep	1.76	1,377,909	1679	276	1.3	0.9	84	27
10-Sep	24-Sep	0.26	1,070,772	1206*	179	0.9*	0.7	85	20
24-Sep	08-Oct	1.69	1,798,922	510	255	1.4	1.2	50	11
08-Oct	22-Oct	0.05	995,510	1955*	216	1.0*	0.4	89	58
22-Oct	07-Nov	0.00	1,899,089	3566	2013	1.6	1.7	44	-10
07-Nov	21-Nov	0.00	1,119,010	4174	233	1.6	1.7	94	-6
Overall		23.67	47,889,243	70763	25652	72	78	63	-11

* indicates load values are estimates, because concentrations were missing.

lack of inflow and equipment malfunctions, the inflow concentrations for 4 inflow loads had to be estimated. The composite concentration for these loads was estimated using the average of concentrations nearest in time and from periods with similar rainfall amounts. For all except the Aug. 13 to Aug. 27 period, the inflow load was greater than the outflow load. The low pollutant reduction efficiency during this period may have been caused by the high discharge rate combined with intense rainfall. That period had the second highest discharge rate combined with more than 3 inches of rainfall. Sediment trapping efficiencies for the individual 2-week periods (column 9) ranged as high as 94% with an overall total of 63%. If the four periods that had estimated loads are removed, the pollutant reduction efficiency decreases to 61%. This overall pollutant reduction efficiency is similar to the efficiency (59%) of several sediment traps on a construction site in Wake County, NC (Line and White, 2001). Assuming that the borrow pit area was about 10 acres, there was a sediment loss of 1.3 ton/ac-yr, which is considerably less than most construction sites and cropland fields.

The efficiency of the sediment trap at reducing both TSS and turbidity levels may be increased by moving the rock stilling dam closer to the inflow pipe. This would contain the turbulence associated with the inflow water into smaller area and would likely facilitate settling in the rest of the trap. Additionally, fence baffles could be installed across the trap with or without flocculent to enhance the trapping efficiency. Increasing the size of the trap or decreasing the flow rate of the effluent may also increase efficiency of the trap.

The inflow and outflow NO_3+NO_2–N concentrations from the sediment trap varied considerably with no apparent trend over time. Six periods had higher outflow compared to inflow concentrations and six periods were reversed. The mean inflow NO_3+NO_2–N concentration was 0.22 mg/L while the average of the outflows was 0.25 mg/L. A paired t test of the data suggested that the inflow and outflow concentrations were not significantly (P=0.278) different. The average of the outflow NO_3+NO_2–N concentrations was less than half of the national background level of 0.6 mg/L for NO_3+NO_2–N in surface waters (USGS, 1999). Also, the median concentrations of NO_3+NO_2–N in Contentnea creek, to which the outflow from the sediment trap drains, was nearly 1 mg/L as measured during the National Water Quality assessment Program (Harned et al., 1995). This suggests that effluent from the borrow pit would not add to the levels of nitrate in Contentnea Creek. The fact that the NO_3+NO_2–N concentrations often increased slightly as effluent passed through the trap may be explained by sampling or analysis variability or by nitrogenous species in the water oxidizing as they went through the sediment trap system. Oxidation was facilitated by the aeration associated with the pit effluent dropping out of the end of the pipe into the basin water causing considerable mixing with air.

The NO_3+NO_2–N load out of the trap varied similar to the concentrations. Like TSS, NO_3+NO_2–N loads for four periods were estimated. The pollutant reduction efficiency was computed from the loads and also varied similar to the NO_3+NO_2–N concentration data. The overall efficiency was negative (-11%) indicating that NO_3+NO_2–N was added to the effluent as it passed through the trap. However, the differences in inflow and outflow NO_3+NO_2–N loads were not significant and therefore the slight increase may have been due to simple variability. The sediment trap was not expected to reduce NO_3+NO_2–N load, because there is no physical mechanism to cause denitrification or filter the water so this result was not surprising. The water pumped into the sediment trap is basically near surface groundwater released through digging and removing soil material; therefore, since this activity adds no nitrogen to the water, there is no reason to believe that effluent from the trap should have any more total nitrogen it than the local groundwater.

The flow-weighted pH, turbidity, and TSS concentration data collected in this study were similar to grab sample data collected from 6 borrow pits in eastern NC. The turbidity of grab samples was significantly less than that of the flow-weighted samples (54 versus 122 ntu) from the Baker pit, but there was not a significant difference in TSS concentrations. Because turbidity can be affected by many factors other than TSS (Line and White, 2001) and some are regionally specific, turbidities can vary widely. The similarity of the TSS concentration data indicates that grab sampling of borrow pit effluent at discrete times is representative of the total outflow. This is reasonable given that effluent is pumped at a relatively consistent rate and the inflow water should be relatively consistent because it is ground water. However, because rainfall events almost always have a significant effect on sediment movement is always advisable to sample outflow during or directly after at least some storm events and record the size of the events.

Site Specific Considerations: Originally actual discharge was not going to be monitored because it was assumed that pumping was at a constant known rate; however, after visiting the site and observing the variability in discharge, the need for discharge monitoring for at least the outflow was evident. Both inflow and outflow samplers were paced by the outflow flowmeter.

This meant that at startup and when inflow changed rapidly a considerable amount of inflow could occur before the outflow and corresponding change in sample pacing occurred; hence, some of the inflow was not sampled as frequently as was warranted. For continuous operation, which was most of the time, this was not an issue.

Conclusions/Recommendations: The following summary of recommendations/conclusions is draw from the data and observations:

1. The efficiency of the stilling basin/sediment trap in trapping TSS was 63% during the year of monitoring, which is similar to sediment traps on NC construction sites (Line and White, 2001). The efficiency of the basin may increase if the rip-rap baffle (fig. 3) was moved closer to the inflow pipe. This should provide a larger area of still/calm water between the inflow and outflow of the basin, which would facilitate settling of sediment. The use of silt fence baffles and/or a flocculent would also likely increase effectiveness of the basin.
2. The export rate of TSS in and turbidity of effluent from the borrow pit and into the stilling basin/sediment trap depend more on rainfall and discharge rate than on excavation activity in the borrow pit.
3. The efficiency of the stilling basin/sediment trap at reducing turbidity levels was 48%; however, the turbidity of outflow samples still averaged 122 ntu. Given the flow rates and the prevalence of clay in NC soils, a combination of adding a flocculant and removing water from the near the top of the water column is likely the only way to consistently achieve an effluent turbidity level of less than 50 ntu, which is the state standard for most receiving waters. The configuration of the pump and inflow pipe would facilitate the application of a flocculant.
4. The sediment trap/stilling basin was not effective at removing NO_3+NO_2 –N from pit effluent; however, the average NO_3+NO_2 –N level in effluent was much less than concentrations in the receiving water (Contentnea Creek) and the national background level.

Wilson CMY Wetland

Description of Site: The Wilson CMY and treatment wetland are located (N35 42.5; W 77 55.4) in the city of Wilson in Wilson County. The monitored drainage area (fig. 5) averages about 325 ft in width and 600 ft in length encompassing about 4.5 acres. Surface slopes in the area are on the order of 1-4%. The upper half of the area is almost totally covered by impervious roof and road surfaces while the lower half is about half imperious asphalt and half gravel parking area and grass; hence, about 75% of the drainage area is impervious. The gravel parking lot normally has between 15 and 30 pickup trucks several dump trucks and other road working equipment. The drainage area is extensively used by trucks and other roadwork related equipment. This equipment enters the drainage area for maintenance in the garage. Before maintenance work begins, the equipment is pressure washed to remove accumulated road dirt. The pressure wash wastewater drains into and through the storm drain system to the treatment wetland via concrete and steel pipes. The garage is the division 4 maintenance shop, so the number of vehicles serviced is considerable. Stormwater runoff from roofs, gravel parking areas, and the asphalt driveways also drain through the storm drains and into the treatment wetland.

The treatment wetland was constructed in July and August, 2001 by widening a stormwater drainage ditch (figure 6) using NC DOT equipment and personnel with Dr. Bill Hunt's (NCSU) design and construction guidance. The excavation resulted in a large area of deep (3-4 ft deep) water near the outlet and a significant area of deep water at the upstream end of the wetland area. These two deep water areas accounted for more than half of the wetland surface area. Wetland vegetation was planted sometime after construction under the guidance of NC DOT. In October, 2001, during visits to install monitoring equipment, observation indicated volunteer vegetation in the standing water areas of the wetland, but few viable wetland plants (figure 6). The design submitted by NCSU recommended 500 Pickerel weed, 200 Arrow arum, 100 Juncus effuses, 20 open water lilies, and an assortment of other wetland plants. However, observation indicated that only 2-3 water lilies, several Juncus along one side, and some Arrow arum along the same side survived until October of 2002 (figure 7). The lack of viable plants likely made the wetland act more like a wet detention pond during the first 8 months of monitoring than a wetland because most stormwater could flow through the wetland with very little contact with vegetation. In order to improve this situation, on June 7, 2002 NCSU and DOT planted 50 water lilies, 200 Pickerel weed, 50 arrow arum, and several lotus plants in the wetland. The plants were concentrated in the shallower water, middle area of the wetland to maximize their chance of survival and their contact with water. Also, 4-5 clumps of Juncus were transplanted from the good stand along the one side of the wetland to the other side where few, if any, wetland plants were growing. Most plants lived and thrived, especially the Pickerel weed to the fall when monitoring restarted (figure 7).

Description of Monitoring: A 3 ft sharp-crested, rectangular weir and associated wingwalls were installed in the channel about 75 ft downstream of the outlet of the storm drain system and 50 ft upstream of the wetland inlet (figure 8). The weir was installed such that its crest was at least 3 inches above the bottom of the channel to insure ponding and relatively tranquil water just upstream of the weir and free flow of water over the weir. These two elements are essential for accurate measurement of discharge past the weir. A 120 degree v-notch weir was installed in the 3.8 ft wide flashboard riser outlet from the wetland. Here again the weir crest was 3-4 inches above the bottom of the outlet culvert to insure free flow of water away from the weir.

An automated sampler with an integrated flowmeter was installed at each weir. The flowmeter used the bubbler method to continuously measure water depth at a point approximately 1-2 ft upstream of the weir crest. Water depth was measured upstream to avoid measuring in the drawdown of the weir. The flowmeter measured depth of water over the weir and continuously converted the depth to discharge using the standard equation for each weir. A stainless steel strainer was connected to the end of the sampler intake tube and mounted vertically to a wooden stake such that 2-3 inches of the strainer was above the water level and 1-2 inches was below. The vertical orientation of the strainer facilitated vertical integration of sample collection, which is very important where oil and grease and other floating contaminants may be present in the runoff.

Rainfall amounts were continuously recorded via an 8-inch tipping bucket recording raingage. A 4-inch plastic nonrecording raingage was also installed at the sites within 3 ft of the recording raingage. When a sufficient amount of rainfall (usually >1 in.) was collected in the nonrecording raingage, the rainfall water was transferred into a laboratory container and shipped with the runoff sample for analysis of nitrogen species.

Results of Monitoring: Summary statistics for monitoring data from 12 of the 13 storm events are shown in Table 4. Only 12 were used in the statistical analyses because the 12/10/01 event was excluded due to low temperature conditions altering the operation of the sampler. A covering of ice over the sampler bubble tube can, conceivably, artificially increase the water depth reading to a level greater than actual conditions. The table also contains the efficiency of the wetland at reducing levels or concentrations (column 7) and loads (column 8) of incoming contaminants. Efficiency was computed by subtracting the outflow concentration or load from the inflow and then dividing by the inflow concentration or load. Since the concentrations are flow-proportional, the difference between concentration and load efficiencies then is simply a factor of the differences in runoff volume. For example, if inflow runoff equaled outflow runoff, then the concentration reduction efficiency would be equal to the load reduction efficiency.

Rainfall and runoff ranged considerably for the 12 storm events providing a range of storm conditions. Outflow from the wetland was generally greater than inflow due to groundwater inflow to the wetland, runoff bypassing the inflow monitoring station, and uncertainties in flow measurement. During the last 3, and possibly more, storms monitored, evidence of runoff entering the wetland from the bank on the south side about 50-70 ft downslope of the inflow monitoring station. This was caused by the diversion ditch filling up with sediment. During normal conditions, this diversion ditch would transport runoff from the gravel parking area and a small building, which made up the lower quarter of the drainage area (figure 9), to a yard inlet connected to the underground storm drain. The drain then conveyed the water to the storm drain system and to the inflow monitoring station. But with this diversion full of sediment, the water overtopped the diversion and flowed over the surrounding land to a low spot downstream of the inflow monitoring station and into the wetland. Observation confirmed this bypassing flow during one storm near the end of the study and there was evidence, in the form of matted grass and a channel, of significant water running down the bank into the wetland; however, the timing of the start of this and the extent are unknown.

Table 4. Summary Statistics for the Wilson CMY Wetland

Parameter	Units	Inflow		Outflow	
		Mean	Range	Mean	Range
Automated rainfall	in	1.02	0.4-1.9	1.02	0.4-1.9
Runoff	1,000 gal	66.1	14-129	98.2	25-196
Peak discharge rate	gpm	708	90-2600	627	75-2500
pH	pH	6.8	6.5-7.1	7.0	6.6-9.9
Turbidity	ntu	52.1	22-106	40.2	21-95
Metals					
Cadmium	ug/L	ND	<2	ND	<2
Chromium	ug/L	3.5	<5-8	3.0	<5-6
Copper	ug/L	ND	<50	ND	<50
Lead	ug/L	25.3	<5-46	13.5	7-33
Nickel	ug/L	ND	<10	ND	<10
Zinc	ug/L	151.7	70-240	115.8	80-250
Inorganic Non Metals					
Chloride	mg/L	4.06	<2-23.2	14.21	5.0-52
Nitrogen, Ammonia	mg/L	0.12	<0.04-0.3	0.08	0.02-0.3
Nitrogen, Nitrate+Nitrite	mg/L	0.19	<0.05-0.4	0.20	0.03-0.62
Nitrogen, TKN	mg/L	0.92	0.25-2.70	0.94	0.46-2.0
Nitrogen, Total	mg/L	1.10	0.32-2.73	1.11	0.65-2.2

Phosphorus, Dissolved	mg/L	0.08	0.01-0.34	0.04	0.01-0.52
Phosphorus, Total	mg/L	0.32	0.06-1.86	0.19	0.10-0.63
Residue, Suspended	mg/L	74	10-145	35	11-134
Residue,Total	mg/L	120	35-278	104	58-181
Aggregate Organics					
COD	mg/L	47.9	12-89	41.7	20-106
Oil and Grease	mg/L	6.79	<5-27	2.63	<5-8
Surfactant	mg/L	0.25	0.1-0.3	0.23	0.1-0.7
Semi-Volatile Organics					
Bis(2-ethylhexyl) Phthalate	ug/L	45.5	<10-170	16.17	<10-49
Phenol	ug/L	1.3	<10-15	ND	ND

Good correlations (figure 10) exist between rainfall and inflow (r^2 = 0.95) and rainfall and outflow (r^2 = 0.94). These data show that the larger the storm the greater the difference between outflow and inflow as would be expected; however, if the difference were caused solely by groundwater inflow, it would likely be less than what was documented. The relatively large difference between inflow and outflow indicates that there was surface runoff bypassing the inflow monitoring site.

The pH and turbidity levels of inflow and outflow were not a concern with the mean turbidity of outflow (Table 4) being less than the 50 ntu state standard (NC DENR, 1997). The turbidity of 7 of the 12 inflow and 9 of 12 single storm event outflow samples were less than 50 ntu, indicating that the turbidity of the runoff was not much of a concern.

Concentrations of the metals cadmium, copper, and nickel were less than the MDL in all storm samples. For cadmium and nickel these concentrations were well below the NC standards for class C surface waters (Table 5). For copper, the standard of 7 ug/L is much less than the MDL of 50 ug/L; thus, the MDL was too high to determine how the concentrations compared to the standard. For chromium, the highest concentration found was only 8 ug/L with a mean of less than 4 ug/L, which was much less than the 50 ug/L state standard. For lead, mean concentrations in samples were 25 ug/L for inflow and 13.5 ug/L for outflow, which were at or below the state standard. Concentrations of 5 inflow, but only 1 outflow samples from individual storms were greater than the standard. Mean concentrations of zinc were at least twice the state standard (50 ug/L) and samples from individual storms were all greater than the state standard. While the state standards for receiving waters do not apply to site runoff, it is a useful benchmark for assessing whether there is a potential pollution problem.

Another way to assess the runoff quality from this site is to compare it to runoff from other urban areas. Concentrations of lead and zinc were much less than the average of first flush runoff (Pb=546 ug/L; Zn=1800 ug/L) for 10 NC industrial sites from Line et al. (1996) and generally greater than the average (Pb=5.3 ug/L; Zn=87.1 ug/L) for a light industrial area in Charlotte, NC (Bales et al., 1999). The means were less than the median event mean concentrations for runoff from 28 urban areas (Table 5) as measured during the NURP (U.S. EPA, 1983) study. Thus, concentrations of metals in runoff from this site were generally less than runoff from other NC industrial sites or urban areas across the nation, even though the concentrations of lead and zinc in some storm samples were slightly greater than NC standards.

Table 5. Standards for Surface Waters and Reported Quality of Urban Stormwater.

	Units	NC Standard for	Urban Stormwater Quality		NC Industrial Sites[d]	
			Range[b]	NURP[c]	Mean	Range

		Class C waters				
Metals						
Cadmium (Total)	ug/l	2	0.05 – 13,730	NA	8	<2-41
Chromium (Total)	ug/l	50	1 – 2,300	NA	214	18-865
Copper (Total)	ug/l	7[a]	0.06 – 1,410	34	414	39-2,223
Lead (Total)	ug/l	25	0.6 – 26,000	144	546	39-3,223
Nickel (Total)	ug/l	88	1 – 49,000	NA	76	<10-333
Zinc (Total)	ug/l	50	7 – 22,000	160	1,800	191-10,080
Inorganic Nonmetals						
Chloride	mg/l	230	0.3 – 25000	NA	NA	NA
Nitrogen						
Total Nitrogen	mg/l	NA	0.32 – 16	NA	2.88	1.10-6.80
Nitrate Nitrogen	mg/l	NA	0.01 – 12	0.68	0.83	0.31-2.10
Ammonia Nitrogen	mg/l	NA	0.01 - 4.3	NA	0.32	0.01-1.36
Total Kjeldahl Nitrogen	mg/l	NA	0.32 – 16	1.5	2.05	0.79-4.70
Total Phosphorus	mg/l	NA	0.01 - 7.3	0.33	0.39	0.07-2.04
Total Residue	mg/L	NA	76 - 36,200	NA	973	190-4718
Total Suspended Residue	mg/L	NA	1 - 36,200	100	828	47-4485
Aggregate Organics						
COD	mg/l	NA	7 – 2200	65	96	23-267
pH		NA	4.5 - 8.7	NA		
Oil and Grease	mg/l	NA	0.001 – 110	NA	6	0-28
Semi-Volatile Organics						
Dichloromethane	mg/l		0.005 - .0145	NA	NA	NA
Tetrachloromethane	mg/l		0.001 - .002	NA	NA	NA
Trichloromethane	mg/l		0.0002 - .012	NA	NA	NA
Benzene	mg/l		0.0035 - .013	NA	NA	NA
Di-n-octyl phthalate	mg/l		0.0004 - .001	NA	NA	NA
Bis(2-ethlyhexyl) phthalate	mg/l		0.007 - .039	NA	NA	NA

[a] Action level, established primarily for NPDES discharges.
[b] Concentrations in urban stormwater (Makepeace et al., 1995).
[c] Data from the Nationwide Urban Runoff Program, NURP (U.S. EPA, 1983).
[d] Concentrations in runoff from 10 industrial sites (Line et al., 1996).

Concentrations of nonmetals ranged widely, but none appeared to be inordinately high. Mean concentration of chloride in inflow and outflow was much less than the state standard of 230 mg/L. Mean concentrations of ammonia nitrogen in inflow and outflow were less than the mean of 0.32 mg/L for 10 NC industrial sites (Table 5) indicating that this site was typical of industrial sites in the state. Nitrate+nitrite nitrogen concentrations were all less than the mean of 1.06 mg/L and total Kjeldahl nitrogen concentrations were also less than the mean of 2.39 mg/L for the 10 industrial sites. Total nitrogen in inflow and outflow total and dissolved phosphorus concentrations for this site were also less than the mean total (1.03 mg/L) and dissolved (0.46 mg/L) phosphorus concentrations from the 10 NC industrial sites (Line et al., 1996). Total nitrogen and phosphorus concentrations in outflow were also similar or less than the average for runoff from a City of Charlotte watershed that encompassed mostly light industries (total nitrogen=1.16 mg/L; total phosphorus=0.24 mg/L) (Bales et al., 1999). Thus, nutrient concentrations in runoff from this site were generally less than other industrial sites in NC.

Mean concentrations of suspended residue (sediment) in inflow and outflow were 74 and 35 mg/L, respectively. The suspended sediment was much less than the average (828 mg/L) from the 10 NC industrial sites monitored by Line et al. (1996) and the average of developed areas (2535 mg/L) of the Piedmont (Line et al., 2002). The TSS concentrations were similar or less than those in runoff from a light industrial area (66.3 mg/L) in Charlotte (Bales et al., 1999) and urban areas nationwide (100 mg/L) (U.S. EPA, 1983). Hence, the concentrations of residue are somewhat less than other industrial sites or urban areas of the state.

For aggregate organics, the mean concentration of COD (inflow=47.9 mg/L) was less than the mean level (98 mg/L) for NC industrial sites (Line et al., 1996). The mean concentration of oil and grease for inflow and outflow samples (6.8 and 2.6 mg/L) were similar or less than the mean (5 mg/L) for 10 industrial sites (Line et al., 1996). Oil and grease (0.001-110 mg/L) and COD (7-220 mg/L) have been have been found in much higher concentrations in urban stormwater according to Makepeace et al. (1995).

Of the 67 semi-volatile organic compounds analyzed for only Bis(2-ethylhexyl) phthalate and phenol were found at levels greater than the MDL. Bis(2-ethylhexyl) phthalate was detected in 12 of 13 samples of inflow with a mean concentration of 45.5 ug/L. Phthalate has been found in urban stormwater at concentrations ranging from 7-39 ug/L (Table 5), so the mean concentration from this site is not far out of the range for urban sites. Bis(2-ethylhexyl) phthalate was one of the most common organic constituents found in runoff from all reported sites during phase I monitoring of the current NPDES program (Pitt and Maestre, 2004). Phthalates have been researched and tested for more than 50 years. Independent scientists, international government bodies and phthalate producers have conducted extensive studies about the safety, health and environmental effects of phthalates, none of which present credible evidence that people are harmed by phthalates. There have been no confirmed reports of adverse health effects (including no human reproductive or developmental effects) from exposure to phthalates; however, there is some evidence of adverse effects of aquatic life.

Phenol was found in the September 14 inflow sample. Phenol can originate from environmental tobacco smoke and thus may have come out of the air as the area smelled like curing tobacco. Phenol is also found in many consumer products and may have come from trash dropped in the area or deposited in the dumpsters located in the area. No phenol was detected in the outflow from the wetland.

Another measure of the severity of the pollutant source is annual export. For the Wilson CMY, this was estimated by first obtaining rainfall data from November, 2001 through October 2002. Most of the rainfall data was collected onsite with a recording raingage with the rest coming from a nearby raingage. Only storms of greater than 0.2 in. accumulation were used as these were most likely to produce runoff, thereby contributing to the pollutant export. Runoff for the year was then determined by summing the runoff for each storm and dividing by the drainage area to yield an annual runoff export as shown in Table 6. For storms that did not have monitoring data, runoff was computed from the rainfall-runoff relationship from storms that were monitored. The total runoff is then combined with the mean storm event concentration to yield and divided by the drainage area to give the pollutant yield for the year as shown in the third column of Table 6. This method is similar to the simple method presented by Schueler (1987), but is much more accurate because it is based on data collected from the site for which the export is being computed.

Since no standards exist for annual pollutant export from industrial or urban sites, the assessment of the severity of the pollutant source must be based on a comparison with similar sites. Pollutant export data for areas in Charlotte designated as light industrial and high density residential/institutional land uses were included in Table 6 for comparison purposes. Of the 9 areas in the Charlotte study, these two land uses had among the lowest and highest annual export of the metals shown in Table 6. Export rates from a medium density residential development in Cary, NC were also included in Table 6 for comparison purposes. Export of chromium, lead, and zinc from the Wilson CMY were greater than the light industrial area, but less than the high density residential/institutional area of Charlotte. Export of copper and nickel is difficult to compare since the concentrations in runoff were nearly always less than the MDL, but it is evident that the export from this site is similar or less than the Charlotte areas. Hence, annual export of metals was similar to the urban areas of Charlotte.

Annual export of nitrogen forms and total nitrogen and total phosphorus were considerably less than corresponding export from a medium density residential area of Cary (Table 6). The total nitrogen export was also less than both the areas in Charlotte indicating that nitrogen export was generally less than typical urban areas. Total phosphorus was greater than the light industrial, but less than the high density residential, areas of Charlotte and less than the residential area of Cary indicating that total phosphorus export was similar or less than many urban areas. Suspended sediment export was less than that of the Charlotte and Cary areas providing considerable evidence that sediment export was less than many urban areas.

Table 6. Annual Pollutant Export from the Wilson CMY.

	Units	Wilson CMY	Light Industrial[1]	High Dens. Res.[1]	Med. Dens. Res.[2]
Drainage Area	ac	4.5	40.3	80.6	6.3
Annual Rainfall	in	35.0	NA	NA	37.7
Runoff	in	19.4	NA	NA	21.5
Metals					
Cadmium	lb/ac-yr	<0.009	NA	NA	NA
Chromium	lb/ac-yr	0.016	0.013	0.164	NA
Copper	lb/ac-yr	<0.220	0.061	0.267	NA
Lead	lb/ac-yr	0.111	0.022	0.150	NA
Nickel	lb/ac-yr	<0.044	0.041	0.056	NA
Zinc	lb/ac-yr	0.666	0.356	0.903	NA
Inorganic Non Metals					
Chloride	lb/ac-yr	17.8	NA	NA	NA
Nitrogen, Ammonia	lb/ac-yr	0.55	NA	NA	2.14
Nitrogen, Nitrate+Nitrite	lb/ac-yr	0.85	NA	NA	2.86
Nitrogen, TKN	lb/ac-yr	4.06	NA	NA	18.5
Nitrogen, Total	lb/ac-yr	4.41	5.0	20.6	21.3
Phosphorus, Dissolved	lb/ac-yr	0.35	NA	NA	NA
Phosphorus, Total	lb/ac-yr	1.39	0.94	4.06	2.05
Residue, Suspended	lb/ac-yr	327	381	3125	346
Residue,Total	lb/ac-yr	525	NA	NA	NA
Aggregate Organics					
COD	lb/ac-yr	210	NA	NA	NA
Oil and Grease	lb/ac-yr	29.8	NA	NA	NA

[1] Data for Mecklenburg County, NC (Bales et al., 1999).

[2] Data from a subdivision in Cary, NC (Line et al., 2002)

<u>Pollutant Reduction Efficiency:</u> The range and average of the 12 individual storm event reduction efficiencies for concentrations and loads are shown in Table 7. The storm of December 10, 2001 was omitted from the efficiency analysis due to uncertainties regarding the proper operation of the sampling equipment (possibly due to icing). Inflow and outflow concentrations and loads for individual storm events were compared using a paired t-test. This statistical test was used because it compares paired data, which reduces the effect of storm to storm variability.

Although variable between storms, overall average peak flow rates for storm events decreased by 8% as a result of the wetland (Table 7). However, during the last 3 events, peak flow rates for outflow were 67% greater than inflow, which may have been caused by runoff water from the lower part of the drainage area bypassing the inflow monitoring station as described above. Outflow discharge volumes from the wetland were generally greater than inflow as shown by the -37% mean reduction. The increase was found to be statistically significant at the 0.05 level using a paired t test. The pH of and outflow was 4% greater than inflow, while the turbidity of outflow was 13% less than inflow on average. Neither of the differences was significant.

Table 7. Summary Statistics for Reduction Efficiency of the Wilson Wetland.

Parameter		Concentration		Loads			Annual
		Range	Mean	Range	Mean	rf<1.0	Export
		%	%	%	%		lb/ac-yr
Peak flow		-50 to 64	8	-	-	-	-
Runoff/discharge		-117 to 17	-37[a]	-	-	-	-
pH		-48 to 7	-4	-	-	-	-
Turbidity		-52 to 76	13	-	-	-	-
Metals							
Cadmium		ND	ND	ND	ND	-	ND
Chromium		-140 to 69	-2	-200 to 76	-23	-	0.02
Copper		ND	ND	ND	ND	-	ND
Lead		3 to 71	42[a]	-38 to 81	20[a]	40	0.11
Nickel		ND	ND	ND	ND	-	ND
Zinc		-24 to 47	19[a]	-108 to 65	-12	25	0.67
Inorganic Non metals							
Chloride		-1200 to 53	-549[a]	-1886 to 46	-385[a]	-558	17.8
Nitrogen, Ammonia		-80 to 85	28	-106 to 90	22	26	0.55
Nitrogen, Nitrate+Nitrite		-660 to 82	-79	-772 to 81	-34	-154	0.85
Nitrogen, TKN		-84 to 68	-22	-222 to 64	-52	-18	4.06
Nitrogen, Total		-103 to 62	-16	-186 to 56	-52	-6	4.41
Phosphorus, Dissolved		-400 to 96	-30	-608 to 95	24	-39	0.35
Phosphorus, Total		-136 to 95	-13	-413 to 94	11	-4	1.39
Residue, Suspended		-74 to 83	47[a]	-117 to 78	22	57	327
Residue,Total		-78 to 71	-6	-252 to 49	-29	12	525
Aggregate Organics							
COD		-69 to 68	0	-264 to 64	-26	3	210
Oil and Grease		-180 to 91	21	-293 to 89	54	ND	29.8
Surfactant		-100 to 80	-24	-262 to 77	-27	-22	-
Semi-Volatile Organics							
Bis(2-ethylhexyl) Phthalate		-380 to 88	19[a]	-574 to 82	37	-47	-

* indicates statistical significance at the 0.05 level.

The overall trapping of metals was generally positive when levels were greater than the MDL (i.e lead and zinc). Samples from only 2 of the storms had chromium concentrations greater than the MDL, so the -2% average reduction is not meaningful. On the otherhand, the 42 and 19% reductions in lead and zinc concentrations are relatively consistent and statistically significant. Reductions in mass loading were less with even an increase in the mass of zinc leaving the wetland as compared to that entering. However, if data from only the 7 storms of less than 1 inch accumulation area used, lead and zinc loads were reduced considerably more than overall. As stated earlier, large storms will affect the overall mass loading reduction efficiency more than smaller ones. Since the vast majority of storms are less than 1 inch, this may be a better gage of overall longterm efficiency than the one that includes all storms.

Reductions in the concentrations of nonmetals varied widely with most being negative. Chloride concentrations and mass loads increased significantly (>500%) through the wetland possibly due to the influx of chloride from ground water or a reservoir of chloride in the soils of the wetland area. Because the levels were relatively low, this increase could have been caused by relatively minor sources of chloride. Nitrate+nitrite nitrogen concentrations and loads increased considerably through the wetland adding to the evidence that there was groundwater inflow into the wetland. There was an overall mean decrease in ammonia nitrogen concentrations and loads through the wetland. This may have been due to plant uptake or conversion of ammonia to other forms of nitrogen. There was a considerable in increase in total Kjeldahl nitrogen concentrations (-22%) and loads (-52%) through the wetland, which may have been the result of organic nitrogen being added to the wetland in the form of plant material. Both dissolved and total phosphorus concentrations increased from inflow to outflow; however, outflow loads were 24 and 11% less than inflow loads. Thus, the efficiency results for phosphorus are mixed, especially since none of the mean efficiencies are statistically significant. For solids or residue, suspended concentrations (47%) and loads (22%) were reduced from inflow to outflow with the reduction in concentration being statistically significant. Omitting the storms of greater than 1 inch raised the load reduction efficiency to 57%, which was expected given that larger storms would tend to wash more sediment through the wetland. Concentrations (-6%) and loads (-29%) of total residue increased through the wetland; however, neither of the increases were significant. Mass loading of total residue decreased from inflow to outflow for storms of less than 1 inch accumulation.

Reductions in concentrations and loads of aggregate organics varied considerably between storm events. For chemical oxygen demand (COD) inflow concentrations (0%) and loads (-26%) were the same or less than outflow. Concentrations (21%) and loads (54%) of oil and grease were lower in the outflow as compared to the inflow indicating a positive treatment effect of the wetland. Contact with plants and an inviting habitat for microbes contributes to the rapid breakdown of oil and grease in the wetland, which may have been reason for the reductions. Surfactant concentration (-24%) and load (-27%) reduction efficiencies were negative for the wetland for unknown reasons. None of the increases or reductions in aggregate organics concentrations or loads were statistically significant indicating that the efficiencies are not high enough or consistent enough to confirm a real treatment effect.

Reductions in concentrations of the semi-volatile organic compound, Bis(2-ethylhexyl) Phthalate averaged 19% and load reductions averaged 37%. The reductions in concentrations were statistically significant and the load reduction was considerable, which provide evidence of a treatment effect; however, the wide range of reduction efficiencies tend to weaken the assertion of a real treatment effect.

Site Specific Considerations: The biggest limitation to the efficiency data was that the wetland had too much deep, open water and not enough plants; hence, it functioned more like a pond than a wetland. Also, the pond/wetland had only very limited retention. For optimum efficiency the outlet should be designed to retain water for an extended period of time with a slow drawdown between storm events. Additionally, the silting in and subsequent overflow of a diversion ditch constructed to channel runoff from the parking lot into the inflow ditch resulted in inflow bypassing the inflow monitoring station and flowing directly into the wetland. The significance of the runoff that bypassed the inflow cannot be determined but was only for runoff originating from the parking area.

Conclusions/Recommendations: The fact that the pools in the wetland were too large and deep and that there was not enough vegetation, prevented an accurate evaluation of how effective a stormwater wetland would be in this situation. In reality, the wetland was more like a detention pond with little retention than a wetland. Recommendations for retrofitting the current wetland/pond to more like a standard treatment wetland are contained in the appendix. The drop in sediment, lead, and zinc concentrations are indicative of a stormwater pond as these generally settle quickly. Considering that the wetland functioned more like a stormwater pond, this was an expected result. The following are other observations/recommendations from the monitoring results:

1. Concentrations of metals in runoff from this site were generally less than runoff from other NC industrial sites or urban areas across the nation. Of the 6 common metals analyzed for, only lead and zinc were found in concentrations greater than NC state standards for receiving waters. For averages of all 12 storm events, only the mean concentration of zinc was greater than NC standards.
2. Total nitrogen and phosphorus concentrations in the outflow from the wetland were similar or less than the average for runoff from a light industrial area in the City of Charlotte, several industrial sites in NC, and an urban area. Thus, nutrient concentrations in runoff from this site were generally less than other urban and industrial areas in NC.
3. Mean concentrations of suspended sediment in inflow and outflow from the wetland were 74 and 35 mg/L, respectively, which are somewhat less than other industrial sites or urban areas of the state.
4. The efficiency of the wetland at reducing concentrations and loads of incoming runoff was poor or negative for most contaminants; however, the only statistically significant negative reduction or increase was for chloride. Statistically significant reductions in lead, zinc, and suspended sediment were documented. Additionally, because the wetland was more like a wet detention pond in hydraulic and vegetation characteristics, the evaluation of its efficiency as a wetland is questionable.
5. Annual pollutant export of metals, nitrogen, phosphorus, and suspended sediment was similar or less than export from several urban areas of NC indicating that, even without a BMP, the export from the site is similar other urban areas.

Wilson CMY Pressure Wash Effluent

Description of Site: The Wilson CMY is located (N35 42.5; W 77 55.4) in the city of Wilson in Wilson County. Before repairs and maintenance work begins, construction and maintenance equipment is pressure washed to remove accumulated road and engine residues. The washing occurs on a concrete pad in front of the garage, which is uncovered and open to the elements. An unknown number of trucks and other equipment are washed on the pad during the normal course of operations. These vehicles contribute varying amounts of pollutants to the pad area. The pressure wash wastewater drains off the vehicle to the pad and into the storm drain system via a flat, yard inlet-type grate. Wastewater then flows through the storm drain system to the treatment wetland via concrete and steel pipes. During storm events rainwater runoff takes the same path to the wetland flushing out accumulated residue on its way.

On 12/4/01 the washwater from the engine and transmission of a tandem axle dump truck was sampled (figure 11). On 1/14/02 the washwater from a single axle dump truck with a salt spreader on the back area was sampled. The truck body, engine, and the salt spreader were washed. On 2/6/02 the washwater from the engine and transmission of a John Deere road grader was sampled; what appeared to be a line painting truck was washed on the pad immediately prior to washing the grader. On 3/6/02 the engine, transmission and frame of a single axle Chevy diesel dump truck was sampled. On 5/16/02 the washwater from a tandem axle dump truck was sampled. The initial pressure wash water appeared to be soapy as lots of suds were evident. The soap was then turned off prior to the actual washing. On 6/25/02 the washwater from the engine and transmission of a tandem axle International dump truck was sampled. On 9/26/02 the washwater from a tri-axle diesel dump truck was monitored. The engine and drive train area were washed. Also, orange-brown water from the bed of the truck ran into the washwater. Light rain was falling prior to and during sampling. On 11/25/02 the washwater from a relatively clean-looking single axle tank truck was sampled. The washwater from the engine and drivetrain of an International diesel dump truck was collected for a second sample. The roof of the maintenance building was being painted on this day.

Photos of all of the vehicles, except the first, are shown in figure 11. The day of the first sampling was thought to be a trip of reconnaissance, and therefore a camera was not brought to the site.

Description of Monitoring: Prior to the start of sampling a 3x3 ft stormwater inlet grate was removed and the excess dirt on the grate lip scraped from the sampling point to minimize the collection of previously deposited pollutants. However, the area was not washed down so pollutants from past washing events or other activities on the pad were present. The sampling was designed to mimic a regular washing so no additional alterations were made.

Wastewater was sampled as it flowed over the lip of the storm drain inlet (figure 11 vehicle wash #2). The same 2-liter plastic sampling container was used for each sampling event. The use of the same container for each vehicle will not affect the results as the results from all vehicles were lumped together. The container was placed in the greatest part of the flow stream 1-3 minutes after flow had started and allowed to fill. For short intervals the container was moved to collect another portion of the flow to attempt to collect a representative portion from all major flow paths (the water flowed over the inlet edge primarily in 2 places). The container was then capped shaken vigorously and emptied into each of the laboratory containers via a plastic funnel that was used for each event. This process was repeated, usually three times, until the laboratory containers were all filled. Lab containers were then capped and placed on ice for overnight shipping to the lab for analysis. Sample collection time usually lasted 15-25 minutes, which coincided with the duration of the pressure wash event.

Results of Monitoring: Summary statistics for effluent from 10 pressure washing events are shown in Table 8 (data for individual events in appendix). The discharge was estimated based on the reported 3 gpm flow rate of the pressure washer and the duration of the washing event. The pH of the effluent was near neutral thus was not a concern. On the other hand, the mean turbidity level was more than 30 times greater than the NC standard for receiving waters (NC DENR, 1997) and therefore is a concern. The high turbidity was likely associated with high suspended residue and total residue concentrations and other associated pollutants. Turbidity values of greater than 1000 ntu were determined by diluting the sample with distilled water and multiplying the resulting value by the dilution factor.

Mean concentrations of all six metals exceeded the corresponding state standards (NC DENR, 1997), some by a large percentage. Mean concentrations of cadmium, copper, lead, nickel, and zinc were greater than the mean concentration in runoff from industrial sites and generally much greater than the average for a light industrial area in Charlotte (Table 5). The copper, lead, and zinc concentrations were also much greater than those for urban runoff documented during the NURP study (U.S. EPA, 1983). Obviously the concentration of total metals in the washwater is a potential problem. However, it is important to remember that volume of effluent water was small, hence the mass loading was small, when compared to most urban stormwater and that the reported values are for total metals, which often a large percentage of the total metals are not available to aquatic biota, because they are associated with deposited sediment.

Concentrations of nonmetals ranged widely, with most appearing to be relatively high. Concentrations of chloride ranged from 27 to 32,000 mg/L with the highest originating from the washing of the salt spreader. Chloride concentration in only two samples was greater than the NC freshwater standard of 230 mg/L. Although the overall mean of the sample concentrations was 3,404 mg/L, if the sample from the salt spreader is omitted, the mean concentration for the other 9 samples was 226 mg/L, which is less than the state standard for class C waters. Chloride concentrations in urban stormwater have ranged from 0.3 to 25,000 mg/L (Makepeace et al., 1995), indicating that the chloride concentrations in washwater were generally within the range of urban runoff.

The concentration of ammonia nitrogen in samples was much greater than the mean (0.22 mg/L) for 10 NC industrial sites monitored by Line et al. (1996). Nitrate+nitrite nitrogen concentrations were often greater than the mean of 1.06 mg/L and total Kjeldahl nitrogen concentrations were also greater than the mean of 2.39 mg/L for the 10 industrial sites. Dissolved phosphorus concentrations for this site were also greater than the mean total (1.03 mg/L) and dissolved (0.46 mg/L) phosphorus concentrations from the 10 NC industrial sites (Line et al., 1996). Total nitrogen and phosphorus concentrations in washwater were also much greater than the average for runoff from a City of Charlotte watershed that encompassed mostly light industries (total nitrogen=1.16 mg/L; total phosphorus=0.24 mg/L) (Bales et al., 1999). Thus, concentrations of nonmetals were generally much greater than stormwater runoff from industrial sites in NC.

Table 8. Summary Statistics for Pressure Washwater at Wilson CMY.

Analyte	Units	Mean	Median	St dev	Min	Max
Discharge	gal	57	60	5	50	60
pH	pH	6.6	7.1	1.1	4.0	7.6
Turbidity	ntu	1,547	1,064	1,208	531	4,390
Metals						
Cadmium	ug/L	102	90	107	1	350
Chromium	ug/L	206	150	198	36	670
Copper	ug/L	4,542	1,050	10,151	210	33,200
Lead	ug/L	958	400	1,659	3	5,600
Nickel	ug/L	154	68	251	27	860
Zinc	ug/L	4,442	3,450	3,311	820	10,600
Inorganic Non Metals						
Chloride	mg/L	3,404	90	10,057	27	32,000
Nitrogen, Ammonia	mg/L	1.38	1.10	1.09	0.28	3.60
Nitrogen, Nitrate+Nitrite	mg/L	4.70	3.34	4.00	0.78	13.0
Nitrogen, Kjeldahl	mg/L	8.84	8.65	4.32	3.40	17.0
Nitrogen, Total	mg/L	13.54	12.05	7.78	4.18	27.0
Phosphorus, Dissolved	mg/L	3.31	1.30	3.93	0.02	10.1
Phosphorus, Total	mg/L	7.05	5.68	5.96	1.18	20.6
Residue, Suspended	mg/L	1,558	1615	708	492	2,740
Residue, Total	mg/L	7,830	2,430	17,083	1,130	56,400
Aggregate Organics						
COD	mg/L	2,975	2,309	1,521	1,190	5,676
Oil and Grease	mg/L	729	393	844	163	2,900
Surfactant	mg/L	3.3	2.4	2.9	0.2	9.9
Semi-Volatile Organics						
Bis(2-ethylhexyl) Phthalate	ug/L	180	180	142	5	340
Butylbenzyl Phthalate	ug/L	20	5	24	5	55
Di-n-Octyl Phthalate	ug/L	11	5	12	5	34
Ideno (1,2,3-cd)pyrene	ug/L	7	5	5	5	18
Fluorene	ug/L	NA	NA	NA	610	610
2-Methylnaphthalene	ug/L	2,250	2,250	919	1,600	2,900

Concentrations of suspended and total residue in inflow and outflow ranged from 1,040 to 56,400 mg/L. The suspended residue (sediment) was similar to the average (1152 mg/L) from the 10 NC industrial sites monitored by Line et al. (1996) and generally less than the average of developed areas (2535 mg/L) of the Piedmont (Line et al., 2002). The levels of suspended residue in washwater were much greater than those from the light industrial area of Charlotte (TSS=66.3 mg/L). Hence, the residue levels are similar to some runoff from industrial sites and much greater than others.

Concentrations of aggregate organics were high. Concentrations of COD and oil and grease were much greater than the mean level (COD=98 mg/L; oil and grease=5 mg/L) for NC industrial sites (Line et al., 1996). Mean levels of COD and oil and grease in stormwater have been reported to range from 7-224 mg/L and 0.001-110 mg/L, respectively (Makepeace et al., 1995); therefore, levels in the washwater were much greater than typical urban stormwater. Concerning surfactants, few, if any, data are available to compare with. The elevated level of surfactant in the 5/16 sample was likely caused by an initial period of washwater containing soap or other sudsy substance.

The semi-volatile organic compound Bis(2-ethylhexyl) phthalate was detected in 3 of 4 samples analyzed. Bis(2-ethylhexyl) Phthalate has a reported range of 7-39 ug/L in stormwater (Makepeace et al., 1995), which indicates the washwater was much worse than urban stormwater. Bis(2-ethylhexyl) Phthalate was the most common organic detected in the NURP urban runoff study (Cole et al., 1984). Di-n-octyl Phthalate has a reported range of 0.4-1.0 ug/L in urban stormwater (Makepeace et al., 1995); hence, the levels in two of the samples were much greater than that expected in urban stormwater.

Fluorene and 2-Methylnaphthalene were found in two samples. Both of these compounds are lighter molecular weight PAHs, which tend to be less persistent in the environment and have less carcinogenic and other chronic impact potential. Fluorene and 2-methylnaphthalene occur in most petroleum products, along with other naphthalenes. The absence of these other naphthalenes (e.g., parent non-alkylated naphthalene) is most unusual and could be due to an analytical artifact or possibly the presence of an extremely weathered (degraded) petroleum product. The concentrations of fluorene and 2-methyl naphthalene are near concentrations known to cause acute toxicity in aquatic organisms.

The elevated levels of many pollutants indicate that the washwater cannot be considered similar or treated like urban stormwater. Allowing this washwater effluent to flow into stormdrains means that it will be flushed down the drains during subsequent precipitation events. Given that each washwater event produces only an estimated 50-70 gallons of water, keeping it separate from runoff and treating only the washwater in a more rigorous way may be a manageable and relatively cost effective approach. The washwater may be treatable to an acceptable level by a series of managed BMPs. These BMPs must include a device to remove the sediment and particulate metals and a filtration or vegetated practice to remove dissolved pollutants. The relatively high level of some metals in the washwater may make phytoremediation, the process of metals uptake by plants and subsequent harvest of plants for the recovery of the metals, economical. Another option would be to treat the washwater effluent using treatment processes similar to what is done for sanitary sewage or industrial effluent.

Site Specific Considerations: The pressure wash operation occurred on an outdoor concrete pad and samples were collected as the washwater dropped into the storm drain collection box; hence, pollutants that had accumulated on the pad for the period between sampling events (1-2 weeks) were washed into the samples. Thus, some pollutants in the samples may have originated from a different vehicle; however, all the pollutants could be expected to be in the stormwater runoff from the site.

Conclusions/Recommendations: The following summary of observations/recommendations are made for the monitoring data:

1. Most pollutants were found in levels greater or much greater than urban stormwater and state surface water standards indicating that the effluent from pressure wash operations such as this is a potentially serious pollution source and therefore, should undergo more rigorous treatment than the typical stormwater BMPs can provide. On the otherhand, the relatively small volume of washwater created for each washing indicates that the mass loading of pollutants is relatively small and thus stormwater would dilute the washwater considerably.

2. Treatment of many of the parameters such as oil and grease, sediment, metals, and nutrients would be facilitated if the water from pressure washing was kept separate from stormwater runoff. This would allow the washwater to be passed through a series of treatment BMPs that could be designed to treat this washwater. These BMPs could then be designed and maintained for the higher level of treatment needed to purify the washwater.
3. Separating the washwater from stormwater runoff would probably reduce pollutant levels in stormwater to the point where they might not be a concern.
4. It appeared from the vehicles and the data that there were no correlations between the vehicle type and the washwater quality, except for the salt spreader, which had much higher chloride and total residue concentrations than the other vehicles. Pollutant levels appear to be dependent on the individual vehicle rather than the type of vehicle.

Alexander CMY Extended Detention Pond

Description of Site: The Alexander CMY extended detention pond is located (N35 55; W 81 9.5) near the town of Taylorsville in Alexander County. The drainage area to the pond averages about 1250 ft by 450 ft or 13.0 acres with most of the land slopes around 5-10% (figure 12). Soils on the area are mapped as Cecil sandy clay loam or Cecil urban complex. The drainage area is 40% impervious (from AMEC). The upper third of the area almost totally covered by impervious roof and asphalt road surfaces while the lower two-thirds is soil and metal stockpile areas and grass. The drainage area appears to be relatively clean and well kept. No significant outdoor maintenance activities occur within the area. Trucks, spreaders, and other equipment are stored under roof. A large (about 70x40 ft and >25 ft high) pile of soil was in the drainage area.

The detention pond was constructed in the fall of 2001 according to AMEC (Ken Trefzger) design and construction instructions. The pond has a design storage volume of 19,735 ft^3 and an extended detention time of 48 hrs. Two rock-lined channels transported most of the runoff from the site to the pond (figure 12) and a concrete riser (figure 13) and 1.5 ft storm drain conveyed water out of the pond. The riser was fitted with a weir plate near the bottom of the pond which had 3 ~1 inch holes in it that allowed water to pass into the riser (figure 13) and out through the culvert. This was the only means of draining the pond below the depth of the grated top of the riser. The banks and adjacent areas were seeded sometime after construction. In October, 2001, during visits to install monitoring equipment, observation indicated vegetation around the pond looked adequate and therefore the construction areas were now stabilized.

Following a snowstorm during the first week of January, 2001, salt spreaders and other equipment were washed off in the drainage area. Other incidents of equipment washing during the period of monitoring likely occurred. Also, in March, 2002 the main channel into the pond was reshaped, thereby creating a significant sediment source.

In the summer of 2003, a rock baffle was installed across the pond about midway between the inflow end and the outlet riser of the pond. In addition, the weir plate to the concrete outlet riser was also removed and a floating intake was fastened to the riser via a 2 inch flexible hose and a plate attached to the end of the hose (figure 14). This floating intake for the outlet riser should withdraw water from the top of the water column thereby facilitating increase sediment settling in the pond. However, the plate on the end of the hose could not be tightened onto the riser because it was thinner than the one that was removed and the bolts bottomed out before drawing the plate tight. As a result, some water leaked around the plate and entered the riser. Thus, not all of the outlet water was drawn from near the top of the water column.

Description of Monitoring: A 4 ft sharp-crested, rectangular weir and associated wingwalls were installed about 15 ft downstream of the confluence of the 2 main stormwater channels feeding the pond (figure 14). This was not the optimum location for the weir and monitoring station, because the channel was relatively steep and the potential for turbulence was high given that the 2 channels came together not far upstream and the channel was relatively steep. In addition, because the water level in the detention pond when full could extend to the weir creating the potential for a submerged weir, the weir could not be located any closer to the pond. The weir was installed such that its crest was at least 3 inches above the bottom of the channel to insure ponding and relatively tranquil water just upstream of the weir and free flow of water over the weir. These two elements are essential for accurate measurement of discharge past a weir.

The outflow from the pond was monitored in the outflow concrete culvert (1.5 ft in diam.) using a combination water depth and velocity measuring probe. The probe was integrated into an automated sampler, which measured flow velocity using the Doppler method and flow depth using a pressure transducer. Using the flow velocity and depth along with the known geometry of the pipe, continuous discharge was computed. At relatively low discharge rates this method of flow measurement is subject to considerable error; however, with the outlet of the culvert being so close to the property boundary fence, a weir could not be installed in the outlet channel. Also, the range of expected discharge rates could be considerable given the potential for water to overtop the outlet riser. These two factors necessitated the use of the Doppler flow meter.

An automated sampler with an integrated flowmeter was installed at each monitoring station. The sampler was programmed to collect flow-proportional samples during each rainfall event. A stainless steel strainer was connected to the end of the sampler intake tube and mounted vertically to a wooden stake. The vertical orientation of the strainer facilitated vertical integration of sample collection, which is very important where oil and grease and other floating contaminants may be present in the runoff. Monitoring began in October of 2001. Due to several instances of loss of power during the months of December and early January, 2002, several storms were missed, but generally runoff from successive storms were monitored.

Refrigerated samplers were programmed to collect flow-weighted samples and place duplicate amounts in 6 separate sampler glass jars. Continuous refrigeration (<4 deg. C) and glass sampler containers were used in accordance with EPA (EPA, 1992) and Standard Methods (APHA et al., 1998) recommendations on handling and preserving samples in the field. Due to the extended length of time required for the pond to empty, samples were often left in the sampler for 2-3 days. Usually the pond was allowed to drain down to at least less than ¼ full before samples were recovered and shipped to the lab for analysis; however, if the pond had not drained sufficiently by Thursday, the sample was recovered and the sampling discontinued for that event. At recovery equal volume aliquots from each sampler jar were poured into appropriate laboratory containers and shipped overnight on ice to the contracted certified lab for analysis. Turbidity and pH measurements were conducted at the NCSU Water Quality Group following recovery of samples from the sampler.

Rainfall amounts were continuously recorded via an 8-inch tipping bucket recording raingage. A 4-inch plastic nonrecording raingage was also installed at the sites within 3 ft of the recording raingage. When a sufficient amount of rainfall (usually >1 in.) was collected in the nonrecording raingage, the rainfall water was transferred into a laboratory container and shipped with the runoff sample for analysis of nitrogen species.

Results of Monitoring: A summary of inflow, outflow, and rainfall data for 11 monitored storm events are shown in Table 9 (raw data in Appendix). Loss of power to the samplers several times (12/13/01; 1/20/02; and 1/23/02) caused the samplers' flowmeters to stop recording discharge prematurely. Additionally, straw applied in March to the reshaped channel area upstream of the inlet weir clogged part of the weir during storms on 3/2/02 and 3/13/02 (figure 14), thereby causing elevated flow readings. Measurement of outflow was also complicated by the large ranges of discharges that could occur. When the concrete riser was not overtopped, discharge rates were relatively low; however, when the riser was overtopped, discharge rates increased to much higher levels. Because infiltration through the bottom of the pond appeared to be insignificant, the total volume of inflow and outflow should be nearly the same. Thus, the outflow runoff volume was used for storms in which the inflow weir was suspected to be clogged with straw or submerged.

Table 9. Runoff data for the Alexander CMY Pond.

Parameter	Units	Inflow		Outflow	
		Mean	Range	Mean	Range
Automated rainfall	in	1.04	0.40-1.94	NA	NA
Runoff	gal	138,365	49,800-336,500	138,690	49,000-336,500
Peak discharge rate	gpm	758	140-2,700	243	30-930
pH	pH	7	6.2-7.1	6	5.9-6.9
Turbidity	ntu	178	71-550	201	35-440
Metals					
Cadmium	ug/L	ND	<2	ND	<2
Chromium	ug/L	20	<5-60	20	9-44
Copper	ug/L	ND	<25	ND	<25
Lead	ug/L	9	<5-30	9	<5-19
Nickel	ug/L	9	<10-19	7	<10-14
Zinc	ug/L	72	<10-124	65	<10-100
Inorganic Non Metals					
Chloride	mg/L	30.9	7-118	37.7	7.2-140
Nitrogen, Ammonia	mg/L	0.20	0.09-0.37	0.22	0.07-0.90
Nitrogen, Nitrate+Nitrite	mg/L	1.56	0.33-12.6	0.51	0.34-1.05
Nitrogen, TKN	mg/L	1.65	0.81-3.1	1.21	0.7-2.3
Nitrogen, Total	mg/L	3.32	1.2-13.9	1.71	1.05-2.71
Phosphorus, Dissolved	mg/L	0.16	<0.02-0.96	0.03	<0.02-0.09
Phosphorus, Total	mg/L	0.44	0.15-1.18	0.22	0.15-0.36
Residue, Suspended	mg/L	148	11-714	124	34-260
Residue,Total	mg/L	322	118-1070	304	140-565
Aggregate Organics					
COD	mg/L	39.2	21-73	22.2	15-27
Oil and Grease	mg/L	ND	<5	ND	<5
Surfactant	mg/L	0.1	0.10-0.12	0.1	0.10-0.15
Semi-Volatile Organics					
All compounds	ug/L	ND	ND	ND	ND

The first three rows of Table 9 contain hydrologic data measured by the samplers. A relatively wide range of storm event rainfall accumulations occurred producing a wide range of runoff volumes. Inflow volume was nearly equal to outflow as was expected given that there was no mechanism for reducing runoff volume. Peak outflow discharge rates were typically less than inflow due to the storage of the pond and the outflow orifice. The outlet riser did overtop on at least 2 storms (12/11/01 and 1/24/02), allowing for high peak outflow rates. For storms that did not overtop the outlet, the peak discharge rate was only 100 gpm with an average of 65 gpm.

The pH and turbidity of inflow and outflow were relatively consistent and not out of the ordinary for runoff. Turbidity levels in inflow and outflow were much greater than the 50 ntu state standard for receiving waters. In addition, mean turbidity of outflow samples were slightly greater than inflow indicating no positive effect from the pond.

Concentrations of metals in inflow and outflow were often less than or near the MDL of the lab indicating little, if any, metals in the runoff. Mean concentrations of cadmium, chromium, and lead were less than the corresponding NC water quality standard. Concentrations of copper in runoff may also be less than the standard; however, the MDL is higher than the standard. Mean concentration of zinc in inflow and outflow samples exceeded the standard of 50 ug/L (NC DENR, 1997). However, concentrations of zinc were much less than the average (1800 ug/L) from NC industrial sites from Line et al. (1996) and less than the average (87.1 ug/L) for a light industrial area in Charlotte (Bales et al., 1999). Also, the mean concentrations were even less than those from urban areas (160 mg/L) in general (U.S. EPA, 1983). Hence, the concentrations of metals were relatively low for runoff from industrial sites.

Concentrations of chloride were well below the NC standard for surface waters (230 mg/L). The only sample with a chloride concentrations greater than 100 mg/L occurred following the snowfall and subsequent washing of road salt spreading equipment in early January, 2002. Recently published data from the USGS NAWQA study of 7563 samples collected from 213 surface water monitoring sites, reported a mean chloride level of 30.3 mg/L, which is similar to concentrations in runoff from this site. Hence, chloride concentrations in inflow and outflow were similar to a wide range of surface water and not a problem.

Mean concentrations of ammonia nitrogen in inflow and outflow from the pond were less than the mean (0.32 mg/L) for 10 NC industrial sites monitored by Line et al. (1996) and well within the range for urban stormwater (Makepeace et al., 1995). The mean nitrate+nitrite nitrogen concentration in inflow was much greater than the outflow due mainly to the high concentration (12.6 mg/L) in the 10/27/03 event, without this event the mean would have been 0.46 mg/L, which was similar to the outflow mean. These means are less than those of industrial site (0.83 mg/L, see Table 5) and general urban (0.68 mg/L, see Table 5) runoff. The mean total Kjeldahl nitrogen concentrations for inflow and outflow were less than the mean of 2.05 mg/L for the 10 industrial sites (Table 5) and similar to the mean for urban runoff (1.5 mg/L) in general (U.S. EPA, 1983). Mean total phosphorus concentrations in inflow and outflow samples were similar to the mean for NC industrial sites (0.39 mg/L from Table 5) and urban runoff in general (0.33 mg/L, U.S. EPA, 1983) indicating that phosphorus losses in runoff were typical of other urban land uses. Total phosphorus in pond outflow were less than the average for runoff from a City of Charlotte watershed that encompassed mostly light industries (total phosphorus=0.24 mg/L) (Bales et al., 1999). Thus, nutrient concentrations in runoff from this site were similar or less than other industrial and urban areas in NC.

Concentrations of suspended residue (sediment) in inflow and outflow averaged 148 and 124 mg/L, respectively. The suspended sediment was less than the average (828 mg/L) from the

10 NC industrial sites monitored by Line et al. (1996) and the average of developed urban areas (2,535 mg/L) of the Piedmont (Line et al., 2002). The concentrations were somewhat greater than the mean (100 mg/L) for urban areas monitored in the NURP study. The fact that the suspended sediment concentrations were greater than concentrations in urban runoff may indicate that treatment is necessary; however, the difference in concentrations is so small that they could be considered similar.

Mean concentrations of chemical oxygen demand (COD) were less than the means from industrial sites (96 mg/L see Table 5) and urban areas (65 mg/L see Table 5) indicating that oxygen demanding substances in the runoff were not a problem. Oil and grease, and surfactant in several storm samples were determined to be near or less than the MDL and thus not a problem.

<u>Pollutant Reduction Efficiency</u>: Concentration and load reduction data were grouped into pre- and post-skimmer periods for before and after the floating intake for the outflow and the rock baffle were installed in the pond. Summary data for reductions in pollutant concentrations and loads are shown in Tables 10 and 11.

Table 10. Reductions in Concentrations for the Alexander CMY Pond.

Parameter		Pre-Skimmer Concentration			Post-Skimmer Concentration		
		Range	Mean		Range	Mean	
		%	%		%	%	
Peak flow		-244 to 96	13		8 to 96	64	
Runoff/discharge volume		-8.3 to 1.5	-1		0.0 to 1.5	0	
pH		0.2 to 2.2	1		-9.1 to 13.4	3	
Turbidity		-33 to 71	17		-214 to 40	-90	
Metals							
Cadmium		ND	ND		ND	ND	
Chromium		-160 to 76	-21		-940 to 44	-314	
Copper		ND	ND		ND	ND	
Lead		-140 to 81	-25		-300 to 37	-114	
Nickel		8 to 71	35		ND	ND	
Zinc		-33 to 36	4		-25 to 42	3	
Inorganic Non Metals							
Chloride		-85 to 26	-38		-20 to 58	7	
Nitrogen, Ammonia		-60 to 22	-8		-143 to 47	-1	
Nitrogen, Nitrate+Nitrite		-41 to 3	-21		-150 to 97	5	
Nitrogen, TKN		-20 to 52	19		-12 to 58	24	
Nitrogen, Total		-16 to 33	10		-9 to 92	30	
Phosphorus, Dissolved		-33 to 38	2		-40 to 99	46	
Phosphorus, Total		-47 to 84	9		-68 to 78	59	
Residue, Suspended		-209 to 46	-65		-690 to 65	-246	
Residue,Total		-35 to 26	-14		-79 to 47	-11	
Aggregate Organics							
COD		30 to 45	35		NA	NA	
Oil and Grease		NA	NA		NA	NA	
Surfactant		NA	NA		NA	NA	
Semi-Volatile Organics							
All compounds		ND	ND		NA	NA	

Table 11. Reductions in Loads for the Alexander CMY Pond.

Parameter		Pre-Skimmer Load Reduction			Post-Skimmer Load Reduction		
		Range	Mean		Range	Mean	
		%	%		%	%	
Metals							
Cadmium		ND	ND		ND	ND	
Chromium		-1.6 to 0.8	-2		-940 to 45	-37	
Copper		ND	ND		ND	ND	
Lead		-137 to 81	-12		-300 to 37	-15	
Nickel		ND	ND		ND	ND	
Zinc		-33 to 37	-1		-25 to 42	14	
Inorganic Non Metals							
Chloride		-100 to 27	-18	*	-20 to 58	10	
Nitrogen, Ammonia		-59 to 22	-3		-143 to 47	-38	
Nitrogen, Nitrate+Nitrite		-53 to 3	-16	*	-150 to 97	70	
Nitrogen, TKN		-20 to 48	30		-12 to 58	21	
Nitrogen, Total		-15 to 28	18		-9 to 92	44	
Phosphorus, Dissolved		-44 to 38	12		-40 to 99	93	
Phosphorus, Total		-53 to 83	26		-68 to 78	77	
Residue, Suspended		-209 to 42	-6		-689 to 65	14	
Residue,Total		-36 to 20	-11		-79 to 47	14	
Aggregate Organics							
COD		NA	NA		NA	NA	
Oil and Grease		NA	NA		NA	NA	
Surfactant		NA	NA		NA	NA	
Semi-Volatile Organics							
All compounds		ND	ND		NA	NA	

* indicates statistically significant at the 0.05 level.

The mean reduction in peak flows (Table 10) increased from 13 to 64% with the installation of the skimmer and baffles indicating that the modifications may have made the pond more effective at flood control. Reductions in runoff volume and pH ranged widely, but on average were about 0. Turbidity ranged from considerable increases to decreases through the pond. Resuspension of clay particles and high flow, which overtopped the concrete riser likely added to the turbidity as runoff passed through the pond. Sampling method may have also resulted in somewhat higher outflow turbidities in that the outflow discharge rates were generally low and thus the depth of water was low meaning that the intake for the outflow sampler had to be installed near the or on the bottom of the outflow culvert. Whereas the inflow discharge rates were often higher and were monitored via a weir. The inflow intake was installed vertically so it was not sampling the bottom of the water column. This difference in locations of sampler intakes in relation to the water column may have caused some bias in sample turbidities; however, this bias would be insignificant if the pond were reasonably effective at reducing turbidities. Given that the pond was not effective, the bias may have been enough to cause the increase in turbidities. In addition, the rock baffle across the pond was constructed too high, which likely cause backwater from the pond to submerge the inflow weir. This submerged condition caused some of the inflow samples to be collected at incorrect times or resulted in some of the inflow samples containing water from the pond. During high inflows, water backed up over the weir causing artificially high depths which would be interpreted by the sampler as being higher than real inflows thereby causing the machine to sample more frequently. Also, backwater from the pond would cause a stilling zone upstream of the weir where heavier sediment would settle out and not reach the sampler intake. These factors likely biased the inflow data resulting in the mean increase in turbidities during the post-skimmer period.

Reductions in concentrations of metals ranged considerably. Only nickel and zinc had lower average outflow concentrations compared to inflow in either period. The modification of the pond did not appear to improve the pond's function at reducing the concentrations of metals in inflow; however, the concentrations were often so low, this may not be a good indication of the pond's effectiveness.

Reductions in concentrations of inorganic nonmetals varied considerably between storms even after modifications were made. Mean reductions in concentrations and loads of chloride, nitrate+nitrite nitrogen, total nitrogen, and dissolved and total phosphorus increased following the installation of pond modification. Even with these increases none of the reductions were statistically significant according to a paired t test likely because of the variability in the efficiencies. Loads of chloride and nitrate+nitrite nitrogen were changed from significantly increasing through the pond to decreasing on average, although not significantly, through the modified pond. Suspended and total residue concentrations and loads increased through the pond during the pre-skimmer period. These increases were not statistically significant and thus may have been caused by many factors; however, the data shows that the pond was not effective at reducing sediment concentrations and loads in its original configuration. Following modifications, the mean suspended and total sediment loads decreased through the pond slightly indicating that with the baffle and floating intake, the pond may be effective at reducing sediment loads. However, given the variability in efficiencies from individual storms monitored in this study, the effectiveness is far from certain.

For aggregate and semi-volatile organics, concentrations in the few runoff samples that were analyzed were less than the MDL; therefore, efficiencies could not be determined.

Site Specific Considerations: The primary limitation to the monitoring data involved the location of the inflow weir. The weir had to be located between the confluence of a side ditch and the pond, which meant that the weir was possibly subject to submerged flow during large rain events. Also, the weir had to be located in a section of channel which had more slope and turbulence than ideal thereby possibly affecting the accuracy of the inflow measurement. Finally, straw applied to a reshaped section of channel upstream of the weir was washed down into the weir (figure 14), which reduced the accuracy of discharge measurements for at least one storm.

Conclusions/Recommendations: The following observations recommendations are made for the monitoring data:

1. Concentrations of the metals, aggregate organics, semi-volatile organics, and most inorganic nonmetals analyzed for were less than state standards or industrial or general urban stormwater monitored from other sites. Suspended sediment and turbidity concentrations were elevated for several storm samples indicating sediment control practices are needed.
2. The extended detention pond was ineffective at significantly reducing most pollutant concentrations or loads of from the site. Adding a rock baffle and floating intake for the outflow riser appeared to improve the effectiveness of the pond; however, there was considerable variability in the data thus this could not be confirmed definitively.

Orange CMY Salt Storage Area

Description of Site: The Orange CMY is located (N36’ 3.1”; W79’ 5.9”) near the city of Hillsborough in Orange County. Road salt and salt spreaders are stored on a 2.6-acre area of the maintenance yard (figure 15). The road salt-sand mixture is stockpiled in a 3-sided roofed building with the open side facing mostly south. The roof and plastic covers prevent rainwater from contacting the salt for the most part, but occasionally a salt plume has been observed on the asphalt pad in front of the building (figure 16). The 12 truck-mounted salt spreaders are hung on open frames such that they are open to rainfall when not in use on trucks. A considerable amount of metal corrugated culvert pipe is stored on site. In April 2002, 5 36” x 20ft; 8, 30” x 20 ft; 7, 24” x 14 ft; 10, 18” x 20 ft; 2, 24” x 20 ft; and several smaller pipes were being stored on the drainage area (figure 16). Few, if any, pipes have entered or left the drainage area during the monitoring. The area has relatively steep slopes 6-10%, but is well vegetated and stable except for a roadside ditch constructed just after the start of the monitoring period. The construction of this ditch, and to a lesser extent the addition of gravel to the road, limits the probable usefulness of the data from this site. Because the rest of the site is stable, sediment originating from the ditch and the gravel road will likely provide a considerable amount of sediment initially after construction and later when stable sediment load to the monitoring station will decline even if no BMPs are installed. This variability in sediment export masks the effect of the level spreader on sediment export.

On March 12, 2003 a level spreader was constructed downslope of the salt storage building. The level spreader was basically a small ditch cut on the contour, which was designed to convey runoff water away form the roadside ditch along the gravel drive and disperse the runoff over the grassed area where the metal pipes are stored. The spreader also connected to the main drainage ditch for the area. A rock checkdam was constructed across this ditch just downstream of the inlet to the level spreader to divert high flows out of this ditch and into the level spreader. The checkdam turned out to be too porous because it allowed nearly all of the runoff water to flow past the inlet to the level spreader. A 20-ft long, 6-inch culvert was installed between the ditch and the level spreader to provide access to the metals pipes on site (figure 17). Following construction, the area around the spreader ditch was seeded and covered with erosion control fabric. The area was allowed to stabilize before monitoring was restarted in June, 2003. Shortly after the start of monitoring, a truck drove across the spreader and damaged the downstream lip of the spreader. NCSU personnel then repaired the lip by added and packing soil by hand along the downstream lip to bring it back to level. NCSU also asked for the grass downslope of the spreader to be cut higher than normal (3-5 inches) to facilitate stormwater treatment; however, this was not done.

Description of Monitoring: A 90 deg. v-notch weir was installed in the open channel leading away from the culvert under the gravel road at the outlet of the drainage area (figure 17). The weir was installed such that the crest or notch was 3-4 inches above the bottom of the channel to facilitate ponding immediately in front of the weir as recommended in installation guidelines. Continuous measurement of the depth of water above the weir crest and computations of discharge were made by the automated sampler. Flow-weighted samples were collected 1-2 ft upstream of the weir. The sampler was programmed to place flow-weighted samples from small

(<15,000 gal) storms in the first set of 6 sampler jars and samples from larger storms in the 2nd set of 6 sampler jars. Rainfall was measured by a raingage installed above this sampler for the first 6 storms and by the same gage installed about 30 yards away at the wash pad for the rest of the storms. Samples were recovered from the sampler as soon as possible after each storm and were transferred to lab containers and shipped overnight on ice to the laboratory for analysis.

Runoff from 19 storm events prior to and 8 following constructing the level spreader was monitored. Metals not found in the runoff from the first 11 storms were dropped from the analysis list for the last 16 storm samples and COD was analyzed only occasionally, because its concentration was relatively low.

Results of Monitoring: A summary of monitoring results are in Tables 12 and 13. Data from individual storms are in the appendix. A considerable range of events were monitored as evidenced by the range of rainfall, runoff, and peak discharge values shown in Table 12. Although the mean storm rainfall is considerably greater post-spreader, the mean runoff is slightly less. This is typical of the effect of level spreaders as the dispersion of concentrated flow facilitates infiltration thereby reducing runoff. Complicating this assertion is that the post-spreader period included only the fall and early winter months, which often have relatively dry soil moisture conditions.

The mean pH of storm runoff was near neutral. The mean turbidity both pre- and post-level spreader was at least twice the NC receiving water standard of 50 ntu. Mean turbidity for runoff from the 8 post-spreader storms was considerably less than pre indicating a positive effect of the spreader.

Concentrations of metals in the runoff were generally low with Cd, Cu, and Ni less than the MDL for all samples analyzed. Only the mean concentration of zinc (95.7 ug/L) was greater than the NC ambient water quality standard (50 ug/L), but were in line with or less than than concentrations from an industrial area in Charlotte (Bales et al., 1999) or selected individual industrial sites across the state (Table 5). Zinc occurs naturally in stone such as was applied to the gravel road; however, the metal drain pipe may also be a source of the zinc. With the considerable amount of corrugated metal pipe in the drainage area, the concentrations of metals in the runoff were less than might be expected.

Concentrations of chloride in storm runoff were greater than the NC standard of 230 mg/L for 16 of 18 storms during the pre-spreader period, but only 2 of 6 (2 storm samples had no Cl analysis) during the post-spreader period. Monitoring data for chloride in industrial or urban stormwater of NC is relatively scarce, but Makepeace et al., 1995 reported that concentrations have ranged from 0.3 to 25,000 mg/L in urban runoff around the world. Hence, runoff from this site is well within the wide range of chloride concentrations reported, but is a potential problem from this site. Improving the salt storage to eliminate salt plumes like the one shown in figure 16 and cleaning or covering salt spreaders following use should reduce Cl concentrations to acceptable levels. Nitrogen and phosphorus concentrations were relatively low being generally less than corresponding mean values from across the US and from industrial sites in NC (Table 5). Concentrations of suspended sediment were elevated in several samples resulting in means of 106 and 50 mg/L for pre- and post-spreader periods. The suspended sediment was much less than the average (828 mg/L) from the 10 NC industrial sites monitored by Line et al. (1996) and the average of developed areas (2535 mg/L) of the Piedmont (Line et al., 2002). The TSS concentrations were similar or less than those in runoff from a light industrial area (66.3 mg/L) in Charlotte (Bales et al., 1999) and urban areas nationwide (100 mg/L) (U.S. EPA, 1983).

Hence, the concentrations of residue are somewhat less than other industrial sites or urban areas of the state.

Concentrations of chemical oxygen demand were less than reported values for similar areas (Table 5). Oil and grease was not detected and surfactant concentrations were relatively low. As expected, no detections of semi-volatile organics were found in the first two storms; thus this analysis was discontinued for subsequent events.

Table 12. Hydrologic and Pollutant Concentration Data for the Salt Storage Area.

Parameter	Units	Pre-Spreader		Post-Spreader	
		Mean	Range	Mean	Range
Automated rainfall	in	0.91	0.26-5.10	1.15	0.59-1.42
Runoff volume	gal	59670	3,780-425,000	58375	26,130-87,150
Peak discharge rate	gpm	388	28-2,200	916	90-2,800
pH	pH	7.4	6.9-8.0	7.1	6.7-7.4
Turbidity	ntu	198	48-385	100	63-228
Metals					
Cadmium	ug/L	ND	<2-2	NA	NA
Chromium	ug/L	8.6	<5-18	2.9	<5-6
Copper	ug/L	ND	<25	NA	NA
Lead	ug/L	11.9	<5-27	3.8	<5-13
Nickel	ug/L	ND	<10	NA	NA
Zinc	ug/L	95.7	50-350	67.4	<10-232
Inorganic Non Metals					
Chloride	mg/L	1007	210-9,900	224	95-600
Nitrogen, Ammonia	mg/L	0.1	<0.04-0.15	0.1	0.1-0.3
Nitrogen, Nitrate+Nitrite	mg/L	0.4	0.19-0.88	0.6	0.3-1.3
Nitrogen, TKN	mg/L	1.2	0.76-2.1	1.6	1.1-2.2
Nitrogen, Total	mg/L	1.7	1.09-2.69	2.2	1.4-3.5
Phosphorus, Dissolved	mg/L	0.1	0.02-0.18	0.2	0.1-0.3
Phosphorus, Total	mg/L	0.3	0.12-0.53	0.3	0.2-0.5
Residue, Suspended	mg/L	106	12-397	50	13-196
Residue,Total	mg/L	962	516-1,130	453	268-1,090
Aggregate Organics					
COD	mg/L	36	21-52	NA	NA
Oil and Grease	mg/L	ND	<5	NA	NA
Surfactant	mg/L	0.24	<0.1-0.4	NA	NA
Semi-Volatile Organics					
All compounds	ug/L	ND	ND	NA	NA

Table 13. Pollutant Loads for the Salt Storage Area of the Orange CMY.

Parameter	Units	Pre-Spreader		Post-Spreader	
		Mean	Range	Mean	Range
Metals					
Cadmium	g	ND	ND	NA	NA
Chromium	g	1.2	0-4.1	0.7	0.2-2
Copper	g	ND	ND	NA	NA
Lead	g	3.0	0.1-21	1.1	0.2-1.3
Nickel	g	ND	ND	NA	NA
Zinc	g	20	0.7-118	15.9	0.86-60.7
Inorganic Nonmetals					

Chloride	g	298,595	4,706-3,350,000	50,498	13,226-156,900
Nitrogen, Ammonia	g	18	0.3-161	27	6-101
Nitrogen, Nitrate+Nitrite	g	83	9-611	121	26-265
Nitrogen, TKN	g	247	16-1609	360	112-756
Nitrogen, Total	g	331	38-2220	481	139-1,021
Phosphorus, Dissolved	g	28	0.3-290	37	9-76
Phosphorus, Total	g	65	2-531	71	17-178
Residue, Suspended	g	14,908	172-7,240	13,674	1,323-64,650
Residue,Total	g	223,014	10,450-1,786,000	96,936	32,557-285,100

Annual pollutant export from the sites was computed by determining rainfall and runoff for all storms of greater than 0.2 in. accumulation occurring during 2003 and combining the total runoff with the mean concentration for the storms monitored and dividing by the drainage area. Like the Wilson CMY, rainfall data on-site was missing, it was obtained from a nearby gage and when runoff was missing, it was estimated using the rainfall-runoff regression equation developed for storms that had the data (runoff=rainfall*57,916-10,296 r^2=0.81). As with many urban sites, the drainage area was difficult to accurately determine. Subtle changes in slopes of graded areas and direction of roof drainage made determining the extent of the area difficult, but an estimate of 2.6 acres was finally made.

Estimates of annual pollutant export are shown in Table 14 along with monitoring estimates from three other urban areas. Export of chromium, lead, and zinc were greater than those from the light industrial, but less than the high density residential areas of Charlotte. Export of copper and nickel were similar or less than both the Charlotte drainage areas. These data indicate that export of metals from the Orange CMY salt storage area is similar, if not less, than other urban areas.

While there are no export data to compare chloride to, the rate shown in Table 14 appears to be quite high as compared to 17.8 lb/ac-yr (Table 6) rate measured at the Wilson CMY. This indicates more effort may be required to keep roadsalt stored at the site contained and covered. Export of nitrogen forms and total nitrogen were similar or less than corresponding export from urban areas in Charlotte and Cary indicating nitrogen export was similar or less than typical urban areas. Total phosphorus export was greater than the light industrial area and less than the high density residential area of Charlotte and less than the residential area of Cary. Hence, phosphorus export was similar to or less than example urban areas. Suspended sediment export was greater than the light industrial, but less than the high density area of Charlotte and greater than the residential area of Cary. This mixed result indicates that sediment export may be greater than many urban areas and thus should be treated prior to discharge from the site.

Like chloride, there is little export data available to compare the COD export to; however, biochemical oxygen demand (BOD) from the light industrial and high density residential areas of Charlotte was 108 and 67 lb/ac-yr, respectively (Bales et al., 1999). Because COD is usually greater than BOD, the 174 lb/ac-yr export for this site is likely similar to urban runoff. The fact that the mean event mean concentration for storm events was less than other urban and industrial runoff supports the assertion that the export would be less or similar.

Table 14. Annual Pollutant Export from the Orange CMY Salt Storage Area.

	Units	Orange CMY	Light Industrial[1]	High Dens. Res.[1]	Med. Dens. Res.[2]

Drainage Area	ac	2.58	40.3	80.6	6.3
Annual Rainfall	in	32.55	NA	NA	37.7
Runoff	in	21.55	NA	NA	21.5
Metals					
Cadmium	lb/ac-yr	<0.005	NA	NA	NA
Chromium	lb/ac-yr	0.042	0.013	0.164	NA
Copper	lb/ac-yr	<0.244	0.061	0.267	NA
Lead	lb/ac-yr	0.065	0.022	0.150	NA
Nickel	lb/ac-yr	<0.049	0.041	0.056	NA
Zinc	lb/ac-yr	0.413	0.356	0.903	NA
Inorganic Non Metals					
Chloride	lb/ac-yr	2223	NA	NA	NA
Nitrogen, Ammonia	lb/ac-yr	0.42	NA	NA	2.14
Nitrogen, Nitrate+Nitrite	lb/ac-yr	2.37	NA	NA	2.86
Nitrogen, TKN	lb/ac-yr	5.96	NA	NA	18.5
Nitrogen, Total	lb/ac-yr	8.38	5.0	20.6	21.3
Phosphorus, Dissolved	lb/ac-yr	0.40	NA	NA	NA
Phosphorus, Total	lb/ac-yr	1.50	0.94	4.06	2.05
Residue, Suspended	lb/ac-yr	638	381	3125	346
Residue,Total	lb/ac-yr	5008	NA	NA	NA
Aggregate Organics					
COD	lb/ac-yr	174	NA	NA	NA
Oil and Grease	lb/ac-yr	ND	NA	NA	NA

[1] Data for Mecklenburg County, NC (Bales et al., 1999).

2 Data from a subdivision in Cary, NC (Line et al., 2002)

Pollutant Reduction Efficiency: The basic premise in evaluating a stormwater practice is to document the pollutant load or export with and without the practice. Because of the level spreader works in conjunction with a grass strip, its efficiency must be measured by monitoring runoff and pollutant loads before and after its implementation. This requires that the drainage area remain consistent both physically and in relevant activities during both the pre- to post-BMP implementation periods in order to isolate the effect of the level spreader.

Average turbidity in storm event samples was considerably greater than the NC standard for receiving waters. The turbidity levels decreased considerably post-level spreader; however, the post-spreader levels were not significantly different than pre according analysis of covariance tests.

Average storm event load (Table 13) for chromium, lead, and zinc decreased 42, 63, and 21%, respectively. While these reductions appear to be considerable, given the relatively low mass loads and the variability in the data, they are not statistically significant according to an analysis of covariance test performed on the pre- and post-BMP rain and metal loading data. The analysis of covariance compares the trend between rainfall and pollutant loading for the pre versus the post-spreader data. The statistical test indicates that the reductions are not definitive given the monitoring data, which is not unexpected given that much of the metal culvert pipe is stored downslope of the spreader an thus runoff from this area would not be treated anyway.

Mean chloride loads decreased 83% following the implementation of the level spreader. Much of this may be explained by the post-spreader monitoring occurring during the fall and early winter when no salt was being used. Additionally, a large pile of roadsalt stored outside in the drainage area (covered) was removed shortly after the spreader was installed. The removal of the salt pile and lack of salt spreading activity may have resulted in reductions in chloride loads regardless of any effect of the level spreader.

Mean storm event loads of nitrogen and phosphorus forms were slightly greater post as compared to pre-spreader, but they were not significantly (by analysis of covariance) greater at the 0.05 levels of significance. Suspended sediment loads were slightly less following spreader implementation, but here again the decrease was not significant.

Site Specific Considerations: The primary limitation of the efficiency data was that there were significant changes to the drainage area during the monitoring period. Regrading a roadside ditch and applying gravel to the access road during the pre-BMP period and removing the large pile of road salt during the post-BMP monitoring period may have affected the results. In addition, damaging the level spreader by running over it with a truck and cutting the grass shorter than was recommended likely negatively impacted the effectiveness of the spreader.

Conclusions/Recommendations: The metals, chloride, and sediment load data indicate that the spreader was somewhat effective, but not definitively so. However, factors such as salt spreading activity, outdoor salt storage, truck damage to the level spreader, improving the roadside ditch, mowing the grass shorter than recommended and applying gravel to the access road likely contributed positively and negatively to the effectiveness data. However, the following conclusions/recommendations can be drawn for the data:

1. Although there is exposed storage of metal pipes in the drainage area, concentrations of metals in runoff were less than NC receiving water standards for all metals except zinc. Zinc concentrations were less than selected industrial areas and sites in NC.
2. Nitrogen and phosphorus concentrations in runoff and export loads were relatively low compared to urban and industrial areas.
3. Chloride and turbidity levels in runoff decreased considerably following the implementation of the level spreader, although these decreases may have been caused by factors other than the spreader.
4. Annual export of nitrogen and phosphorus was similar or less than export from three other urban areas in NC. Suspended sediment export was greater than 2 of the 3 urban areas indicating that greater effort may be required to control sediment movement.
5. Although there exists little data from urban areas on chloride export, annual export of chloride was high compared to the Wilson CMY site indicating that there was potential for decreasing this export. This was also evident from observations at the site.
6. Given the activity on the site, the level spreader should be constructed out of a hard material such as concrete or a stable crossing provided.

Orange CMY Washwater Discharge

Description of Site: The Orange CMY is located (N36’ 3.1”; W79’ 5.9”) near the city of Hillsborough in Orange County. As part of normal maintenance equipment is hosed off with pressurized water to wash to remove accumulated soil, road dirt, and grime. The washing occurs on an uncovered gravel pad near the back of the yard. The washpad area is about 61 ft by 44 ft and the gravel is 6-10 inches deep. A concrete curb was constructed along the perimeter of the pad to both contain the gravel and channel the runoff to the storm drain outlet. A 4 in. perforated underdrain pipe was laid along the curb to facilitate the movement of washwater to the outlet drain. Unknown numbers of trucks and other equipment are washed on the pad during the normal course of daily operations. The wash wastewater drains off the vehicle to the pad and flows through the gravel until it is collected by a curb drain system that empties into a storm drain and out through an open channel (figure 18).

Description of Monitoring: A 90 deg. v-notch weir was installed in the open channel leading away from the storm drain. The weir was installed such that the crest or notch was 3-4 inches above the bottom of the channel to facilitate ponding immediately upstream of the weir as recommended for measurement of discharge. Continuous measurement of the depth of water above the weir crest and computations of discharge were made. Flow-proportional samples were collected 1-2 ft upstream of the weir via a vertical stainless steel intake and discharge tubing connected to the sampler. The sampler was programmed to place nonstorm discharge in the first 6 sampler jars and storm discharge in the 2nd 6 sampler jars. An 8-in. diameter tipping bucket raingage was connected to the sampler and if greater than 0.02 inches of rain fell in an hour the sample was considered storm discharge, otherwise it was nonstorm. Samples were recovered from the sampler jars about weekly. Samples were transferred to lab containers and placed on ice for overnight shipment to the lab.

Results of Monitoring: Data from seven samples of nonstorm washwater were collected and five samples of storm event runoff from the wash pad are summarized in Table 15. The pH level was near neutral for storm and nonstorm samples; however, the turbidity was much greater than the NC standard of 50 ntu (NC DENR, 1997). The high turbidity was likely associated with high suspended solids concentrations, which came from the material washed off trucks or possibly material washed off the gravel.

Average concentrations of chromium, copper, lead, and zinc in nonstorm samples were greater than NC state standards for freshwater; however, given that the discharge rates were low, the overall export of pollutants was also low (Table 16). The mean concentrations for all six metals were less than those for selected industrial site in NC (Table 5, Line et al., 1996) and similar to urban runoff (Table 5). Concentrations in storm event samples were much lower (Table 15) likely due to dilution from rainwater.

The mean concentration of chloride in storm event samples was much greater than the NC freshwater standard for receiving waters. Both storm and nonstorm mean chloride concentrations were elevated by one sample each, which was collected during the winter and had concentrations in excess of 3700 mg/L.

The mean nitrate nitrogen concentrations from both storm and nonstorm samples were greater than the NURP values from urban runoff in general (Table 5) and slightly greater than selected NC industrial sites. Total Kjeldahl nitrogen concentrations in nonstorm samples were also greater than the NURP and NC industrial sites means (Table 5), but the storm samples were less. Concentrations of total phosphorus forms were similar with nonstorm being greater and storm less than reported. The concentrations in storm samples are more representative of runoff from the site as storm runoff will move the pollutants off-site. The nonstorm discharge was so low that it will usually result in no off-site discharge. Thus, the nitrogen and phosphorus concentrations are similar or less than reported urban and industrial storm runoff.

The nonstorm suspended sediment or residue concentrations were much greater than storm. This indicates that the residue particles are relatively fine or they would not be carried to the monitoring station by the low nonstorm flows. The particles likely are mostly soil clay or silt particles, but could also be metal, stone, or rubber particles that have washed off the transportation equipment. Concentrations in storm samples were similar to NURP means and much less than selected NC industrial sites (Table 5). The nonstorm mean is much greater than reported for NURP urban and NC industrial runoff; however, it falls well within the range of reported values for urban storm water as reported by Makepeace et al. (1995). It is not strictly appropriate to compare washwater to stormwater, because the flows are much less, but if this concentrated low flow reaches a stream with low dry weather flows, it could have a significant effect. Thus, providing a small detention pond for capturing dry weather flows would be advisable.

Levels of the aggregate organic COD were similar to NURP urban runoff and selected NC industrial sites. Levels of oil and grease in storm samples were less than the MDL and were greater than the MDL in only 2 of the 6 nonstorm samples. However, one of the samples had a concentration of 31 mg/L, which was quite high for stormwater. Due to the variable nature of the washing effluent (highly dependent on which truck is being washed) many samples should be collected to accurately reflect the level of oil and grease in effluent. Two samples were analyzed for semi-volatile organics, but only a small amount of Phthalate was found in one of the samples.

Site Specific Considerations: none

Conclusion/recommendations: Given the relatively few samples collected and the variable nature of the activity on the wash pad, definitive conclusions are not appropriate; however, the following general conclusions can be drawn:

1. Washwater and stormwater runoff from the gravel washpad contained metals, inorganic nonmetals, and aggregate organics at relatively low levels compared to washwater from the pressure wash operation at the Wilson CMY. Still elevated levels of some pollutants such as suspended solids and chloride, especially in the nonstorm washwater samples, could be a potential problem.
2. Construction of a small detention pond to contain the nonstorm discharges is recommended to prevent these more polluted flows from reaching dry weather streams where they could significantly increase pollutant concentrations in low flows. Flushing the stored discharge out during storm runoff would generally cause an insignificant increase in pollutant concentrations because of the dilution with storm runoff.

Table 15. Monitoring Data from the Gravel Washpad at the Orange CMY.

Parameter	Units	Storm Event		Non storm	
		Mean	Range	Mean	Range
Automated rainfall	in	0.63	0.2-1.17	0.08	0-0.48
Runoff volume	gal	7,331	1130-14,000	1287	555-2,565
Peak discharge rate	gpm	55	18-118	36	7-90
pH	pH	7.8	7.4-8.2	7.7	7.2-8.2
Turbidity	ntu	138	85-218	985	247-2210
Metals					
Cadmium	ug/L	<2	<2	<2	<2-16
Chromium	ug/L	8	<5-17	104	17-342

Copper	ug/L	25	<25	117	<50-250
Lead	ug/L	6	<10-13	49	<5-120
Nickel	ug/L	5	<10	41	<10-92
Zinc	ug/L	62	40-90	261	90-520
Inorganic Nonmetals					
Chloride	mg/L	758	14-3,700	5,455	19-38,000
Nitrogen, Ammonia	mg/L	0.04	<0.04-0.08	0.1	<0.04-0.62
Nitrogen, Nitrate+Nitrite	mg/L	0.89	0.18-2.05	1.2	<0.05-5.5
Nitrogen, TKN	mg/L	0.78	0.45-1.20	2.9	1.60-3.80
Nitrogen, Total	mg/L	1.67	0.63-3.25	4.1	2.15-8.70
Phosphorus, Dissolved	mg/L	0.03	0.01-0.05	0.0	<0.01-0.05
Phosphorus, Total	mg/L	0.22	0.08-0.46	1.1	0.40-2.13
Residue, Suspended	mg/L	107	40-236	2,169	384-6,790
Residue,Total	mg/L	1,497	168-6,060	11,705	637-64,500
Aggregate Organics					
COD	mg/L	23.8	12-31	123	29-264
Oil and Grease	mg/L	<5	<5.0	7.1	<5-31
Surfactant	mg/L	0.2	<0.1	1.6	0.3-3.0
Semi-volatile Organics					
Bis(2-ethylhexyl) Phthalate	ug/L	7.3	<10-22	<10	<10
All other compounds	ug/L	ND	ND	ND	ND

Table 16. Pollutant Loads from the Orange CMY Wash Pad.

Parameter	Units	Storm Event		Non storm	
		Mean	Range	Mean	Range
Metals					
Cadmium	g	ND	ND	ND	ND
Chromium	g	0.2	0.03-0.58	0.5	0.04-1.4
Copper	g	0.7	0.11-1.32	0.6	0.05-1.02
Lead	g	0.1	0.03-0.26	0.3	0.02-0.70
Nickel	g	0.1	0.02-0.26	0.2	0.01-0.38
Zinc	g	1.8	0.21-4.77	1.3	0.19-2.13
Inorganic Nonmetals					
Chloride	g	39498	161-196,060	152	66-292
Nitrogen, Ammonia	g	1.3	0.1-4.2	0.3	0.1-0.8
Nitrogen, Nitrate+Nitrite	g	12.0	8.8-22.0	6.8	0.1-32.1
Nitrogen, TKN	g	18.7	5.1-43.5	12.6	4.8-18.7
Nitrogen, Total	g	30.7	13.9-54.6	19.4	6.1-50.7
Phosphorus, Dissolved	g	0.7	0.1-1.4	0.1	0.0-0.2
Phosphorus, Total	g	5.3	0.8-12.2	5.1	1.2-8.7
Residue, Suspended	g	2817	351-7,154	9,844	916-27,810
Residue,Total	g	68713	2210-321,120	12,961	1,605-34,480
Aggregate Organics					
COD	g	754	307-1620	457.3	141-899
Oil and Grease	g	ND	32-132	28	<5-31
Surfactant	g	6.41	3-16	7.10	1-12

Orange CMY Soil Storage

Description of Site: The Orange CMY is located (N36’ 3.1”; W79’ 5.9”) near the city of Hillsborough in Orange County. The overall drainage area is about 4 acres with about 0.5-1.0 acres of pine woods off-site. Slopes for the area are moderate ranging from 3-6%. Topsoil, stone, and fill material are stockpiled on part of the area (figure 19). Also, some metal is stored in the area. The area that is not used for stockpiling soil appears to be relatively stable with considerable vegetation and thus should not contribute significant amounts of sediment to the monitoring site. In 2002, a large 10-15 ft high, horseshoe-shaped berm was constructed in the area where soil material had been previously stored. The berm appeared to be used to facilitate stockpiling of soil and stone. This berm may have increased the sediment yield from the site given that it is relatively steep and large.

In March or April, 2003 a sediment trapping device was installed around the road culvert just upslope of the monitoring station (figure 20). The device consisted of a riprap berm faced with a layer of #57 stone. There was also a small trench around the upslope perimeter of the device seemingly to promote ponding of water before the water passed through the berm. The device was similar in function and construction to the outlet of a standard sediment trap or in-channel checkdam.

Description of Monitoring: Runoff from 46 storm events prior to and 18 following the implementation of the sediment trapping device was monitored. Samples were collected and analyzed for suspended sediment and turbidity for most of the events (data is in appendix).

Runoff monitoring was accomplished by installing a 3-ft rectangular weir in the open channel leading away from the culvert under the gravel road. The weir was installed such that the crest was 2-4 inches above the bottom of the channel to facilitate ponding immediately in front of the weir as recommended in installation guidelines. Continuous measurement of the depth of water above the weir crest and computations of discharge were made by the automated sampler. Flow-proportional samples were collected 1-2 ft upstream of the weir. The sampler was programmed to place flow-weighted samples from storms in the plastic sampler bottles. Rainfall was measured by a raingage installed about 30-60 yards away. Rainfall for several events was not monitored due to power failures at the site. For these storms rainfall from a site in Carrboro was used.

Samples were recovered from the sampler as soon as possible after each storm and were transported to the NCSU lab for analysis. Because these samples were analyzed for sediment and turbidity only, they were not refrigerated in the field; however, they were refrigerated in the lab until analysis.

Results of Monitoring: A summary of monitoring results is included in Table 17, while the data for individual storms is in the appendix. Annual rainfall increased from the pre- to post BMP periods, while the annual runoff decreased. The decrease in runoff may have been caused by the post-BMP period encompassing mostly only summer and fall months, which typically have dryer antecedent moisture conditions than the all-year round conditions encompassed during the pre-BMP period.

The mean turbidity levels for storm event samples decreased from 1152 to 624 ntu following the installation of the sediment trapping device. While this decrease is considerable, the post-BMP mean is still considerably greater than the NC receiving water standard of 50 ntu. In fact, all of the 15 post-BMP individual storm samples had turbidities greater than 200 ntu indicating that this sediment control practice is not adequate for reducing turbidity to the receiving water standard.

The mean concentrations of TSS in the runoff decreased post-BMP similar to the turbidity. The mean post-BMP TSS concentrations were still much greater than those of urban stormwater from NURP sites (Table 5), but were less than those from selected NC industrial sites (Table 5). The mean TSS concentrations was also much greater than the concentration (66.3 mg/L) in runoff from a light industrial area in Charlotte (Bales, et al., 1999). The TSS export or load also decreased following the installation of the BMP; however, it still exceeded the range of total solids exported (0.63-2.34 ton/ac-yr) from six Mecklenburg County urban areas (Ferrell, 2001).

Table 17. Summaries of Monitoring Data for the Soil Storage Area.

	Rain	Runoff	Turbidity			TSS Concentration			TSS Load
			Mean	Range	No.	Mean	Range	No.	Mean
	in/yr	gal/yr	ntu	ntu		mg/L	mg/L		ton/yr
Pre-BMP	20.4	2,568,277	1152	44-6580	38	997	25-7480	39	6.58
Post BMP	28.9	1,916,779	624	208-1234	15	526	168-1075	15	3.21
Change (%)	41.7	-25.4	-45.8			-47.2			-51.2

Pollutant Reduction Efficiency: Statistical analysis of the data was performed to determine if the apparent reductions were statistically significant. Analysis of covariance on the storm event rainfall and runoff amounts suggested no significant difference between pre- and post-BMP runoff. A similar analysis of storm event rainfall versus TSS loads also indicated that there was no significant effect of the sediment control device. The variability in the data, perhaps caused by the modifications to the site during the pre-BMP period, likely masked the effect of the practice. This result does not necessarily mean that the practice was ineffective only that it could not be documented statistically. Statistical significance supporting effectiveness data provides more definitive proof of the effect of the device.

Site Specific Considerations: As with the level spreader, in order to accurately document an effect of the sediment control device, a stable drainage area with relatively consistent activity throughout the monitoring duration was required. The construction of the large berm/hill for facilitating materials loading and the cutting of the pine trees on the adjacent land, were significant changes to the drainage area which reduced the probability of documenting a significant change.

Conclusions/Recommendations: The following additional conclusions/recommendations can be drawn from the data:

1. Although difficult, monitoring of borrow pit effluent must include sample collection during or shortly after storm events. In any case, it would be helpful to know the number of days prior to collecting the grab sample that a significant rainfall event occurred.
2. Varying amounts of soil material were stored on site during the period of monitoring; however, it appears that the sediment loss per storm is more closely dependent on the intensity and duration of the storm event than the amount of soil

material in the area at the time of the storm. This observation would likely change if nearly all of the stockpiled soil material were removed and the area was seeded to stabilize it.

3. While turbidity, TSS concentrations, and TSS export decreased more than 45% following the installation of a sediment control device, the decreases were not statistically significant (0.05 level) according to an analysis of covariance. Changes in the drainage area during the pre-BMP period likely contributed to increased variability in sediment load data and thus decreased statistical sensitivity to changes in sediment loss.
4. Even after the sediment control device was installed, turbidity and TSS concentrations were greater than NC receiving water standards and runoff from several urban areas.
5. An additional or enhancements to the existing sediment control practice is needed to further control sediment loss from the site. Extended storage of runoff or the addition of a flocculent or floating discharge pipe could be used to modify/enhance the existing practice. A vegetative practice such as a grass strip or small wetland could be used following the existing practice to remove sediment left in the effluent.

CONCLUSIONS

While site specific conclusions are included in the above section, the following more general overall conclusions can be drawn from the data:

1. The sediment trap in this study, like those on monitored residential construction sites, removed about 60% of the sediment from borrow pit effluent and reduced turbidity significantly, although outflow from the trap still had an average turbidity of 122 ntu. Thus, additional treatment is required to reduce the turbidity to the receiving water standard of 50 ntu.
2. The concentrations of metals, nitrogen, phosphorus, aggregate organics, and sediment in runoff from the Wilson, Alexander, and salt storage area of the Orange CMY were, with a few exceptions, similar or less than those in runoff from urban and industrial areas of NC.
3. The efficiency of the extended detention pond was poor, while the efficiencies of the constructed wetland, the level spreader, and the sediment trap at the Orange CMY could not be determined due to site-specific difficulties. The constructed wetland had too much deep water, too few plants, and little to no storage volume. The level spreader sustained damage from being driven over and had several significant changes to the drainage area during the monitoring period. Harvesting of trees and the creation of a large berm in the soil storage area, which drained to the sediment trap at the Orange CMY, during the monitoring introduced too much random variability into the runoff for a definitive evaluation of the efficiency of the sediment trap.
4. Effluent from steam pressure-washing of vehicles at the Wilson CMY had very high levels of many pollutants. Because the volume of effluent was quite small, the actual

mass loading of pollutants was not great; however, isolation and treatment of this effluent will likely dramatically reduce pollutants in stormwater runoff from the site.

5. Concentrations of pollutants, with the exception of chloride which was high in several samples collected during the winter, in effluent from a gravel washpad at the Orange CMY were generally similar to or less than runoff from monitored NC industrial and comparable urban areas.

RECOMMENDATIONS

While site specific recommendations are included in one of the above sections, the following more general broad recommendations can be drawn from the data and on-site observations:

1. In general it appears that the runoff from the three NC DOT industrial sites in this study was, with a few exceptions, of similar or better quality than that from NC industrial or urban areas. Thus, the focus of stormwater mitigation efforts should be on “hot spots” such as pressure wash operations and areas of a lot of road salt storage and/or handling activity.
2. Maintaining good quality stormwater requires that pollutant sources such as oil spills/leaks, road salt, unnecessary materials, and exposed soil be minimized on-site. Hence, education for all employees regarding dealing with these issues is needed.
3. Evaluating the efficiency of practices such as level spreaders using a single downstream monitoring station before-after BMP implementation approach requires that the drainage area remain as stable or as consistent as possible apart from the implementation of the BMP during the 2-year minimum monitoring period. Hence, selecting sites where no changes in the drainage area are expected for at least a 2-year period is essential. Obviously, this requirement limits where this approach can be used.
4. Extended detention ponds, like the one at the Alexander CMY, are an ineffective BMP for reduction of pollutant export; therefore, they should only be implemented in the basic configuration for peak discharge reduction. If modified to reduce flow through and dewater from the top of the water column, the pond may be effective; however, this modified pond still should be evaluated.
5. Most county maintenance yards, such as the Orange and Alexander CMYs, runoff from areas excluding wash pads had little to no oil and grease, surfactant, or semi-volatile organic compounds; therefore, these could be eliminated from future monitoring. Also, for sites with relatively little storage of exposed metal, sample analysis for metals could be eliminated.
6. Monitoring criteria for this project followed requirements for NPDES stormwater permit monitoring, which is focused on characterizing pollutant export; however, BMPs should be evaluated under a wide variety of storm conditions not just for storms similar in accumulation and duration to the median for the region that occur after 72 hours of dry weather (U.S. EPA, 1992). Because BMPs must be effective for a wide variety of storms, the storm criteria must be broadened and the dry weather criteria shortened to facilitate wetter antecedent conditions.

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LIST OF FIGURES

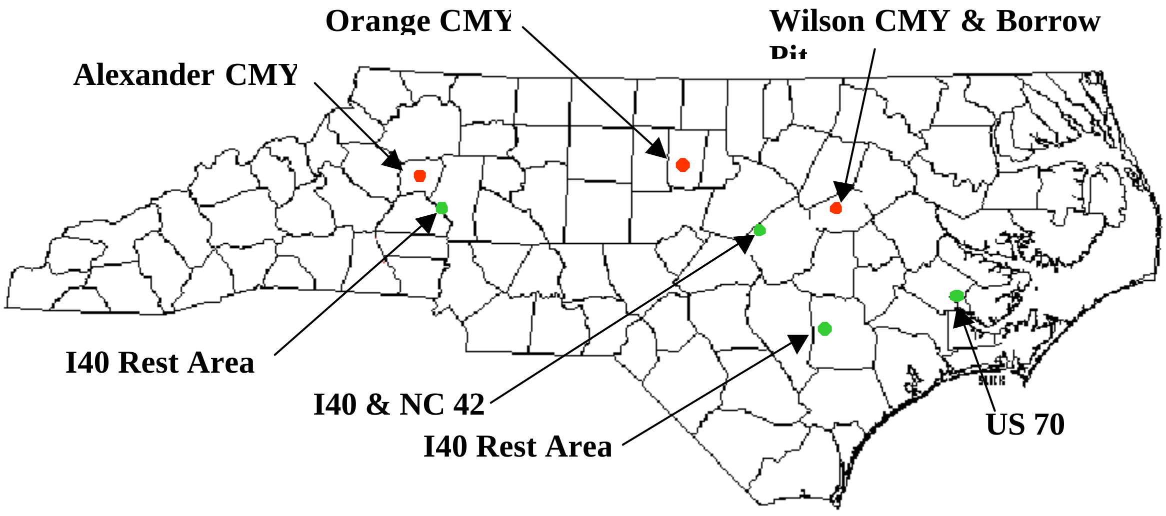

Figure 1. Locations of industrial (3 on top) and highway sites (4 on bottom).

Figure 2. Baker Borrow pit during excavation (left) and completed (right).

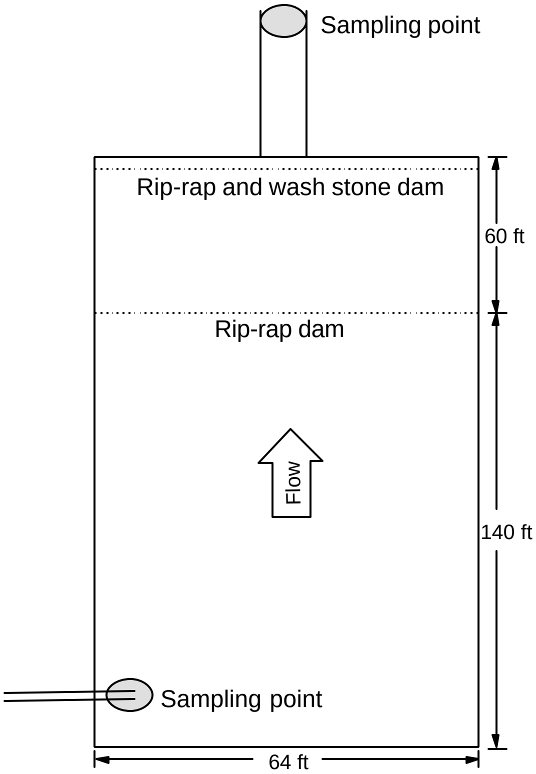

Figure 3. Schematic drawing of the Baker borrow pit.

Figure 4. Sediment trap (right) and monitoring weir (right).

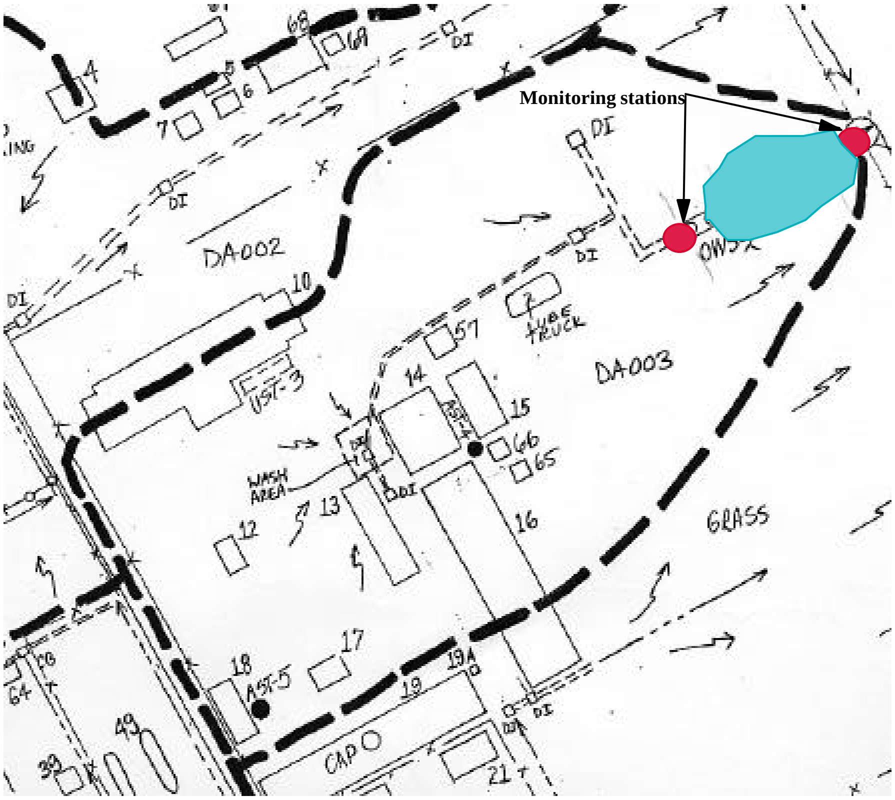

Figure 5. Map of Wilson CMY wetland drainage area (wetland is shaded area).

Figure 6. Wilson stormwater drain before and after construction of wetland in October, 2001.


Figure 7. Wilson wetland prior to and after replanting in July 2002.


Figure 8. Wilson wetland inflow weir and oil slick on inflow water.


Figure 9. Lower part of the drainage (right) and diversion to carry runoff to drain inlet.

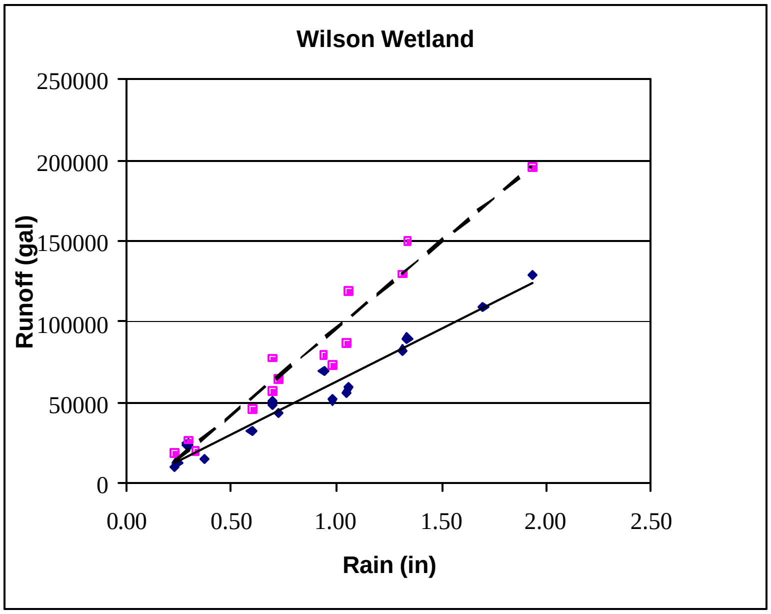

Figure 10. Rainfall versus runoff for inflow and outflow (dashed line) from wetland.

Photo not available Vehicle Wash #1 (12/4/01)	 Vehicle Wash #2 (1/14/02)
 Vehicle Wash #3 (2/6/02)	 Vehicle Wash #4 (3/6/02)

Vehicle Wash #5 (5/16/02) Vehicle Wash #6 (6/25/02)

Vehicle Wash #7 (9/26/02) Vehicle Wash #8 (11/25/02)

Vehicle Wash #9 (11/25/02) Vehicle Wash #10 (1/15/03)

Figure 11. Photos of the vehicles from which washwater was collected.

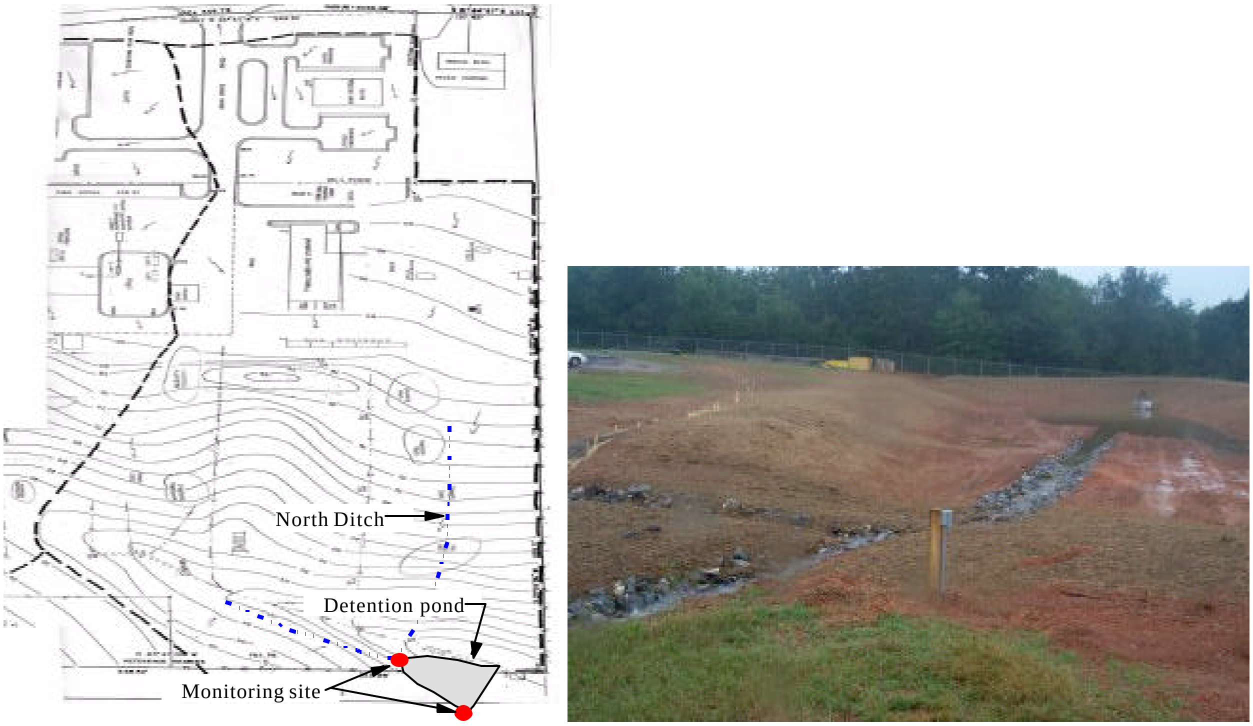

Figure 12. Map of Alexander CMY (left) and photo of inflow tributaries (right).

Figure 13. Outside view (left) and inside view (right) of outlet riser.

Figure 14. Floating intake (left) and inflow weir with straw (right).

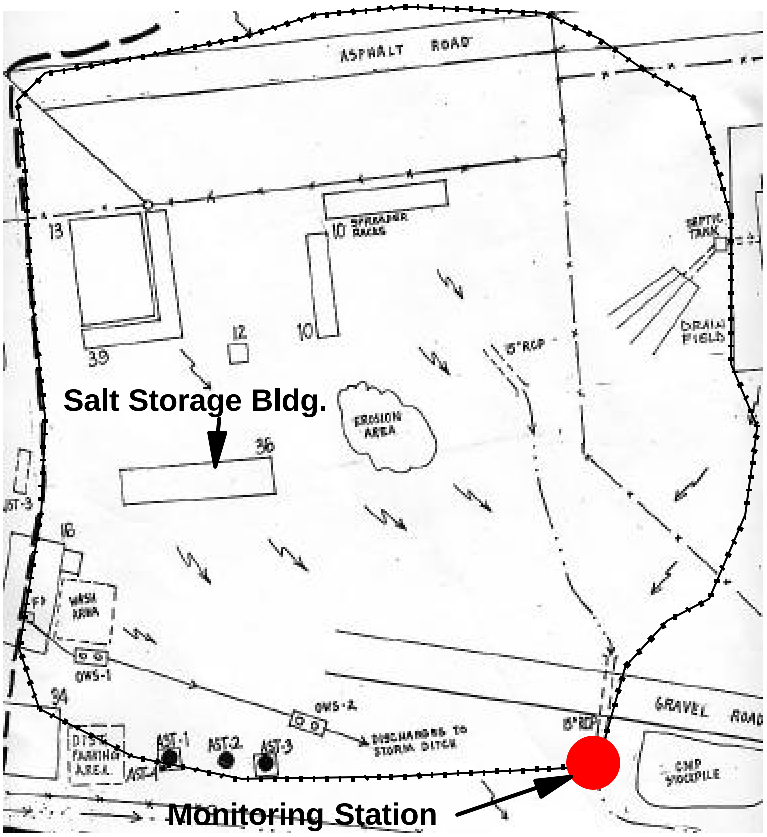

Figure 15. Map of Orange CMY salt storage area.

Figure 16. Drainage area for Orange CMY (left) and salt storage building (right).

Figure 17. Monitoring weir (left) and level spreader (right) at Orange CMY.

Figure 18. Gravel was pad at Orange CMY.

Figure 19. Soils storage area before (left) and after (right) berm constructed.

Figure 20. Sediment control device for the soil storage area of the Orange CMY.

APPENDICES

Exhibit 1. Wilson Wetland Modifications: The following modifications to the constructed wetland and the Wilson CMY were recommended in a memo to DOT dated February 4, 2003:

The current stormwater pond/wetland at the Wilson CMY contains two relatively large areas of deep water (>2 ft) one at the inlet and the other mostly along the north side of the downstream half, which does not support a wetland ecosystem. We recommend that the deep water areas be partially filled in with soil material cut from the north bank. The inlet deep water pool could be reduced by creating a shallow water shelf extending out from the north bank as shown in the figure below. The lower deep water area could be reduced by creating a shelf extending out from the north bank to almost the south bank. Two 15-25 ft in diameter areas should be left as a deepwater (>1 ft deep) micropools near the inlet and outlet to provide added diversity to the aquatic habitat.

It is estimated that 200-250 yd^3 of fill will be needed to fill in the deepwater area. This could be obtained from cutting 10-15 ft from about a 60-80 ft section of the north bank of the current pond/wetland. The fill would be pushed into the deepwater area to raise its ground surface to within 3-5 inches of the current water surface creating a shallow marsh area. A slightly deeper (6-10 in.) 6-8 ft wide channel should be left along the south side of the current pond/wetland to provide a deep marsh area for the wetland.

A sediment forebay should be constructed in the channel to the wetland. This will trap larger sediment prior to entering the wetland. A simple rip rap and wash rock checkdam across the channel (fig. 2) could be installed to slow the water and allow sediment to deposit.

Vegetation is the key to maximizing the effectiveness of a stormwater wetland. Juncus and Carex species should be used generously and are good candidates for such an impacted sight due to their winter hardiness. This is beneficial in that there is less net release of nitrogen in the dormant winter season as with other herbaceous perennials. Though this may produce a quite homogeneous-looking wetland with little aesthetic value, it is the best way to attack the current filtering capacity inadequacies. The Carex and Juncus species provide year round life, no large net output of nitrogen due to dormancy, and the density of stems and tightly interwoven fibrous root system sieve and entrap sediments. Large amount of surface area provided by Juncus allows for attachment of hydrocarbons. Though heavy metals and hydrocarbons are expected remain on site they will be filtered out of surface waters and entrapped within soil substrates due to normal sedimentation rates and continuous vertical growth/layering of root system.

Recommended Species:
Juncus effuses (Soft rush)
Scirpus americanus
Panicum vergatum
Carex lurida (Lurid sedge)
Carex stricta (Tussock sedge)
Carex crinata var. crinata (Fringed sedge)

Plant the above wetland species on the shallow marsh (<5 in) areas on approximately 2 ft centers. The newly created low marsh area would be about 1600 ft^2, which would require about

400 plants. Given the recommended plants cost between $0.70-0.90 (depending on supplier) for bare root and some plugs, the cost of plants would be around $320.00. Some of these plants may be transplanted from on-site supplies.

Plant bushes and/or trees at drop structure for added soil stability. Plant additional trees and bush species of the same ecotype on border of water surface. Species must be able to tolerate continuously saturated soils and some inundation year round. They will not add value to filtering capacity of the wetland system only topographic stability. Additionally, some shading may prevent algal accumulations during summer season.

The outlet structure should be such that allows for a slow drawdown of the water surface from the ‘normal’ post storm level (bottom of the current weir). This variation in water surfaces promotes vigorous vegetative growth and provides some stormwater storage. The current weir could be left in place and two 0.75 in. slotted or screened pipes added that extend through the weir plate about 6-8 inches below the bottom of the current weir.

The sediment trap/forebay should be cleaned/dredged as needed to maintain sediment levels less than one-third the height of the rock dam. After planting the vegetation should be inspected monthly until establishment. (“Establishment” should be determined by practiced ecologist/biologist.) Inspection and nuisance species removal performed quarterly in first two years, then yearly thereafter. Adjust outlet weir height in order to vary hydroperiod as found naturally in such wet systems. Seek hydrologist/wetland specialist for specific guidance on hydroperiod variation. Do not mow or weed-eat within 20 feet of wetland or channel edge at any time of the year. Let it grow naturally and unkemptly.

Juncus is currently present on site and can be used for periodic transplanting. Chop one rootball to make one large clump into many and transplant in areas of 0-5” of water. Recommend allowing good growth and then thinning for transplanting. Do not transplant or plant during summer or drought.

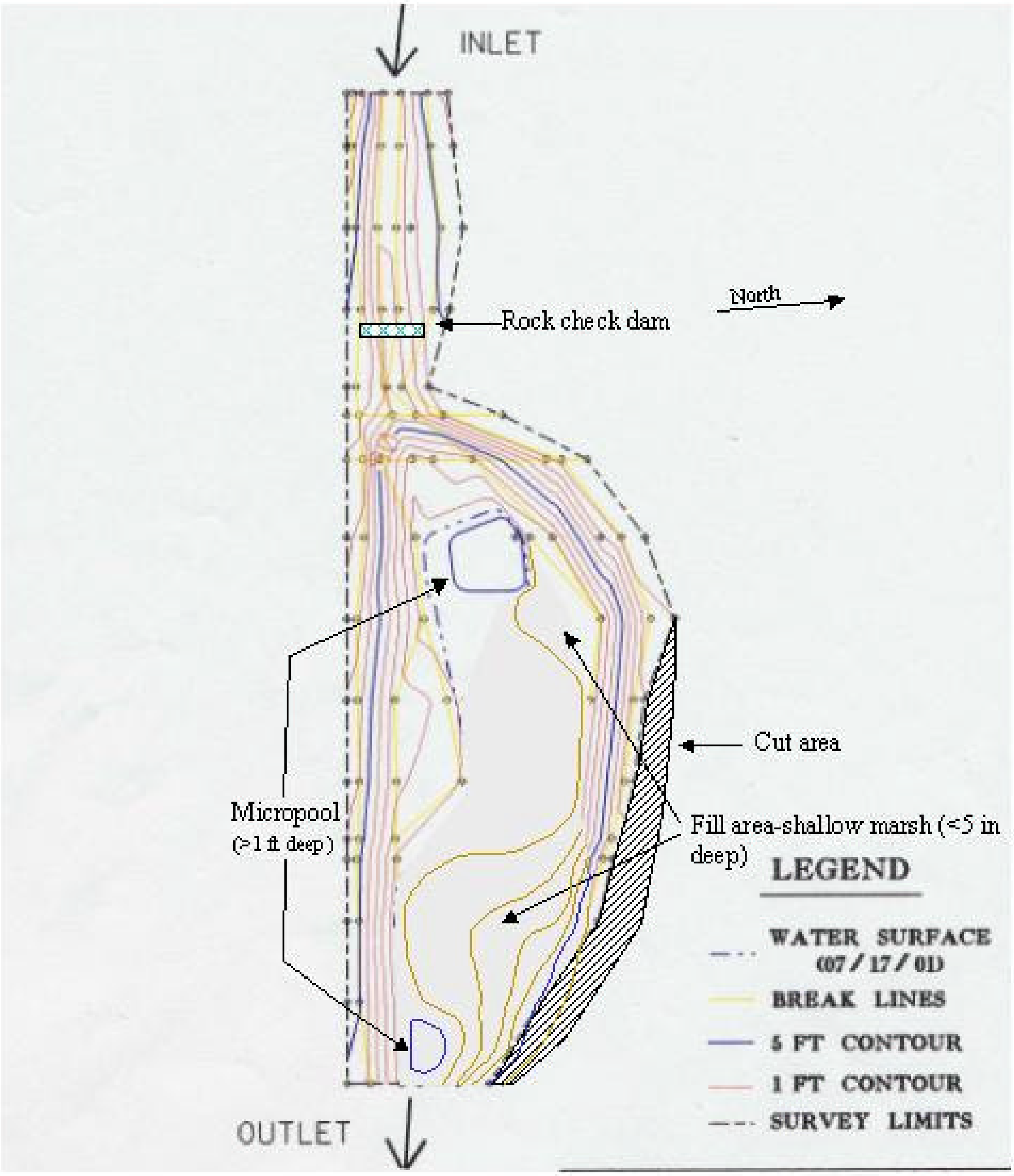

Figure 2. Recommended changes to Wetland.

Exhibit 2. Inflow Data for the Wilson CMY Wetland:

Analyte	11/24/01	12/10/01	01/19/02	01/23/02	02/07/02	03/02/02	09/14/02	10/21/02	10/29/02	11/06/02	11/16/02	12/05/02	12/13/0
Maximum runoff (gal)	107538	51325	119758	161307	128312	114870	237072	85541	73321	89208	129534	163751	85541
Manual Rainfall (in)	NA	NA	1.1	1.62	1.2	1.12	3.27	0.97	1.34	0.95	1.25	1.34	0.8
Automated rainfall (in)	0.88	0.42	0.98	1.32	1.05	0.94	1.94	0.70	0.60	0.73	1.06	1.34	0.70
Runoff (gal)	97890	14412	52300	82676	56569	69720	129089	49537	32462	43110	84410	69100	51276
Peak Q (gpm)	430	90	475	700	420	520	2600	950	700	800	300	320	280
pH	6.6	NA	6.9	6.54	6.95	7.02	6.47	6.68	6.51	6.7	7.07	6.95	7.07
Turbidity (ntu)	30	NA	57	81	36	106	94.5	42	36.5	62	21.7	33.5	24.5
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	1	1	1	1	1	1	1	1	1	1	1	1	1
Chromium	**2.5**	**2.5**	5	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	7	8	**2.5**	**2.5**	**2.5**
Copper	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead	16	ND	46	28	21	20	34	24	35	46	12	11	10
Nickel	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**5**	ND
Zinc	210	70	130	160	80	240	130	130	170	160	80	170	160
Inorganic Non Metals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	3.2	10.1	2.9	10.4	2	23.2	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Nitrogen, Ammonia	0.31	**0.02**	0.07	0.24	0.11	0.05	0.18	0.28	0.13	0.06	**0.02**	**0.02**	**0.02**
Nitrogen, NO_3+NO_2	0.44	**0.03**	0.07	0.26	0.08	**0.03**	0.14	0.26	0.24	0.15	0.07	0.19	0.40
Nitrogen, TKN	-	1.10	0.96	0.95	0.94	2.70	1.10	0.67	0.59	0.72	0.25	0.81	0.48
Nitrogen, Total		1.13	1.03	1.21	1.02	2.73	1.24	0.93	0.83	0.87	0.32	1.00	0.88
Phosphorus, Diss.	0.25	0.03	0.03	0.04	0.10	0.34	0.10	0.03	0.02	0.02	0.01	0.02	0.01
Phosphorus, Total	0.36	0.16	0.19	0.15	0.2	1.86	0.24	0.18	0.19	0.19	0.06	0.11	0.08
Residue, Suspended	42	10	145	110	67	67	77	104	90	101	24	43	23
Residue,Total	111	106	169	155	80	278	102	140	133	115	35	58	59
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	79.9	44.9	62.2	39.3	61.2	88.8	33.6	46	52.2	27.4	11.9	47.5	24.3
Oil and Grease	5	2.5	2.5	6	5	27	5	11	10	2.5	2.5	2.5	2.5
Surfactant	0.3	0.3	0.1	0.1	0.1	1.0	0.2	0.2	0.2	0.1	0.1	0.3	0.2
Semi-Volatile Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Bis(2-ethylhexyl) Phthalate	61	11	5	43	25	69	41	12	12	40	11	170	57
Phenol	ND	ND	ND	ND	ND	ND	15	ND	ND	ND	ND	ND	ND

Exhibit 3. Outflow Data for the Wilson CMY Wetland:

Analyte	11/24/01	12/10/01	01/19/02	01/23/02	02/07/02	03/02/02	09/14/02	10/21/02	10/29/02	11/06/02	11/16/02	12/05/02	12/13/0
Runoff (gal)	96887	25000	73475	130000	86760	80000	160000	57530	26950	64954	119000	150000	72560
Peak Q (gpm)	280	75	390	750	380	520	2500	730	250	550	390	480	300
pH	7.01	NA	6.58	6.57	6.85	6.86	6.56	9.85	6.75	6.85	6.93	7.11	6.6
Turbidity (ntu)	38.0	NA	37.0	68.0	26.0	25.3	94.5	32.0	21.0	35.0	23.5	51.0	31.0
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	**2.5**	**2.5**	5	**2.5**	**2.5**	**2.5**	6	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**
Copper	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead	13	13	19	16	9	11	33	13	10	16	7	9	6
Nickel	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
Zinc	160	250	110	130	80	90	140	80	90	90	90	210	120
Inorganic Non Metals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	8.4	12.2	24.8	52.2	25.9	10.9	5.8	5.8	7.4	6.8	5	10.4	7.1
Nitrogen, Ammonia	0.17	0.27	0.02	0.20	0.07	0.09	0.06	0.21	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Nitrogen, NO_3+NO_2	0.43	0.62	0.24	0.46	0.15	0.19	0.03	0.27	0.07	0.17	0.19	0.05	0.10
Nitrogen, TKN	-	1.60	0.78	1.20	0.88	0.86	2.00	0.84	0.81	0.66	0.46	1.20	0.65
Nitrogen, Total	-	2.22	1.02	1.66	1.03	1.05	2.03	1.11	0.88	0.83	0.65	1.25	0.75
Phosphorus, Diss.	0.15	0.52	0.01	0.02	0.04	0.02	0.16	0.02	0.01	0.01	0.02	0.03	0.03
Phosphorus, Total	0.41	0.63	0.11	0.13	0.10	0.10	0.49	0.14	0.19	0.12	0.10	0.26	0.16
Residue, Suspended	32	15	36	39	23	23	134	31	31	17	18	21	11
Residue,Total	128	163	122	171	101	80	181	79	104	62	58	94	73
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	97.4	105.6	27.1	27.1	24.4	28.2	56.8	30.5	52.2	24.3	19.6	79.6	33.6
Oil and Grease	6	8	7	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	6	**2.5**	**2.5**	**2.5**	ND
Surfactant	0.3	0.7	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.3
Semi-Volatile Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Bis(2-ethylhexyl) Phthalate	28	49	24	**5**	11	17	21	12	10	15	**5**	25	21

Exhibit 4. Data for the Wilson CMY Washwater Samples:

Analyte	MDL	12/04/01	01/14/02	02/06/02	03/06/02	05/16/02	06/25/02	09/26/02	11/25/02	11/25/02	01/15/03
Runoff (gal)		60	60	60	50	60	60	60	50	50	60
pH		7.4	6.3	4.0	7.4	7.4	6.2	7.1	7.6	7.2	5.9
Turbidity (ntu)		950	1000	535	885	2515	1127	1180	2355	4390	531
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	2	12	35	350	120	184	89	135	**1**	**1**	90
Chromium	5	100	170	390	173	290	130	36	37	68	670
Copper	50	670	310	2360	370	4390	1430	610	210	1870	33200
Lead	5	710	**3**	5600	250	1050	400	340	140	400	690
Nickel	10	31	120	100	51	159	64	56	27	72	860
Zinc	10	2300	2600	10400	3400	10600	3400	3500	820	3700	3700
Inorganic Non Metals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	2	31.4	32000	36.5	100	190	79.2	42.5	1410	120	27
Nitrogen, Ammonia	0.04	1.09	0.98	3.00	1.30	1.40	3.60	0.34	0.28	0.69	1.10
Nitrogen, NO_3+NO_2	0.05	6.48	0.78	4.18	3.22	10.00	13.00	2.41	0.83	2.61	3.45
Nitrogen, Kjeldahl	0.15	10.00	3.40	9.50	4.40	17.00	13.00	12.00	6.50	7.80	4.80
Nitrogen, Total		16.48	4.18	13.68	7.62	27.00	26.00	14.41	7.33	10.41	8.25
Phosphorus, Diss.	0.01	10.00	0.61	0.05	0.59	10.10	4.52	4.64	0.84	1.75	0.02
Phosphorus, Total	0.05	10.40	2.08	5.70	3.20	20.60	10.20	9.80	1.63	5.66	1.18
Residue, Suspended	1	1040	2740	1750	1460	2400	1820	1760	492	642	1480
Residue,Total	1	2590	56400	2990	2140	3860	2040	3160	1130	1720	2270
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	5	5676	2318	2000	5220	4240	1942	2300	2740	2120	1190
Oil and Grease	5	163	195	312	469	920	494	316	2900	1300	219
Surfactant	0.1	NA, broke	0.2	0.8	2.6	9.9	2.2	2.4	2.4	5.7	3.1
Semi-Volatile Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)*	(ug/l)*	(ug/l)
Bis(2-ethylhexyl) Phthalate	10	NA, broke	47	230	130	ND	330	340	ND	ND	ND
Butylbenzyl Phthalate	10	NA	ND	ND	ND	55	ND	55	ND	ND	12
Di-n-Octyl Phthalate	10	NA	ND	34	13	ND	ND	ND	ND	ND	ND
Ideno (1,2,3-cd)pyrene	10	NA	ND	ND	ND	ND	18	ND	ND	ND	ND
Fluorene	270*	NA	ND	ND	ND	ND	ND	ND	610	ND	ND
2-Methylnaphthalene	270*	NA	ND	ND	ND	ND	ND	ND	2900	1600	ND

Exhibit 5. Data for the Inflow to the Alexander CMY Pond:

Analyte	12/11/01	01/19/02	01/24/02	02/07/02	03/02/02	03/13/02	08/04/03	08/16/03	08/22/03	10/27/03	11/06/03
Rainfall (in)	1.35	1.12	1.94	0.88	0.85	0.80	0.74	1.26	1.00	0.40	1.13
Runoff (gal)	327696	101222	336500	77995	106075	120000	98213	137250	63023	49750	104290
Peak Q (gpm)	270	240	750	140	750	1800	530	600	260	300	2700
pH	NA	NA	6.67	6.69	6.51	6.52	6.81	6.81	7.05	6.23	6.34
Turbidity (ntu)	NA	210	119.5	101.5	201.5	NA	117	92	71	139	551
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	NA	NA
Chromium	5	15	7	12	38	50	15	**3**	**3**	16	60
Copper	**25**	**25**	**25**	**25**	**25**	**25**	**31**	**31**	**31**	NA	NA
Lead	3	9	5	6	13	17	6	**3**	**3**	**3**	30
Nickel	**5**	12	**5**	**5**	17	19	**3**	**3**	**3**	NA	19
Zinc	70	110	60	70	80	110	70	40	50	**9**	124
Inorganic Non Metals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	11.8	118	77	37.1	24.3	17.6	10.2	10.8	17.3	6.9	9.3
Nitrogen, Ammonia	0.14	0.15	0.09	0.19	0.14	0.20	0.32	0.37	0.31	0.16	0.12
Nitrogen, NO_3+NO_2	0.54	0.37	0.36	0.49	0.33	0.46	0.42	0.56	0.65	12.60	0.42
Nitrogen, Kjeldahl	NA	0.81	1.10	1.00	1.20	1.80	1.70	2.10	3.10	1.30	2.40
Nitrogen, Total	NA	1.18	1.46	1.49	1.53	2.26	2.12	2.66	3.75	13.90	2.82
Phosphorous, Ortho	0.09	0.05	0.06	0.06	0.03	0.02	0.02	0.37	0.96	0.01	0.05
Phosphorous, Total	0.20	0.18	0.15	0.15	0.46	0.75	0.19	0.51	1.18	0.19	0.85
Residue, Suspended	28	105	11	34	145	292	97	28	19	153	714
Residue,Total	118	341	234	183	273	448	196	188	246	249	1070
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	21.1	30.1	NA	NA	43.3	NA	28.6	NA	NA	NA	73
Oil and Grease	2.5	2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
Surfactant	NA	0.12	NA	NA	0.1	NA	NA	NA	NA	NA	NA
Semi-Volatile Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA

Exhibit 6. Data for the Outflow from the Alexander CMY Pond:

Analyte	12/11/01	01/19/02	01/24/02	02/07/02	03/02/02	03/13/02	08/04/03	08/16/03	08/22/03	10/27/03	11/06/03
Runoff (gal)	322859	100700	336500	77995	106075	130000	98213	137250	63023	49000	104000
Peak Q (gpm)	930	82	630	60	70	80	30	420	240	30	100
pH	NA	NA	NA	6.54	6.47	6.51	5.9	6.34	6.47	6.56	6.92
Turbidity (ntu)	NA	280	35.15	105	133.5	NA	213	289	223	83	444
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	NA	NA
Chromium	13	10	12	16	9	35	27	26	18	9	44
Copper	**25**	**25**	**25**	**25**	**25**	**25**	**31**	**31**	**31**	NA	NA
Lead	6	8	8	10	**2.5**	13	10	10	8	**3**	19
Nickel	**5**	11	**5**	**5**	**5**	14	6	**2.5**	5	NA	13
Zinc	70	70	80	80	60	100	70	50	50	**8.5**	72
Inorganic Non Metals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	8.7	140.0	82.4	62.2	42.7	32.5	12.2	11.5	7.2	8.2	7.4
Nitrogen, Ammonia	0.13	0.24	0.07	0.19	0.15	0.22	0.17	0.90	0.20	0.10	0.10
Nitrogen, Nitrate+Nitrite	0.62	0.53	0.35	0.52	0.4	0.65	0.41	0.41	0.34	0.38	1.05
Nitrogen, Kjeldahl	NA	0.84	0.70	1.20	0.84	0.86	1.90	2.30	1.30	0.74	1.40
Nitrogen, Total	NA	1.37	1.05	1.72	1.24	1.51	2.31	2.71	1.64	1.12	2.45
Phosphorus, Ortho	0.09	0.03	0.04	0.08	0.03	0.02	0.03	0.02	0.01	0.01	0.02
Phosphorus, Total	0.2	0.15	0.22	0.23	0.21	0.12	0.32	NA	0.26	0.11	0.36
Residue, Suspended	73	116	34	66	87	157	178	192	150	54	260
Residue, Total	150	460	275	248	261	330	325	336	253	140	565
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	14.7	21	NA	NA	23.7	NA	27	NA	NA	NA	24.4
Oil and Grease	2.5	2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
Surfactant	NA	0.15	NA	NA	0.1	NA	NA	NA	NA	NA	NA
Semi-Volatile Organics	none	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA

Exhibit 7. Data for the Orange CMY Salt Storage Area:

Analyte	1/23/02	3/2/02	3/17/02	3/21/02	3/27/02	4/1/02	5/13/02	7/24/02	7/26/02	8/28/02	8/31/02	9/15/02	10/11/02	10/16/02
Auto Rainfall (in)	0.69	0.80	0.53	0.26	0.28	0.55	0.48	1.18	0.28	1.01	2.76	0.54	5.74	1.04
Runoff (gal)	50600	30630	16000	7430	5770	12820	10158	64140	3657	9775	121150	3780	425000	61831
Peak Q (gpm)	200	230	170	28	75	100	510	2200	60	180	380	34	1700	200
pH	8.0	7.3	7.5	7.6	7.6	7.6	7.4	7.0	7.8	7.3	7.7	NES	7.4	7.3
Turbidity (ntu)	282	288	275	196	430	288	532	385	117	182	96	NES	91	96
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	1	1	2	1	1	1	1	1	1	1	1	1	NA	NA
Chromium	9	10	13	9	18	13	16	17	6	**3**	**3**	**3**	**3**	**3**
Copper	**25**	**25**	**25**	**25**	**25**	**25**	**25**	**25**	**25**	**25**	**25**	25	NA	NA
Lead	10	13	18	11	17	15	23	27	7	26	**3**	**3**	13	10
Nickel	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**NA**	**NA**
Zinc	110	130	100	70	100	90	120	140	50	90	50	60	50	60
Inorganic Non Metals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	1200	730	370	430	400	295	290	344	340	210	360	390	580	430
Nitrogen, Ammonia	0.08	0.15	0.14	0.02	0.08	0.05	0.30	0.16	0.02	0.07	0.02	0.02	0.10	0.05
Nitrogen, NO_3+NO_2	0.33	0.47	0.61	0.54	0.52	0.32	0.59	0.84	0.63	0.88	0.33	0.30	0.38	0.28
Nitrogen, TKN	NA	1.10	1.20	1.00	1.20	1.05	2.10	1.70	1.30	1.30	0.76	1.10	1.00	1.30
Nitrogen, Total	NA	1.57	1.81	1.54	1.72	1.36	2.69	2.54	1.93	2.18	1.09	1.40	1.38	1.58
Phosphorous, Ortho	0.09	0.09	0.07	0.05	0.05	0.06	0.08	0.13	0.02	0.07	0.08	0.05	0.18	0.14
Phosphorous, Total	0.36	0.31	0.34	0.28	0.4	0.335	0.53	0.49	0.16	0.28	0.18	0.12	0.33	0.27
Residue, Suspended	120	185	149	62	284	136.5	397	291	69	112	29	12	45	40
Residue,Total	2280	1510	910	971	1130	836.5	1030	970	755	573	723	738	1110	883
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	25.6	29.7	40.3	NA	49.1	NA	52.2	47.6	NA	33.6	20.6	NA	22.5	NA
Oil and Grease	2.5	2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Surfactant	0.05	0.3	NA	NA	NA	NA	NA	NA	NA	0.4	0.2	NA	NA	NA

Semi-Volatile Organics	(ug/l) ND	(ug/l) ND	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA	(ug/l) NA

Exhibit 7. Data for the Orange CMY Salt Storage Area (continued):

10/28/02	11/6/02	11/12/02	11/16/02	12/4/02	12/13/02	5/18/03	6/9/03	7/2/03	7/22/03	9/4/03	9/18/03	9/23/03	10/29/03	12/11/03
1.45	NA	NA	1.17	1.60	0.89	0.92	1.21	1.66	0.59	0.86	1.42	1.22		1.10
76040	36720	56280	64040	89316	66015	41910	52510	111000	87150	26127	53170	41066	26880	69100
500	280	320	110	NA	340	150	750	1000	2800	340	250	1600	90	500
7.5	7.5	7.8	7.3	7.1	6.9	7.5	NA	7.1	7.0	6.7	7.3	7.1	7.4	6.9
100	98	106	90	48	145	122	77	62	228	91	95	94	63	92
(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
NA	NA	NA	NA	NA	NA		**1**	NA	NA	NA	NA	NA	NA	NA
5	11	12	NA	NA	7	5	**3**	**3**	6	**3**	**3**	**3**	**3**	**3**
NA	NA	NA	NA	NA	NA	NA	31	NA	NA	NA	NA	NA	NA	NA
6	6	9	NA	NA	**3**	8	**3**	**3**	13	**3**	**3**	**3**	**3**	**3**
NA	NA	NA	NA	NA	NA	NA	**5**	NA	NA	NA	NA	NA	NA	NA
50	60	60	50	350	120	100	60	60	9	60	50	60	**9**	232
(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
460	250	370	190	9900	2600	NA	NA	NA	240	170	110	94.7	130	600
0.02	0.02	0.05	NA	NA	NA	0.22	0.05	0.24	NA	0.32	0.06	0.08	0.06	0.07
0.27	0.22	0.20	0.19	NA	0.37	0.51	0.13	0.63	0.66	1.30	0.56	0.56	0.27	0.40
0.97	0.89	1.30	1.00	NA	1.30	1.90	1.90	1.80	1.90	2.20	1.40	1.40	1.10	1.10
1.24	1.11	1.50	1.19	NA	1.67	2.41	2.03	2.43	2.56	3.50	1.96	1.96	1.37	1.50
0.06	0.13	0.07	NA	NA	NA	0.14	0.07	0.12	0.23	0.32	0.19	0.17	0.09	0.18
0.22	0.23	0.2	0.19	NA	0.29	0.35	0.21	0.23	0.54	0.45	0.32	0.28	0.17	0.32
29	25	28	28	NA	59	29	25	26	196	27	18	39	13	58
965	516	733	NA	NA	NA	682	531	278	NA	394	288	268	320	1090
(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)

NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA

Exhibit 8. Data for the Orange CMY Washpad:

Analyte	5/13/02	5/18/02	6/17/02	6/18/02	7/12/02	7/16/02	1/22/03	7/20/02	7/24/02	8/30/02	11/18/02	12/13/02
Automated Rainfall (in)	0.48	0.00	0.00	0.00	0.00	0.00	NA, ice	0.20	0.20	0.69	1.17	0.89
Wash Runoff (gal)	2565	1082	555	900	1081	1540	NA, ice	1130	4337	3410	13778	14000
Peak discharge rate (gpm)	90	28	7	26	27	36	NA, ice	18	118	42	28	70
pH	8.1	7.6	8.2	7.7	7.7	7.8	7.2	8.2	7.6	8.1	7.6	7.4
Turbidity (ntu)	255	247	786	467	2030	2210	897	132	218	85	110	148
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	**1**	**1**	**1**	**1**	**1**	**1**	16	**1**	**1**	**1**	**1**	**1**
Chromium	41	342	17	28	160	69	68	7	17	3	3	11
Copper	60	240	25	25	250	120	99	25	25	25	25	25
Lead	19	97	11	9	82	120	3	6	13	3	5	3
Nickel	14	92	5	11	60	39	66	**5**	**5**	**5**	**5**	**5**
Zinc	180	340	90	90	520	310	300	50	90	40	40	90
Inorganic Non Metals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	30	19	31	28	48	32	38000	38	17	20	14	3700
Nitrogen, Ammonia	0.02	0.20	0.04	0.06	0.02	0.04	0.62	0.02	0.02	0.05	0.02	0.08
Nitrogen, Nitrate+Nitrite	0.55	0.41	0.62	0.11	0.03	5.50	1.00	2.05	1.34	0.68	0.18	0.21
Nitrogen, Total Kjeldahl	1.60	2.70	2.30	3.00	3.80	3.20	3.60	1.20	0.76	0.68	0.45	0.82
Nitrogen, Total	2.15	3.11	2.92	3.11	3.83	8.70	4.60	3.25	2.10	1.36	0.63	1.03
Phosphorous, Ortho	0.01	0.01	0.01	0.01	0.05	0.01	0.01	0.02	0.05	0.05	0.01	0.03
Phosphorous, Total	0.40	1.45	0.57	1.25	2.13	1.16	0.95	0.19	0.46	0.14	0.08	0.23
Residue, Suspended	492	6790	436	384	3450	1740	1890	82	236	40	42	135
Residue,Total	804	8420	764	637	4600	2210	64500	516	538	205	168	6060
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	28.9	48.6	67.2	264.0	196.0	72.4	181.0	NA	29	24	12	31
Oil and Gease	2.5	2.5	2.5	31.0	2.5	2.5	6.0	NA	2.5	2.5	2.5	2.5
Surfactant	0.5	2.5	NA	0.3	3.0	NA	NA	NA	NA	0.4	ND	0.3
Semi-Volatile Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Bis(2-ethylhexyl) Phthalate	NA	NA	NA	NA	22	ND	ND	NA	NA	NA	NA	NA

Exhibit 9. Data for the Orange CMY Soil Storage Area:

Date	Rain in	Runoff gal	Peak gpm	TSS mg/L	Turbidity NTU	TSS lb
14-Oct-01	NA*	36950	580	1620	857	499
10-Dec-01	NA*	122000	450	990	754	1008
17-Dec-01	NA*	25000	85	193	465	40
24-Dec-01	NA*	5000	40	217	315	9
06-Jan-02	NA*	65000	NA	25	44	14
19-Jan-02	1.18	135000	290	NA	NA	268
21-Jan-02	0.20	10933	70	NA	NA	18
23-Jan-02	0.93	94002	210	238	368	186
07-Feb-02	0.65	25800	88	193	344	42
02-Mar-02	0.80	23800	180	500	742	99
13-Mar-02	0.16	6402	30	330	407	18
17-Mar-02	0.53	31888	180	184	254	49
31-Mar-02	0.43	6220	82	80	197	4
13-May-02	0.48	9740	400	3350	3880	45
28-Jun-02	0.41	15810	550	1620	2211	214
01-Jul-02	NA	11521	108	7480	6580	719
11-Jul-02	0.40	16243	125	1730	2343	234
20-Jul-02	0.20	6247	90	1275	1535	66
23-Jul-02	NA	120371	1900	2480	2550	2491
26-Jul-02	0.25	24970	135	1470	1825	306
15-Aug-02	0.28	3173	65	1375	1741	36
17-Aug-02	0.18	7181	65	1120	1390	67
24-Aug-02	0.42	20650	700	NA	NA	128
27-Aug-02	0.34	22115	180	NA	NA	67
29-Aug-02	2.76	412290	720	362	494	1244
16-Sep-02	0.54	57978	100	403	533	195
27-Sep-02	0.15	570	18	1830	2365	9
10-Oct-02	5.40	718700	NA	NA	NA	2168
15-Oct-02	1.04	92356	270	818	1840	630
22-Oct-02	NA	4202	NA	193	299	7
28-Oct-02	1.45	108143	900	1073	1270	968
05-Nov-02	0.81	52936	360	471	616	208
12-Nov-02	0.74	83800	420	772	894	539
16-Nov-02	1.17	92430	150	212	358	163
04-Dec-02	NA	163000	800	NA	NA	68

06-Dec-02	NA	30700	75	50	63	13
11-Dec-02	NA	22000	150	207	271	38
13-Dec-02	0.89	148100	550	323	633	399
30-Dec-02	1.68	115000	NA	510	1168	489
08-Jan-03	0.69	153200	NA	560	515	716
04-Feb-03	0.01	3991	18	NA	NA	4
06-Feb-03	0.09	65880	135	114	167	63
18-Feb-03	0.44	45133	275	NA	NA	94
22-Feb-03	0.95	130609	1040	250	233	272
27-Feb-03	1.03	162680	470	2290	2090	3109
Sediment control device installed						
26-Apr-03	0.32	9424	95	NA	NA	29
06-May-03	0.19	657	9	368	378	2
14-May-03	0.68	37171	800	620	906	192
17-May-03	1.19	86124	295	168	243	121
22-May-03	1.81	206213	475	168	208	289
25-May-03	0.70	60407	630	348	406	175
07-Jun-03	1.05	60443	570	480	557	242
02-Jul-03	1.96	212654	1120	368	640	653
13-Jul-03	0.52	15136	215	280	437	35
05-Aug-03	0.36	85393	1900	NA	NA	257
08-Aug-03	0.27	4682	68	360	378	14
13-Aug-03	0.51	12576	320	1015	1157	107
31-Aug-03	0.16	3793	115	NA	NA	31
04-Sep-03	0.86	22610	360	975	1075	184
18-Sep-03	1.42	44262	190	405	541	150
22-Sep-03	1.26	70973	1150	920	940	545
14-Oct-03	0.67	19000	nd	1075	1234	170
28-Oct-03	0.70	20000	NA	345	256	58

SECTION II

HIGHWAY SITES

SUMMARY

In June, 1998 an NPDES stormwater permit was issued to the NC Department of Transportation (NC DOT). As part of the permit, the NC DOT committed to a program of research and BMP implementation on its industrial and highway facilities. Part of the research program included monitoring stormwater runoff and BMP effectiveness from highway facilities. The primary objective of this study was to monitor the pollutant reduction effectiveness of stormwater BMPs implemented on industrial and highway facilities. A secondary objective was to characterize runoff and pollutant export from various industrial and highway contributing areas. This report includes the results of monitoring at 5 highway sites, one each in Johnston (DOT Division 4), Craven (DOT Division 2), Catawba (DOT Division 12), Duplin (DOT Division 3), and Buncombe (DOT Division 13) counties. The level spreader grass strip BMP was located between the eastbound on ramp and east bound lanes of I40 at the intersection with NC 42 in Johnston County. The BMP consisted of a 24 ft wide by 56 ft long Bermudagrass strip with a level spreader at the upslope end. It received runoff from about 0.86 acres, which included a section of heavily traveled two-lane highway, NC 42, and the much of the bridge over I40. The Craven county BMP was a roadside swale with a parabolic cross section, which was 8 ft wide and 200 ft long and was covered by dense Centipede grass. The nearly flat swale had an underdrain and a raised outlet to facilitate ponding, which made it function more like a bioretention area than a stormwater conveyance device. The swale received runoff from a section of Business 70 that included a traffic light intersection and a bridge deck over the Trent River. The Catawba county BMP was a 44 ft wide by 100 ft long bioretention area with a treatment column of 3-6 inches of hardwood mulch, 2.6 ft of engineered soil material, and a layer of wash stone over a network of 6 inch perforated underdrains. The bioretention area treated runoff from a 0.69 acre area, which consisted mostly of a semi-tractor trailer parking in the eastbound rest area off I40. The Duplin county BMP was an irregularly-shaped bioretention area constructed similar to the Catawba county one. The BMP received runoff from a 2.9-acre area, which was composed of a car parking area, a small restroom building, and surrounding grassed areas. The Buncombe county BMP was a 50 ft wide by 100 ft long bioretention area. Its treatment column consisted of 3-6 inches of hardwood mulch, 3 feet of engineered soil material, and a 10-inch layer of wash stone covering a network of 6-inch perforated underdrains. The BMP received runoff from 2.74 acres of the I40 highway corridor near Black Mountain, NC. Due to backwater and other hydraulic conditions the bioretention areas in Craven and Buncombe counties had problems with monitoring of outflow and thus only inflow data are reported herein.

The monitoring protocol consisted of montoring inflow, outflow, on-site rainfall, and collecting flow-proportional samples for 12 to 15 storm events via automated samplers. All samples, except those collected at the Buncombe county site, were cooled to less than 4 degrees Celsius on site until recovery and then shipped on ice to a state-certified lab for analysis of total suspended solids or residue (TSS), total solids or residue (TS), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N, nitrate nitrogen (NO_{3+2}-N), total phosphorus (TP), and dissolved phosphorus (Diss. P). Samples collected at the Buncombe county bioretention area were generally recovered every 2 weeks and analyzed for TSS. Selected samples were also analyzed for metals (Cd, Cr, Cu, Pb, Ni, and Zn), chloride, aggregate organics, and semi-volatile organic compounds such polycyclic aromatic hydrocarbons. Rainfall and discharge were continuously monitored. Discharge was monitored using open channel flow devices such as weirs and culverts.

Pollutant removal efficiencies were computed for three BMPs (Table 1) by subtracting the total outflow pollutant loads from inflow, dividing the difference by the inflow load and multiplying by 100. The level spreader-grass strip BMP had the best overall effectiveness with reduction efficiencies in all pollutants, which ranged from 24 to 83%. Some of the effectiveness of this BMP can be attributed to the 49% reduction in runoff volume, which was primarily the result of the high infiltration rate of the grass strip. The level spreader-grass strip also reduced the mass of Pb and Zn from inflow to outflow for three monitored storms by 72 and 71%, respectively. The Catawba county bioretention area reduced pollutant loads in inflow for every pollutant shown, except NO_{3+2}-N. This increase in NO_{3+2}-N, the negligible decrease in runoff volume, and the area's topography suggest that groundwater from surrounding areas may have contributed to outflow. In addition, the BMP reduced the mass of chromium, lead, and zinc in inflow from three monitored storms by 66-87%. The roadside swale was the least effective of the three BMPs, especially for phosphorus, which actually increased considerably from inflow to outflow. Runoff volume also increased from inflow to outflow indicating the influx of water to the underdrain from sources other than the inflow culvert. The mass of Zn in inflow from three monitored storms was reduced by 67%. Of the 10 inflow samples analyzed for polycyclic aromatic hydrocarbons (67 different compounds) only 6 contained any of the compounds at levels greater than the method detection limit (MDL) and these samples contained only 2 of the compounds namely, bis(2_ethylhexayl) Phthalate and phenol. Of the 6 outflow samples from the three BMPs, only 1 contained a compound (bis(2_ethylhexayl) Phthalate at a level greater than the MDL. For the Buncombe county bioretention area, 11 flow-proportional samples of inflow were analyzed for TSS and turbidity documenting a mean of 61 mg/L and 23 ntu, respectively. For the bioretention area in Duplin county monitoring results from 10 storm events documented a mean TSS concentration in inflow of 36 mg/L and a turbidity of 16 ntu.

Table 1. Summary of Pollutant Removal Efficiencies and Reductions in Runoff.

	Reduction in Pollutant Mass Loading							Runoff	
Practice	TSS	TP	Diss P	TKN	NO_{3+2}-N	NH_3-N	TN	Peak	Vol.
	%	%	%	%	%	%	%	%	%
Level Spreader	83	48	24	66	49	75	62	23	49
Div. 12 Bioretention[1]	77	46	69	32	-156	39	13	64	-16
Roadside Swale[2]	74	-152	-1239	6	5	11	6	44	-22

[1] Due to the low elevation of the underdrain compared to the surrounding land, groundwater inflow may have influenced the removal efficiencies for nitrogen and phosphorus, especially the increase in NO_{3+2}-N.

[2] Groundwater influx from the surrounding area to the underdrain or road runoff entering the swale between the monitoring stations may have contributed to the poor nitrogen and phosphorus reduction efficiencies and/or the increase in outflow volume.

As indicated by the footnotes in Table 1, there were various factors influencing the documentation of BMP efficiencies including the probable influx of near surface groundwater into the underdrains of the Div. 12 bioretention area and the roadside swale. The groundwater would have little to no effect on TSS, as there is usually little or no TSS in groundwater, but may have a significant effect on nitrogen and/or phosphorus efficiency depending on its quality. In addition, nitrogen and phosphorus in the soil, mulch, and plant material used to construct the BMP may have contributed to reducing the efficiency of the BMPs. The relatively low pollutant levels in the inflow contributed to reduced efficiency in that even relatively small additions of nitrogen and phosphorus from construction materials or rainfall on the BMP itself might significantly reduce efficiencies. Low TSS levels in inflow also contributed to reduced efficiency given that 21 of the 41 samples of outflow had TSS concentrations less than the MDL. Concentrations of some nitrogen and phosphorus species in outflow were also less than the MDL. Other site specific factors affecting the efficiencies of each BMP are discussed in the report.

In summary, the following general conclusions and recommendations can be drawn from the monitoring data, while more specific ones are included in the individual BMP sections:

- Each of the three BMPs was efficient (74-83% removal) at reducing incoming TSS loads. The BMPs likely would have been shown to be even more efficient if inflow TSS loads had been greater.
- Regarding nitrogen and phosphorus, the removal efficiency of the level spreader-grass strip BMP was good, while the efficiencies for the other two BMPs was mixed due to site specific reasons or to the fact that the BMP may not be effective for some pollutants. For example, the Div. 12 bioretention area was not effective at reducing NO_{3+2}-N, which may have been the result of groundwater influx into the underdrain or that the bioretention area simply was not effective at treating NO_{3+2}-N.
- Although data was limited (only 3 samples per BMP analyzed for metals), each of the BMPs appeared to be effective at reducing metals in inflow. The mass of Zn, which tends to remain in solution and therefore be more difficult to remove, in inflow was reduced by 67-87% for the storms monitored.
- Concentrations of polycyclic aromatic hydrocarbons (67 different compounds) in the two outflow samples per site were always less than corresponding levels in the inflow samples. While this is only limited data, it appears that the BMPs would be effective at reducing the levels of these compounds.
- While the three BMPs reduced peak flow rates from 23 to 54%, only the level spreader-grass strip significantly reduced the runoff volume.
- The levels of pollutants in inflow were nearly the same or less than corresponding levels in highway and urban runoff from other NC and nationwide studies. These relatively low levels of pollutants likely decreased the removal efficiencies of the BMPs, especially TSS for which many outflow samples were less than the MDL.

The following are some general recommendations/observations for future BMP implementation and monitoring efforts:

- To minimize the effect of site specific conditions and document the true efficiency of the BMP, experimental sites must be carefully chosen from the perspective of facilitating monitoring. Ideally this means choosing sites that would not have any groundwater influx to the underdrains, but if influx is a possibility, sites should be instrumented to account for groundwater influx.
- Each potential BMP study site should be assessed in regard to the possibility of backwater at the inflow and outflow monitoring site. If backwater is a possibility, another site should be considered, especially if the outflow site is affected.

- The selection and planting of vegetation should be carefully considered, especially for the bioretention areas. Vegetation on the bioretention areas was spotty, whereas thriving more dense low input vegetation would likely have improved the efficiency of this BMP. Research on the best vegetation to use in bioretention areas is continuing so some trial and error in determining the best plants may be needed.
- Delaying monitoring of the BMP for at least a year after construction would help reduce the temporary release of pollutants, especially phosphorus, to the outflow that results from soil disturbance and planting.
- The BMPs should be evaluated during each season of the year to determine an annual efficiency. Biological activity affects the efficiency of the BMP; thus, changes in biological activity throughout the year may affect the efficiency of the BMP.

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INTRODUCTION

The quality of runoff from urban and industrial land use areas is of increasing concern in the U.S. In the National Water Quality Inventory, 1990 Report to Congress, the 50 states estimated that roughly 30 percent of identified cases of water quality impairment are attributable to storm water discharges from urban/industrial areas (U.S. EPA, 1992). This assessment has prompted an effort, conducted through the National Pollutant Discharge Elimination System (NPDES) storm water permitting program, to characterize storm water discharges and develop pollution prevention plans and BMPs to control this runoff/discharge. Many individual industries, municipalities, and transportation facilities are now required to obtain NPDES permits for their stormwater discharges.

In June, 1998 the NC Division of Water Quality (NC DWQ) issued an NPDES stormwater permit to the NC DOT. As part of the permit, the NC DOT committed to a program of research, employee training, BMP implementation, and public education related to stormwater. Part of the research program included monitoring stormwater runoff and BMP effectiveness from highway facilities. While a considerable amount of monitoring data for runoff from highway facilities has been collected nationwide (Driscoll et al., 1990; Smith and Lord, 1990; Wu et al., 1998), few data exist on the effectiveness/efficiency of BMPs to treat highway runoff, especially in the Southeast. However, data on the effectiveness of stormwater BMPs installed in urban areas across the nation has been collected and compiled in a national database by the ASCE and EPA. Data from the national database for areas climatically similar to North Carolina (i.e. Baltimore-Washington; Austin, TX; and northern two-thirds of Florida) and data from studies in North Carolina and Virginia were summarized by Wossink and Hunt (2003) as shown in Table 2.

Table 2. Median Removal Efficiency for BMPs installed in Southeast and Mid-Atlantic Sites.

Type	TSS		TP		NO_3-N		TN		Zn	
	Eff. %	No. Sites	Eff. %	No. Sites	Eff. %	No. Sites	Eff. %	No. Sites	Eff. %	No. Sites
Wet Ponds	65	27	46	28	43	16	28	27	51	24
Wetlands	61	14	33	14	55	8	22	14	49	6
Sand Filters	79	12	59	11	-57	11	41	12	64	11
Bioretention areas	NA	-	71	5	16	4	45	4	89	4

Source: Wossink and Hunt (2003).

While these data provide an estimate of efficiency for similar conditions, they were collected from sites that, for the most part, were not primarily highways. The high traffic volume and specific hydrologic characteristics of highway corridors may result in significantly different pollutant removal efficiency. Additionally, implementing BMPs along highways often involves modifying the standard designs to fit the spatial and hydrologic restraints, thereby creating questions as to how the modifications affect the efficiency. Thus, evaluating the efficiency of BMPs used along highways through accurate defensible monitoring is much needed. The purpose of this project was to document, through water quality monitoring, the pollutant removal efficiencies of stormwater BMPs implemented on highway facilities.

Grass strips are areas of close-growing grass planted on the contour of relatively gently sloping land, which are designed to remove pollutants from overland runoff as it passes through the strip. Grass strips or filter strips are widely used in agricultural and to a lesser extent urban settings. The main abuses of grass strips that have led to decreased effectiveness are that of too much runoff for adequate treatment and allowing concentrated flow through the strip which effectively short circuits the strip (Schueler, 1987). Concentrated flow can also occur if the flow path through the strip is too long (>100 ft). Thus, the designer must be careful to limit the drainage area to the strip, provide a level spreader at the upslope edge of the strip to spread the runoff evenly over the strip, and construct the strip on the contour to prevent significant concentration of runoff. The level spreader grass-strip BMP in this study was located in Johnston County (Division 4) and received runoff from a section of NC 42 near I40. The level spreader and grass strip were carefully constructed to encourage sheet flow through the 56 ft of bermudagrass sod.

Roadside swales are often grassed channels constructed along roadways to convey water to a designated point. In conveying runoff some of the runoff may infiltrate into the soil and pollutants may be filtered out of the runoff thereby providing pollutant removal. Enhancing these swales by placing a checkdam or outlet structure across the swale and an underdrain under the surface of the swale facilitates infiltration of runoff into the soil thereby potentially increasing the effectiveness of the swale. The enhanced swale in this study was located along business U.S. 70 in Craven County (Division 2) and received runoff primarily from an intersection and a section bridge deck. The swale had a parabolic cross section, was 200 ft long, and had a dense Centipede grass sod as its vegetation.

Bioretention areas consist of relatively porous soil overlaying one or a series of underdrains. Often, mulch or other ground cover is placed on the flat surface of the soil and water tolerant vegetation is planted in the soil. Runoff is conveyed to the area and spreads over the level surface of the soil before percolating through it to the underdrains and out into the storm drain system. As the runoff water moves through the soil pollutants area removed by various physical, biological, and chemical processes. These devices are a relatively new stormwater practice and as such the design and specifications are in flux. There were three bioretention areas monitored during this study: one each along I40 in Catawba, Duplin, and Buncombe counties. The Catawba County (Div 12) bioretention area was located in the eastbound rest area and received runoff primarily from a semi-tractor truck parking area. The area was 100ft long and 44ft wide with 2-3ft of soil material over a series of underdrains and was covered with hardwood mulch and planted in various water tolerant plants including Juncus and iris. The Duplin County bioretention area was located in the I40 rest stop near Warsaw (Divison 3). It received runoff from a car parking area and the grassed area inside the parking area and around the restroom building. The bioretention area was constructed similar to the one in Catawba County. The Buncombe County (Division 13) bioretention area was located between the eastbound ramp from US 70 to I40 and I40 near Black Mountain. It received runoff primarily from the I40 overpass over US 70. The area was nominally 100ft long and 50ft wide and was constructed similar to the other two.

OBJECTIVES

The primary objective of this project was to identify and evaluate through monitoring the efficiency of structural BMPs in removing pollutants of concern from stormwater. A secondary goal was to characterize stormwater runoff from NC DOT's industrial, borrow pit, and highway facilities. Meeting both objectives required monitoring storm event runoff; thus, only storm event samples were collected. The primary objective of evaluating BMPs meant that monitoring stations were located as close to the inflow and outflow of the BMP as possible. Subsequently, the inflow monitoring station was, at 3 sites, somewhat removed from the source area, which made it less useful for characterizing runoff from the DOT facilities involved. The configurations of these sites are described in detail in the following sections.

METHODOLOGY AND PROCEDURES

Evaluating the effectiveness/efficiency of highway BMPs at treating runoff requires that the installed BMP is effective and also that it is installed in such a way as to facilitate monitoring. Monitoring is facilitated by having one well defined inflow conveyance to and outflow from the device. Both inflow and outflow should have a location that provides free flowing water at all times to provide for the use of weirs and other open channel flow measuring devices. Also, for the best evaluation of efficiency, the highway BMP should have no significant surface or ground water entering the BMP other than what passes through the inflow monitoring station. While there have been many BMPs installed at highway facilities, relatively few lend themselves to accurate, reliable monitoring; therefore, site selection is an important part of the methodology. The sites in this study (figure 1) were selected by DOT personnel from among the many highway BMPs that they have installed.

In addition to site selection, determining which storm events to monitor was also necessary. The NPDES storm water discharge permit application requires that only storms of at least 0.1 inch accumulation following a period of 72 hours of dry weather be monitored (US EPA, 1992). For this study, the overwhelming majority of data are from storms of at least 0.2 inches accumulation following a 72-hour period of insignificant runoff; however, since the project's primary objective was to document BMP efficiency and not characterize runoff, data from some storms that were not preceded by 72 hours of dry weather were included. This was especially true for the Black Mountain site, which every storm event was sampled. In addition, DOT personnel requested that the monitoring be focused on the runoff from the first inch of rainfall as this is the focus of state regulations. Thus, the sampler pacing at each location was programmed to collect samples at a frequency that would fill all the jars in the machine during the first inch of rainfall. Thus, runoff from rainfall of considerably greater than 1 inch was not sampled, which occurred for only a few storms.

Adequately evaluating the efficiency of stormwater BMPs required the monitoring of storm events and that at least 14 storm events be monitored. The 14 storm event minimum was based on Strecker et al. (2001), who used analysis of variance on existing monitoring data to determine that between 5 and 29 samples (average of 14) were required to detect a 20% change in concentration of total suspended solids, copper, and phosphorus with 80% confidence.

The primary objective of evaluating BMP efficiency required that the monitoring stations be located as close to the BMPs as possible. Therefore, each BMP the monitoring station was located immediately upstream and downstream of the practice (CALTRANS, 2000) in order to minimize effects of extraneous runoff water. In many cases this necessitated installing weirs inside a storm drain manhole making access and discharge monitoring relatively difficult. This also often meant that the station was somewhat removed from the pollutant source areas making the characterization of source areas less definitive.

Monitoring Methods: While the method of discharge monitoring varied by site and will be described for each site separately below, discharge monitoring frequency, sample collection and handling was basically the same for each site. Water depth was monitored by the integrated flowmeter every minute and saved in 5-minute increments. Flow-proportional samples of inflow and outflow from each BMP were collected during storms. The pacing or volume of runoff between samples was set such that at least 5 individual subsamples were collected for each storm event as multiple samples are required to adequately characterize the entire storm event hydrograph (CALTRANS, 2000). The samples were stored glass jars in a refrigerator (<4 deg C) for 4-48 hours until they were recovered by NCSU personnel, transferred to appropriate laboratory-supplied containers, and shipped overnight on ice to the state certified laboratory for analysis.

The Division 13 bioretention area was an exception to this protocol in that samples were recovered every 2 weeks. All 11 samples collected were analyzed for TSS and turbidity, while only 2 were analyzed for nitrogen and phosphorus forms. For these two sampling periods duplicate samples were obtained by the machine and one placed in a pre-acidified (H_2SO_4 to pH<2) jar from which the nutrient sample was recovered and the other in a nonacidified jar. The acid was added to minimize microbial activity in the samples analyzed for nitrogen and phosphorus forms. Microbial activity in the TSS and turbidity samples should not significantly affect TSS as it is primarily inert, but may affect turbidity if a sample contains a lot of easily degradable solids as organic matter. Because the samples were stored in the dark, growth of algae and other similar organisms should be insignificant. A chain-of-custody form accompanied the sample from the time of recovery from the sampler through laboratory analysis to track its handling.

Glass jars were used in the refrigerated samplers as required for oil and grease analysis (US EPA, 1992; APHA et al., 1995). Refrigerated samplers were used because immediate storage at <4 deg C is required for almost all of the parameters analyzed for (APHA et al., 1995) and is also recommended in the NPDES stormwater sampling guidance (US EPA, 1992) for composite samples collected by automated samplers. Laboratory-supplied containers were pre-acidified with the appropriate acid as shown in Table 3. The MDLs and methods of analyses are also included in Table 3. The state certified lab used appropriate quality control procedures to produce accurate reliable data. Additionally, turbidity and pH measurements were conducted on nonacidified samples at the NCSU Water Quality Group within 2-4 hr. of recovery from the sampler. Because the holding time for the turbidity and, especially, pH measurements far exceeds recommendations, these data are somewhat questionable. The turbidity measurement for most samples, which were refrigerated immediately, is more defensible because immediate cooling reduced the microbial activity that could potentially change the clarity of the water.

Table 3. Storage, Preservation, and Analysis Methods.

	Units	Container	Preservation	MDL	Method
Metals					
Cadmium	ug/L	P or G[1]	HNO_3 to pH<2, <4 C	2	3113B[2]
Chromium	ug/L	P or G[1]	HNO_3 to pH<2, <4 C	5	3113B[2]
Copper	ug/L	P or G[1]	HNO_3 to pH<2, <4 C	50	3113B[2]
Lead	ug/L	P or G[1]	HNO_3 to pH<2, <4 C	5	3113B[2]
Nickel	ug/L	P or G[1]	HNO_3 to pH<2, <4 C	10	3113B[2]
Zinc	ug/L	P or G[1]	HNO_3 to pH<2, <4 C	10	3113B[2]

Inorganic Non Metals					
Chloride	mg/L	P or G[1]	none	2	325.2[3]
Nitrogen, Ammonia	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.04	4500-NH_3H[2]
Nitrogen, NO_{3+2}	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.05	353.2[3]
Nitrogen, TKN	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.15	351.2[3]
Nitrogen, Total	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.19	TKN+NO_{3+2}
Phosphorus, Dissolved	mg/L	P or G[1]	none	0.05	365.1[3]
Phosphorus, Total	mg/L	P or G[1]	H_2SO_4 to pH<2, <4 C	0.05	365.4[3]
Residue, Suspended	mg/L	P or G[1]	<4 C	1	2540D[4]
Residue,Total	mg/L	P or G[1]	<4 C	1	2540B[4]
Aggregate Organics					
COD	mg/L	P or G[1]	H_2SO_4, <4 C	5	410.4[3]
Oil and Grease	mg/L	G	HCL to pH<2, <4 C	5	1664[5]
Surfactant	mg/L	P or G[1]	<4 C	0.05	425.1[3]

[1] G=glass with Teflon lined cap, P=plastic, <4 C means cool to less than 4 degrees Celsius.

[2] 18th Edition Standard Methods for the Examination of Water and Waste Water.

[3] Chemical Analysis of Water and Wastes (U.S. EPA, 1983).

[4] 17th Edition Standard Methods for the Examination of Water and Waste Water.

[5] U.S. EPA, EPA-821-B-94-004b.

BMP Efficiency Calculations: Inflow and outflow pollutant loads were computed for each storm event as shown in the following equation:

$$\text{Event Load} = (\text{flow proportional concentration}) \times (\text{runoff volume})$$

In most cases the runoff volume was the volume of runoff for the whole storm; however, for storms greater that 1 inch of rainfall, the runoff volume applied only to the volume of runoff sampled, which was designed to be the runoff resulting from the first 1 inch of rainfall. In addition, for some storms at the Division 12 bioretention area and the Division 2 enhanced swale there was outflow prior to the storm event. This rate of discharge was applied to the entire event and subtracted from the event runoff volume.

Pollutant reduction efficiencies were computed from both the concentration and load data. The concentration efficiency for each storm was computed using the following equation:

$$\text{Concentration Efficiency} = \frac{(\text{inflow} - \text{outflow})}{\text{inflow}} \times 100$$

where inflow and outflow are the inflow and outflow flow proportional concentrations for the storm event. There are several possible ways to compute the overall efficiency for load reductions including computing the efficiency for each event and taking the average of all and summing the loads from each event and then computing the efficiency. The first method weights each storm equally, which is often not the reality. The second method was reported as a more appropriate method (Strecker et al., 2001) and is depicted in the following equation:

$$\text{Load Efficiency} = \frac{(\Sigma\,\text{inflow load} - \Sigma\,\text{outflow load})}{\Sigma\text{inflow load}} \times 100$$

where the inflow and outflow loads are the inflow and outflow load for each storm event.

Statistical Analysis: While the computed efficiency is an appropriate measure of the effectiveness of the device it does not take into account the variability of the data. For this reason statistical analyses of the data were performed to further support the pollutant reduction efficiency numbers. Because the inflow and outflow data were paired, meaning they occurred for the same event and were not randomly selected among all events, a paired t test was an appropriate test for comparing inflow and outflow data (Ott, 1984). This method takes into account the often large differences between storm event pairs. Also, since some of the storm event data were not normally distributed log transformations of the data were performed. Strecker et al. (2001) reported that lognormal distributions were a valid approximation of the storm event water quality data they examined.

Pollutant Export Calculations: Annual pollutant export was computed for the level spreader-grass strip BMP and the Division 12 bioretention area based on the pollutant concentration and discharge at the inflow to each BMP. Both of these BMPs had a channel and a high flow bypass device between the primary pollutant source area and the BMP (these are described in detail in the following section), which may have affected pollutant concentrations and/or runoff volumes between the source and the inflow monitoring station. Nevertheless, annual pollutant export was computed by summing the pollutant load for each storm event during the year of monitoring and dividing by the contributing area as depicted in the equation below:

$$\text{Pollutant Export} = \frac{\Sigma \text{ Storm loads}}{\text{Drainage area}}$$

Because not all of the storms occurring during the year were monitored, rainfall, runoff, and pollutant loads for some of the storms had to be estimated. Rainfall was obtained from a nearby continuously recording raingage. Runoff for unmonitored storms was estimated from the rainfall using a linear regression equation developed from the storms that were monitored. The pollutant load for each storm was then estimated by multiplying the average flow-proportional concentration for the monitored storms by the estimated runoff for each storm. This method is similar to the simple method presented by Schueler (1987), but is much more accurate because it is based on data collected from the site for which the export is being computed. Site specific equations and data are presented in the following section.

RESULTS

A general description of contributing area and highway BMPs are presented by site in the following section. Summaries of the data are included in the text while the data for individual storms are presented in the appendix. When the concentration of an analyte in a sample was less than the MDL, half of the MDL was reported (bold typeface in tables) and used in the computation of loads and summary statistics. However, when all of the samples had concentrations less then the MDL for an analyte, a ‘ND’ was reported in the summary statistics. Also, when both inflow and outflow concentrations for a particular storm were less than the MDL, the values were excluded from the analysis comparing inflow to outflow loads. Thus, half the MDL was used only when either the inflow or outflow concentration was greater than the MDL.

Storm event loads were computed by multiplying the concentration of the contaminant in the composite sample by the volume of runoff for the event or the period. At the request of DOT staff, the samplers were programmed to only sample the runoff computed to result from the first 1 inch of rainfall; therefore, some of the runoff from storms of greater than 1 in. was not sampled. For example, the storm on 8/18/03 produced 1.21 inches of rain and 23,363 gal of inflow; however, the sampler was programmed to collect 500 gal/sample and 3 samples/jar. Hence, all 12 jars were full after 18,000 gal and no more sample was collected from the remaining 5,363 gallons of inflow. Since the outflow sampler was programmed the same way, the effect on the efficiency calculation of not sampling the tail of the hydrograph may have been negligible, but this is unknown.

The efficiency of the highway BMPs will be presented as both a concentration and a load reduction. The concentration reduction is simply the mean of the reductions for each storm event, which was computed by subtracting the outflow from inflow concentration and dividing by the inflow. This concentration reduction efficiency tends to be more useful for pollutants such as NH_3-N which can cause immediate harm to aquatic organisms at high levels. The overall load reduction efficiency was computed by subtracting the sum of the outflow loads for each event from the sum of the inflow loads and dividing by the sum of the inflow loads. In contrast to simply averaging the efficiency from each of the storms, this method weights storms with higher absolute pollutant loads greater than those with lower loads. Using the sum of the loads should be more representative of overall field conditions. Load reduction efficiencies are more useful for the majority of pollutants, which cause surface water degradation as they accumulate.

In order to lend perspective to the data, the inflow concentrations will be compared to highway runoff data reported by Wu and Allan (2001) as shown in Table 4 and to NC standards for receiving waters and urban stormwater as shown in Table 5. It is important to note that outflow from none of the BMPs drains directly into a classified receiving water, but that the standards are presented for comparison purposes. The standards generally represent levels of elevated risk, but do not predict negative water quality impacts for specific situations. Actual site-specific and event specific impacts depend on many factors including the level, timing, and duration of a given pollutant level; the bioavailability of the compound; and the simultaneous exposure to other stressors.

Table 4. NC and National Highway Event Mean Concentrations for Highway Runoff.

	TSS	COD	NO_{3+2}-N	TKN	OP-P	Pb	Zn
	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	ug/L
NC Highways[1]	37	39	0.40	1.37	0.12	6	64
National[2]	93	84	0.66	1.48	0.29	234	217

[1] Wu and Allan (2001)

[2] Driscoll et al. (1990)

Table 5. Standards for Surface Waters and Reported Quality of Urban Stormwater.

	Units	NC Standard for Class C	Urban Stormwater Quality Range[b]	NC Industrial Sites[d]	
				Mean	Range

		waters	NURP[c]			
Metals						
Cadmium (Total)	ug/l	2	0.05 – 13,730	NA	8	<2-41
Chromium (Total)	ug/l	50	1 – 2,300	NA	214	18-865
Copper (Total)	ug/l	7[a]	0.06 – 1,410	34	414	39-2,223
Lead (Total)	ug/l	25	0.6 – 26,000	144	546	39-3,223
Nickel (Total)	ug/l	88	1 – 49,000	NA	76	<10-333
Zinc (Total)	ug/l	50	7 – 22,000	160	1,800	191-10,080
Inorganic Nonmetals						
Chloride	mg/l	230	0.3 – 25000	NA	NA	NA
Nitrogen						
Total Nitrogen	mg/l	NA	0.32 – 16	NA	2.88	1.10-6.80
Nitrate Nitrogen	mg/l	NA	0.01 – 12	0.68	0.83	0.31-2.10
Ammonia Nitrogen	mg/l	NA	0.01 - 4.3	NA	0.32	0.01-1.36
Total Kjeldahl Nitrogen	mg/l	NA	0.32 – 16	1.5	2.05	0.79-4.70
Total Phosphorus	mg/l	NA	0.01 - 7.3	0.33	0.39	0.07-2.04
Total Residue	mg/L	NA	76 - 36,200	NA	973	190-4718
Total Suspended Residue	mg/L	NA	1 - 36,200	100	828	47-4485
Aggregate Organics						
COD	mg/l	NA	7 – 2200	65	96	23-267
pH		NA	4.5 - 8.7	NA		
Oil and Grease	mg/l	NA	0.001 – 110	NA	6	0-28
Semi-Volatile Organics						
Dichloromethane	mg/l		0.005 - .0145	NA	NA	NA
Tetrachloromethane	mg/l		0.001 - .002	NA	NA	NA
Trichloromethane	mg/l		0.0002 - .012	NA	NA	NA
Benzene	mg/l		0.0035 - .013	NA	NA	NA
Di-n-octyl phthalate	mg/l		0.0004 - .001	NA	NA	NA
Bis(2-ethlyhexyl) phthalate	mg/l		0.007 - .039	NA	NA	NA

[a] Action level, established primarily for NPDES discharges (NC DENR, 1997).

[b] Concentrations in urban stormwater (Makepeace et al., 1995).

[c] Data from the Nationwide Urban Runoff Program, NURP (U.S. EPA, 1983).

[d] Concentrations in runoff from 10 industrial sites (Line et al., 1996).

Level Spreader-Grass Strip (Division 4)

Description of Site: The Division 4 level spreader-grass strip BMP is located between the east bound ramp from Hwy 42 to I40 and I40 in Johnston county (N35 36; W 78 33). The characteristics of the drainage area are shown in Table 6 and in figure 2. The area is composed of a section of heavily traveled two-lane road (NC 42) and a traffic light intersection between the road and the ramps to I40 and part of a bridge over I40 (figure 3). The BMP was constructed in the fall of 2002; however, due to extended drought and subsequent poor plant growth that fall, Bermuda grass sod was installed in the Spring of 2003 to replace the original vegetation. The sod grew and made a dense vegetative mat over the entire areas (figure 3). The grass strip is 24 ft wide and 56 ft long (figure 4). A survey of the area determined the longitudinal slope to be 5.2%

and cross slope negligible. The area of the grass strip and adjacent banks was 0.11 acres. This area was covered with dense vegetation and therefore should not contribute sediment, but may contribute runoff during high intensity rainfall, to the outlet monitoring station.

Table 6. Characteristics of the Drainage Area to the Level Spreader-Grass Strip.

Item	Description
Drainage area (DA)	0.86 acres
Imperviousness of DA	49%
2003 Average Daily Traffic (NC 42)	24,000
Pavement type	Asphalt
Soil composition	Native
Vegetation	Bermudagrass

Stormwater runoff from the road flows down a rip-rap lined ditch to a concrete box installed in the bottom of the channel (figure 4). The concrete box is drained by a 6 inch diameter PVC pipe installed near the bottom of the box. When runoff rates from the road exceed the capacity of the pipe the flow overtops the concrete box and continues down the channel; thus, some of the road runoff can bypass the BMP. The pipe carries water to the inlet of the level spreader where there is a weir installed to measure the discharge rate. Runoff water exits the pipe into a concrete-lined forebay area and ponds up to >1 ft deep (~170 ft^3) before passing over a level lip and into the grass strip. The concrete forebay has a series of small holes along the bottom to slowly drain water from the forebay into the grass strip. At the downslope end of the strip a small 'v' ditch conveys water off the strip and into a rock-lined channel. The 'v' ditch is vegetated with dense Bermudagrass and hence is not a source of sediment.

Description of Monitoring: A rectangular-shaped concrete block box was constructed around the inflow pipe and a 1ft rectangular weir installed along one side of the box through which the water entered the level spreader (figure 5). The concrete box was needed to raise the level of the incoming water to a level higher than the lip of the level spreader in order to facilitate monitoring of flow via a weir. The ponded water in the box also served to reduce the energy of the water flow down the inflow PVC pipe.

The weir was installed on the side of the box such that its crest was at least 1 inch above the lip of the level spreader to enable free flow over the weir even when water was flowing over the spreader lip. The sampler bubble tube was fastened to the inside of the concrete box at the level of the weir crest to facilitate discharge monitoring. A stainless steel intake strainer attached to the sampler intake line was fastened vertically to the inside of the box at about the level of the weir crest for sample collection. The vertical orientation of the strainer facilitated vertical integration of sample collection, which is very important where oil and grease and other floating contaminants may be present in the runoff.

A 120 degree v-notch weir was installed in the 'v' ditch leading away from the downslope end of the grass strip to monitor outflow (figure 5). The sampler bubble tube was attached to a stake about 1 ft upstream and at the level of the weir crest to measure discharge. A stainless steel intake strainer attached to the sampler intake line was fastened vertically just upstream of the weir at about the level of the weir notch for sample collection. The vertical orientation of the strainer facilitated vertical integration of sample collection, which is very important where oil and grease and other floating contaminants may be present in the runoff.

An automated sampler with an integrated flowmeter was installed at each weir. The flowmeter used the bubbler method to continuously measure water depth. Water depth was measured upstream to avoid measuring in the drawdown of the weir. The flowmeter was programmed to continuously convert the depth to discharge using the standard equation for each weir. The flowmeter was used to control sample collection such that flow-proportional samples were collected by the automated sampler.

Individual flow-proportional samples were place in 12 glass jars, which were inside a continuously refrigerated space. Continuous refrigeration (<4 deg. C) and glass sampler containers were used in accordance with EPA (EPA, 1992) and Standard Methods (APHA et al., 1995) recommendations on handling and preserving samples in the field. As soon as possible after each monitored storm event, equal volume aliquots from each sampler jar were poured into appropriate laboratory containers and shipped overnight on ice to the contracted certified lab for analysis. Turbidity and pH measurements were conducted at the NCSU Water Quality Group as soon as possible after recovery of samples from the sampler.

Rainfall amounts were continuously recorded via an 8-inch diameter tipping bucket recording raingage. A plastic nonrecording raingage was also installed at the site. For the August 18, 2003 storm, rainfall (usually >1 in.) was collected in the nonrecording raingage to allow for analysis. The rainfall water was transferred into a laboratory container and shipped with the runoff sample for analysis of nitrogen forms.

In September 2003, at the request of NC DOT personnel an additional automated sampler was also installed in the ditch between the highway outfall and the inlet to the level spreader in order to collect a sample of highway runoff. Because no flow measuring device was installed, the sampler was programmed to collect samples based on time intervals. The programming was such that the machine began sampling every 8 minutes when the water level in the ditch increased to a level indicating flow through the ditch. All 12 jars were filled during the 9/4/03 storm. A composite sample was made and sent to the lab for analysis at the same time the samples from the inflow and outflow for the BMP were recovered.

Results of Monitoring: The inflow to the BMP likely was not the same as runoff from the road because of the possibility of treatment between the road and the inflow to the BMP and the probability of road runoff bypassing the BMP. Runoff from the road storm drain exited into a rock-lined channel that was constructed slightly uphill for a distance, thereby forming a small detention pond. This area of ponded water likely facilitated settling of solids during low flow conditions. Additionally, at higher flows, some of the runoff from the road can bypass level spreader when the capacity of the pipe to the BMP is exceeded. To assess these possibilities, runoff from one storm (9/5/03) was sampled at the road storm drain, the level spreader inflow monitoring site, and at the outflow. The concentrations of all analytes were highest at the outlet of the road storm drain (column 3) as compared to the other two locations (Table 7). While this suggests there was treatment between the road and the BMP inflow several other factors must be considered. First, the sample at the road was collected based on time intervals which means that a disproportionate amount of sample was collected during low flows resulting in less dilution of the sampled runoff. Second the differences between the road and inflow samples were not significant and could be attributed to random or sampling variability.

The last two columns of Table 7 compare the efficiency of the system of treatment practices by using the road sample data as compared to the inflow sample data. As shown in columns 6 and 7 the efficiencies may be greater using the road data; however, using this data would not be an accurate assessment of the level spreader/grass strip due mainly to the possibility of road runoff bypassing the BMP inflow.

Table 7. Monitoring Data for Road, Inflow, and Outflow Monitoring Locations.

		Road	Inflow	Outflow		Eff Road %	Eff Inflow %
Runoff (1,000x)	gal	NA	3.7	2.0		NA	45
Peak discharge rate	gpm	NA	30	14		NA	53
pH	pH	6.2	6.6	6.6		-6	0
Turbidity	ntu	45	30	5		89	83
Metals							
Cadmium	ug/L	**1**	**1**	**1**		NA	NA
Chromium	ug/L	**2.5**	NA	NA		NA	NA
Copper	ug/L	**31**	**31**	**31**		NA	NA
Lead	ug/L	**2.5**	NA	NA		NA	NA
Nickel	ug/L	**2.5**	**2.5**	**2.5**		NA	NA
Zinc	ug/L	160	NA	NA		NA	NA
Inorganic Nonmetals							
Chloride	mg/L	**1**	NA	NA		NA	NA
Nitrogen, Ammonia	mg/L	1.10	0.93	0.05		95	95
Nitrogen, NO_3+NO_2	mg/L	0.50	0.50	0.25		50	50
Nitrogen, TKN	mg/L	3.30	2.40	1.80		45	25
Nitrogen, Total	mg/L	3.80	2.90	2.05		46	29
Phosphorus, Diss.	mg/L	0.09	0.07	0.06		33	14
Phosphorus, Total	mg/L	0.21	0.20	0.17		19	15
Residue, Suspended	mg/L	29	17	7		76	59
Residue, Total	mg/L	82	78	84		-2	-8
Aggregate Organics							
COD	mg/L	77.3	NA	NA		NA	NA
Oil and Grease	mg/L	**<6**	**<6**	**<6**		NA	NA
Surfactant	mg/L	0.5	0.3	0.2		60	33

Summaries of field and laboratory analysis results for inflow and outflow resulting from monitoring 14 storm events are shown in Table 8, while the data for individual storms are shown in the Appendix. The mean inflow per storm event was nearly twice as much as outflow indicating relatively high infiltration rates in the bermudagrass strip. This trend was also documented during the 6 storms that occurred during the winter months (12/4/03-2/12/04) thereby indicating that infiltration continued at about the same rate even when the grass was dormant.

The mean of the peak discharge rates for inflow and outflow were about the same; however, the median inflow was considerably greater than the outflow. The peak discharge for the outflow was generally less than inflow except for 2 intense rain events on 6/18/03 and 8/18/03. The rainfall intensity during these events was high enough to create runoff from the 0.11 acres of area including and surrounding the grass strip, which is downstream of the inflow monitoring site, but upstream of the outflow monitoring site. For the other 12 events the average peak discharge rate at the inflow and outflow was 75 and 56 gpm, respectively. Hence, for most events a 25% reduction in peak discharge can be expected.

The mean pH for inflow and outflow samples was similar. Both were near neutral and thus should not have a significant affect on surface water quality. This is common for highway runoff as slightly acidic rainfall is rapidly neutralized on contact with road dust derived from organic and inorganic salts (Morrison et al., 1990). The mean turbidity of inflow (52 ntu) was 46% greater for inflow compared to outflow (28 ntu). This decrease was statistically significant at the 0.05 level according to a paired t test conducted on the turbidity measurements from the 14 events. The outflow turbidity was well below the NC surface water standard of 50 ntu for all but the 2/3/04 event.

Concerning metals, samples from the first three events were analyzed for cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn). Concentrations of Cd, Cu, and Ni were below their respective MDLs for each sample. Mean concentrations of Cr (6.5 ug/L), Pb (9.0 ug/L), and Zn (190 ug/L) were mostly greater than the MDL in inflow but only Zn (66.7 ug/L) was greater than the MDL in the outflow. The levels of Cd, Cu, and Pb in inflow were similar or less than corresponding concentrations in nationwide highway runoff (Driscoll et al., 1990) and in runoff from NC highways (Wu et al., 1998). The concentrations of Cd, Cr, Pb, and Ni in the outflow from all three storms were less than standards for NC class C receiving waters (Table 5). Because the MDL for Cu (62 ug/L) was much greater than the NC standard (7 ug/L), concentrations greater than the standard could not be determined. Concentrations of Zn were greater than the NC standard or 50 ug/L in one out of the 3 outflow samples collected. Thus, metals in outflow were generally not a problem even if the outflow was discharged directly into a surface water body.

Table 8. Summary Statistics for Inflow and Outflow for the Level Spreader-Grass Strip.

Parameter	Units	Inflow			Outflow		
		Mean	Median	Range	Mean	Median	Range
Automated rainfall	in	0.65	0.55	0.29 – 1.21	0.65	0.55	0.29 – 1.21
Runoff (1,000x)	gal	16.7	18.4	3.6 – 23.3	8.6	7.3	0.9 – 25.9
Peak discharge rate	gpm	104	79	30 – 280	109	58	7 – 400
pH	pH	6.8	6.8	6.6 – 7.3	6.8	6.9	6.7 – 7.0
Turbidity	ntu	52	47	22 – 93	28	21.8	5 – 69
Metals							
Cadmium	ug/L	1.0	1.0	<2	1.0	1.0	<2
Chromium	ug/L	6.5	6.0	<5 – 11	2.5	2.5	<5
Copper	ug/L	31	31	<62	31	31	<62
Lead	ug/L	9.0	10.0	6 – 11	2.5	2.5	<5
Nickel	ug/L	2.5	2.5	<5	2.5	2.5	<5
Zinc	ug/L	190	190	180 – 200	66.7	50.0	50 – 100
Inorganic Nonmetals							
Chloride	mg/L	1.4	1.0	<2 – 2.2	1.0	1.0	<2
Nitrogen, Ammonia	mg/L	0.8	0.8	0.26 – 1.5	0.5	0.5	<0.04 – 1.3
Nitrogen, NO_3+NO_2	mg/L	0.6	0.6	0.18 – 0.84	0.5	0.4	0.15 – 1.32
Nitrogen, TKN	mg/L	2.0	1.9	1.0 – 2.9	1.6	1.5	1.0 – 3.2
Nitrogen, Total	mg/L	2.5	2.4	1.35 – 3.64	2.1	2.1	1.27 – 4.15
Phosphorus, Diss.	mg/L	0.1	0.1	0.02 – 0.16	0.1	0.1	0.03 – 0.27

Phosphorus, Total	mg/L	0.2	0.2	0.13 – 0.29	0.2	0.2	0.12 – 0.34
Residue, Suspended	mg/L	36	28	15 – 79	10	7.0	<5 – 34
Residue, Total	mg/L	188	110	70 – 1240	216	77	39 - 1920
Aggregate Organics							
COD	mg/L	62.2	61.1	44.8 – 80.6	31.0	31.0	25.3 – 36.7
Oil and Grease	mg/L	**3**	**3**	**<6**	**3**	**3**	**<6**
Surfactant	mg/L	0.3	0.3	0.1 – 0.4	0.2	0.2	0.2

Mean concentrations of inorganic nonmetals were all greater in inflow compared to outflow. Concentrations of NO_3+NO_2-N, dissolved P, and TSS in inflow were less than corresponding concentrations in runoff from highways nationwide as reported by Driscoll et al. (1990), while levels of TKN were greater for this site than the nationwide data. By far the greatest difference occurred in the TSS concentrations which were much lower from this site (36 mg/L) than the nationwide data (93 mg/L). The cause of this may be that traffic volume was less at this site, grass on the shoulder along the road filtered the TSS from the runoff, or that TSS in the higher discharge rates bypassed the BMP.

The mean chloride concentration in outflow was well below the state standard of 230 mg/L (Table 5). While there are no standards for nitrogen, phosphorus, and sediment, it is useful to compare the concentrations of these constituents to runoff from other land uses. Median concentrations of NO_{3+2}-N, TKN, TP, and TSS in outflow were less than or equal to those measured in urban runoff during the NURP study (Table 5) indicating that the quality of the outflow was at or better than urban runoff nationwide.

Levels of aggregate organics were determined for only 3 samples. The COD concentration in the outflow was about half that in the inflow. Both inflow and outflow concentrations were less than those measured in urban runoff during the NURP program (Table 5). Both oil and grease and surfactant were below or near their respective MDLs and thus were their concentrations were relatively low.

Three samples were analyzed for 67 semi-volatile organic compounds including polycyclic aromatic hydrocarbons (PAHs). Of these only Bis(2-ethylhexyl) Phthalate was found (2 inflow samples and 1 outflow sample) at a concentration greater than the MDL, and then only slightly greater. These data indicate that there were few semi-volatile organic compounds in the runoff and also that, if these compounds were in the runoff, the BMP may be effective at treating them.

Analysis of the bulk rainfall sample documented concentrations of NH_3-N, NO_{2+3}-N, and TKN of 0.56, 0.49, and 0.83 mg/L, respectively. These concentrations were combined with the total rainfall water, as computed by multiplying the measured accumulation by the inflow drainage area, to provide an estimate of the mass of nitrogen in rainfall for the 14 storm events. This mass was then divided by the mass of nitrogen in inflow to determine the proportion of inflow nitrogen originating from precipitation. These proportions for NH_3-N, NO_{2+3}-N, and TKN were 0.59, 0.78, and 0.39. This indicates that a significant amount of the nitrogen load in the inflow was from rainfall.

Pollutant Reduction Efficiency: Reductions in pollutant concentrations and loads are shown in Table 9. The range is the maximum and minimum decrease for individual storm events. The 49% reduction in peak flow rate is important given that highway corridors are highly impervious and thus often generate elevated peak flows. The reductions in peak flows decreased as peak inflow increased as shown in figure 6. This was expected given that when inflow to the grass strip exceeded its infiltration rate then there would be no reduction in peak flows. The negative reductions resulted from rainfall intensities for two storms (6/18/03 and 8/18/03) exceeding the infiltration rate of the grass strip and its surrounding area, resulting in runoff from the surrounding area adding to the inflow (figure 7). The peak 30-minute rainfall intensities for the 6/18/03 and the 8/18/03 storms were 1.9 and 1.2 inches/hour. Runoff reductions ranged from -11 to 95% (Table 9) with 12 of 14 storms having less outflow than inflow. While the average reduction for all storms was 23% storms, the overall volume of outflow was 49% less than inflow (Table 9). In general, the larger the storm the lower the runoff reduction (figure 6). This was expected given that for larger storms the ground under the grass strip becomes saturated and the infiltration rate decreases, thereby allowing more inflow to pass to the outlet weir.

Reductions in pH for individual storms varied, but were near 0%. Reductions in turbidity ranged from 16 to 83% for individual storms and averaged 48% for all storms combined. Reductions decreased from 59% for the 8 storms preceding the installation of the UNC Charlotte monitoring equipment to 33% for the 6 storms following. This indicates that the disturbance caused by the installation and maintenance of the passive sampling bottles and other equipment in the grass strip may have reduced the effectiveness of the BMP.

Of the 6 metals analyzed for, only Zn was found at concentrations greater than the MDL for all three inflow and outflow samples. The efficiencies for individual storms were relatively consistent ranging from 72 to 75% for concentrations and from 52 to 89% for loads. Of the metals involved, ionic forms of Cu and Pb tend to rapidly adsorb to suspended particles whereas Zn and Cd tend to remain in solution (Morrison et al., 1990). The relatively high reduction in Pb was expected given the similar reduction in TSS and the affinity of Pb to adsorb to solids. The relatively high reduction in Zn, which tends to remain unbound and thus more difficult to remove from runoff water, indicates that the BMP would likely be effective at reducing concentrations of other metals in the inflow also.

Concentration and load reduction efficiencies for inorganic nonmetals varied, but were mostly positive. Only one of the three inflow samples contained Cl at concentrations greater than the MDL and for this event the BMP reduced the concentration by 55% and load by 82%. On average, concentrations of NH_3-N decreased 36% and loads 75% from inflow to outflow. Both of these reductions were statistically significant at the 0.05 level. The average NH_3-N reduction for 8 storms occurring before 10/31/03 was 45%, while the reduction for the 6 storms after was only 23%. This indicates that the BMP may be more efficient during the active growing season. Average reductions in NO_{3+2}-N, TKN, and TN concentrations were similar ranging from 11 to 17%. Only the mean reductions in TKN and TN were consistent and great enough to be statistically significant. Load reductions were considerably greater ranging from 49 to 66% and all three were significant. Reductions in concentrations of NO_{3+2}-N, TKN, and TN were similar for the storms occurring in the growing and nongrowing season.

On average dissolved P concentrations in runoff increased through the BMP. The increase was 23% during the growing season and 145% during the nongrowing season. The large increase during the nongrowing season corresponded to the period of disturbance for the UNC Charlotte study, thus the increase cannot be attributed to lack of plant growth alone. The fact that the dissolved P concentrations were relatively low means that even a small source of phosphorus such as some soil loosened by removing the passive sample bottles could have caused the increases. The average reduction in dissolved P loads was 24% which was not statistically significant. Like dissolved P, there was an average increase in TP concentration for all storms, which was not statistically significant. However, there was a 9.4% reduction in TP concentrations during the growing season followed by a 39% increase in concentrations during the nongrowing season. Overall, there was a statistically significant 48% reduction in TP load with much of this occurring during the growing season.

Table 9. Summary Statistics for Reduction Efficiency of the Level Spreader Grass Strip.

Parameter	Data	Concentration		Loads		Annual
	Points	Range	Mean	Range	Overall	Export
	no.	%	%	%	%	kg/ha-yr
Peak flow	14	-67 to 80	23	-	-	-
Runoff/discharge	14	-11 to 95	49[1]	-11 to 95	49[1]	-
pH	9	-4 to 4	-0.7	-	-	-
Turbidity	14	16 to 83	48[1]	-	-	-
Metals						
Cadmium	3	ND	ND	ND	ND	ND
Chromium	3	58 to 77	68	28 to 85	73	ND
Copper	3	ND	ND	ND	ND	ND
Lead	3	58 to 77	70	57 to 83	81	ND
Nickel	3	ND	ND	ND	ND	ND
Zinc	3	72 to 75	74	52 to 89	82	ND
Inorganic Non metals						
Chloride	3	ND	ND	ND	ND	ND
Nitrogen, Ammonia	14	-19 to 95	36[1]	-31 to 99	75[1]	1.4
Nitrogen, NO_3+NO_2	14	-100 to 64	11	-122 to 94	49[1]	1.9
Nitrogen, TKN	13	-14 to 62	17[1]	-3 to 95	66[1]	4.5
Nitrogen, Total	13	-21 to 59	14[1]	-35 to 95	62[1]	6.5
Phosphorus, Diss.	14	-83 to 50	-98[1]	-186 to 95	24[1]	0.4
Phosphorus, Total	14	-113 to 44	-11	-39 to 94	48[1]	0.7
Residue, Suspended	14	11 to 91	70[1]	52 to 100	83[1]	41
Residue, Total	14	-55 to 53	17	17 to 95	54[1]	684
Aggregate Organics						
COD	3	44 to 55	49	38 to 81	70	NA
Oil and Grease	3	ND	ND	ND	ND	NA
Surfactant	3	-100 to 33	-33	-199 to 73	40	NA

[1] indicates inflow and outflow were significantly different at the 0.05 level using a paired t test.

Suspended sediment concentrations decreased from inflow to outflow during every storm with the mean being 70%. Concentration reductions during the growing and nongrowing seasons were 76 and 63% respectively. The concentrations of TSS in inflow (max=79 mg/L) were relatively low, which may have reduced the efficiency. The TSS load reduction ranged from 52 to 100% with an overall decrease of 83%. Load reductions were 85 and 81% in the growing and nongrowing periods, thereby indicating little effect of plant growth on sediment retention. Sediment deposition and build up in the grass strip is one of the major factors that contributes to deterioration of the efficiency of the level spreader-grass strip BMP; however, in this case the stilling area of the level spreader will cause much of the heavy sediment to deposit before it reaches the grass, thereby preventing significant build-up of sediment in the grass strip. Also the relative ease of cleaning out the level spreader should keep sediment from accumulating in the spreader to the point where it would enter the grass strip. Reductions in TS concentrations ranged more widely than TSS and averaged only 17%. Load reductions were somewhat more consistent and averaged a statistically significant 54%.

Due to the few samples analyzed for aggregate organics, the reduction efficiencies are not very meaningful. Reductions in COD concentrations and loads were consistently and considerably positive for all three storm events indicating that the BMP was effective at reducing COD levels. Oil and grease concentrations were less than the MDL for the samples analyzed; the effectiveness of the BMP could not be determined. The surfactant concentrations were so low and the inflow and outflow differences so slight that for the reduction efficiency is essentially meaningless.

The TSS and TN reduction efficiencies of this BMP were greater than corresponding median removal efficiencies for wet ponds, wetlands, sand filters, and bioretention areas as reported in the literature (Wossink and Hunt, 2003). The removal efficiencies for TP, NO_{3+2}-N, and Zn were in the middle or near the upper end of the reported ranges for each pollutant.

Load reduction efficiencies of most pollutants would likely have been greater if, to a certain extent, concentrations in inflow were greater. Neither the level spreader nor the grass strip appeared to be stressed by the levels of sediment or other pollutants in the inflow. Four outflow storm samples had TSS levels less than the MDL; thus, one-half the MDL (2.5 mg/L) was used in the computation of efficiency, but this concentration might have been less. Also, the efficiency might have been greater if the weep holes along the bottom of the level spreader had been open thereby allowing it to drain completely between rain events. The level spreader often had standing water in it for several days after the previous rain event.

Annual pollutant export from the highway corridor was also computed. Because the site was not monitored for an entire year, export during part of the year had to be estimated. This was accomplished by obtaining rainfall accumulations for all storms greater than 0.25 in. that were not monitored. Generally, storms of less than 0.25 in produced little runoff and thus were ignored. Storm event runoff, or inflow to the BMP, was then determined by using the following rainfall-runoff relationship computed from the 27 storms for which the rainfall and inflow were monitored:

$$\text{Event Runoff (gal)} = \text{rainfall (in.)} \times 10{,}250 + 6{,}294 \qquad r^2 = 0.51$$

where the coefficients were computed from linear regression of the monitoring data. Inflow from monitored storms was 58% of the estimated total inflow for the year. The mean concentration from samples collected during the 14 sampled storms was then multiplied by the estimated storm runoff for each storm that was not sampled to compute the total annual load. Total loads for all storms were then summed to determine the pollutant export for the year and divided by the inflow drainage area (0.35 ha) to yield the annual export as shown in Table 10. Outflow export was then determined by multiplying the pollutant load removing efficiency (Table 9) of the BMP by the inflow export.

Table 10. Annual Export from the Highway Corridor to the Level Spreader-Grass Strip.

Site	NH_3-N	NO_{2+3}-N	TKN	TN	Diss P	TP	TSS	TS
	------------------------------ kg/ha-yr ------------------------------							
Level spreader-in	5.7	3.8	13.3	17.0	0.5	1.3	243	1267
Level spreader-out	1.4	1.9	4.5	6.5	0.4	0.7	41	684
U.S Highways[1]	NA	4.1	10.8	14.9	NA	3.4	1,966	NA

Charlotte Highways[2]	8.3	11.0	14.8	25.8	2.6	5.8	1,273	2,814

[1] Chui et al. (1982).

[2] Wu et al. (1998).

The annual export of nitrogen forms from the highway section (level spreader-in) was similar to those of U.S. Highways and considerably less than the corresponding export from Charlotte highways as estimated by Wu et al. (1998). Annual export of phosphorus forms and sediment from the study site were much less than those from U.S. Highways or the Charlotte highway sites. Export rates of pollutants from highways is potentially highly variable depending on many factors including traffic volume and the nitrogen and phosphorus concentrations in rainfall. The traffic volume on this section of NC 42 was unknown, but was likely much less than the Charlotte highways.

Site Specific Considerations: Several characteristics of the monitoring site affect the applicability of the data to other sites. The first of these is that the BMP did not receive direct road runoff. The >200 ft vegetated channel between the road culvert and the inlet to removed some of the pollutants from the runoff and the drop inlet box (figure 4) allowed some runoff water at high discharges to bypass the BMP. The effect of these two factors was unknown, but it is highly likely that much of the course sediment leaving the road was deposited in the ditch before it reached the BMP. Had this sediment been in the inflow to the BMP, it would have raised the TSS removal efficiency of the BMP. Another consideration is that the BMP was cut into the side of a hill. This put the elevation of the grass strip below the surrounding area, consequently the depth to groundwater below the grass strip was less than the surrounding area. This may have reduced the infiltration capacity of the soil somewhat. It also meant that during intense rainfall runoff from the area around the grass strip could run onto the strip and add to the outflow, thereby reducing the efficiency of the BMP. Finally, the addition of sampling within the grass strip may have changed the results. The maximum and mean outflow turbidities were 36 and 30 ntu prior to, and 69 and 39 ntu following, the installation of additional monitoring equipment within the grass strip in October of 2003. These increases suggest that the outflow turbidity may have been increased by the disturbance associated with the installation and maintenance of the additional monitoring equipment. While the disturbance appeared to be minimal, the low levels of pollutants in the outflow meant that even small disturbances could significantly change the results.

Site Specific Conclusions: This level spreader-grass strip BMP was efficient at reducing both concentrations and loads of incoming pollutants, especially sediment (Table 9). The efficiency would likely have been higher if the concentrations of pollutants in the inflow were somewhat higher and if the grass strip had not been disturbed. From the data the following conclusions can be drawn:

1. The level spreader-grass strip reduced TSS concentrations and loads by 70 and 83%, respectively. The increased reduction in loads as compared to concentrations was the result of a 49% decrease in outflow versus inflow.
2. Reductions in loads of nitrogen forms ranged from 49 to 79% while those for phosphorus ranged from 24 to 48% thereby indicating significant reductions of these pollutants in surface runoff.

3. Only 3 samples were analyzed for metals as only Zn was found at levels greater than the MDL, but the BMP appeared to be effective at removing Zn from the inflow.
4. The BMP reduced peak discharge rates for 10 of the 14 storms monitored. For only 2 of the relatively high intensity rainstorms did peak flow increase.

Site Specific Recommendations: From a monitoring and functional standpoint of the BMP itself, this site was the best of the 5 BMPs evaluated. The following are some observations:

1. During the project, little sediment accumulated in the relatively large concrete forebay of the level spreader indicating that the size of the forebay could seemingly be reduced, but it does provide a safety factor in case of a spill of soil, concrete, or other solids being carried to the grass strip. In addition, the area of water ponding at the outlet of the road culvert likely caused much of the larger sediment to settle out of the water column and not reach the forebay; hence, at other sites the seemingly large capacity of the forebay may be needed.
2. To better evaluate how the BMP treats road runoff, a more efficient means of transporting road runoff to the BMP is needed.

Enhanced Roadside Swale (Division 2)

Description of Site: The Division 2 enhanced roadside swale BMP is located along business 70 in New Bern (N35’ 6’’; W 77’ 2’’). Characteristics of the drainage area and the swale are shown in Table 11 and in figure 8. The area is composed of part of a concrete bridge that spans the Trent River near its confluence with the Neuse River, a small section of Hwy 70 (business), and a traffic light intersection (figure 9). The amount of runoff from the bridge was unknown because a drain to the river was only partially plugged. Hence, some of the runoff from the bridge could have flowed through this drain to the river and some could have continued on to the inlet to the monitoring site.

Table 11. Characteristics of the Drainage Area to the Roadside Swale.

Item	Description
Drainage area (DA)	1.1 acres[1]
Imperviousness of DA	87%
2003 Average Daily Traffic	11,000
Pavement type	Asphalt
Soil composition	Thin layer of topsoil for grass establishment, filter material is “Washed ASTM C33 Fine Aggregate Concrete Sand”
Vegetation	Centipede grass

1 Due to a partially plugged bridge drain the drainage area cannot be definitively determined.

Road runoff is conveyed to the BMP via a 1.5 ft diameter pipe that outlets into a rock-lined forebay (8 ft x 40 ft) before entering the upslope end of the grassed swale. The swale is on the order of 8 ft wide and 200 ft long and consists of dense Centipede sod (figure 9). The Centipede grass provided excellent cover, except for a small section along the slope between the road and the bottom of the swale (figure 10) This area may also have been subject to direct runoff from the pavement of highway 70 Business into the middle of the swale (hence missed inflow monitoring station). While the composition of the soil material under the sod is unknown, it appeared to be dominated by sand and its depth was estimated to be 3 ft. or less. At the downslope end of the swale, two concrete risers convey water out of the swale. A 6 inch underdrain empties into the first riser, which would thus carry the drainage from the swale. The top of the second riser is at a slightly lower elevation than the 1st so that high surface flows enter this riser exclusively. Since the outlet monitoring equipment was installed in the 1st riser, only drainage water was monitored.

Description of Monitoring: Initially an area-velocity probe was installed in the 1.5 ft diameter storm drain at the inlet to the forebay. During the first 3-4 storm events the flow rate in the pipe did not exceed 70 gpm, which was relatively low for accurate measurement using the area-velocity probe. Hence, a 1 ft sharp-crested rectangular weir was installed over the end of the pipe to facilitate more accurate measurements of the range of flow rates (fig 8). The crest of the weir was positioned about 3 inches above the bottom of the pipe to provide a ponded area upstream of the weir, which is required for accurate discharge measurements. The crest of the weir was at least 1.5 ft above the bottom of the forebay, therefore, backwater from downstream of the weir should not be a problem. A stainless steel intake strainer attached to the sampler intake line was fastened to the bottom of the pipe just upstream of the weir.

At the outlet, a 120 degree v-notch weir was installed in the concrete riser between the outlet of the drain pipe and the outlet pipe of the riser (figure 11). The sampler bubble tube was attached to a stake about 1 ft upstream and at the level of the weir crest to measure discharge. A stainless steel intake strainer attached to the sampler intake line was fastened vertically just upstream of the weir at about the level of the weir notch for sample collection. The vertical orientation of the strainer facilitated vertical integration of sample collection, which is very important where oil and grease and other floating contaminants may be present in the runoff.

An automated sampler with an integrated flowmeter was installed at each weir. Water depth was measured 3-6 inches upstream of each weir to avoid measuring in the drawdown of the weir. The flowmeter was programmed to continuously convert the depth to discharge using the standard equation for each weir. The flowmeter was used to control sample collection such that flow-proportional samples were collected by the automated sampler. Sampler pacing was set to collect samples as frequently as practical so that the rising and falling limbs of the hydrographs would be adequately represented in the composite sample for each storm.

Individual flow-proportional samples were place in 12 glass jars, which were inside a continuously refrigerated space. Continuous refrigeration (<4 deg. C) and glass sampler containers were used in accordance with EPA (EPA, 1992) and Standard Methods (APHA et al., 1995) recommendations on handling and preserving samples in the field. As soon as possible after each monitored storm event, equal volume aliquots from each sampler jar were poured into appropriate pre-acidified laboratory containers and shipped overnight on ice to the contracted certified lab for analysis. Turbidity and pH measurements were conducted at the NCSU Water Quality Group as soon as possible after recovery of samples from the sampler.

Rainfall amounts were continuously recorded via an 8-inch diameter tipping bucket recording raingage. The originally installed raingage was eventually replaced after it quit working for a couple of storms. A plastic nonrecording raingage was also installed at the site as a backup.

Results of Monitoring: Summaries of field and laboratory analysis results for inflow and outflow are shown in Table 12. Rainfall accumulations for the 14 storm events ranged from 0.29-2.84 in. with an average of 1.16 in. This range of storms should represent most storms occurring during a year. Inflow and outflow for the events was also considerable ranging from 4,000-95,800 gal. with averages of 27,200 and 33,200 gal., respectively. For 10 of the 14 storm events outflow from the site was greater than inflow. Generally, storms occurring during wet antecedent soil conditions or storms with high rainfall accumulation produced greater volume of outflow compared to inflow. The greater volume of outflow was generally attributed to an extended period of moderate flow compared to greater and shorter periods of inflow (figure 11). This indicates that the outflow could be attributed to near surface ground water entering the outflow drain pipe or, possibly but less likely, runoff entering the swale between the inflow and outflow monitoring stations. The fact that the bottom of the swale was at about river level meant that the ground water table was close to the elevation of the drain pipe even in dry conditions. In addition, outflow continued at low flow rates for several days after the storm event, which is characteristic of ground water input. The total volume of ground water inflow for each event was impossible to quantify without an extensive investigation of the subsurface flow regime. Peak inflow rates were greater than outflow for all 14 storms, which was expected given the relatively high storage capacity of the swale compared to the total volume of runoff for each event.

Table 12. Summary Statistics for Inflow and Outflow for the Enhanced Swale.

Parameter	Units	Inflow			Outflow		
		Mean	Median	Range	Mean	Median	Range
Automated rainfall	in	1.16	0.90	0.29 – 2.84	NA	NA	NA
Runoff (1,000)	gal	27.2	17.2	5.5 – 84.6	33.2	23.4	4.0 – 95.8
Peak discharge rate	gpm	465	480	80 – 1250	253	260	63 - 550
pH	pH	7.4	7.5	6.7 - 7.6	7.7	7.7	7.4 – 7.8
Turbidity	ntu	14	10	4 - 34	13	13	4 - 20
Metals							
Cadmium	ug/L	ND	ND	ND	ND	ND	ND
Chromium	ug/L	ND	ND	ND	ND	ND	ND
Copper	ug/L	ND	ND	ND	ND	ND	ND
Lead	ug/L	ND	ND	ND	ND	ND	ND
Nickel	ug/L	ND	ND	ND	ND	ND	ND
Zinc	ug/L	32.2	36.0	**8.5** – 52.0	ND	ND	ND
Inorganic Non Metals							
Chloride	mg/L	1.13	1.00	**1**-2	3.91	3.70	1.0 - 7.6
Nitrogen, Ammonia	mg/L	0.22	0.21	**0.02** – 0.49	0.14	0.09	0.06 – 0.49
Nitrogen, NO_3+NO_2	mg/L	0.30	0.23	0.07 - 0.49	0.26	0.16	0.03 – 1.20
Nitrogen, TKN	mg/L	0.74	0.65	0.25- 1.7	0.55	0.50	**0.14** – 1.2
Nitrogen, Total	mg/L	1.04	0.96	0.36 – 2.16	0.81	0.74	0.25 – 1.70
Phosphorus, Diss.	mg/L	0.01	0.01	**0.01**- 0.02	0.11	0.08	0.04 – 0.44
Phosphorus, Total	mg/L	0.10	0.10	0.03 – 0.22	0.19	0.15	0.09 – 0.71
Residue, Suspended	mg/L	24	18	9 – 67	5	**3**	**3** – 12
Residue, Total	mg/L	61	60	**19** – 119	130	125	76 - 248
Aggregate Organics							
COD	mg/L	21.2	21.2	**7**– 35.6	24.9	24.9	**7**– 43.1
Oil and Grease	mg/L	5.3	5.3	**2.5**-7.6	**2.5**	**2.5**	**2.5** – 7.6
Surfactant	mg/L	0.12	0.1	**0.05** – 0.2	0.16	0.2	0.10 – 0.20

The range of pH levels for storm events was near neutral with little change from inflow to outflow. The range of turbidity levels was low with the highest inflow and outflow values being only 34 and 20 ntu, which is considerable less than the state standard for receiving waters of 50 ntu. As expected with such low levels, there was little difference between turbidities of inflow and outflow samples.

Inflow and outflow samples from 3 storms were analyzed for metals. Only Zn was found at concentrations greater than the MDL and that in only inflow samples from 2 of the events. Hence, concentrations of metals in the runoff from these road sections were low.

Concentrations of inorganic nonmetals in inflow and outflow ranged considerably with some being greater in inflow and some in outflow. Concentrations of chloride (Table 12) were generally greater in outflow compared to inflow; however, both were much less than the NC standard (230 mg/L) for receiving waters. The increase in chloride concentrations might be attributed to the brackish water from the nearby Trent River intruding on the near surface ground water that flowed into the drain pipe. Mean concentrations of nitrogen forms in the outflow were also low being less than the corresponding concentrations for national and NC highways (Table 4) and urban runoff as documented during the NURP study (Table 5). Concentrations of dissolved and total phosphorus were greater in outflow compared to inflow samples for 12 of the 14 storms. However, concentrations of dissolved P in outflow were still less than those for national and NC highways (Table 4) and the TP was 42% less than the mean for the NURP study (Table 5).

Concentrations of TSS were generally quite low for all samples, but were greater in inflow compared to outflow for all 14 storms. Concentrations of TSS in outflow were less than the MDL for 9 of 14 samples indicating that a greater concentration, to an extent, of TSS in inflow would likely have made the reductions greater. Concentrations of TSS in outflow were far less than reported highway (Table 4) or urban runoff (Table 5) monitoring data. Unlike TSS, levels of TS in outflow were considerably greater than inflow for 13 of the 14 storms. This could be attributed to many factors including the influx of brackish near-surface ground water from the nearby Trent River.

Aggregate organics including COD, oil and grease, and surfactant were all relatively low and thus only 3 samples were analyzed for each. The one storm (6/11/04) that had significant COD levels in inflow (35.6 mg/L) had a slightly greater concentration in outflow (43.1 mg/L), which indicates that the swale may not be effective at reducing COD concentrations. Similar results were observed for surfactant, in that, the outflow concentrations were slightly greater than inflow for 2 of the 3 storm samples.

The samples from three storms were analyzed for 67 semi-volatile organic compounds. Only phenol was found at a concentration greater than the corresponding MDL and that in only one (for the 5/3/04 storm) of the three inflow samples. Outflow samples had no detections of any of the compounds. While the fact that this section of road and bridge were relatively new and that they were concrete may have been some of the reason for the absence of these compounds, it appears that the roads are not a significant source of these compounds. Further, the inflow sample that contained phenol was collected 3-4 weeks after a small pile of what appeared to be spilled concrete was observed in the intersection that drains to the inflow pipe.

Pollutant Reduction Efficiency: The pollutant reduction efficiencies for the enhanced swale are shown in Table 13. The reductions in peak flow rates averaged 44%, which was statistically significant. Outflow runoff volume exceeded inflow by an average of 21%, which was also statistically significant. The increase in runoff volume could be attributed to a combination of near surface ground water influx into the underground drain in the swale or influx of runoff from the highway along the swale. Increases in pH and turbidity from inflow to outflow were variable, but on average were small and not statistically significant.

Of the 6 metals, only Zn was found at concentrations greater than the MDL; therefore, it was the only with a computed reduction efficiency. While only 3 samples were analyzed for metals, the 58% and 67% reductions in concentrations and loads indicates that the swale would be effective at reducing metals concentrations in inflow.

Reduction efficiencies of the nine inorganic nonmetals varied widely. Chloride concentrations and loads increased more than 188% from inflow to outflow. The increased chloride likely came from ground water influx into the drain pipe. Statistical analysis of the results was not conducted due the relatively few data. Storm by storm reductions concentrations and loads of NH_3-N, NO_3+NO_2-N, TKN, and TN varied widely, but on average were mildly positive. The reduction in nitrogen from inflow to outflow was likely caused by a combination of factors including an influx of ground water with relatively low nitrogen levels, denitrification in the regularly saturated soil, and uptake by the grass. The relatively large increases in both dissolved and total phosphorus were unexpected and unexplainable. Possible sources of phosphorus could be topsoil or fertilizer, but the use and extent of these on the site are unknown. Concentrations of nitrogen and phosphorus in near surface groundwater are unknown, but the median concentration of TP and NO_3-N for the Trent River at Pollocksville, NC for 1996-2000 was 0.13 mg/L and 0.04 mg/L, respectively (NC DENR, 2001). Given that the median concentration of TP and NO_3-N in inflow was 0.10 mg/L and 0.30 mg/L, influx of water from the nearby river would tend to increase the phosphorus concentration of the outflow, while decreasing the concentration of NO_3-N.

Reductions in TSS concentrations and loads were positive for every storm averaging 77 and 74%. These reduction efficiencies were relatively consistent and statistically significant indicating a real treatment effect of the swale. The fact that 9 of the 14 outflow samples had concentrations less than the MDL indicates that the efficiency of the swale would have been higher, to an extent, with a greater inflow of TSS.

Reductions in aggregate organics were impossible to determine with certainty given that only three samples were analyzed, but the limited data does appear to show that the swale would not be effective at reducing the concentrations or loads of COD or surfactant.

Because only one (phenol) of the 67 semi-volatile organic compounds was found at levels greater than its MDL, and that in only one of the three inflow samples analyzed, the pollutant reduction efficiency for these compounds could not be determined.

The TSS and Zn removal efficiencies of the swale were near the high end of the range of reported removal efficiencies for wet ponds, wetlands, sand filters, and bioretention areas, while the efficiencies for NO_{3+2}-N and TN were near the low end of their respective ranges (Wossink and Hunt, 2003). The TP removal efficiency was much less than for the other four BMPs. The low nitrogen and negative phosphorus efficiencies were likely the result of an influx of near-surface ground water into the underdrain as evidenced by greater outflow than inflow volume. Thus, the efficiency results were mixed when compared to other stormwater BMPs.

Annual pollutant export from this site could not be determined because the size of the drainage area is unknown. As reported previously a drain on the bridge deck was only partially stopped, which if completely stopped would significantly increase the drainage area to the swale. The variable nature of this drain makes determining the drainage area, and hence the export rates, impossible.

Table 13. Summary Statistics for Reduction Efficiency of the Enhanced Roadside Swale.

Parameter	Data	Concentration		Loads		Annual
	Points	Range	Mean	Range	Overall	Export
	no.	%	%	%	%	kg/ha-yr
Peak flow	14	0 to 78	44[1]	-	-	-
Runoff/discharge	14	-111 to 46	-21[1]	-111 to 46	-22[1]	-
pH	11	-16 to 2	-4	-	-	-
Turbidity	14	-100 to 59	-9	-	-	-
Metals						
Cadmium	3	ND	ND	ND	ND	NA
Chromium	3	ND	ND	ND	ND	NA
Copper	3	ND	ND	ND	ND	NA
Lead	3	ND	ND	ND	ND	NA
Nickel	3	ND	ND	ND	ND	NA
Zinc	3	0 to 84	53	50 to 79	67	NA
Inorganic Non metals						
Chloride	7	-660 to 0	-242	-905 to -0.3	-188	NA
Nitrogen, Ammonia	14	-320 to 82	20[1]	-432 to 82	11	NA
Nitrogen, NO_3+NO_2	14	-163 to 81	8	-455 to 90	5	NA
Nitrogen, TKN	13	-50 to 71	14	-88 to 68	6	NA
Nitrogen, Total	13	-29 to 64	17[1]	-82 to 71	6	NA
Phosphorus, Diss.	14	-8700 to -117	-1640[1]	-11000 to -74	-1239[1]	NA
Phosphorus, Total	14	-546 to 27	-123[1]	-707 to 46	-152[1]	NA
Residue, Suspended	14	47 to 93	77[1]	32 to 95	74[1]	NA
Residue, Total	14	-642 to 36	-176[1]	-981 to 12	-193[1]	NA
Aggregate Organics						
COD	3	-21 to 0	-7	-156 to 0	-96	NA
Oil and Grease	3	ND	ND	ND	ND	NA
Surfactant	3	-260 to 50	-103	-111 to 63	-84	NA

[1] indicates statistical significance at the 0.05 level using the paired t test.

Site Specific Considerations: The low levels of solids and some nutrients in the inflow likely reduced the efficiency of the swale. Near surface groundwater influx to the underdrain of the swale may have affected the efficiencies. Evidence for influx was that the TS concentrations and loads increased from inflow to outflow by more than 175%, while the TSS concentrations and loads decreased. This means that the increase in TS must be the result of a large increase in dissolved solids, since total solids is the sum of dissolved solids and TSS. This suggests that near-surface ground water that flowed into the drain pipe was high in dissolved solids, which is reasonable given that the Trent River is near the site and it has higher dissolved solids than surface runoff. Influx from the Trent river would also help explain the increased phosphorus in the outflow as the river water has a higher concentration of phosphorus.

Site Specific Conclusions: This enhanced roadside swale BMP was somewhat efficient at reducing both concentrations and loads of nitrogen and very efficient at reducing incoming TSS (Table 13). From the data the following conclusions can be drawn:

1 The enhanced roadside swale reduced TSS concentrations and loads by 77 and 74%, respectively. The lower efficiency of load reduction compared to concentration was the result of a 22% increase in outflow versus inflow.
2 Negative phosphorus and low nitrogen removal efficiencies likely resulted from the influx of near surface ground water into the underdrain of the swale.
3 While concentrations of metals in most samples were less than or near the MDL, the 67% removal efficiency documented for Zn indicates that if there were metals in the inflow the swale would be effective at removing them.

Site Specific Recommendations: From a functional standpoint the BMP appeared to work well; hence, the following recommendations focus on monitoring considerations:

1. The reduction efficiency of TSS and possibly nitrogen forms would likely have been higher if the concentrations in the inflow were somewhat higher and if ground water influx was eliminated. The monitoring evaluation of the swale would be made more definitive by selecting a location that was free from the influence of a nearby river.
2. For sites where groundwater tables are high, groundwater monitoring must be conducted.

Bioretention Area (Division 12)

Description of Site: The Division 12 bioretention area is located in the eastbound rest area off I40 in Catawba county (N35 44; W 81 6). Characteristics of the drainage area and the bioretention area are shown in Table 14 and figures 12 and 13. The area is composed of a truck parking area, which is totally impervious, and the area around it, which is mostly vegetated. The parking area appears to have considerable truck traffic (figure 14), although the number of trucks using the lot was unknown. Runoff from the truck parking area flows through an 18 in. concrete storm drain, an emergency spill basin, and eventually into a concrete junction box (figure 14). Runoff water has 2 ways of exiting the junction box depending on the inflow rate. At low flows, all of the water leaves through an 8 in. diameter PVC pipe that carries water to the inflow of the bioretention area. At high inflow rates, water leaves the box via the PVC pipe and another storm drain with its invert elevation 8-15 inches higher than that of the PVC pipe. Thus, if the inflow rate is high enough some of the runoff can bypass the inflow to the bioretention area. Stormwater is conveyed by the aforementioned PVC pipe to the rock-lined forebay of the bioretention area. Runoff water then ponds 2-3 ft deep before passing into the bioretention area (figure 15). Standing water was often observed in the forebay for extended periods of time.

Table 14. Characteristics of the Drainage Area to the Div 12 Bioretention Area.

Item	Description
Drainage area	1.32 acres
Imperviousness of DA	46%
2003 ADT of I40 rest area	37,000
Pavement type	Asphalt
Soil composition	Aged Hardwood Mulch over Sand & Soil Mixture
Vegetation	Switchgrass, Soft Rush, Ironweed, Joe Pye weed, etc.

The bioretention area was constructed in the spring of 2003 with a design water quality volume for the area was 2248 ft^2, which is the volume of runoff predicted for a 1 inch storm event. The treatment area is about 100 ft long and 44 ft wide (figure 12). The treatment column consists of 2-3 inches of mulch, 2.6 ft of engineered soil material, a filter fabric layer, and a layer of wash stone over a 6 in. perforated underdrain. A sample of the soil material from several locations near the surface was collected in the spring of 2005 and analyzed. The soil sample had a pH of 6.5, and a phosphorus index (PI) of 30, which was similar to samples collected by DOT (pH=6.0 & 6.4; PI=36 & 22). The relatively low phosphorus index indicated that the soil material should be effective at retaining the phosphorus in the inflow.

Various water tolerant plants were growing on the surface of the area at the start of monitoring in July, 2003. By May, 2004 there were still plants in the bioretention cell, but most did not appear to be thriving (figure 15). Daylillies were planted on the mulched banks of the area to provide a stable and aesthetically pleasing surrounding area (figure 15). Filtered water from the underdrain system collects in an outflow concrete riser and exits the riser via a 12 in. concrete pipe.

Description of Monitoring: A rectangular-shaped plywood box was constructed and fitted around the inflow pipe. A 1.5 ft sharp-crested, rectangular weir was installed on one side of the box to facilitate discharge monitoring. The weir was installed such that its crest was at least 9 inches above the bottom of the box so that water will pond in the box and overflow the weir without any significant velocity. In this way their will be relatively tranquil water just upstream of the weir and free flow of water over the weir. These two elements are essential for accurate measurement of discharge past the weir. A stainless steel intake strainer attached to the sampler intake line was fastened vertically to the inside of the box at about the level of the weir crest for sample collection.

A 120 degree v-notch weir was installed in the 12 inch diameter outlet culvert to measure outflow. The outside edge of the weir plate was cut to fit over the upper lip of the concrete pipe and the notch was cut to be about 1.5 inches above the bottom of the pipe to facilitate free flow over the weir. This weir was replaced by a larger 120 deg v-notch weir, which extended across the manhole when outflow rates increased to greater than 90 gpm. A stainless steel intake strainer attached to the sampler intake line was fastened vertically just upstream of the weir at about the level of the weir notch for sample collection. The vertical orientation of the strainer facilitated vertical integration of sample collection, which is very important where oil and grease and other floating contaminants may be present in the runoff.

The top of the monitoring manhole was constructed at an elevation higher than the invert of an overflow drain pipe installed in the berm of the bioretention area. This configuration prevented water from flowing over the top of the manhole, which had a metal grate over it, and falling onto the weir; thus, the outflow measured drainage water only. During the course of the monitoring, there was no observed evidence of a significant amount of water flowing through the overflow drain and thereby bypassing the outflow monitoring station.

An automated sampler with an integrated flowmeter was installed at each weir. The flowmeter used the bubbler method to continuously measure water depth at a point approximately 1-2 ft upstream of the weir crest. Water depth was measured upstream to avoid measuring in the drawdown of the weir. The flowmeter measured depth of water over the weir and continuously converted the depth to discharge using the standard equation for each weir. The flowmeter was used to control sample collection such that flow-proportional samples were collected by the automated sampler.

Refrigerated samplers were programmed to collect flow-weighted samples and place each sample successively in 12 glass jars. Continuous refrigeration (<4 deg. C) and glass sampler containers were used in accordance with EPA (EPA, 1992) and Standard Methods (APHA et al., 1995) recommendations on handling and preserving samples in the field. As soon as possible after each monitored storm vent, aliquots from each sampler jar were poured into appropriate laboratory containers and shipped overnight on ice to the contracted certified lab for analysis. Turbidity and pH measurements were conducted at the NCSU Water Quality Group as soon as possible after recovery of samples from the sampler.

Rainfall amounts were continuously recorded via an 8-inch tipping bucket recording raingage. A plastic nonrecording raingage was also installed at the site.

In November, an automated sampler was installed at the upstream end of the spill basin, which is upstream of the inflow pipe to the bioretention area. The sampler did not have a refrigerator as this site did not have AC power, but was powered by a battery. The sampler was connected via a 200 ft cable to the inflow sampler and programmed that it would sample at the same time as the inflow sampler. Thus, both machines collected flow-proportional samples based on the inflow to the bioretention area. The intake for the sampler was attached to a stake and secure near the outlet of the storm drain which emptied into the spill basin. The main reason this location was chosen was that the runoff should be well-mixed given the turbulence created by the water leaving the drain and it is at the upstream end of the basin.

Results of Monitoring: Field data and laboratory analysis results for inflow and outflow samples are shown in Table 15. Cumulative rainfall varied considerably for the 15 storm events monitored ranging from 0.2 to 1.85 inches thereby providing data for a variety of conditions. The average outflow was about 16% greater than inflow for the 15 storm events. This difference may be attributed to the influx of surface and ground water from the area immediately around the bioretention cell contributing to outflow. The bioretention area was constructed at a lower elevation than the surrounding area making its drain pipes at least 10 ft deeper than the surrounding ground surface; therefore ground water could easily be entering the bioretention area, especially during winter months when ground water levels rise. Further, for the 9 monitored storms occurring between June and October, outflow was 12% less than inflow, but for the 6 monitored storms occurring between November and April, outflow was 58% greater than inflow. In addition, precipitation falling directly on the bioretention cell and surrounding area, which was estimated at 0.19 ac, would contribute water to the outflow, but not the inflow. The peak discharge was generally greater for inflow compared to outflow indicating that the bioretention area might be effective for flood control purposes.

The average pH of inflow and outflow were nearly the same and both were only slightly acidic; thus, the pH of the runoff was not a problem. The turbidity of outflow was slightly greater than inflow, but both were considerably less than the 50 ntu standard for all storm events.

Samples from three storms were analyzed for metals. Cr and Pb were found at low concentrations in one of the inflow samples whereas Zn was found in all three inflow samples. Only Zn was found in the three outflow samples, but at concentrations less than the NC receiving water standard of 50 ug/l. This indicates that concentrations of metals were not a serious concern.

Concentrations of inorganic nonmetals varied widely. Mean concentrations of chloride were greater in outflow compared to inflow, but both were less than the NC standard for 4 of the 5 storms monitored. The outflow for the storm occurring on 12/11/03 had a concentration of 270 mg/L, which may have resulted from some de-icing salt being applied or spilled in the area. The average ammonia nitrogen concentration of inflow was somewhat elevated being greater than levels in runoff from NC industrial sites (Table 5); however, the mean concentration in outflow was considerable less. Concentrations of nitrate nitrogen were just the opposite with levels in inflow relatively low and concentrations in outflow greater than those for NC industrial sites (Table 5). Concentrations of total Kjeldahl and total nitrogen were similar to those from NC industrial sites (Table). The total Kjeldahl nitrogen concentration was greater than those from highways (Table 4) as would be expected considering that there was grass, ornamental plants, and possibly pet waste in and around this site, which would be absent from most highways. Dissolved and total phosphorus concentrations were nearly equal in inflow and outflow samples and the concentration in outflow was less than the concentrations from urban runoff or NC industrial sites (Table 5). Dissolved phosphorus concentrations were similar to those reported for studies involving NC and national highways (Table 4). Concentrations of suspended residue in inflow and outflow were less than for highways (Table 4), urban and industrial runoff (Table 5). Levels of total residue were considerably greater than suspended residue, but still much less than in runoff from NC industrial sites (Table 5).

Mean concentrations of aggregate organics for the three samples analyzed were relatively low. Level of COD was less than urban stormwater and runoff from NC industrial sites (Table 5) and in the range of runoff from highways (Table 4). Concentrations of oil and grease were less than the MDL and concentrations of surfactant were relatively low.

Table 15. Summary Statistics for Inflow and Outflow for the Div 12 Bioretention Area.

Parameter	Units	Inflow			Outflow		
		Mean	Median	Range	Mean	Median	Range
Automated rainfall	in	0.88	0.54	0.18-1.85	NA	NA	NA
Runoff (1,000)	gal	21.0	15.6	7.3-50	22.6	17.4	7-38
Peak discharge rate	gpm	310	330	85-450	114	70	50-450
pH	pH	6.5	6.5	6.2-7.0	6.6	6.6	6.2-6.9
Turbidity	ntu	17	13	6-26	17	17	4-37
Metals							
Cadmium	ug/L	ND	ND	ND	ND	ND	ND
Chromium	ug/L	4	ND	<5-8	ND	ND	ND
Copper	ug/L	ND	ND	ND	ND	ND	ND
Lead	ug/L	4	ND	<5-7	ND	ND	ND
Nickel	ug/L	ND	ND	ND	ND	ND	ND
Zinc	ug/L	233	200	170 –330	35.7	40	20-47
Inorganic Non Metals							
Chloride	mg/L	14.8	2.9	2.1-51	56.8	4.3	<2-270
Nitrogen, Ammonia	mg/L	0.89	0.9	0.5-1.3	0.49	0.5	0.1-0.9
Nitrogen, NO_3+NO_2	mg/L	0.40	0.4	0.2-0.7	1.27	1.3	0.5-2.3
Nitrogen, TKN	mg/L	3.38	2.8	2.2-6.5	2.35	1.8	1.0-5.1
Nitrogen, Total	mg/L	3.78	3.3	2.4-7.2	3.62	3.4	2.6-6.1
Phosphorus, Diss.	mg/L	0.27	0.3	0.2-0.4	0.10	0.1	<0.02-0.4
Phosphorus, Total	mg/L	0.39	0.3	0.3-0.6	0.23	0.2	0.1-0.4
Residue, Suspended	mg/L	29	30	<5-70	7	3	<5-22
Residue, Total	mg/L	72	68	<38-168	152	105	51-544
Aggregate Organics							

COD	mg/L	50	43	39-68	20	21	17-22
Oil and Grease	mg/L	**ND**	NA	<6	**ND**	NA	<6
Surfactant	mg/L	0.3	NA	0.3	0.2	0.2	0.1-0.3

Runoff from the truck parking area was monitored upstream of the spill basin to characterize the effect of the spill basin on water quality. Table 16 contains data from the spill basin and inflow sampler for two storm events. The last column contains the average of the differences between spill basin and inflow for the two events. As shown pH and turbidity for the 2 sites are nearly the same. For chloride, there was no difference between concentrations at the spill basin and the inflow. For nitrogen and phosphorus compounds and total residue, average concentrations were greater at the inflow sampler compared to the upstream end of the spill basin, indicating no treatment effect by the spill basin. For some of the compounds, the concentration at the inflow sampler was less for one storm, but not both. Concentrations of suspended residue decreased from the spill basin to the bioretention inflow sampler for the first event and increased for the second. This was expected given that there are no significant physical or chemical processes occurring in the spill basin to reduce pollutants over time, since the runoff enters the basin and quickly passes through. There is only limited or no permanent storage capacity in the basin when the emergency valve is open. Possibly for small storms with little runoff some sediment and other pollutant deposition occurs in the basin, but the deposited material is washed through during subsequent storm(s). In addition, pollutants may become attached to rock rip-rap during the first storm or 2 thereby discoloring the rock, but after that the capacity to retain pollutants appears to be minimal.

Table 16. Comparison Between the Spill Basin and Bioretention Inflow.

Parameter	Units	Spill Basin		Inflow		Ave
		11/21/03	12/11/03	11/21/03	12/11/03	Difference
						%
Automated rainfall	in	0.85	0.82	0.85	0.82	
pH	pH	6.5	6.8	6.5	6.7	1.0
Turbidity	ntu	10	30	8	31	8.3
Chloride	mg/L	3.4	NA	3.4	51.1	0
Nitrogen, Ammonia	mg/L	0.52	0.44	0.74	0.52	-13.2
Nitrogen, NO_{2+3}	mg/L	0.20	0.19	0.20	0.24	-22.3
Nitrogen, TKN	mg/L	2.60	1.50	2.20	2.40	-21.0
Nitrogen, Total	mg/L	2.80	1.69	2.40	2.64	-49.9
Phosphorus, Dissolved	mg/L	0.27	0.13	0.29	0.25	-26.2
Phosphorus, Total	mg/L	0.38	0.27	0.34	0.44	30.1
Residue, Suspended	mg/L	32	53	**3**	70	-7.3
Residue,Total	mg/L	53	94	**19**	168	-30.2

Pollutant Reduction Efficiency: Runoff monitoring was conducted during 15 storm events; however, the summary data in Table 17 were computed from only 13 events. Data from the storm on 11/21/03 was not included due to a structural problem with the bioretention area and data from the storm of 4/12/04 was not included due to recent planting activity in the bioretention area.

Overall the bioretention area BMP's efficiency at reducing pollutant levels and loads was mixed. On average the BMP reduced peak discharge considerably while the average runoff volume increased (Table 17). As described above the increase in runoff volume was attributed to groundwater influx from the surrounding area. The pH and turbidity of inflow was about the same as outflow. It is important to note that levels of pH and turbidity in inflow were low, which means that very little treatment was necessary and, in the case of turbidity, maybe even possible.

In regard to metals, analysis of samples from three storms documented that the bioretention area reduced Cr, Pb, and Zn concentrations in inflow from 64 to 82% (Table 17). The Cr and Pb reductions were based on only 1 storm as concentrations in the other 2 samples were less than the MDL. Concentrations of Cd, Cu, and Ni in all samples were less than the MDL. This limited data indicates that the bioretention area can potentially be efficient at reducing incoming levels of metals, especially those metals that are primarily associated with solids.

For inorganic nonmetals the pollutant reduction efficiencies were mixed. Chloride levels increased considerably from inflow to outflow, while ammonia nitrogen levels decreased. Nitrate+nitrite nitrogen levels and loads increased while total Kjeldahl nitrogen levels and loads decreased from inflow to outflow. Overall the total nitrogen load from inflow to outflow decreased. Concentrations and loads of dissolved and total phosphorus and suspended residue decreased from inflow to outflow. The fact that suspended residue and dissolved phosphorus decreased from inflow to outflow for every storm and total phosphorus decreased for all but one storm, lends strong evidence for a significant treatment effect for these pollutants. Total residue concentrations and loads increased from inflow to outflow indicating that the bioretention area supplied dissolved solids to the runoff, because the suspended solids decreased.

Several samples were analyzed for aggregate organics. Results from three storm samples documented considerable reductions in COD concentrations and loads. Concentrations of oil and grease were less than the MDL in both inflow and outflow. One inflow and outflow sample had concentrations of surfactant greater the MDL, but both concentrations were the same. Hence, it appears from the COD data that the bioretention area has the potential to reduce aggregate organics, but more data are needed to confirm this.

The semi-volatile organic compounds Bis(2-ethylhexyl) Phthalate and phenol were found in the inflow sample of the 7/24/03 storm, but none was found in the outflow sample. Samples from the 10/9/03 storm were also analyzed for these compounds, but none were detected. Hence, the limited data indicates that the bioretention area may be efficient at reducing semi-volatile organic compounds in runoff, but there was not enough data to establish this with any certainty.

While there was no efficiency reported for TSS in the literature, the Zn removal efficiency of this BMP was near the reported median efficiency reported in the literature for bioretention areas (Wossink and Hunt, 2003). The TP, NO_{3+2}-N, and TN efficiencies for this BMP were considerably less than those reported in the literature. The lower efficiencies may have resulted from some nitrogen or phosphorus being released from the hardwood mulch applied to the surface of the treatment area or fertilizer being applied to the banks of the treatment area to facilitate the growth of the flowers planted along the banks. Nitrogen and phosphorus input from both of these sources would not have been accounted for by inflow sampling. The relatively recent construction of the BMP and the replanting that occurred in April, 2004 may have contributed to the release of nitrogen and phosphorus into the outflow. Monitoring data from two bioretention areas in Connecticut collected by Dietz and Clausen (2005) documented that the phosphorus concentration of the outflow from the underdrain decreased exponentially from more than twice the inflow initially to about the same as the inflow during a year of monitoring. They surmised that the disturbance of the soil at the beginning of monitoring caused the release of phosphorus to the underdrain. This indicates that nitrogen and phosphorus leaching during the first year after disturbance may be considerably greater than subsequent years.

Table 17. Summary Statistics for Reduction Efficiency of the Div. 12 Bioretention Area.

Parameter	Data	Concentration		Loads		Annual
	Points	Range	Mean	Range	Overall	Export
	no.	%	%	%	%	kg/ha-yr
Peak flow	13	-5 to 88	64	-	-	-
Runoff/discharge	13	-82 to 77	-16	-	-	-
pH	8	-12 to 3.3	-2	-	-	-
Turbidity	13	-83 to 37	-7	-	-	-
Metals						
Cadmium	3	ND	ND	ND	ND	NA
Chromium	3	69	69	70	70	NA
Copper	3	ND	ND	ND	ND	NA
Lead	3	64	64	66	66	NA
Nickel	3	ND	ND	ND	ND	NA
Zinc	3	72 to 94	82	77 to 94	87	NA
Inorganic Non metals						
Chloride	3	-428 to -63	-158	-799 to -63	-767	NA
Nitrogen, Ammonia	13	-39 to 87	42[1]	-136 to 90	23[1]	12.2
Nitrogen, NO_3+NO_2	13	-384 to -57	-257[1]	-766 to -26	-254[1]	5.4
Nitrogen, TKN	13	-21 to 71	28[1]	-106 to 63	11[1]	46.3
Nitrogen, Total	13	-48 to 46	-3	-30 to 36	-17	51.7
Phosphorus, Diss.	13	0 to 89	62[1]	14 to 91	57[1]	3.7
Phosphorus, Total	13	-56 to 80	44[1]	-25 to 81	37[1]	5.4
Residue, Suspended	13	43 to 94	79[1]	44 to 95	76[1]	390
Residue, Total	13	-336 to 8	-95[1]	-451 to 11	-198[1]	985
Aggregate Organics						
COD	3	48 to 75	57	41 to 76	57	NA
Oil and Grease	3	ND	ND	ND	ND	NA
Surfactant	1	0	0	0	0	NA

[1] indicates statistical significance at the 0.05 level using the paired t test.

An estimate of annual export from the contributing area to the bioretention area is shown in column 7 of Table 17. This export rates were computed for the period of August 2003 through July 2004 using the average concentration for each pollutant from the monitored storms and the storm event discharge. Event runoff for storms not monitored was computed using the following equation:

$$\text{Event Runoff (gal)} = \text{rainfall (in.)} \times 41{,}651 - 1{,}220 \qquad r^2 = 0.78$$

which was developed with data from 22 storm events in which both rainfall and runoff were monitored. The ammonia and total Kjeldahl nitrogen exports were much greater and the NO_{2+3}-N export was slightly greater than monitored urban areas in Cary, NC (Line et al., 2002). The source of the organic nitrogen is unknown, but seemed to be consistent across the 15 samples collected. The total phosphorus export was also greater than that from urban areas in Cary, NC (Line et al., 2002). The export of TSS was similar to a residential subdivision in Cary, NC and near the lower end of the range of TSS export from various land uses in Mecklenburg County (Bales et al., 1999). Additionally, the annual TSS loads for highways in the National Database ranges from 314 to 11,850 kg/ha; hence, annual TSS export was near the lower end of what would be expected from highways.

Site Specific Considerations: Three site specific factors likely influenced the pollutant removal efficiencies of this BMP that were specific to this location. The first was that the bioretention area was built in an area that was significantly lower in elevation than the surrounding area, which increased the probability of groundwater influx into the underdrains. The BMP also had a lot of daylilies planted around it, which increased the probability that nitrogen and phosphorus would be introduced to the BMP as a result of the flower planting and not runoff from the parking area. Along with this is the realization that the vegetation planted in the treatment area did not thrive and, in fact, had to be replanted. Thriving vegetation can significantly increase nitrogen, phosphorus, and water uptake, which can enhance the efficiency of the BMP. The third factor was that the BMP was relatively new, which, as discussed above, increased the possibility that phosphorus, and possibly, nitrogen was leached from the soil material of the bioretention area itself.

Site Specific Conclusions: This bioretention area BMP was very efficient at reducing both concentrations and loads of incoming phosphorus and TSS (Table 17). The reduction efficiency of TSS and possibly nitrogen and phosphorus forms would likely have been higher if the concentrations in the inflow were somewhat higher and if ground water influx from the surrounding area was eliminated. From the data the following conclusions can be drawn:

1. Monitoring results show that bioretention area reduced TSS concentrations and loads by 79 and 76%, respectively. Both reductions were statistically significant.
2. Given the small amount of sediment entering the BMP and the size and effectiveness of the bioretention area, the size of the forebay could likely be reduced, but it does provide storage if sand or other material is washed into the BMP.
3. The efficiency of the bioretention area at reducing nitrogen was mixed with considerably negative reductions for NO_{2+3}-N and moderately positive reductions for NH_3-N and TKN. The increase in NO_{2+3}-N may have been the result of groundwater influx; however, other unpublished studies conducted by NCSU have indicated increased NO_{2+3}-N concentrations in outflow from bioretention areas. Research into the effect of elevating the underdrain to provide a saturated soil layer which will promote denitrification and a corresponding reduction in NO_{2+3}-N levels is continuing.
4. Dissolved and total phosphorus concentration and load reductions were significant ranging from 44 to 69%.
5. Metals concentrations and loads were reduced from 64 to 87% during three monitored storm events indicating effective removal of metals.
6. The BMP reduced peak discharge considerably, but overall runoff volume increased due possibly to the influx of groundwater and rainfall falling on the BMP itself. Further, for the 9 monitored storms occurring between June and October when groundwater levels are often low, outflow was 12% less than inflow, but for the 6 monitored storms occurring between November and April, outflow was 58% greater than inflow.

Site Specific Recommendations: From a hydraulic standpoint the BMP appeared to work well; hence, the following recommendations focus on monitoring considerations:

1. Groundwater monitoring should be included for sites like this where groundwater influx appears to be a good possibility such as was the case at this site. An impermeable layer could also be used to isolate the bioretention area for monitoring purposes.
2. A bioretention area should be in place for at least a year prior to the start of monitoring to allow for the initial flush of nutrients, particularly phosphorus, prior to the start of monitoring. Additionally, a soil(s) with a relatively low phosphorus content should be used to minimize the potential flush of phosphorus.
3. Careful selection and planting of vegetation should be conducted to enhance the efficiency of the bioretention area. Research on the best vegetation to use is continuing; thus, some trial and error is necessary.

Warsaw Bioretention Area (Division 3)

Description of Site: The Division 3 bioretention area was located in the I40 rest stop near Warsaw, NC (N34’ 59” W78’ 10”). The drainage area characteristics are shown in Table 18. The area was composed of an asphalt parking lot area, a small building, and several areas of grass and landscape plants (figure 16). The bioretention area has a small rock lined forebay (8 ft in diam.) where the runoff from the rest area enters via an 8 in. PVC pipe. Both surface and drainage water exits through a concrete riser with a grate inlet on the top (figure 17). An 18 in corrugated plastic pipe conveys water from the riser to a roadside ditch downstream of the bioretention area. A variety of water tolerant plants including Juncus were growing in the treatment area during the period of monitoring.

Table 18. Characteristics of the Drainage Area to the Div 3 Bioretention Area.

Item	Description
Drainage area	2.92 acres
Imperviousness of DA	23%
2003 ADT of I40 rest area	I-40 = 17,000 and NC 24 = 8,900
Pavement type	Asphalt parking, concrete sidewalks
Soil composition	Aged Hardwood Mulch over Sand & Soil Mixture
Vegetation	River Oats, Blue Flag Iris, Cord Grass, etc.

Description of Monitoring: A weir box was constructed and fitted over the PVC inflow pipe (figure 18). Water exited the box via a 1 ft sharp-crested rectangular weir. The crest of the weir was positioned about 3 inches above the bottom of the box to provide a ponded area upstream of the weir, which is required for accurate discharge measurements. The crest of the weir was at least a 1.5 ft above the bottom of the forebay, therefore, backwater from downstream of the weir should not be a problem. A stainless steel intake strainer attached to the sampler intake line was fastened vertically in the box such that the bottom of the strainer was 2 inches below the crest of the weir and the top extended to about 4 inches above the crest of the weir.

At the outlet, a 120 degree v-notch weir was installed over the end of the pipe leading away from the outlet riser (figure 18). The weir elevated the water level in the pipe at least 2 inches higher than the water level in the roadside ditch, which was expected to keep the water from the ditch from entering the pipe during relatively small to medium sized storm events and facilitate free flow of water over the weir during most events. The sampler bubble tube was attached to the upstream side of the weir where continuous water depth measurements were made. A stainless steel intake strainer attached to the sampler intake line was placed on the bottom of the pipe upstream of the weir. The intake strainer was not mounted vertically as the water was not deep enough and the effluent was unlikely to carry enough larger sediment so as to warrant the vertical integration of sample collection.

An automated sampler with an integrated flowmeter was installed at each weir. Water depth was measured upstream of each weir to avoid measuring in the drawdown of the weir and the standard weir equation was used to convert depth measurements to discharge. The flowmeter was used to control sample collection such that flow-proportional samples were collected by the automated sampler. Sampler pacing was set to collect samples as frequently as practical so that the rising and falling limbs of the hydrographs would be adequately represented in the composite sample sent for analysis.

Individual flow-proportional samples were place in a 2.5 gallon glass jar, which was inside a refrigerated space in the sampler. Continuous refrigeration (<4 deg. C) and glass sampler containers were used in accordance with EPA (EPA, 1992) and Standard Methods (APHA et al., 1995) recommendations on handling and preserving samples in the field. As soon as possible after each monitored storm event, aliquots from each sampler jar were poured into appropriate pre-acidified laboratory containers and shipped overnight on ice to the contracted certified lab for analysis. Turbidity and pH measurements were conducted at the NCSU Water Quality Group as soon as possible after recovery of samples from the sampler.

Rainfall amounts were continuously recorded via an 8-inch diameter tipping bucket recording raingage. A plastic nonrecording raingage was also installed at the site as a backup.

Results of Monitoring: Monitoring results for the Div 3 bioretention area are shown in Table 19. Backwater from the roadside ditch was observed in the outlet pipe for the 4/10/04 and 4/13/04 storms (figure 19) thereby compromising the outflow sampling, as a result the outflow data is not reported. For less intense storms backwater from the ditch into the outflow pipe is likely not a problem, but this was unknown. The 10 storms monitored included a considerable range of rainfall accumulations and resulting runoff volumes as shown in rows 1 and 2. The average pH and turbidity were well within guidelines for stormwater. Two of the samples were analyzed for metals with all concentrations, except Zn being less than the MDL and NC freshwater standards. Both samples had Zn concentrations greater than 100 mg/L, which is twice the freshwater standard, but the levels were much less than Zn in highway runoff nationally (Table 4).

Mean concentrations of inorganic nonmetals in the inflow were less or within the range of reported values for urban stormwater in general (Table 5). Chloride concentration in two samples was much less than the NC standard for surface waters. Concentrations of nitrogen and phosphorus forms were similar to or less than corresponding concentrations from highways in NC and nationwide (Table 4). The concentration of suspended residue was less than highway runoff from NC and national studies (Table 4). The concentration of COD in two samples was greater than the mean concentration in runoff from NC highways but less than from highways nationwide (Table 4) and less than from urban stormwater (Table 5).

Table 19. Summary Statistics for Inflow for the Div 3 Bioretention Area.

Parameter	Units	Inflow				Export
		Mean	Median	Range		kg/ha-yr
Automated rainfall	in	0.83	0.71	0.29-1.48		NA
Runoff (1,000)	gal	22.4	18.2	6.1-40.1		NA
Peak discharge rate	gpm	340	360	160-490		NA
pH	pH	6.9	6.8	6.4-7.6		NA
Turbidity	ntu	16	14	7-29		NA
Metals						
Cadmium	ug/L	ND	ND	ND		NA
Chromium	ug/L	ND	ND	ND		NA
Copper	ug/L	ND	ND	ND		NA
Lead	ug/L	4	4	2.5-6.0		NA
Nickel	ug/L	ND	ND	ND		NA
Zinc	ug/L	110	110	101-118		NA
Inorganic Non Metals						
Chloride	mg/L	1.9	1.9	1.0-2.8		NA
Nitrogen, Ammonia	mg/L	0.53	0.44	0.17-1.6		2.7
Nitrogen, NO_3+NO_2	mg/L	0.48	0.39	0.12-1.15		2.4
Nitrogen, TKN	mg/L	1.50	1.40	0.47-2.7		7.6
Nitrogen, Total	mg/L	2.0	1.81	0.76-3.56		10.1
Phosphorus, Diss.	mg/L	0.10	0.05	0.01-0.24		0.5
Phosphorus, Total	mg/L	0.23	0.18	0.09-0.40		1.2
Residue, Suspended	mg/L	36	32	19-59		180
Residue, Total	mg/L	73	68	42-111		372
Aggregate Organics						
COD	mg/L	50.5	50.5	39.4-61.6		NA
Oil and Grease	mg/L	3	3	3		NA
Surfactant	mg/L	0.2	0.2	0.2		NA

Nitrogen, phosphorus, and suspended sediment export from the inflow drainage area was computed by developing a linear regression relationship between rainfall and discharge from the 10 monitored storms. Daily rainfall totals for a year beginning March 16, 2004 were obtained from a raingage in Chatham County from which discharge was computed via the regression equation. The average concentrations from the monitored storms were used with the discharge computed from the regression equation to estimate the pollutant load for each daily rainfall. The sum of the daily estimates was then used to compute the estimated annual load as shown in Table 19 column 7.

The annual export of all nitrogen forms was much less for this rest area as compared to the Division 12 rest area. The nitrogen export was also similar to corresponding export from urban areas in Cary, NC (Line et al., 2002) and the total nitrogen export was near the middle of the range from urban land uses in Mecklenburg County, NC (Bales et al., 1999). Dissolved and total phosphorus export was also relatively low as compared to urban land uses in Cary and Charlotte. The TSS export was considerably less than urban land uses in Cary and Charlotte and near the low end of the range from highway as reported in the national database. Thus, pollutant export from this rest area was relatively low.

Site Specific Recommendations: From a functional standpoint the BMP appeared to work well; hence, the following recommendations focus on monitoring considerations:

1. Groundwater monitoring should be included for sites like this where groundwater influx appears to be a good possibility.
2. The possibility of water from off site backing up onto the site must be eliminated prior to the selection as a monitoring site.

Black Mountain Bioretention Area (Division 13)

Description of Site: The Division 13 bioretention area is located between the eastbound on ramp of US 70 to I40 and I40 at Black Mountain (N35' 37.2"; W82' 18.4"). The drainage area to the inflow to the site was 2.74 acres and was almost 96% impervious (Table 12). The bioretention area is rectangular being about 100 ft long and 50 ft wide (figure 30). Runoff water entering the area must percolate through 3-4 inches of hardwood mulch and 3 feet of engineered soil before entering a 10 inch layer of no. 57 stone. Three 6 inch perforated HDPE drain lines were located in the stone layer to carry drainage water to the outlet storm drain manhole. There was a variety of water tolerant plants growing on the surface of the bioretention area; however, they did not appear to be thriving.

Table 12. Characteristics of the Drainage Area to the Div. 13 Bioretention Area.

Item	Description
Drainage area	2.75 acres
Imperviousness of DA	96%
2003 ADT of I40/US 70	32,000
Pavement type	Asphalt roadway, concrete bridgedeck
Soil composition	Aged Hardwood Mulch over Sand & Soil Mixture
Vegetation	Butterfly Weed, Purple Coneflower, Soft Rush, Brown-eyed Susan, etc.

Description of Monitoring: Inflow enters the BMP via a 15 in. pipe, which empties into a forebay before flowing over a level spreader into the bioretention cell. The invert of the inflow pipe is at a lower elevation than the normal pool water height of the forebay creating a backwater situation in the inflow pipe (figure 30). This situation rules out the use of most open channel flow measuring methods/devices, because the free flow of water is inhibited. Hence any discharge measurement device must measure water depth and velocity necessitating the use of the area-velocity meter. The meter's probe was mounted to the bottom of the pipe about 2 ft upslope of the end of the pipe. The probe was located up in the pipe as far as practical to avoid the end effects of the pipe during low water levels in the foreby. The use of the area-velocity meter is somewhat problematic in that it does not accurately measure low flows (water depths< 2 in. and/or velocities< 0.1 ft/s). This measurement limitation could introduce considerable error for storms that have a significant period of low intensity rainfall and consequently low inflow rates. Because of the backwater from the forebay, the inflow sampler's intake was installed about 2-3 ft from the upper end of the pipe to try to limit sampling of backwater. Backwater from the forebay would likely have less suspended sediment and possibly other pollutants which could bias the inflow pollutant levels.

Monitoring of the outflow was conducted by installing a 120 deg v-notch weir in the outflow concrete riser/manhole. The weir was installed across the bottom of the riser between the drain pipe from the bioretention cell and the outflow culvert. The crack between the weir and the riser was sealed with plumber's putty; however, the seal was not permanent. In May, 2005 it became evident that a noticeable amount of water was escaping under the weir and as a result the weir was resealed with tar. Tar was not used initially, because it contains compounds that may have been involved in the monitoring analysis. Also, in late April water was observed to be flowing into the outlet culvert, but not through the drain leading to the outflow weir (figure 32). Thus, drainage water was leaving the bioretention area and bypassing the weir, which when combined with the leaky weir, could cause the outflow volume to be less than the actual volume.

The notch of the weir was 2-3 inches from the bottom so that water was ponded upstream of the weir and water flowing over the weir drained away without creating a submerged weir condition. The flowmeter depth measuring bubble tube and the stainless steel sampler intake strainer were installed 3-4 inches upstream of the weir to minimize measurement in the drawdown section of the weir. The strainer was mounted vertically to facilitate vertical integration of sample collection.

<u>Results of Monitoring</u>: Due to personnel and funding constraints, this site was visited only once every 2-3 weeks unlike the other sites which were visited the day after a storm event to recover samples and data. The 2-week holding time without refrigeration limited the sample analysis to TSS only for all except two of the samples. Hence, a sample may represent the runoff from several storms occurring during the period. For the two samples analyzed for nitrogen and phosphorus species, half the collected sample was pre-acidified with sulfuric acid to preserve the sample until it was recovered during a site visit. The other half of the sample, which was not acidified, was analyzed for TSS. Samples were not analyzed for dissolved phosphorus because acidification is not an appropriate preservation method.

As shown in Table 13, only inflow results are reported due to the problems with monitoring the outflow as outlined in the previous section. Rainfall and inflow discharge varied considerably for the periods of monitoring. The mean turbidity of inflow samples was less than 50 ntu indicating acceptable water clarity. While the mean NO_{3+2} nitrogen concentration was less than those monitored in NC and nationally (Table 4), the ammonia and total Kjeldahl nitrogen concentrations were much greater. The two monitoring periods ending on 4/15/05 and 4/27/05 were considerably different indicating that the high concentrations for samples of 4/15/05 may have been only a one-time occurrence. Total phosphorus concentrations were somewhat higher than expected. The mean TSS concentration in inflow was greater than for monitored NC highways, but less than data from a national study (Table 4). This indicates that the TSS concentrations were typical for highways.

Table 13. Summary Statistics for Inflow for the Black Mountain (Div 13) Bioretention Area.

Parameter	Units	Inflow				
		Mean	Median	Range	no.	
Automated rainfall	in	1.61	1.41	0.66-3.26	11	
Runoff (1,000)	gal	195.5	138.4	51-776	11	
Peak discharge rate	gpm	1500	1000	560-4,000	11	
Turbidity	ntu	22.6	23	6-47	11	

Nitrogen, Ammonia	mg/L	3.2	NA	NA	2	
Nitrogen, NO_3+NO_2	mg/L	0.3	NA	NA	2	
Nitrogen, TKN	mg/L	8.5	NA	NA	2	
Nitrogen, Total	mg/L	8.8	NA	NA	2	
Phosphorus, Diss.	mg/L	NA	NA	NA	NA	
Phosphorus, Total	mg/L	1.0	NA	NA	2	
Residue, Suspended	mg/L	61	42	32-122	11	
Residue, Total	mg/L	99	NA	NA	2	

Site Specific Recommendations: From a functional standpoint the BMP appeared to work well with the exception being that the water appeared to run mostly to the southwest corner of the bioretention area. The following recommendations focus on monitoring considerations:

1. Monitoring of inflow could have been facilitated by raising the invert of the inflow pipe to reduce or eliminate submerged flow conditions.

Quality Assurance Results

There is uncertainty or error associated with any water quality monitoring effort conducted in the field. Sources of uncertainty can be divided into at least the following three areas: hydrologic measurements, sample collection and handling, and laboratory analysis. The following paragraphs discuss each of these sources with respect to this project.

Uncertainty in hydrologic measurements can result from a combination of factors including the accuracy of the water level measuring equipment, icing or discharges greater than monitoring capacity, and debris clogging the monitoring devices. The accuracy of the bubbler flow modules, which were the most used flowmeters during the study, was 0.01 ft. This error increased as the temperature varied from 77 degree F. The uncertainty in these measurements was minimized by continually adjusting the depth to the known correct depth at every visit to the site.

Perhaps the main cause of uncertainty in hydrologic measurements was debris falling into the raingage or getting caught in a weir. Debris in raingages was minimized by installing the gages in open areas and adding deterrents for birds. In addition, gages were checked and cleaned during every site visit (1-2 weeks) and for the most part appeared to be clean and working properly. However, many sites were easily accessible such as the Div 2 swale and subject to unknown intervention by people. Most sites did not have significant debris that could get caught in the weir even so this chance was minimized by using rectangular or wide angle (120 degree) weirs. Also, the weirs were checked and cleaned regularly.

Uncertainty in sample collection and handling was minimized in the following ways. One chain-of-custody form was used from sample collection through laboratory analysis to track all sample handling activities. All tubing and sample containers in sampling equipment was thoroughly washed or was replaced with new prior to installation at a site. Immediate refrigeration to less than 4 deg. C and glass jars were used as sample containers in accordance with sample handling requirements outlined in Standard Methods (APHA et al., 1995).

To test the cleanliness of the equipment and that of the laboratory containers and the handling of the samples, an equipment blank was conducted. For this, a sample of laboratory distilled water was drawn through the sampler at the Wilson CMY and handled as a regular sample. Analysis of the sample documented that all metals and inorganic nonmetals concentrations were less than the MDL, except TS, which was 17 mg/L. The TS may have come from the sampler intake tubing, the air, or possibly from residue on the glass sample containers. Results from another equipment blank conducted on a different sampler that was installed at the Warsaw rest stop in division 3, documented that concentrations of all inorganic nonmetals were less than the MDL, except NH_3-N, which was 0.12 mg/L. The origin of the NH_3-N was unknown; however, the sampler container was cleaned, sampler intake lines were replaced with new tubing, and proper handling procedures were reiterated to technical staff.

To assess the variability associated with sample collection and analysis techniques, two samples for laboratory analysis were made from the samples collected from one storm event at the Orange CMY and the division 4 level spreader. Each sampler places its sample in one of 12 individual jars and then the person who recovers the sample must make a composite sample from the sampler jars for laboratory analysis. The analysis of duplicate samples assesses how repeatable the compositing technique is and also indirectly the repeatability of the lab analysis. The analysis results for the duplicate samples are shown in Table 15. All results that are greater than 15% different between duplicates are indicated by an asterisk. Only Cr and NH_3-N concentrations in duplicate samples were greater than 15% and both of these concentrations were relatively low with the NH_3-N concentrations being at the MDL. Thus, the compositing technique appeared to be adequate. Also, the laboratory analysis was repeatable or the results from the duplicates would have been different.

The grab sample test at the Wilson CMY involved collecting duplicate samples of washwater effluent for laboratory analysis. These results (Table 15) show that concentrations of several analytes in the duplicate samples differed by more than 15%. These differences were likely caused by the high concentrations of solid residue in the samples. The solids vary in the effluent due to changing flow rates and also vary in the sample as a result of the difficulty of keeping them in solution when transferring the sample from the collection container to the laboratory containers. This underscores the difficulty of collecting representative samples from effluent with high solids concentrations and also documents the uncertainty associated with the reported results.

Another possible source of uncertainty is in laboratory analysis. The Charlotte-Mecklenburg Utilities lab is a state certified lab and as such maintains a rigorous quality control program.

Table 15. Analysis of Duplicate Samples.

		Sampler Composite Technique Test				Grab Test	
Parameter	Units	Orange CMY		Level Spreader		Wilson CMY	
Turbidity	ntu	NA	NA	NA	NA	531	604
Metals							
Cadmium	ug/L	1	1	NA	NA	89	99
Chromium	ug/L	15*	10*	NA	NA	130*	170*
Copper	ug/L	25	25	NA	NA	1430	1540
Lead	ug/L	15	14	NA	NA	400	340
Nickel	ug/L	5	5	NA	NA	64	68
Zinc	ug/L	100	80	NA	NA	3400	3600
Inorganic Non Metals							
Chloride	mg/L	300	290	NA	NA	27.0	27.6
Nitrogen, Ammonia	mg/L	0.04*	0.05*	1.50	1.70	1.10	1.20
Nitrogen, NO_3+NO_2	mg/L	0.31	0.32	0.69	0.71	3.45	3.86
Nitrogen, TKN	mg/L	0.99	1.10	2.90	3.00	4.80*	8.60*

Phosphorus, Diss.	mg/L	0.06	0.06	0.04	0.04	0.02*	0.02*
Phosphorus, Total	mg/L	0.33	0.34	0.20	0.21	1.18*	2.55*
Residue, Suspended	mg/L	133	140	38	39	1480*	1080*
Residue, Total	mg/L	836	837	136	136	2270*	1600*
Aggregate Organics							
COD	mg/L	NA	NA	NA	NA	1942	1680
Oil and Grease	mg/L	NA	NA	NA	NA	494*	352*

* indicates at least 15% difference in duplicate samples.

CONCLUSIONS

In summary, the following general conclusions and recommendations can be drawn from the monitoring data, while more specific ones are included in the individual BMP sections:

- Each of the three BMPs was very efficient at reducing the TSS loads in inflow with the overall removal efficiencies ranging from 74 to 83%. The overall TSS, and to a lesser extent nutrient, removal efficiencies of the BMPs likely would have been greater if inflow pollutant levels had been greater as evidenced by the fact that 21 of the 41 samples of outflow had TSS concentrations less than the MDL. In addition, several outflow samples had nitrogen and phosphorus concentrations that were less than the MDL.
- The effectiveness of the BMPs at reducing loads of nitrogen and phosphorus forms was mixed due to site specific reasons or to the fact that the BMP may not be effective for some pollutants. For example, the Div. 12 bioretention area was not effective at reducing NO_{3+2}-N, which may have been the result of groundwater influx into the underdrain or that the bioretention area simply was not effective at treating NO_{3+2}-N. The influx of near surface groundwater from the surrounding area to the underdrain of the roadside swale likely contributed to greater levels of phosphorus in outflow as compared to inflow.
- Although data was limited (only 3 samples per BMP analyzed for metals), each of the BMPs appears to be effective at reducing, at least some, of the metals in the inflow.
- Concentrations of polycyclic aromatic hydrocarbons (67 different compounds) in the two outflow samples per site were always less than corresponding levels in the inflow samples, when the concentrations in the inflow were greater than the MDL. While this is only limited data, it appears that the BMPs would be effective at reducing the levels of these compounds.
- While the three BMPs reduced peak flow rates from 23 to 54%, only one, the level spreader-grass strip, significantly reduced the inflow runoff volume.
- The levels of pollutants in inflow were nearly the same or less than corresponding levels in highway and urban runoff from other NC and nationwide studies. These relatively low levels of pollutants likely decreased the removal efficiencies of the BMPs, especially TSS for which many outflow samples were less than the MDL.

RECOMMENDATIONS

It is also recommended that future monitoring efforts consider the following:

- To minimize the effect of site specific conditions and document the true efficiency of the BMP, experimental sites must be carefully chosen from the perspective of facilitating monitoring. Ideally this means choosing sites that would not have any groundwater influx to the underdrains, but if influx is a possibility, sites should be instrumented to account for it. The possibility of backwater at the inflow and outflow monitoring site also must be considered, especially if the outflow site is affected.
- To characterize initial pollutant additions from the BMP itself, water with known concentrations of pollutants should be applied to the BMP and the outflow monitored. Delaying monitoring of the BMP for at least a year after construction would also help reduce the effect of an initial flush of nutrients resulting from soil disturbance during construction and planting.
- The BMPs should be evaluated during each season of the year. Biological activity affects the efficiency of the BMP; thus, changes in biological activity throughout the year may affect the efficiency of the BMP, especially when vegetation is part of the BMP.
- At least 2, and preferably 3, BMPs at different sites should be monitored to establish the efficiency of the BMP. Repeatability under similar conditions is the only way to establish the efficiency of a BMP.
- Sample analysis for oil and grease, pH, Cd, Cu, Ni, and semi-volatile organic compounds can be omitted for most highway sites, because their concentrations are often less than the MDL. However, for selected sites, such as truck parking areas, these parameters should be included for at least a limited number of storms.
- The target of a 72-hr period of no runoff between storms included in the evaluation of a BMP should be relaxed. Because storms occur more closely in time, including some storms with a shorter dry period and some with longer dry interstorm periods will more accurately represent actual conditions. The highly variable nature of wash-off from storms and pollutant buildup on highway facilities make the no-runoff period mean little.
- For bioretention areas, alternate designs with more vegetation, less and/or a different kind of mulch, smaller forebays, and a narrower soil filter zone could be evaluated. These alterations would reduce the cost and space requirements with possibly little to no reduction in efficiency. Providing a saturated zone for an extended period in the bioretention area may also help reduce nitrogen outflow.

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LIST OF FIGURES

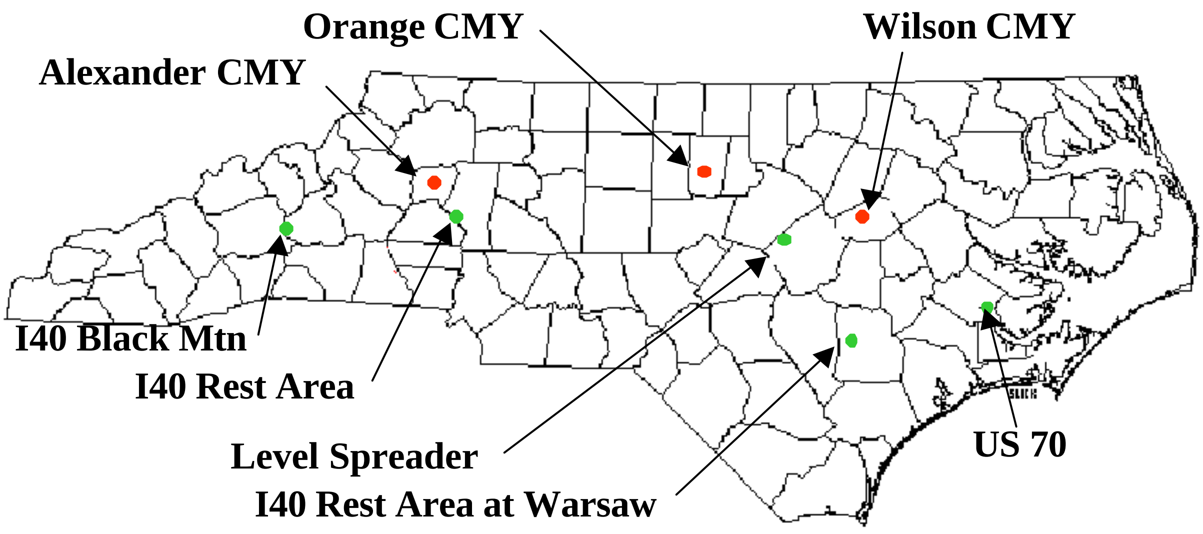

Figure 1. Locations of 5 highway BMP monitoring sites (green dots).

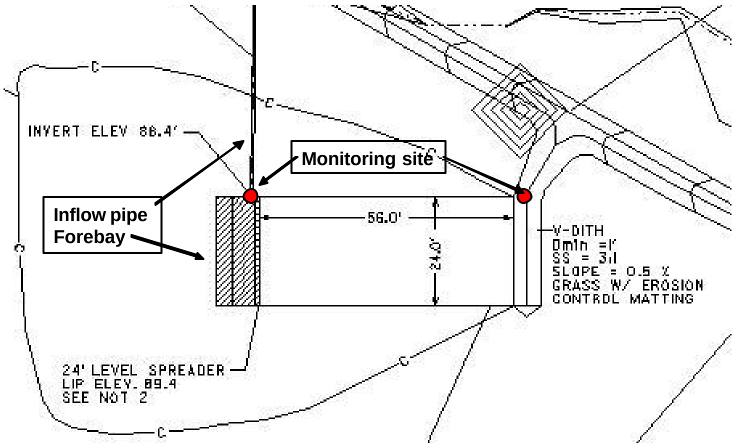

Figure 2. Plan view of level spreader-grass strip.

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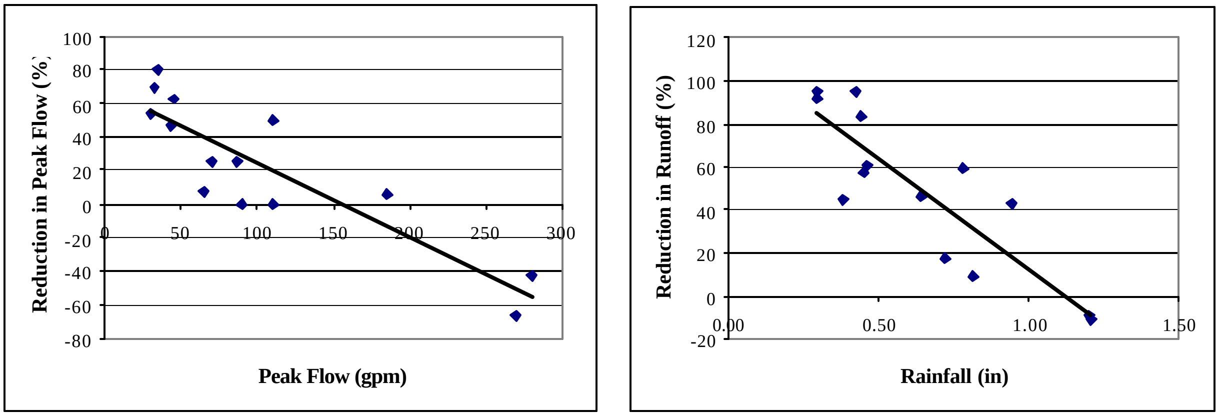

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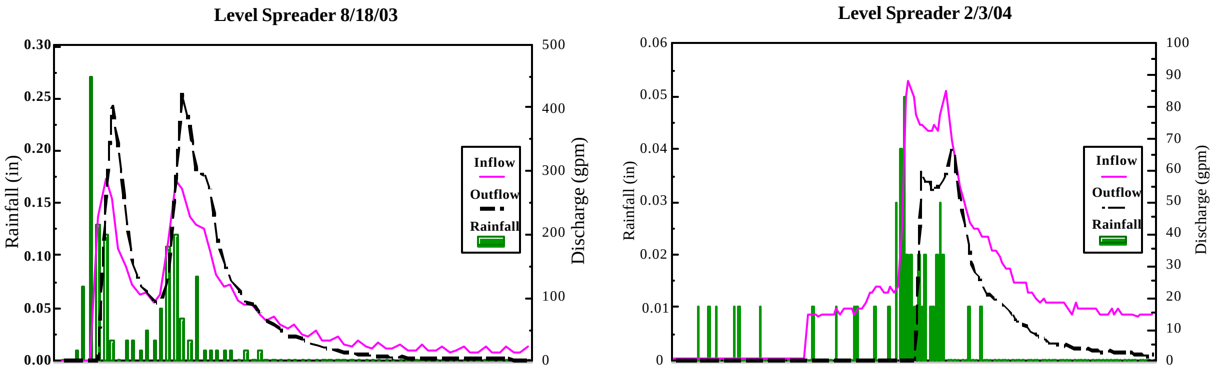

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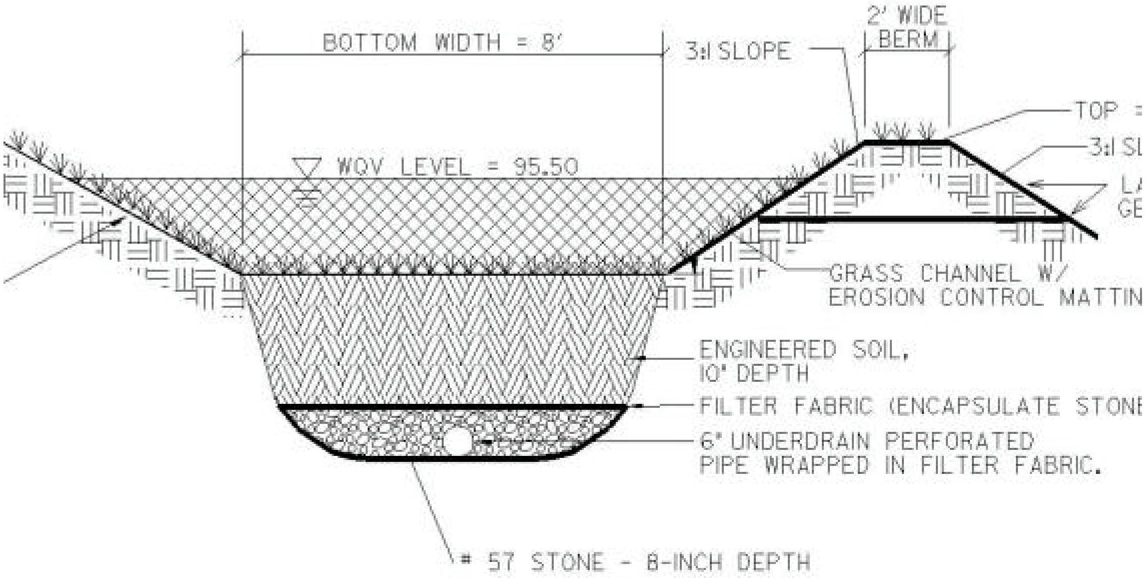

Figure 8. Typical cross section of enhanced swale.

Figure 9. Part of drainage area to the swale (left) and the enhanced roadside swale (right).

Figure 10. Area of exposed soil and thin sod (left) and inlet weir (right).

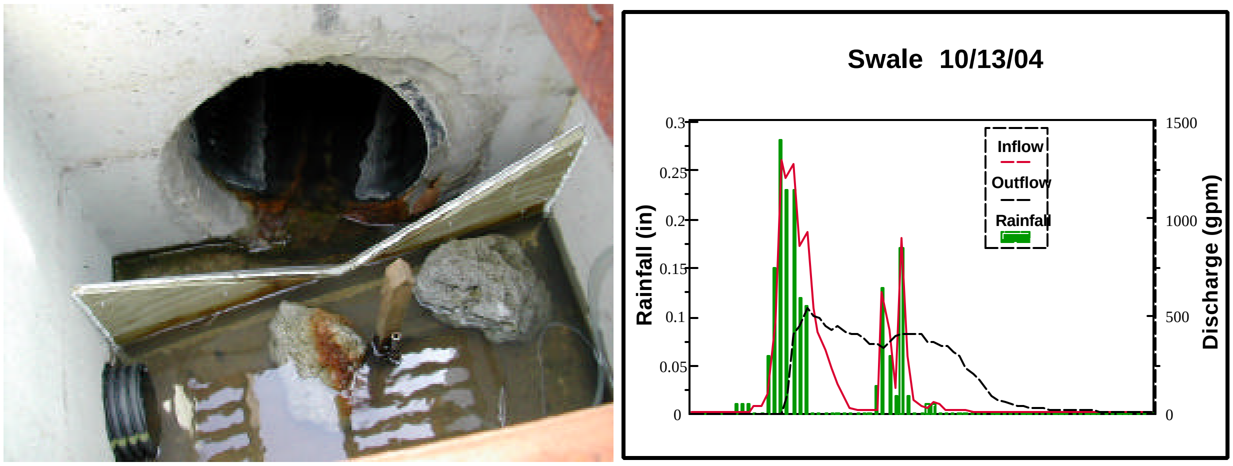

Figure 11. Outlet weir in concrete riser (left) and example hydrograph (right).

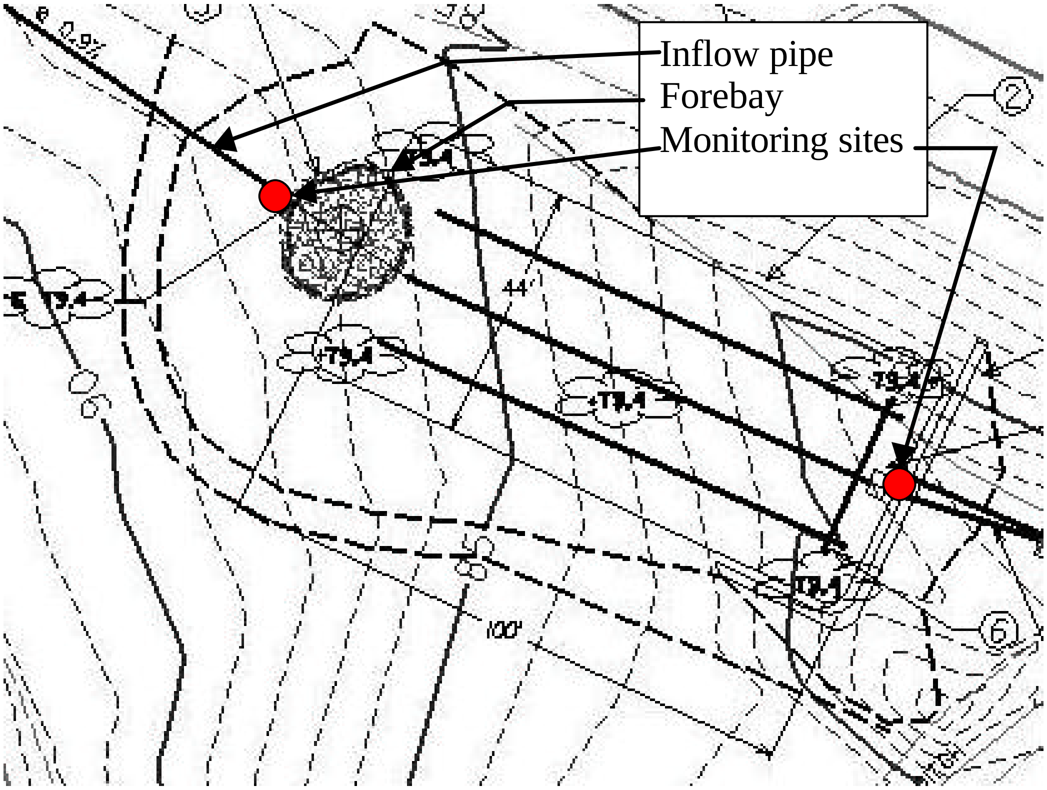

Figure 12. Plan view of Division 12 bioretention area.

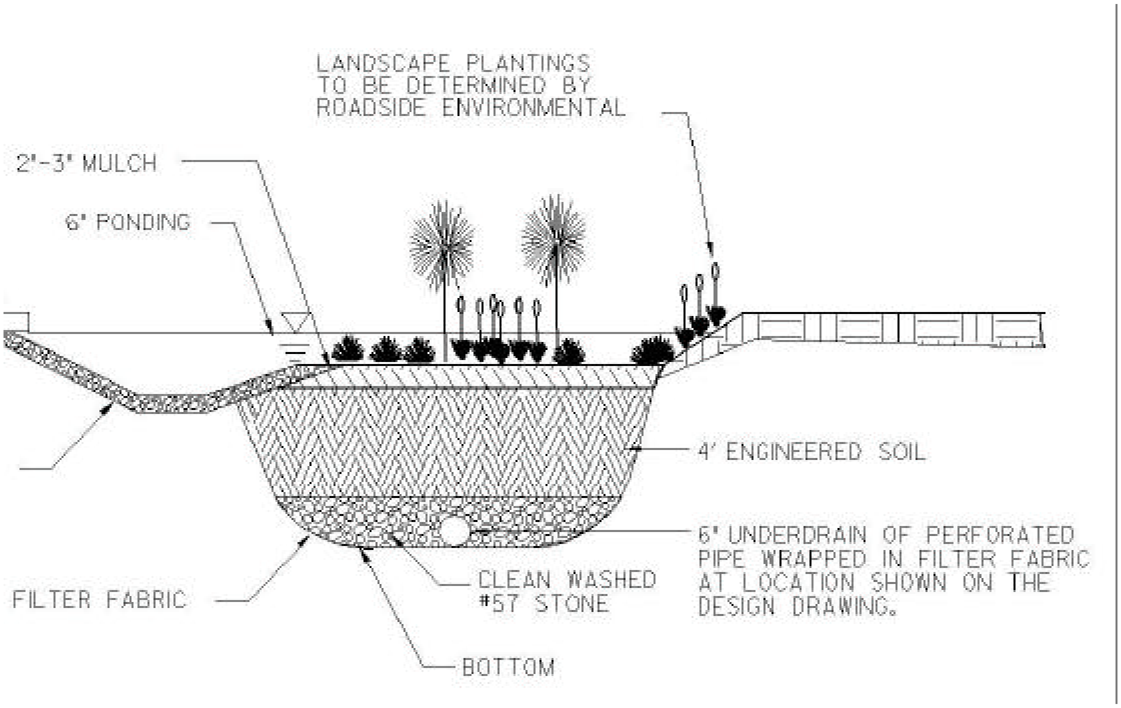

Figure 13. Typical cross section of bioretention area.

Figure 14. Truck parking area (left) and spill basin and stormwater junction box (right).

Figure 15. Ponded water in forebay (left) and state of plants in May, 2004 (right).

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Figure 18. Inflow monitoring weir box (left) and outflow monitoring weir (right).

Figure 19. Ditchwater backing up into outflow pipe (left) and debris in inflow weir (right).

Figure 20. Division 13 bioretention area (left) and inflow pipe (right).

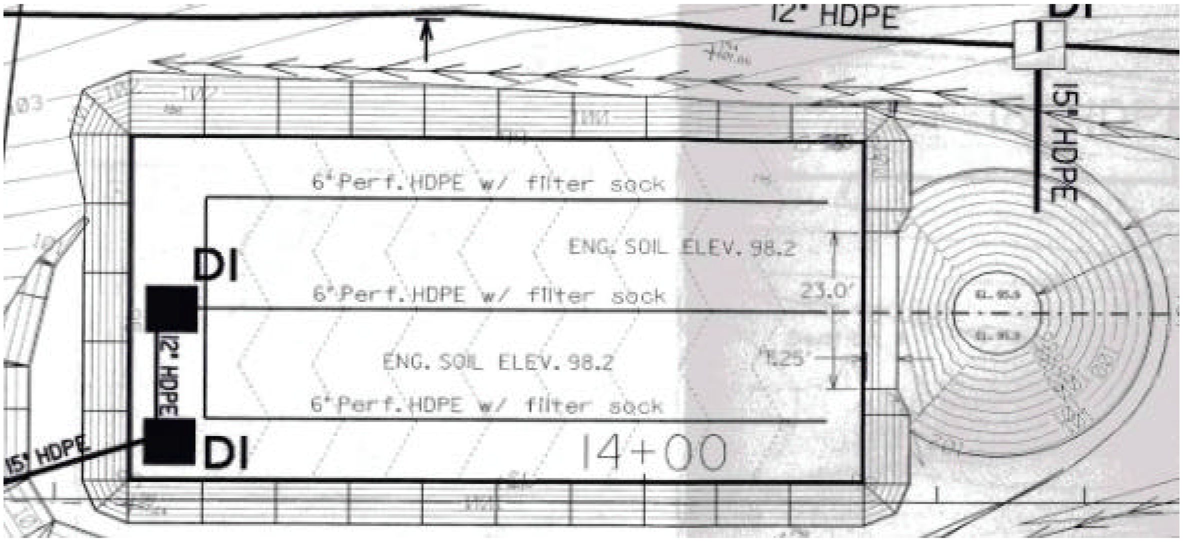

Figure 21. Plan view for division 13 bioretention area.

Figure 22. Underdrain monitoring weir (left) and overall outflow drain box (right).

APPENDICES

Exhibit 1. Inflow Data for the Level Spreader-Grass Strip

Analyte	06/16/03	06/18/03	07/29/03	08/18/03	09/05/03	10/09/03	10/15/03	10/29/03	12/04/03	12/11/03	12/14/03	01/18/04	02/03/04	02/12/04
Manual rain (in)	NA	1.8	0.91	1.47	0.48	0.54	NA	2.03	0.55	1.53	0.93	0.35	0.98	0.78
Auto. rain (in)	0.46	1.20	0.78	1.21	0.38	0.58	0.29	0.94	0.44	0.81	0.72	0.29	0.45	0.64
Runoff (gal)	7900	12500	20549	23363	3695	18332	16900	18570	19890	19785	15960	19254	14450	22960
Peak Q (gpm)	110	270	90	280	30	35	45	110	43	185	65	33	87	70
pH	NA	6.75	6.71	6.63	6.6	6.86	7.02	6.65	7.04	6.88	7.04	7.33	6.71	6.67
Turbidity (ntu)	22	72	36	41	30	61	71	44	93	58	30	33	88	50
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	**1**	**1**	**1**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chromium	6	11	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Copper	**31**	**31**	**31**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	10	11	6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	**2.5**	**2.5**	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc	180	200	190	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NonMetals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	**1**	**1**	2.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nitrogen, Ammonia	0.61	0.26	1.30	0.63	0.93	0.93	0.77	0.63	1.50	0.71	1.20	1.20	0.75	0.45
Nitrogen, NO_3+NO_2	0.42	0.18	0.70	0.66	0.50	0.84	0.46	0.58	0.69	0.33	0.78	0.77	0.52	0.35
Nitrogen, TKN	1.70	1.60	2.90	1.50	2.40	2.80	1.80	1.50	2.90	1.40	1.90	2.10	2.00	1.00
Nitrogen, Total	2.12	1.78	3.60	2.16	2.90	3.64	2.26	2.08	3.59	1.73	2.68	2.87	2.52	1.35
Phosphorus, Diss.	0.02	0.12	0.08	0.16	0.07	0.09	0.04	0.08	0.04	0.07	0.06	0.08	0.14	0.06
Phosphorus, Total	0.17	0.29	0.18	0.25	0.20	0.21	0.19	0.16	0.20	0.21	0.13	0.16	0.25	0.15
Residue, Suspended	46	70	19	23	17	18	35	20	38	69	15	27	79	28
Residue,Total	96	116	76	88	78	111	113	76	136	108	70	208	1,240	113
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	61.1	44.8	80.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oil and Grease	**3**	**3**	**3**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Surfactant	0.4	0.1	0.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Bis(2-ethylhexyl) Phthalate	**5**	16	13	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Exhibit 2. Outflow Data for the Level Spreader-Grass Strip

Analyte	06/16/03	06/18/03	07/29/03	08/18/03	09/05/03	10/09/03	10/15/03	10/29/03	12/04/03	12/11/03	12/14/03	01/18/04	02/03/04	02/12/04
Manual rain (in)	NA	1.8	0.91	1.47	0.48	0.54	NA	2.03	0.55	1.53	0.93	0.35	0.98	0.78
Auto. Rain (in)	0.46	1.20	0.78	1.21	0.38	0.58	0.29	0.94	0.44	0.81	0.72	0.29	0.45	0.64
Runoff (gal)	3123	13700	8383	25900	2031	915	1410	10570	3350	17990	13185	1020	6180	12400
Peak Q (gpm)	55	450	90	400	14	7	17	110	23	175	60	10	65	52
pH	NES	6.9	6.88	6.83	6.63	NES	NA	6.89	6.76	6.91	7.02	NES	NA	6.55
Turbidity (ntu)	12.0	35.5	12.0	19.0	5.0	30.5	22.0	21.5	43.0	40.0	20	19.0	69.0	42.0
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	**1**	**1**	**1**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chromium	**2.5**	**2.5**	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Copper	**31**	**31**	**31**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	**2.5**	**2.5**	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	**2.5**	**2.5**	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc	100	50	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NonMetals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	**1**	**1**	**1**	**1**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nitrogen, Ammonia	**0.02**	0.31	0.20	0.41	0.05	0.72	0.19	0.50	0.83	0.41	0.52	1.30	0.63	0.50
Nitrogen, NO_3+NO_2	0.33	0.15	0.37	1.32	0.25	0.95	0.44	0.50	0.56	0.34	0.44	0.87	0.53	0.27
Nitrogen, TKN	NA	1.50	1.10	1.30	1.80	3.20	1.70	1.40	1.70	1.10	1.10	2.00	1.90	1.00
Nitrogen, Total	NA	1.65	1.47	2.62	2.05	4.15	2.14	1.90	2.26	1.44	1.54	2.87	2.43	1.27
Phosphorus, Diss.	0.03	0.09	0.06	0.08	0.06	0.10	0.07	0.16	0.14	0.22	0.10	0.27	0.26	0.08
Phosphorus, Total	0.17	0.18	0.12	0.14	0.17	0.25	0.20	0.20	0.22	0.32	0.17	0.34	0.32	0.15
Residue, Suspended	8	18	**2.5**	6	7	**2.5**	7	**2.5**	10	16	5	**2.5**	34	25
Residue,Total	67	55	39	59	84	115	94	62	89	69	70	211	1920	86
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	NES	25.3	36.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oil and Grease	NES	**3**	**3**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Surfactant	NES	0.2	0.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Bis(2-ethylhexyl) Phthalate	NES	11	**5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Exhibit 3. Inflow Data for the Enhanced Roadside Swale.

Analyte	02/26/04	03/16/04	04/11/04	04/27/04	05/03/04	06/01/04	06/11/04	06/18/04	08/13/04	08/21/04	08/27/04	09/01/04	09/06/04	10/13/04
Manual rain (in)	0.9	1.4	1.5	0.7	3.25	0.2	NA	NA	5.9	0.45	0.5	4.7	3.50	2.8
Auto. rain (in)	1.20	NA	NA	0.60	2.31	0.29	0.70	0.55	1.98	0.41	0.32	2.84	1.10	1.66
Runoff (gal)	7050	21600	27195	7716	42004	5513	9337	9257	58610	12830	12064	84631	30200	54000
Peak Q (gpm)	90	300	520	220	520	80	450	280	1150	510	315	1150	800	1250
pH	7.5	7.0	6.7	7.5	7.6	7.6	7.5	7.5	na	na	7.5	7.4	7.4	7.6
Turbidity (ntu)	34	10	33	14	9	32	13	5	10	6	4	6	10	6
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	NA	NA	NA	NA	**1.0**	NA	**1.0**	NA	**1.0**	NA	NA	NA	NA	NA
Chromium	NA	NA	NA	NA	**2.5**	NA	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA
Copper	NA	NA	NA	NA	**31.0**	NA	**31.0**	NA	**31.0**	NA	NA	NA	NA	NA
Lead	NA	NA	NA	NA	**2.5**	NA	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA
Nickel	NA	NA	NA	NA	**2.5**	NA	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA
Zinc	NA	NA	NA	NA	**8.5**	NA	36.0	NA	52.0	NA	NA	NA	NA	NA
Inorganic NonMetals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	NA	**1.00**	NA	NA	**1.00**	NA	**1.00**	NA	**1.00**	**1.00**	2.00	**1.00**	**1.00**	na
Nitrogen, Ammonia	0.06	0.25	0.42	0.23	0.11	0.17	0.45	0.23	0.10	0.10	0.18	0.49	0.10	0.25
Nitrogen, NO_3+NO_2	0.12	0.18	0.46	0.36	0.07	0.35	0.48	0.85	0.49	0.26	0.13	0.19	0.11	0.13
Nitrogen, TKN	0.36	0.80	1.70	0.85	0.33	1.10	1.50	0.54	0.53	0.33	0.65	0.75	**0.25**	0.64
Nitrogen, Total	0.48	0.98	2.16	1.21	0.40	1.45	1.98	1.39	1.02	0.59	0.78	0.94	0.36	0.77
Phosphorus, Diss.	**0.01**	**0.01**	0.01	0.02	**0.01**	0.02	0.01	**0.01**	0.01	**0.01**	**0.01**	**0.01**	**0.01**	0.02
Phosphorus, Total	0.11	0.11	0.22	0.14	0.08	0.15	0.12	0.12	0.09	0.05	0.05	0.03	0.04	0.06
Residue, Suspended	33	45	67	27	15	35	29	16	15	9	9	10	11	20
Residue,Total	78	71	119	84	**19**	111	53	60	57	60	60	**19**	**19**	42
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	NA	NA	NA	NA	**6.8**	NA	35.6	NA	**ND**	NA	NA	NA	NA	NA
Oil and Grease	NA	NA	NA	NA	**3.0**	NA	ND	NA	7.6	NA	NA	NA	NA	NA
Surfactant	NA	NA	NA	NA	0.2	NA	0.1	NA	**0.1**	NA	NA	NA	NA	NA
Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Phenol	NA	NA	NA	NA	17.0	NA	**5.0**	NA	**5.0**	NA	NA	NA	NA	NA

Exhibit 4. Outflow Data for the Enhanced Roadside Swale.

Analyte	02/26/04	03/16/04	04/11/04	04/27/04	05/03/04	06/01/04	06/11/04	06/18/04	08/13/04	08/21/04	08/27/04	09/01/04	09/06/04	10/13/04
Runoff (gal)	8,813	27,000	37,470	6,185	53,187	4,050	19,735	14,446	74,238	12,800	6,538	95,801	44,000	60,600
Peak Q (gpm)	88	300	240	75	160	63	295	280	380	110	140	550	360	500
pH	8.1	7.6	7.8	7.5	7.7	7.8	7.8	7.6	na	na	7.4	7.8	7.6	7.7
Turbidity (ntu)	44.0	20.0	15.0	14.0	14.0	13.0	14.0	4.0	12.0	6.0	5.0	6.0	6.0	10.0
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	na	na	na	na	**1.0**	na	**1.0**	na	**1.0**	na	na	na	na	na
Chromium	na	na	na	na	**2.5**	na	**2.5**	na	**2.5**	na	na	na	na	na
Copper	na	na	na	na	**31.0**	na	**31.0**	na	**31.0**	na	na	na	na	na
Lead	na	na	na	na	**2.5**	na	**2.5**	na	**2.5**	na	na	na	na	na
Nickel	na	na	na	na	**2.5**	na	**2.5**	na	**2.5**	na	na	na	na	na
Zinc	na	na	na	na	**8.5**	na	**8.5**	na	**8.5**	na	na	na	na	na
Inorganic NonMetals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	na	7.60	na	na	**1.00**	na	na	na	**1.00**	4.60	3.70	**1.00**	6.90	na
Nitrogen, Ammonia	**0.02**	0.18	0.07	0.25	**0.02**	0.06	0.08	0.21	0.42	0.07	0.06	0.30	0.09	0.12
Nitrogen, NO_3+NO_2	0.20	0.10	0.22	0.46	**0.11**	0.32	1.26	0.30	0.16	0.11	0.03	0.15	0.06	0.16
Nitrogen, TKN	0.42	1.20	0.56	1.10	**0.14**	0.66	0.44	0.51	0.71	**0.25**	0.39	0.54	0.31	0.49
Nitrogen, Total	0.62	1.30	0.78	1.56	0.25	0.98	1.70	0.81	0.87	0.36	0.42	0.69	0.37	0.65
Phosphorus, Diss.	0.44	0.12	0.09	0.04	0.12	0.05	0.05	0.07	0.07	0.06	0.06	0.11	0.09	0.11
Phosphorus, Total	0.71	0.30	0.18	0.15	0.20	0.11	0.13	0.16	0.14	0.09	0.10	0.13	0.10	0.16
Residue, Suspended	12.0	12.0	**2.5**	6.0	**2.5**	**2.5**	6.0	**2.5**	8.0	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**
Residue,Total	192	248	76	119	80	141	131	95	118	159	148	87	141	81
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	na	na	na	na	**6.8**	na	43.1	na	nd	na	na	na	na	na
Oil and Grease	na	na	na	na	**2.50**	na	nd	na	**2.50**	na	na	na	na	na
Surfactant	na	na	na	na	0.10	na	0.20	na	0.18	na	na	na	na	na
Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Phenol	na	na	na	na	**5.0**	na	**5.0**	na	na	na	na	na	na	na

Exhibit 5. Inflow Data for the Division 12 Bioretention Area.

Analyte	07/21/03	08/17/03	08/23/03	10/09/03	12/04/03	12/11/03	03/18/04	03/31/04	06/04/04	06/16/04	06/22/04	06/25/04	09/07/04
Manual rain (in)	NA	0.55	0.2	NA	NA	1.1	na	na	0.4	na	na	na	3
Auto. rain (in)	0.18	0.42	0.29	0.52	0.43	0.82	0.53	1.49	0.52	0.54	0.51	0.78	1.43
Runoff (gal)	7300	13820	10250	22000	15580	34510	10800	29000	12320	14720	17180	35168	50311
Peak Q (gpm)	400	450	420	350	85	220	125	170	420	300	340	320	450
pH	6.58	6.16	6.26	6.49	6.62	6.67	na	6.70	6.98	na	na	na	6.33
Turbidity (ntu)	19	9	9	23	13	31	15	38	12	8	19	6	26
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Cadmium	**1**	**1**	NA	**1**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chromium	8	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Copper	**31**	**31**	NA	**31**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	7	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	**2.5**	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc	330	200	NA	170	NA	NA	NA	NA	NA	NA	NA	NA	NA
Inorganic NonMetals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	NA	2.4	NA	2.1	NA	51.1	NA	NA	NA	NA	NA	NA	na
Nitrogen, Ammonia	0.81	0.93	0.57	0.78	1.20	0.52	0.63	1.30	0.85	0.80	1.10	1.00	1.02
Nitrogen, NO_3+NO_2	0.39	0.58	0.40	0.22	0.29	0.24	0.49	0.73	0.58	0.26	0.49	0.45	0.26
Nitrogen, TKN	4.50	2.70	2.50	5.20	4.20	2.40	2.60	6.50	2.50	2.30	3.70	2.80	3.80
Nitrogen, Total	4.89	3.28	2.90	5.42	4.49	2.64	3.09	7.23	3.08	2.56	4.19	3.25	4.06
Phosphorus, Diss.	0.23	0.25	0.21	0.38	0.35	0.25	0.20	0.42	0.22	0.17	0.33	0.20	0.40
Phosphorus, Total	0.46	0.33	0.30	0.48	0.43	0.44	0.27	0.64	0.30	0.30	0.48	0.32	0.56
Residue, Suspended	44	12	39	12	10	70	35	53	9	44	30	30	29
Residue,Total	68	53	76	52	100	168	75	123	50	61	78	67	70
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	67.6	43.2	NA	39.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oil and Grease	**3**	NA	NA	**3**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Surfactant	NA	NA	NA	0.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Bis(2-ethylhexyl) Phthalate	42	NA	NA	**5**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Phenol	65	NA	NA	**5**	NA	NA	NA	NA	NA	NA	NA	NA	NA

Exhibit 6. Outflow Data for the Division 12 Bioretention Area.

Analyte	07/21/03	08/17/03	08/23/03	10/09/03	12/04/03	12/11/03	03/18/04	03/31/04	06/04/04	06/16/04	06/22/04	06/25/04	09/07/04
Runoff (gal)	7030	15924	8550	17424	28350	58700	16000	38000	8937	12630	18410	27700	37100
Peak Q (gpm)	70	70	70	170	50	170	70	90	50	70	80	60	450
pH	6.74	6.87	6.93	6.72	6.65	6.45	6.40	6.60	6.92	na	na	na	6.24
Turbidity (ntu)	25.5	6.5	6.0	33.0	15.0	20.0	21.0	37.0	22.0	7.0	12.0	4.0	17.0
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	**1**	**1**	NA	**1**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chromium	**2.5**	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Copper	**31**	**31**	NA	**31**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	**2.5**	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	**2.5**	**2.5**	NA	**2.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc	20	40	NA	47	NA	NA	NA	NA	NA	NA	NA	NA	NA
Inorganic NonMetals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	**1**	3.9	NA	4.3	NA	270	NA	NA	NA	NA	NA	NA	NA
Nitrogen, Ammonia	0.26	0.83	0.14	0.45	0.68	0.72	0.08	0.90	0.22	0.83	0.30	0.53	0.49
Nitrogen, NO_3+NO_2	1.33	1.89	1.65	1.00	1.38	1.01	0.77	1.45	2.26	1.26	1.28	1.35	1.08
Nitrogen, TKN	1.30	1.80	1.00	5.10	3.10	2.90	2.60	4.60	1.70	2.10	1.40	1.30	1.80
Nitrogen, Total	2.63	3.69	2.65	6.10	4.48	3.91	3.37	6.05	3.96	3.36	2.68	2.65	2.88
Phosphorus, Diss.	0.05	0.08	0.07	0.16	0.14	0.08	0.02	0.11	0.09	0.17	0.12	0.12	0.16
Phosphorus, Total	0.09	0.12	0.09	0.23	0.18	0.14	0.42	0.44	0.18	0.25	0.20	0.21	0.29
Residue, Suspended	**2.5**	**2.5**	5	**2.5**	**2.5**	7	20	22	**2.5**	**2.5**	**2.5**	**2.5**	13
Residue,Total	77	103	107	87	136	544	327	232	105	84	72	76	112
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	17.2	22.1	NA	20.7	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oil and Grease	**3**	NA	NA	**3**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Surfactant	0.1	NA	NA	0.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Bis(2-ethylhexyl) Phthalate	**5**	NA	NA	**5**	NA	NA	NA	NA	NA	NA	NA	NA	NA
Phenol	**5**	NA	NA	**5**	NA	NA	NA	NA	NA	NA	NA	NA	NA

Exhibit 7. Inflow Data for the Division 3 Bioretention Area.

Analyte	03/16/04	4/1/2004	04/10/04	04/27/04	05/03/04	05/12/04	05/20/04	06/01/04	06/11/04	06/18/04
Manual rain (in)	0.35	0.64	4.55	1.46	na	1.75	2.80	1.56	0.84	0.59
Auto. rain (in)	0.29	0.48	0.97	1.26	na	1.48	0.39	1.37	0.71	0.48
Runoff (gal)	9290	18236	40101	39292	na	37423	6705	36161	8367	6179
Peak Q (gpm)	160	160	480	490	na	400	360	360	275	375
pH	7.3	7.6	6.7	6.5	7.1	6.4	6.9	6.7	6.6	7.5
Turbidity (ntu)	29	27	15	13	23	7	20	10	9	11
Metals	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Cadmium	na	**1.0**	na	**1.0**	na	na	na	na	na	na
Chromium	na	**2.5**	na	**2.5**	na	na	na	na	na	na
Copper	na	**31.0**	na	**31.0**	na	na	na	na	na	na
Lead	na	**2.5**	na	6.0	na	na	na	na	na	na
Nickel	na	**2.5**	na	**2.5**	na	na	na	na	na	na
Zinc	na	101.0	na	118.0	na	na	na	na	na	na
Inorganic NonMetals	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Chloride	na	**1.00**	na	2.80	na	na	na	na	na	na
Nitrogen, Ammonia	0.60	0.37	0.59	0.45	0.17	0.33	1.60	0.42	0.22	0.56
Nitrogen, NO_3+NO_2	0.63	0.49	0.66	1.15	0.12	0.16	0.86	0.16	0.29	0.27
Nitrogen, TKN	1.50	1.30	1.80	1.40	1.70	1.40	2.70	1.40	0.47	1.30
Nitrogen, Total	2.13	1.79	2.46	2.55	1.82	1.56	3.56	1.56	0.76	1.57
Phosphorus, Diss.	0.05	0.04	0.04	0.19	0.22	na	0.08	0.24	**0.01**	0.05
Phosphorus, Total	0.17	0.16	0.19	0.31	0.40	0.38	0.17	0.31	0.09	0.14
Residue, Suspended	48	32	31	31	40	25	59	19	39	31
Residue,Total	84	64	62	72	111	61	87	51	95	42
Aggregate Organics	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
COD	na	61.60	na	39.40	na	na	na	na	na	na
Oil and Grease	na	**3.00**	na	**3.00**	na	na	na	na	na	na
Surfactant	na	0.20	na	0.20	na	na	na	na	na	na
Organics	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
Bis(2-ethylhexyl) Phthalate	na	**5.0**	na	13.0	na	na	na	na	na	na
Phenol	na	57.0	na	16.0	na	na	na	na	na	na
Naphthalene	na	**5**	na	**5**	na	na	na	na	na	na

Exhibit 8. Inflow Data for the Division 13 Bioretention Area.

Analyte	10/12/04	10/28/04	11/08/04	11/19/04	12/08/04	12/16/04	12/30/04	01/20/05	03/10/05	03/31/05	04/15/05	04/27/05
Manual rain (in)												
Auto. rain (in)	0.66	0.93	1.51	1.32	1.24	1.07	1.49	1.77	2.62	2.61	3.26	0.79
Runoff (gal)	93,000	51,040	133,916	142,800	114,509	109,263	181,921	240,988	776,629	318,814	150,460	32,600
Peak Q (gpm)	3100	560	1000	1000	2900	1250	670	4,000	1350	610	650	900
pH	na	na	na	na	na	na	na	na	na	na	na	na
Turbidity (ntu)	13	26	23	11	20	6	25	35	na	47	15	28
Inorganic NonMetals												
Nitrogen, Ammonia											5.9	0.45
Nitrogen, NO_3+NO_2											0.12	0.38
Nitrogen, TKN											15.0	2.0
Nitrogen, Total											15.1	2.4
Phosphorus, Diss.											NA	NA
Phosphorus, Total											1.6	0.38
Residue, Suspended	32	82	37	29	98	33	52	122	na	111	42	34