ABSTRACT

Title of Thesis:	FIELD EVALUATION OF HYDROLOGIC AND WATER QUALITY BENEFITS OF GRASS SWALES WITH CHECK DAMS FOR MANAGING HIGHWAY RUNOFF
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Managing highway runoff is a complex storm water management problem. This research is an input/output field study that specifically examines the hydrologic and water quality benefits of having grass swales with an additional pre-treatment area and incorporation of check dams for managing highway runoff at a Maryland highway. These swales manage the hydrology of the stormwater by increasing the lag time (2-3 hours), reducing the overall average peak (32-44%) and reducing the total runoff volume (4-46%). The overall mass pollutant loads are reduced for TSS (38-62%), nitrate (92-95%), nitrite (54-71%), lead (78-82%), copper (56-70%) and zinc (67-79%). On the other hand, TKN (-120 to 44%), TP (-5 to 40%) and chloride (-61 to -4%) show mass increase. Compared to previous study, swales with check dams do not show any significant improvement over swales without check dams. However, a check dam swale with a pretreatment area has higher reduction of the overall mass pollutants removal for all pollutants except for TSS.

FIELD EVALUATION OF HYDROLOGIC AND WATER QUALITY BENEFITS OF GRASS SWALES WITH CHECK DAMS FOR MANAGING HIGHWAY RUNOFF.

By

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Chapter 1

INTRODUCTION

Non-point source pollution occurs when rainfall or snowmelt runs over land or through the ground, and collects and deposits pollutants into streams, lakes, or groundwater. According to the U.S Environmental Protection Agency (EPA), non-point source pollution is the leading cause of water quality problems (USEPA 1994). Non-point sources include overland runoff from agricultural, industrial, urban areas, construction sites, roads, parking lots, and other open spaces. Furthermore, Novontny and Harvey (1994) noted out that almost 50% of the total water pollution in the developed world comes from non-point source pollution.

Highway stormwater runoff is one of the significant sources of runoff pollution potentially impacting receiving water ecosystems due to the nature of the pollutant pathways. Besides that, development of highways causes increases in impervious areas and indirectly reduces vegetation. Vegetation such as trees, shrubs, and wetlands, intercept and store significant amounts of precipitation and reduce the erosive forces of rain and runoff. Therefore, due to more impervious surfaces, soil compaction and vegetation removal, the movement of water through the environment and the water quality will be altered. Eventually, a variety of problems may develop such as increased flooding, increased sedimentation and erosion of the receiving water body. In one study by the American Forests (1998), conversion of forest to impervious cover resulted in an estimated 1.2 billion cubic feet (29%) increase in runoff during a major storm event and replacing this lost of stormwater retention capacity with reservoirs and other engineered systems would cost about $2.4 billion ($2 per cubic foot).

Currently, the Maryland State Highway administration (SHA) is exploring the use of Low Impact Development (LID) technologies for addressing complex stormwater management challenges. LID practices are innovative engineered systems that are design to manage stormwater by replicating the site's predevelopment hydrologic regime, incorporating design techniques that infiltrate evapotranspirate and reuse runoff (USEPA 2007).

LID technologies that have been used in many SHA designs include grass swales and grass filter strips. Swales are shallow vegetated channels that convey stormwater and grass filter strips are vegetated areas that are intended to treat sheet flow from adjacent impervious areas. Both systems remove pollutants by filtration through grass and infiltration through soil prior to discharge to a downstream drainage system or receiving waters. According to Lee et al. (1998), the major pollutant removal mechanisms in vegetative controls are sedimentation of suspended solids, infiltration, and adsorption to plant and soil surfaces. Indirectly, from the hydrological aspect, grass swales help to reduce runoff velocities and reduce runoff peaks. However, one of the challenges associated with filter strips is the difficulty to maintain sheet flow since it is frequently dominated by concentrated flow, which results in little or no treatment of stormwater runoff. Therefore, in recent stormwater manuals, filter strips are considered as a beneficial technique for stormwater volume reduction rather than as a pretreatment practice on some of the sites (MDE 2000). Moreover, in order to increase the detention time of the water on the swales, check dams are often installed within the grass swale. This will allow more time for the water to infiltrate.

Figure 1. Grass swale with filter strip located on Maryland Route 32

Swales are relatively easy to design and maintain, and aesthetically appealing, especially for highway use. For some sites, it could be the most cost effective treatment technique. Figure 1 shows an example of grass swale with filter strip. A difference between swales and other stormwater treatment practices such as gutters and detention ponds are the method used to size the treatment. Most stormwater treatment practices are sized by volume of runoff, but swales are designed based on flow rate. For flood control purposes, it is required that the stormwater treatment practices are able to reduce the peak flows for at least 10-year storm events (Claytor and Schueler 1996), and for channel protection, the stormwater treatment practice needs to be designed to reduce the peak flows for at least 1.5-year to 2-year storms (Schueler 1987, Rosgen 1996). A project to specifically study the effects of grass swales on drainage by Kercher et al. (1983) measured a significant decrease in runoff from the swales in comparison to curb and gutter system. This is an advantage since less area is needed for downstream stormwater detention ponds. Among the thirteen rain events that were monitored, the grass swale area only produced runoff during three events compared to every event with curb and gutter area. In the same report, it was indicated that they could save AU$6100 if grass swales were constructed and maintained. The traditional curb-and-gutter system would cost AU$13,000 (net present value over 25 years).

Pollutant removals by swales are considered site specific and swale performance depends highly on the grass cover (type, density), type of soil, runoff quality and channel design. Yousef et al. (1987) recommended that grassed swales should be regarded as primary stormwater treatment facilities that convey stormwater to secondary treatments such as detention basins and wetlands. Currently, the information on water quality improvements for swales is limited and inconsistent as a result of the complexity of swale operation. In general, swales are effective in removing large particles such as suspended solids but during intense storms, settled particles are potentially subject to resuspension, resulting in net export of pollutants, especially for nutrients (Yu et al. 2001).

This research project site was constructed on Maryland Route 32 near Savage, Maryland, consisting of two individual swales with different designs but nearly identical roadway drainage areas. The monitoring location is the same as the previous study by Stagge (2006) where two swales were constructed in the median of a four-lane (two in each direction) limited access highway that which received runoff laterally from the southbound roadway lanes. The first swale had a sloped grass pretreatment area adjacent to the roadway and the second swale was identically constructed but without the pretreatment area. On each of these swales, two vegetated check dams were installed. Both swales drain the runoff to an inlet where water flow and quality measurements are made. Ten target pollutants that are considered as being most problematic from highway runoff are monitored, specifically total suspended solids (TSS), nitrate-N, nitrite-N, total Kjeldahl nitrogen (TKN), total phosphorus (TP), chloride (Cl), copper (Cu), lead (Pb), zinc (Zn), and cadmium (Cd). In total, 24 storm events were analyzed over a period of 2 years. Since both swales drain to an inlet where water flow and quality measurements are made, input/output study is done by having direct highway runoff as the input and swales flow as the output. A goal of sampling one storm event per month was established.

Stagge (2006) investigated 22 storm events over a period of 1.5 years, with 18 storm events that contained associated pollutants data. His results showed significant peak reduction (50-53%), delay of the peak flow (33-34 min) and reduction of total runoff volume (46-54%). Statistically, the grass swales exhibited significant removals, represented by the Event Mean Concentration (EMC) of total suspended solids (41-52%), nitrite (56-66%), zinc (30-40%), lead (3-11%), copper (6-28%) and cadmium. Cadmium removal is difficult to quantify since most of the effluents are below the detection limit. On the other hand, nutrients such as nitrate, TKN and total phosphorus exhibited variable removal capabilities ranging from -1% to 60%. The negative sign shows that the swales are actually exporting the pollutant into the runoff. The swales also exported chloride at a significant level (216 – 499 mg/L). Stagge (2006) concluded that the pretreatment grass filter strip showed no significant water quantity or quality improvement and that the swale itself is the most important treatment mechanism.

The focus of this study was to investigate the effectiveness of vegetated check dams on swale performance. This study had four objectives. The first objective was to study the overall efficiency of grass swales with native check dams on roadway runoff pollutant removal and peak runoff reduction. The second objective was to examine at the effect of the shallow sloped grass pre-treatment area adjacent to the grass swale. The third objective was to compare the effectiveness of swales incorporating native check dams with swales that do not have any check dams. Research regarding the effectiveness of swales without check dams was previously completed at the same site by Stagge (2006). Finally the fourth objective was to provide a comprehensive literature review on grass swale performance.

In order to archive those objectives, two hypotheses are made. First, the pretreatment area prior to the grass swale significantly impacts the hydrology and water quality by slowing runoff velocities, providing more infiltration into underlying soils and filtering out sediment and other pollutions. Second, by having check dams within the grass swales, temporary ponding areas within the swale will be created, reducing the runoff velocity and indirectly increasing the retention time, eventually promoting more infiltration through the soil and filtration through the grass swale.

This research quantified the importance of the pretreatment area prior to the grass swale and the importance of having check dams within the grass swales. The results of this research will assist the SHA in providing the best management practices adjacent to their highways in order to manage stormwater runoff.

Chapter 2

LITERATURE REVIEW

2.1 Stormwater Runoff Characterization

Highway runoff consists of major water quality constituents that are summarized in Table 2-1 together with their common expected concentration. According to the National Cooperative Highway Research Program (NCHRP 1999), the primary source for total suspended solids is pavement wear and vehicle maintenance. Roadside fertilizer application contributes to the amount of phosphorus, nitrate, nitrite and TKN in stormwater runoff. Most chloride source comes from deicing salts, especially during winter. Tire wear, bearing wear and lubricating oil and grease are the primary sources for copper, lead and cadmium, while zinc comes from metal plating, engine parts and brake lining wear.

Table 2-1. Summary of the primary constituents of stormwater runoff and the typical expected concentration.

Constituent	Expected Concentration	Sources
Total Suspended Solids (TSS)	45 - 798 mg/L	Barrett et al. (1995)
Nitrate (total as N)	0.013 - 2.5 mg/L	Barrett et al. (1995)
Nitrite (total as N)	0.306 - 1.4 mg/L	Barrett et al. (1995)
TKN	0.355 - 55.0 mg/L	Barrett et al. (1995)
Chloride	20 - 400 mg/L	Kaushal et al. (2005)
Phosphorus	0.113 - 0.998 mg/L	Barrett et al. (1995)
Copper (Cu)	5 - 200 ug/L	Davis et al. (2001)
Lead (Pb)	5 - 200 ug/L	Davis et al. (2001)
Zinc (Zn)	20 - 5000 ug/L	Davis et al. (2001)
Cadmium	< 12 ug/L	Davis et al. (2001)

2.1.1 Total Suspended Solids (TSS)

Total suspended solids consist of particles that are suspended in water and can be separated from water by a filtration process. Sources for TSS in highway runoff include soil erosion, the road surface, pavement wear, vehicles, and atmospheric deposition. TSS is an important water quality parameter because as TSS increases, the turbidity of the water will increase and eventually block penetration of sunlight into the water. This will eventually increase the temperature of water and decrease the levels of dissolved oxygen. In other words, the photosynthesis process will be interrupted due to less sunlight. Therefore, less oxygen is produced for aquatic organisms. According to the U.S Environmental Protection Agency, TSS in any water body should not exceed 30 mg/L, which is the same as the regulation that applies to most of the municipal wastewater treatment plants (DEQ 2007).

2.1.2 Nutrients

Nitrogen and phosphorus are the two nutrients that are a major concern in stormwater runoff. Nitrogen is derived from decomposing organic matter, animal waste, fertilizers and atmospheric deposition. With the exception of atmospheric deposition, phosphorus comes from the same sources (Schueler 1994). Excess nutrients in water can accelerate algae production in the water bodies, known as eutrophication. Eventually, these algae die, sink to the bottom and decompose. Decomposition will decrease the amount of oxygen in water due to its oxygen consumption.

2.1.3 Chloride

Chloride is a negatively charged ion that can be found in deicing chemicals that are applied on highways during the winter season to manage ice and snow problems. Common deicing chemical compounds include sodium chloride (NaCl), calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$). These compounds leave residues of chloride ions on the highway surface (TFHRC 2007). Water with elevated amounts of chloride can affect some aquatic life. For example, some fishes can only tolerate salt levels as low as 400 mg/L (Hanes et al. 1970).

2.1.4 Heavy Metals

The sources of heavy metals in highway runoff are mainly ordinary wear of brakes, tires and vehicle parts. According to the study done at Milwaukee and Cincinnati by Sansalone et al. (1995), the amount of heavy metals in the environment has changed through out the years. For example, the EMC values for lead in Milwaukee in the late 1970s and early 1980s are much higher compared to the EMC values for lead in Cincinnati in 1995. The decrease was due to leaded gasoline that was banned by the government in 1995. On the other hand, the EMC values for zinc in Cincinnati in 1995 are much higher compare to the zinc in Milwaukee in the late 1970s and early 1980s due to the increased use of galvanized and corrosion resistant automobile parts containing plating that includes Zn, and the used of Zn in the manufacture of tires. These two places are comparable since both have an urban setting and similar traffic volumes.

Since heavy metals have toxic effects on aquatic life and humans, the Maryland Department of the Environment (MDE 2005) establishes aquatic toxicity limits that should be used as a guideline for toxicity levels. Four heavy metals that will be monitored in this project are zinc, copper, lead, and cadmium. The acute toxicity limits for zinc, lead, copper and cadmium are 120 μg/L, 65 μg/L, 13 μg/L and 2 μg/L, respectively (MDE 2005).

2.2 Grass Swale Mechanisms

Highway runoff seeps through the swale and soil through infiltration, percolation and filtration. However, those processes are complicated since they depend on the condition of the soils (permeability, hydraulic conductivity, moisture) and type of grass. The water quality constituents are either dissolved or particulate bound. Particulate pollutants such as total suspended solids usually can be removed by physical processes such as filtration by the grass. The dissolved pollutants, such as metals, can be removed by microbial means, adsorption, and phytoremediation.

Phytoremediation is a set of processes that uses plants to remove contamination in groundwater, surface water and leachate (FRTR 2008). Therefore, a grass swale can act as a media for phytoextraction to occur. In order for phytoextraction to occur, the contaminant must be bioavailable. The contaminant should exist as free ions, soluble complexes or adsorbed to inorganic soil constituents at ion exchange sites. For example, some metals such as zinc and cadmium exist in exchangeable, readily bioavailable form but some metals such as lead occur as soil precipitates (less bioavailable forms) (USEPA 2008).

2.3 Grass Swale Performance

This section focuses on grass swale performance towards removing pollutants. Typically, grass swales performance depends on the swale design, swale length, flow rate, particle size distribution and seasons. The study that compares the performance of grass swales that includes check dams and grass swales without check dams will be discussed separately in Section 2.4.

2.3.1 Total suspended solid (TSS)

Deletic (2005) summarized that efficiency of grassed areas in sediment removal depends on the grass type (density and thickness of grass blades), terrain characteristics (slope, size and length in the flow direction), soil type (infiltration capacity, roughness), sediment characteristics (size and density of particles), and rainfall characteristics (intensity and duration). Most of the literatures shows that grass swales are very efficient in removing total suspended solids, with Event Mean Concentration (EMC) removals reported as 69% (Deletic and Fletcher 2006), 85% (Barrett et al. 1998), 79-98% (Backstrom 2002a) and 41-52% (Stagge 2006).

Furthermore, Deletic and Fletcher (2006) discussed the results of controlled field tests on a grass filter strip in Aberdeen, Scotland (5 m long with average longitudinal slope of 7.8%) and a grass swale in Brisbane, Australia (65 m long with average longitudinal slope of 1.6%). In both studies, TSS concentrations were recorded along the grass for artificial inflow of water and sediment of different flow rates and sediment concentrations. The study in Aberdeen focused more toward the performance of the grass filter strips relative to different sediment particle size ranges from 0-0.58, 5.8-22, 22-57 and 57-180 μm along the strip. Inflow and outflow concentrations were recorded for one hour. The results show that the TSS concentration decreased along the grass strip in the form of an exponential decay, with the smallest particles size having the lowest sediment concentration (Figure 2-1).

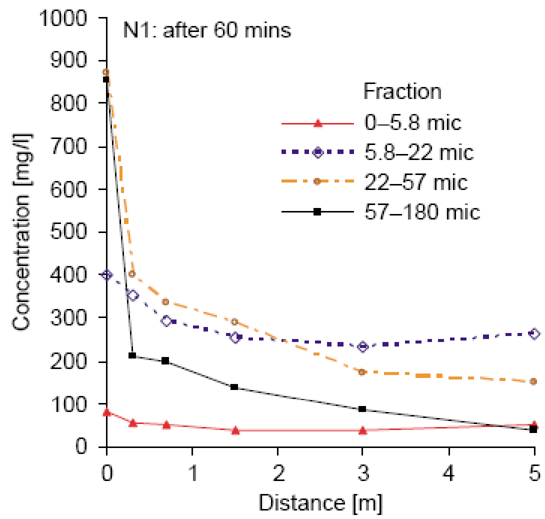

Figure 2-1. Concentration of four composite sediment fractions along the Aberdeen grass strip 60 min after the experiment started (Deletic and Fletcher 2006) (mic = μm).

In other words, swales trapped larger particles more efficiently than smaller particles especially if the vegetation is thin. This phenomenon can be seen in the simulated runoff event study by Backstrom 2003 (Figure 2-2) where particles larger than 25 μm were retained in the swale while particles range between 9 to 15 μm were easily transported out of the swale.

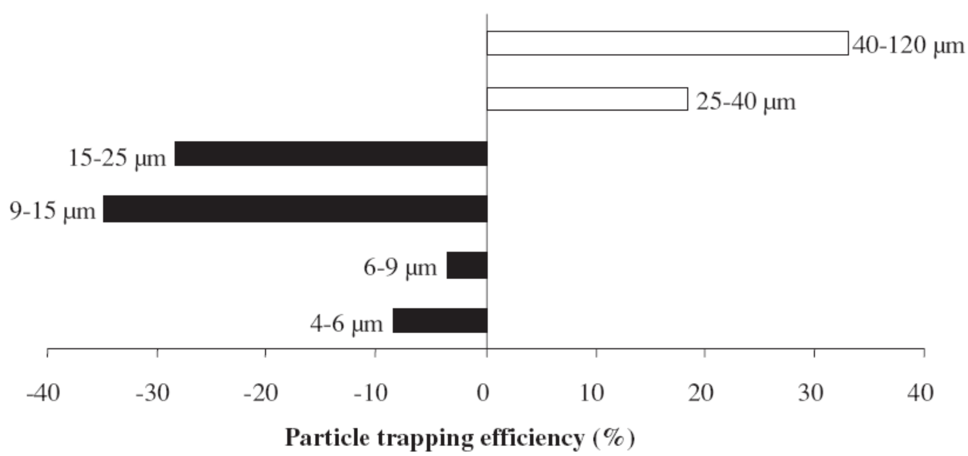

Figure 2-2. Particle trapping efficiencies observed at the Sodra Hamnleden site (Backstrom 2003).

The study in Brisbane placed more emphasis on treatment performance for TSS, total phosphorus (TP) and total nitrogen (TN). The results indicate that the form of the exponential decay is a function of flow. The higher the flow rate, the less sediment is deposited. With higher flow rates, less time is available for filtration to occur and therefore, less deposition to occur. This phenomenon is shown in Figure 2-3.

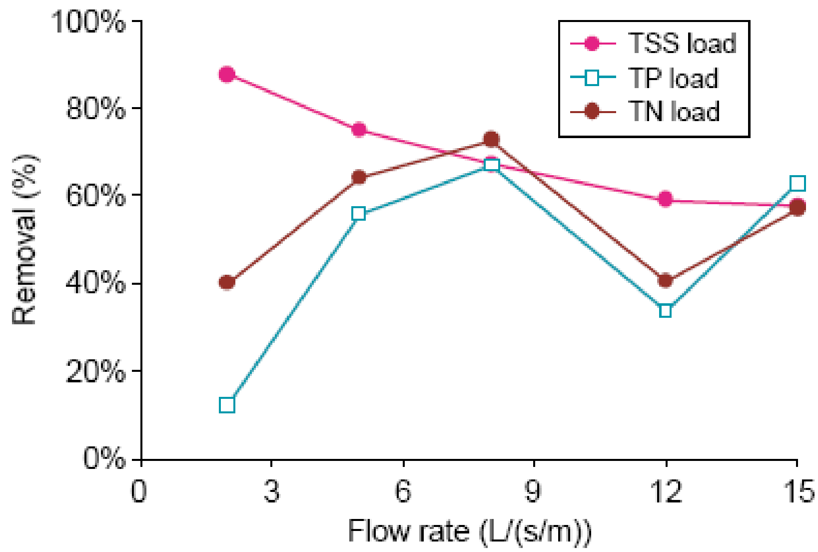

Figure 2-3. Removal of TSS, TP and TN load percent as a function of flow rate; the Brisbane swale (Deletic and Fletcher 2006).

Furthermore, TSS removal is also a function of influent suspended solids concentrations (Backstrom 2003). The study was done on 110 m long grass swale located along the roadside at Sodra Hamnleden, Lulea, Sweden. It seems that no significant removal occurred in the swale when the influent concentrations of TSS were below approximately 40 mg/L. This agrees with Ellis (1999) since she also found out that small reduction of TSS occurred if the inflow concentration was below 30 to 40 mg/L. The results of Backstrom (2003) are compared to two other studies in Figure 2-4. From the figure, results of Lorant (1992) and Backstrom (1998) shows that swales were effective (removal efficiencies more than 50%) when influent suspended solids concentrations are above 100 mg/L. The Backstrom (1998) study was done on a 70 m long trapezoidal swale in a residential area in Sweden while the study in 2003 was done a 110 m long triangular swale along the roadside. Although the influent loading rate is truly site specific, the influent water quality is still an important site condition that influences the pollutant removal performance (Barrett et al. 1998).

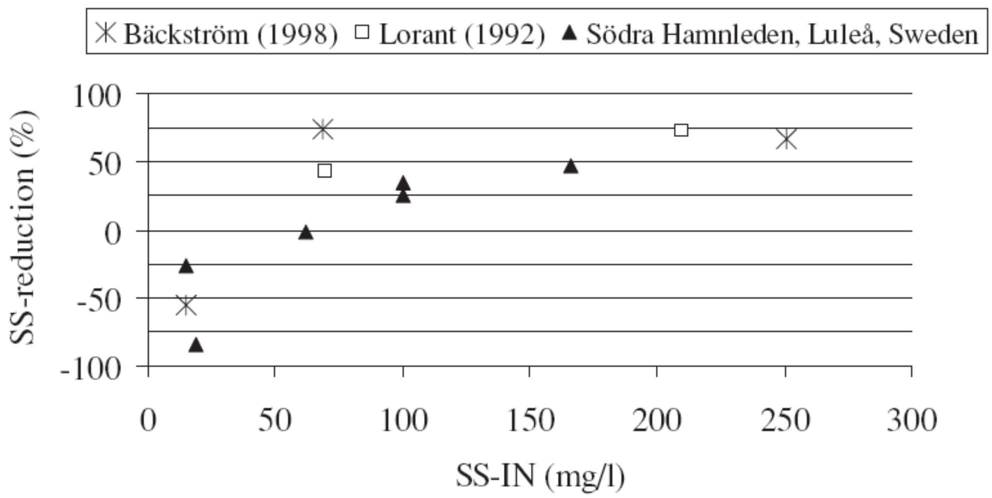

Figure 2-4. Reduction in Suspended Solids (SS) concentration at different influent SS concentrations for three different studies (Backstrom 2003).

Seasonal effects also play an important role in swale removal efficiencies for TSS. According to Walsh et al. (1997), during growing season, the combined filtering capacity of the dead and live grasses in the swale helps to remove more suspended solids compared to the dormant season. Besides that, Soderlund (1972) found that during winter season, less suspended solids were trapped in a vegetated waterway compared to warmer seasons. The change was from 75% reduction to only 30% reduction. This phenomenon occurs due to the swale being covered by the snow and therefore, flow resistance and filtering effects are lower compared to the rest of the seasons.

2.3.2 Nutrients (nitrate-N, nitrite-N, total Kjeldhl nitrogen (TKN), total phosphorus (TP))

The removal of nutrients by swales varies widely. In some cases, swales tend to export the nutrients into the runoff. This phenomenon occurred due to the vegetation itself or fertilization that contributes to nutrient loads, particularly after mowing (Patron 1998). Furthermore, nitrogen removal itself is a function of denitrification, biostorage (plant and animal uptake) and changes in soil storage (Deletic et al., 2006). Phosphorus removal is highly depends on physical processes that includes infiltration, deposition and filtration since phosphorus is considered as particle-bound pollutants (Barrett et al., 1998; Rose et al., 2003).

In a study by Barrett et al. (1998), two grassed areas along a busy motorway in Austin, Texas was monitored. Following are the characteristics of the grassed area: 15.8 m and 17.2 m cross-section length, 1055 m and 356 m centerline length, 9.4 and 12.1% cross-section slopes, and 1.7 and 0.73% centerline slopes. Measured pollutant reductions were similar for both sites, which were 31-61% for total phosphorus and total nitrogen. Stagge (2006) on the other hand, obtained variable removal capabilities ranging from -1% to 60% for nutrients such as nitrate, TKN and total phosphorus.

Another study of swales adjacent to a highway in Florida by Yousef et al. (1987) reports lower removal efficiencies than Barrett et al. (1998). It recorded that TP removal efficiency was 25 and 30% for swales at Maitland and EPCOT, respectively. In the same study, nitrogen removal is also low; averaging 11 and -7% respectively. The poor performance for soluble materials is due to the relatively high hydraulic loading in these study sites and therefore, the swales has less time for infiltration, filtration and deposition of the pollutants to occur. However, having a high infiltration rate can allow a significant impact on the removal efficiencies since Krecher et al. (1983) measured removal rates over 99% for total phosphorus (TP), total kjeldahl nitrogen (TKN) and total nitrate (TN). The grass swale received stormwater from a residential subdivision in Florida.

From Figure 2-3, it is clearly shown that removal of TN and TP for the grass swale in Brisbane is not flow-dependent compared to the TSS removal in the same study. However, this is not the case for natural conditions specifically for TP, since according to Ball et al. (1998), most of TP will be attached to fine sediment. Therefore, the higher the flow rate, the harder the pollutant to be removed from the swale and vice versa. In other words, to enhance the physical removal processes for phosphorus, dense vegetation should be used so that the orthophosphate that is already bound to the suspended sediment within the stormwater will be removed by the physical processes. On the other hand, the results of TN in Figure 2-3 are more acceptable since TN is often found to be in more soluble form in nature (Deletic et al. 2006).

2.3.3 Chloride (Cl)

Currently, there is no literature that compares the removal of chloride by grass swales. However, chloride is still a major source of pollutant in stormwater runoff especially during snow events and the snow-melting seasons. This agrees with results obtained by Stagge (2006) where chloride was actually being exported at a significant level (216 – 499 mg/L) by the swales, especially during the winter season and snow-melting season. Chloride adversely affects soil fertility by impacting soil structure and water transport through the soil (Marsalek 2003). This agrees with Amrhein et al. (1992) where sodium ions (Na^{+}) may replace Ca^{2+} and Mg^{2+} cations and leach out trace metals that may contaminate the groundwater.

2.3.4 Heavy metals (copper (Cu), lead (Pb), zinc (Zn) and cadmium (Cd))

Unlike organic compounds, the removal of metals from runoff is important since they are not degraded in the natural environment. According to the study by Sansalone et al. (1997), metals in urban roadway stormwater are either in the dissolved form or particulate bound. Metals that are mainly in dissolved form are Zn, Cd, and Cu while Pb is mainly particulate bound.

Kayhanian et al. (2007) analyzed highway runoff quality in California and concluded that generally, large proportions of most metals are bound to particulate matter in runoff. Lead has the highest proportion present as particulates (83%). This agrees with Sansalone et al. (1997) where lead was found mainly particulate bound. Arsenic, cadmium, chromium and zinc are between 60 and 65% in the particulate fraction and followed by copper and nickel between 50 and 55%. Therefore, lead, cadmium, chromium and zinc are expected to be highly removed since at least 50% of these metals can be effectively removed from runoff by targeting the particulate fraction. The colloidal binding effect will also help to enhance the removal. Colloidal binding is defined as the process where the metals complex or bind with inorganic or organic components of the suspended solids or natural organic matter. The complexation can affect the movement of the metals in the environment. For example, zinc usually had a higher removal tendency compared to copper since colloidal binding for zinc is lower than copper (Jensen et al. 1999). In other words, it is easier to remove zinc because copper has a high affinity to bound to dissolved organic complexes and colloids. Elliott et al. (1986) and Narwal and Singh (1995) also observed greater sorption affinity for Cu than for Zn on different types of mineral soils with varying amounts of organic compounds under acidic conditions.

They also found out that increased levels of organic compounds limited the mobility of both metals, especially Cu.

Furthermore, Yousef et al. (1987) indicates that the removal of metals by swales will be greater for species that are present as charged ions. In this case, adsorption onto particles is the important removal mechanism. The particles are subsequently removed by sedimentation.

The metals EMC values vary between each study. For example, Barrett et al. (1998) measured reductions of 68-93% for Zn and Fe; 68-93% for Pb. Stagge (2006) obtained lower reduction, between 30-40% for Zn, 3-11% for Pb and 6-28% for Cu. Kretcher et al. (1983) measured a removal rate over 99% for Pb. The high reduction was due to high infiltration rates on the site. The study at the Sodra Hamnleden site (Backstrom 2002b), also had Zn as the highest removal rates. However, the swale at Sodra Hamnleden site acted as a source for Cu, Pb and Zn during low influent concentration events. Specifically for Cu, the concentrations of total and dissolved copper were lower in the road runoff compared with swale runoff for all events. The EMC values for dissolved copper were two to four times higher in swale runoff than in road runoff. In this case, a pool of colloidal copper must had accumulated in the swale prior to the research and was released from the swale during the study. Again, this result reinforces the fact that Cu had a high tendency to bind with organic matter in the soils and tends to be released throughout time.

Seasoned variations also affect the removal efficiency of metals by grass swales. The study by Backstrom (2003) at three grassed swales in central Lulea, Sweden during the melt period (March-April) 2000 indicates that total metals are retained to a large degree in a snow-covered swale (78-99% removal). The results of the study are in Table 2-2.

Table 2-2. pH, suspended solids (SS) and metal concentrations in snow and snowmelt in 3 roadside swales in Lulea (March-April 2000) (Backstrom 2003).

				Total			Dissolved		
		pH	SS (mg/l)	Cu (μg/l)	Pb (μg/l)	Zn (μg/l)	Cu (μg/l)	Pb (μg/l)	Zn (μg/l)
Site A Bodenv.	Snow	6.91	1,800	214	212	525	4.78	0.177	13.6
2000–03–29	Melt water	6.89	13	15.3	2.44	33.4	7.00	0.105	18.0
	Reduction	–	99%	93%	99%	94%	–46%	41%	–32%
Site B Hertsöv.	Snow	6.69	1,000	83.7	55.9	275	1.43	0.137	13.5
2000–04–10	Melt water	6.70	12	5.00	1.93	60.5	1.84	0.097	56.7
	Reduction	–	99%	94%	97%	78%	–29%	29%	–320%
Site C Lulsundet	Snow	6.99	5,400	520	189	1240	2.00	0.143	6.37
2000–04–10	Melt water	7.03	240	21.9	7.43	72.8	3.28	0.090	16.0
	Reduction	–	96%	96%	96%	94%	–64%	37%	–151%

2.4 Performance of Grass Swale with Check Dams

Addition of check dams on grass swales could attenuate the runoff flow, provide ponding behind the check dams and further enhance infiltration and settling by temporarily blocking the flow of water. These will eventually promote pollutant removals. At this point, very limited information is available looking at the effects of check dams on swale performance.

A study by Kaighn and Yu (1996) shows that pollutant removal was impacted more by the presence of check dams rather than changes in slope. The study was done between grass swales with check dams and grass swales without check dams, but having equal length and having different slopes. Yousef et al. (1985) also agrees that incorporating check dams in swale design would have a significant impact on pollutant removal performance.

Furthermore, the study by Yu et al. (2001) consists of field tests on grass swales in Taiwan and Virginia. In Taiwan, the swale is 30 m long with a 1% longitudinal slope. It has a midpoint triangular weir that acts as check dam. The test was done with and without the midpoint check dam by using synthetic runoff. In Virginia, the swale is 274.5 m long, 3% longitudinal slope and check dams at 175 m and 237.5 m from swale inlet. The swale is known as Goose Creek swale (GC) and it receives runoff from State Route 7. The results of both sites are listed in Table 2-3.

Table 2-3. Pollutant mass removal for total suspended solids (TSS), chemical oxygen demand (COD), Total nitrogen (TN) and Total Phosphorus (TP) (Yu et al. 2001).

	Experiment	Length (m)	Mass Removal (%)			
			TSS	COD	TN	TP
TA	check dam	15	75.2	55.7	24.2	41.2
	outlet	30	69.7	62.9	20.9	76.9
TB	check dam	15	74.4	48.0	13.6	34.0
	outlet	30	86.3	45.6	23.1	58.1
TC	outlet	30	47.7	33.9	20.0	50.3
TD	outlet	30	67.2	42.7	13.8	28.8
GC	upper	238	29.7	NT	NT	73.4
GC	lower	99	97.2	NT	NT	96.8
GC	entire swale	274.5	94.0	NT	NT	98.6

Note: "T" designates Taiwan Swale; "GC" designates Virginia Swale; NT = not tested.

From Table 2-3, four scenarios (TA, TB, TC and TD) were tested on the Taiwan swale. TA and TC were conducted at a higher flow rate (4.0 x 10^{-3} m^3/s) and TB and TC are conducted at lower flow rate (0.9 x 10^{-3} m^3/s). For both flow rates, the mass removal at the outlet with the check dam is higher compared to the outlet without any check dam. However, the lower flow rate scenario produced higher mass removal since the detention time is almost double compared to the higher flow rate. This shows that the check dam helps to remove the pollutants since it increased the detention time and allowed more time for the runoff to be filtered by the grass and infiltrate into the soils that eventually reduced the runoff volume.

For the results from the Virginia swale, it seems that the lower section and the entire swale showed better performance compared to the upper section. This shows that the length of the swale and the number of check dams play an important role in increasing mass removals.

Besides that, the Virginia swale was also able to infiltrate larger volumes of runoff compared to other swales. With the presence of two check dams and the long swale, complete captured events will occur for storms less than approximately 12.7 mm total precipitation. However, for a shorter swale (30 m), complete captured events will occur from storms with less than 5 and 7 mm total precipitation (Kaighn and Yu 1996).

2.5 Grass swale specification design for pollution control

There are a few important parameters of grass swale that could help to increase the performance of the swale. Those parameters are: swale length, slope, flow velocity and residence time. Moreover, from Section 2.4, it is clearly shown that by incorporating check dams in the grass swale design, it will help to increase the swale performance. Ferguson (1998) proposed some empirical design criteria such as the water velocity should be less than 0.15 m/s, swale length should be at least 60 m and residence time in the swale should be at least 9 minutes. Furthermore, Yu et al. (2001) combined results of eight studies in the literature to demonstrate the theoretical relationship between swale design characteristics and pollutant removal of TSS and TP (Urban Best Management Practices 1994, 1996; Yu et al. 1994; Kaighn and Yu 1996). Both pollutants were chosen since usually regulations are written in terms of sediment and phosphorus removal.

Figure 2-5 shows that the rate of removal reaches a plateau when swales are longer than approximately 75 m regardless of slope. However, having a maximum longitudinal slope of 3% will produce removal efficiency more than 50%. In Figure 2-6, TP shows no trend between length and slope. This reemphasis the fact that swales generally are not considered efficient for nutrients removal.

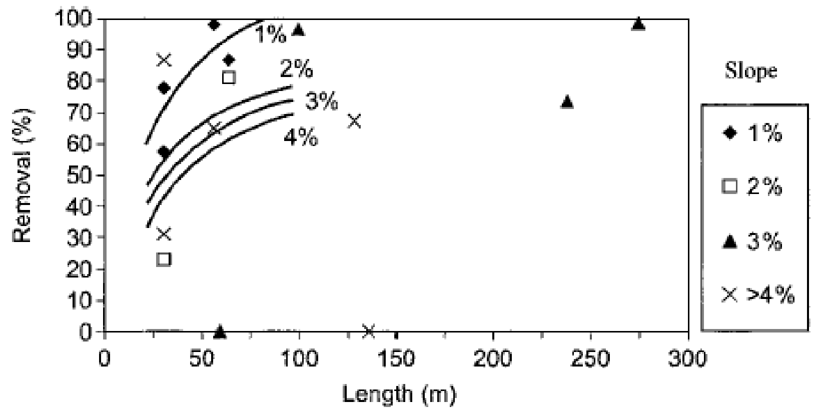

Figure 2-5 The relationship between swale total suspended solids removal efficiency, length and slope (Yu et al. 2001). *Curves are meant to show estimated trends.

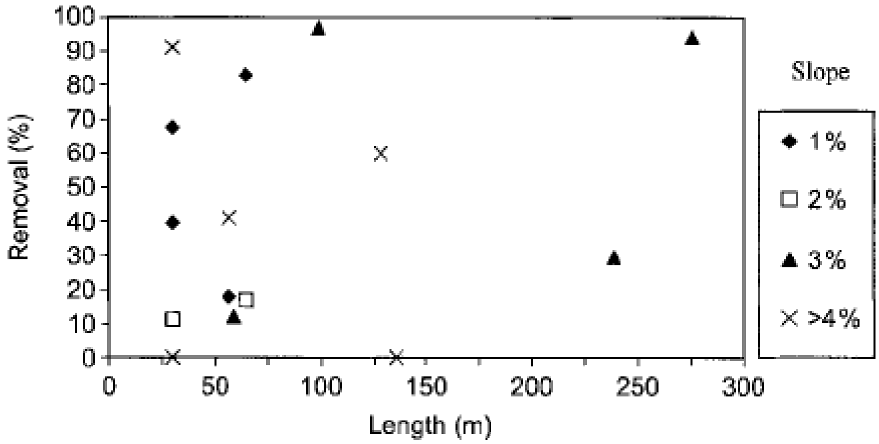

Figure 2-6 Relationship between swale total phosphorus removal efficiency, length and slope (Yu et al. 2001).

Regarding the residence time factor, there is no clear break point time at which the swale will perform the best, but we do know that the particle trapping efficiencies increased exponentially with residence time (Yu et al. 2001).

Interestingly, the ratio between swale area and contributing impervious area could also predict the removal (%) for suspended solids and zinc. The results combination from the full-scale study at Sodra Hamnleden, together with results from three roadside grassed swales in USA (Barrett et al. 1998) and Canada (Lorant 1992) concluded that the ratio should approach 1 in order to have high pollutant removals (>75%) for suspended solids and zinc (Backstrom 2003).

2.6 Pollutant mass loads during rain events.

Pollutant mass loads are another parameter that is more useful than pollutant concentration (EMCs), since it gives more insight on the long-term performance of a grassed swale area rather than each individual event. For example, at the Sondra Hamnleden site, the overall mass load reduction for suspended solids was 70% even though negative removals were observed during several rain events (Table 2-4). The calculations are based on four rain events with a total precipitation of 47.4 mm. Copper and zinc had a lower overall mass load reduction compared to suspended solids, which are 34% and 66%, respectively.

Table 2-4. Total mass flows of water and pollutants at Sodra Hamnleden site (Backstrom 2003).

	Water (m^3)	Suspended solids (kg)	Copper Total (g)	Copper Dissolved (g)	Zinc Total (g)	Zinc Dissolved (g)
From road to swale	19	2.1	0.56	0.11	2.2	0.59
From swale to recipient	8.7	0.63	0.37	0.15	0.73	0.20
Load reduction (%)	54	70	34	−27	66	66

2.7 Toxicity of urban highway runoff with respect to storm duration.

It is important to know the toxicity of urban highway runoff with respect to storm duration, especially to the aquatic species in the receiving water body. Kayhanian et al (2008) indicated that toxicity varies throughout the storm events for both freshwater and marine species toxicity tests. In the same study, Kayhanian et al (2008) found that generally the concentrations of dissolved and total copper and zinc are substantially higher during the early portion of the runoff, which correlates well with the observed first flush toxicity effects. Furthermore, Kayhanian et al (2008) identifies a method published by USEPA called Toxicity Identification Evaluations (TIEs) which basically identifies toxicity in water. The results for TIEs in this study indicated that copper and zinc are the primary cause of toxicity in about 90% of the samples evaluated with these procedures. In some cases, the greatest degree of toxicity was observed during the early stages of a storm event when lower runoff volume was discharged. The study also found out that in most cases, more than 40% of the toxicity was associated with the first 20% of discharged runoff volume and on average, 90% of the toxicity was observed during the first 30% of storm duration.

The study by Stagge (2006) shows that although the input runoff shows high initial concentrations of zinc and copper, when analyzed in terms of first flush mass delivery, it is nearly constant for both metals. This suggests that dissolved zinc and copper are the predominant species initially and therefore, both metals do not exhibit first flush trends.

Chapter 3

METHODOLOGY

3.1 Site Description

The research site has been constructed on Maryland Route 32 near Savage, Maryland – Exit 38A (I-95N). It is located just south of the Vollmerhausen Road over pass (Figure 3-1). The site consists of two individual swales with different designs but nearly identical roadway drainage areas. The monitoring location is the same as the previous study by Stagge (2006), where the two swales are constructed in the median of a four-lane (two in each direction) limited access highway which receives runoff laterally from the southbound roadway lanes (Figure 3-2). The only condition that differs from Stagge's (2006) study is that two check dams are installed within each of the swales.

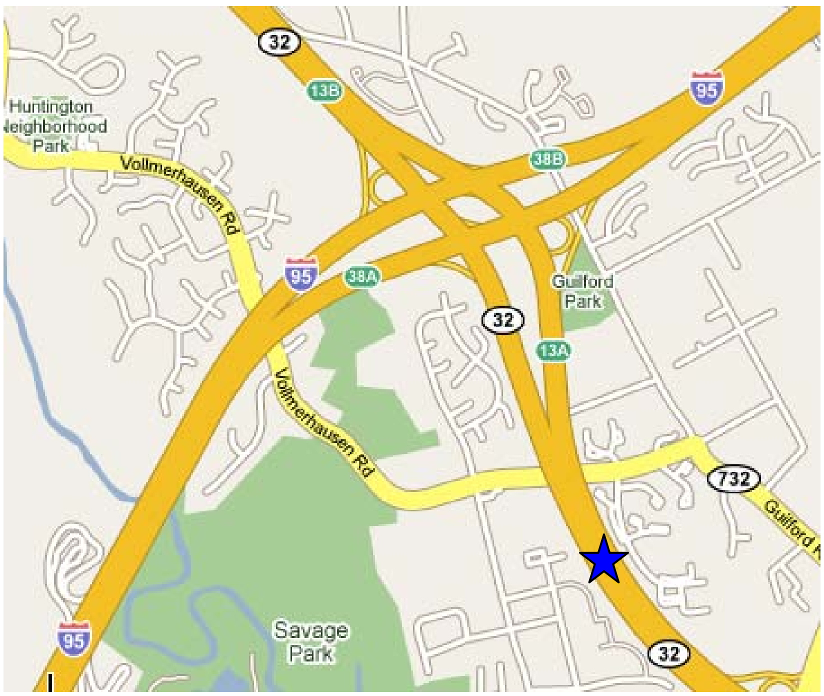

Figure 3-1. Route 32 grass swale research site (credit to: www.maps.google.com).

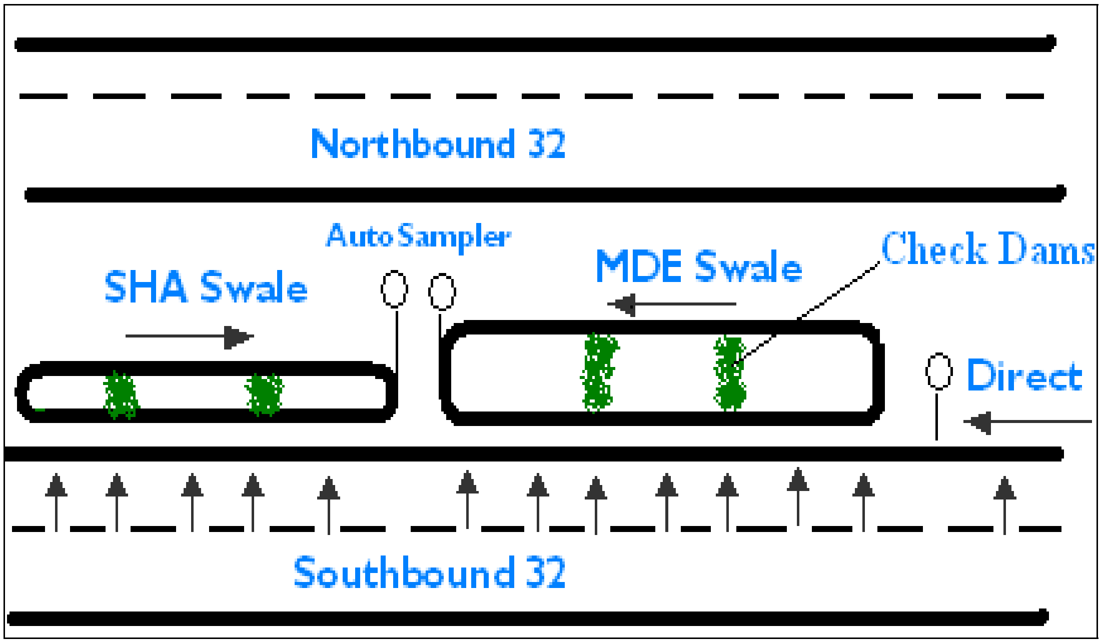

Figure 3-2. Diagram of site layout (Maryland Route 32). The arrows represent the highway runoff.

Each check dam was installed using three staggered row of Panicum Virgatum 'Heavy Metal', a sturdy plant that will remain standing either in heavy rain or snow. There were planted 12 inches (0.31 m) on center with 26 plants total. All check dams were constructed with identical cross-section design with a 2 ft (0.61 m) bottom width and side slopes of 3:1 and 4:1 on either side of the swale. Each check dams is 3 feet wide. Figure 3-3 shows typical sections of the check dams that were installed on the swales.

The vegetation covers that were used for the grass swale and the pretreatment area consist of 90% tall fescue, 5% Kentucky bluegrass and 5% perennial ryegrass. The top soils of the swales had an organic content between 1.5-10% by weight and a pH value between 6.0 and 7.5. The grading distribution of the soil (by weight) is 20-75% sand (2.0-0.05 mm), 10-60% silt (0.050-0.002 mm) and 5-30% clay (less than 0.002 mm).

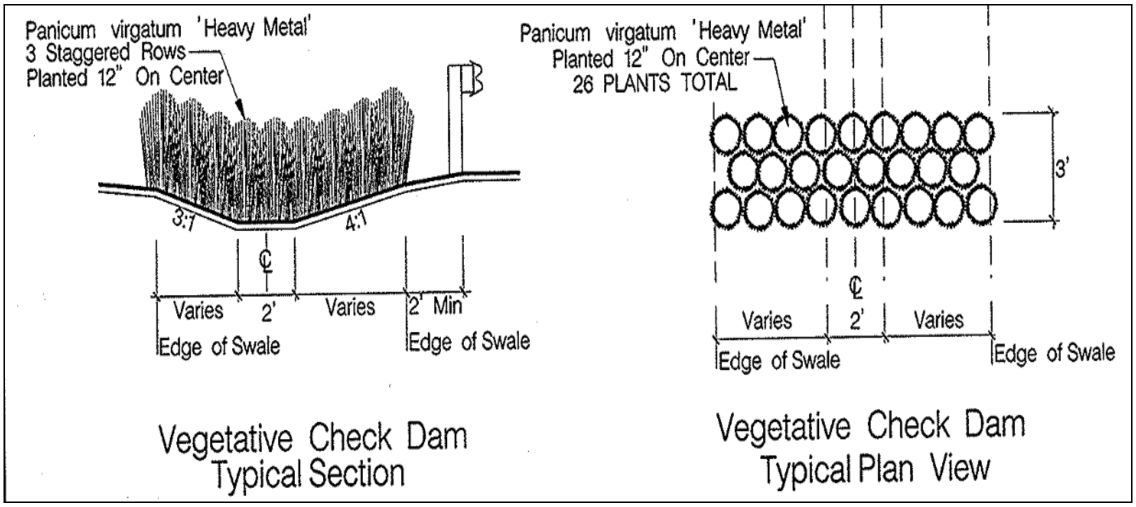

Figure 3-3. Vegetative check dam typical section (Maryland Route 32).

The first swale is constructed based on Maryland Department of the Environment (MDE) guidelines, with a sloped filter strip between the roadway and the swale channel. The filter strip is 15.2 m wide with a 6% slope on the southern side of the MDE swale. The distance between the two check dams on MDE swale is about 60.5 m (199 ft).

The second swale, to the north, known as the SHA swale was identically constructed but without the pretreatment area. The distance between the two check dams on the SHA swale is about 59.8 m (196 ft).

The third sampling area is a concrete channel that collects runoff sample directly from the highway located south of the swales. By having this third sampling point, instantaneous flow input and water quality from the highway surface can be obtained for comparing performance purposes.

All three sampling points had essentially identical roadway drainage areas. Specific design characteristics for those sampling points are listed in Table 3-1. These characteristics are similar with Stagge (2006) except for swale area for the SHA. Both grass swale area were checked and it seems that the swale area for SHA is 0.312 ha instead of 0.169 ha. Therefore, the new area is used for all the calculations. Figure 3.4 – 3.6 present photos of the swales with check dams.

Table 3-1. Design characteristics for three sampled channels.

	Direct	**SHA Swale with Check Dams**	**MDE Swale with Check Dams**
Roadway Area (ha)	0.271	0.224	0.225
Swale Area (ha),A_s	0	0.312	0.431
Total Area (ha),A_T	0.271	0.393	0.656
Channel Material	Concrete	Grass	Grass
Channel Slope	0.2%	1.6%	1.2%
Channel Length (m)	168	198	137
Pretreatment Slope	-	-	6%
Pretreatment Width (m)	-	-	15.2 (from roadway to channel center)

Figure 3-4. Vegetated Check Dams on SHA Swale, Maryland Route 32 (August 2007)

Figure 3-5. Vegetated Check Dams on MDE Swale, Maryland Route 32 (October 2007).

Figure 3-6. Close up of Vegetated Check Dams on MDE Swale, Maryland Route 32 (after storm event) (December 2007).

3.2 Monitoring Equipment and Protocol

Sampling occurs at a 125° V-notch wooden weir located at the end of each swale and the concrete channel. The flow rates were recorded by ISCO Model 6712 Portable Samplers and rainfall data was recorded by an ISCO 674 Tipping Bucket Rain Gauge with 0.0254 cm sensitivity in 2 minutes increments. Details of the sampler can be found in Stagge (2006). Table 3-2 indicates the sampling time for each sampling point with an emphasis on collecting more samples in the early portion of the storm event. However, the direct sampling was lengthened accordingly since there are a few hours of time lag before grassed swales trigger due to initial abstraction and infiltration.

Table 3-2. Sampling times for storm events at Route. 32

	Time Frame	
Sample	**Direct**	**Both Swales**
1	zero minutes	zero minutes
2	20 minutes	20 minutes
3	40 minutes	40 minutes
4	1 hour	1 hour
5	1 hr 20 min	1 hr 20 min
6	2 hr	1 hr 40 min
7	2 hr 40 min	2 hr
8	3 hr 20 min	2 hr 20 min
9	4 hr 20 min	2 hr 40 min
10	5 hr 20 min	3 hr 40 min
11	6 hr 20 min	4 hr 40 min
12	8 hr	6 hr

In August 2007, the housing of the portable sampler for the SHA swale was hit in an accident and the new housing was installed on site in September 2007. However, in order to avoid another accident, both samplers (SHA swale and MDE swale) were installed closer towards the southbound lanes of Route 32 rather than the northbound lanes. Nonetheless, this does not affect sampling data.

All samples were collected within 24 hours of a storm event and transported to the Environmental Engineering Laboratory, College Park, MD. TSS and nutrients analyses are immediately processed; 100 mL of sample was preserved for metal analyses using six drops of concentrated trace level HNO_3 and a 200 mL sample was preserved for TKN analysis using 12 drops of concentrated H_2SO_4. Metal digestion was completed within two weeks and analyses were carried out within 6 months.

3.3 Analytical Methodology & Procedures

All analyses were performed according to Standard Methods (APHA et al. 1995). Tables 3.3 summarize the analytical methods that were used to determine the pollutant concentration from highway runoff on Route 32 during storm events and the detection limit of each method. Further details can be found in Stagge (2006).

Table 3-3. Summary of the Analytical Method and detection limit for each analysis

Pollutant	Standard Method (APHA et al. 1995)	Detection Limit (mg/L)
Total Suspended Solids (TSS)	2540 D	1
Total Phosphorus	4500-P	0.24
Total Kjeldahl Nitrogen (TKN)	4500-N_{0rg}	0.14
Copper	3030 E	0.002
Lead	3030 E	0.002
Cadmium	3030 E	0.002
Zinc	3030 E	0.0025
Chloride	Dionex DX-100 ion chromatograph	2
Nitrate	Dionex DX-100 ion chromatograph	0.1 as N
Nitrite	4500-NO_2^- B	0.01 as N

3.3.1 Total Suspended Solids (TSS)

Standard Method Section 2540 D (APHA et al. 1995) was used to analyze TSS. Glass-fiber filters with 47 mm diameter (Pall Corporation) and the aluminum dish were pre- weighed. 70 mL from each sample were filtered through the glass fiber filter, placed on the aluminum dish and left to dry in the oven for 24 hours (103^o – 105^o). Then, both the dried filter and the aluminum dish were weighed again to determine the total suspended solids.

3.3.2 Phosphorus

Standard Method Section 4500-P (APHA et al. 1995) was used. This analysis consists of two parts: 1) Persulfate Digestion Method 2) Stannous Chloride Method. The first part is critical since it converts all forms of phosphorus into dissolved orthophosphate. The second part determines the concentration of the dissolved orthophosphate by a colorimetric method. Ammonium molybdate was used since it reacts under acid conditions to form molybdophosphoric acid. It was then reduced by stannous chloride to intensely colored molybdenum blue. Finally, the intensity of the blue colored molybdenum was measured using a Shimadzu model UV160U spectrophotometer at 690 nm. Samples absorbances were compared against absorbance obtained from the standard concentrations of 0.24, 1.2 and 3 mg/L as P. All standards were prepared by using 1000 mg/L stock solution (Fisher Scientific).

3.3.3 Nitrite

Standard Method Section 4500-NO_2^- B (APHA et al. 1995) was used. It is a colometric method where a reddish purple azo dye color develops upon mixing the filtered samples with the indicating reagent. The absorbance of each sample was measured spectrophotometrically (Shimadzu model UV160U) at 543 nm. Samples absorbances were compared against absorbance obtained from the standard concentrations of 0.02, 0.08, 0.12, 0.24 mg/L as N. All standards were prepared by using 1000 mg/L stock solution (Fisher Scientific).

3.3.4 Nitrate and Chloride

Both analyses were performed using a Dionex ion chromatograph (model DX-100) via injection of 5 mL of sample into a 1.3 mM sodium carbonate/1.5 mM sodium bicarbonate eluent. Samples were compared against standard concentrations of 0.2, 0.4, 1.0, 1.4, 2.0 mg/L as N and 1, 3, 5, 8 mg/L Cl^-. All standards were prepared by using 1000 mg/L stock solution of nitrate and chloride.

3.3.5 Total Kjeldahl Nitrogen (TKN)

Standard Method Section 4500-N_{org} (APHA et al. 1995) was used. The Kjeldahl method determines nitrogen in the trinegative state and the term "Kjeldahl nitrogen" was applied to the results because ammonia nitrogen was not removed in the initial phase of the analysis. Three main steps were involved: 1) digestion of the sample 2) distillation of the digested sample 3) titration of the distilled sample. .

3.3.6 Cadmium, Copper, Lead and Zinc

Standard Method Section 3030 E (APHA et al. 1995) was used. First, 100 mL samples were digested using nitric acid digestion. Then, cadmium, copper and lead were analyzed on the furnace module of a Perkin Elmer Model 5100 ZL (Zeeman Furnace Module) atomic absorption spectrophotometer. Zinc was analyzed on the flame module of the same instrument. Standard concentrations that were used for the furnace model range from 4 μg/L to 50 μL and for the flame model range from 0.05 mg/L to 0.7 mg/L.

3.4 Quality Assurance (QA) and Quality Control (QC)

All glassware was acid washed with 0.1 M HNO_3 and cleaned using deionized water. Field blanks were collected once every 4 monitored storms in order to make sure that no contamination occurred on site that can affect the samples. Blanks were created by pouring deionized water in a cleaned bottle at the time of sample collection and the exact same analyses were run on the field blanks for all pollutants. Results of those blanks were low enough to be considered negligible for the samples.

In order to check the calibration curves for all of the analyses, standard concentrations were checked regularly. In cases where the data were below the method detection limit (MDL) (Table 3.3), the constituent will be indicated as having less than the detection limits when listed and if any statistical procedures are involved; half of the detection limit is used. This agrees with the US EPA recommendation where if less than 15 percent of all samples are nondetected, the MDL/2 approach should be used; but these simple substitution methods tend to perform poorly in statistical test when the nondetect percentage is substantial (Gilliom and Helsel 1986).

3.5 *Flow Calculation*

Swale flows were monitored by using a bubble flow meter that records the depth behind a thin wooden plate V-notch weir at each sampling point. For accuracy purposes, the bubbler modules were zeroed before every storm to ensure the same datum was used for every storm. Usually the height measurement showed minimal variation with time. The sampler is triggered when the water behind the weir reaches 0.1 ft. At that point, the sampler will be enabled, flow measurement will be recorded and samples will be collected. According to ASTM standards (2001), the flow rate over a triangular weir is determined by:

$$Q = \frac{8}{15}(2g)^{1/2} C_e \tan(\frac{\theta}{2})(H_e)^{5/2} \qquad (3\text{-}1)$$

where C_e = discharge coefficient

H_e = effective head

g = gravity

Θ = angle of the V-notch

Effective head, H_e, is the measured water head above the weir notch (in meters) plus adjustment for the combined effects of viscosity and surface tension for water at ordinary temperatures (4 to 30°C). In this study, the adjustment is considered negligible and therefore can be neglected since the angle of the V-notch is large (ASTM 2001). Each V-notch weir angle is 125° and a C_e value of 0.585 (ASTM 2001) was used for all calculations. With that, equation 3-1 simplifies to be:

$$Q_{weir} = 2.65 H_e^{5/2} \qquad (3\text{-}2)$$

The design criteria (ASTM 2001) recommend measuring the head, H_e at a distance of 4 times the maximum head in order to eliminate the drawdown effect and to ensure that the velocity head is negligible. Due to physical limitations, the location of the bubble line where the head was measured is located exactly adjacent to the weir. Therefore, Stagge (2006) developed a relationship between head at the weir, H_{weir} and H_e by using Bernauli's equation and the physical geometry of the weir opening. As a result, the calculated flow through the weir is:

$$Q = 2.65(1.2276 H_{weir})^{5/2} \qquad (3\text{-}3)$$

By using the method of estimating the total percentage error of a flow measured by a V-notch in ASTM 2001, Stagge (2006) found that the estimated error for this study is 3%.

3.6 Hydrology Data Evaluation and Calculations

A mass balance and a flow balance around the swale are used as tools to accurately model the hydrology and pollutant concentrations within the swales. Both mass and flow input output varies with respect to time. The flow balance and mass balance are pictured in Figure 3-7.

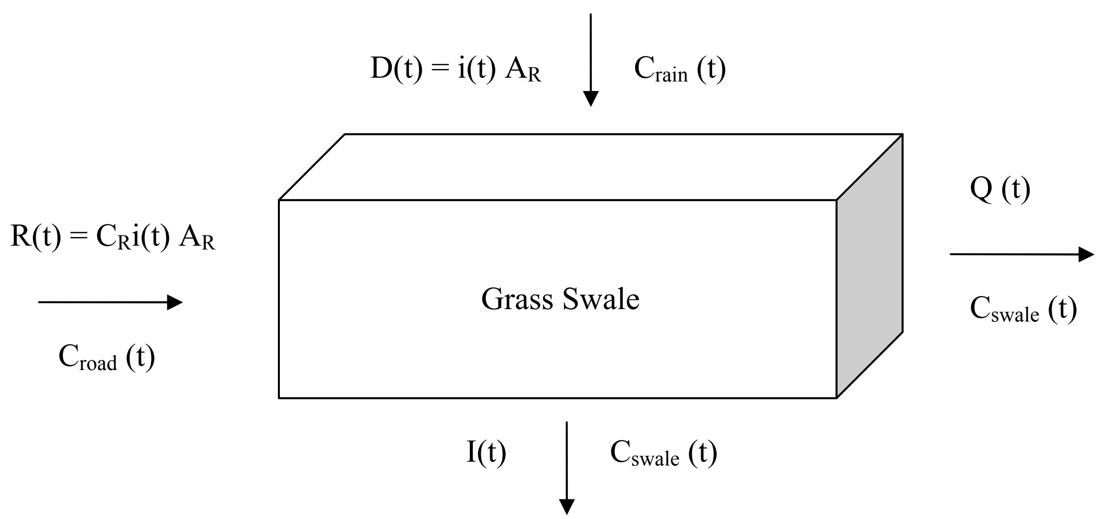

Figure 3-7. Grass swale mass and flow balance model.

where,

$D(t)$ = Flow from rainfall directly into swale (L/s)

$Q(t)$ = Flow leaving the swale (L/s)

$I(t)$ = Infiltration into the swale media (L/s)

R(t) = Runoff from the highway (L/s)

C_R = Highway runoff coefficient

i (t) = Rainfall intensity (m/hr)

A_R = Drainage area of the roadway surface (m^2)

C_{rain} (t), C_{road} (t), C_{swale} (t) = Pollutant concentration in the rainfall, roadway flow and swale

From Figure 3-7, the flow balance (Equation 3-4) around the swale is derived:

$$R(t) + D(t) - I(t) = Q(t) \tag{3-4}$$

3.6.1 *Infiltration through the swale*

In this study, one of the swale inputs is from direct precipitation of rainfall on the swale. For comparison purposes, it is important to exclude the rainfall on the swale from the discharge of the swale. Without subtracting the rainfall on the swale, there will be differences in the input flows for each channel due to the differences in total drainage area causes by the additional area of the swales. By excluding the rainfall, direct comparison can be made between the quality and quantity of the highway runoff collected at the three sampling points since we are assuming that the grass swale receives water only from roadway surfaces. Therefore, we need to take into account how much water from the rainfall infiltrates into the ground and how much becomes runoff that goes out as the flow of the swale. Infiltration through the swale will start soon after the rain starts, up to the point where the ground is saturated. At that point, any rainfall that falls on the swale will become overland flow. This phenomenon is called saturation-excess overland flow and can be derived from the Horton equation. The amount of water that infiltrates into the ground is called the maximum infiltration capacity, given by the Horton equation (Hornberger et al. 1998):

$$f_{\max} = f_c + (f_o - f_c)e^{-t/K} \tag{3-5}$$

where,

f_{max} = maximum infiltration capacity of the soil

f_o = initial infiltration capacity

f_c = final infiltration capacity

t = elapsed time from start of rainfall

K = decay time constant

In this study, the maximum infiltration capacity of the soil, f_{max} is obtained from the relationship between the total rainfall depth for 23 storm events and duration of the storms. Among these 23 storm events, only 13 events produced flow from the swales and the remaining 10 events are considered complete captured events since no swale flow was produced. Complete captured events also indirectly indicate that all rainfall infiltrates into the swale. Therefore, the relationship between the rainfall depth and duration for the complete captured events will provided the threshold amount of rainfall that can be infiltrated into the swale (f_{max}). Any rainfall above the threshold was considered as overland flow which eventually will be part of the swale flow that needs to be excluded from the discharge of the swales. Details about this relationship are discussed further in Section 4.2.1.

3.6.2 *Total grass swale discharge, Q_{swale} (Effective Flow)*

The grass swales discharge consists of the direct rainfall on the swale and the runoff from the highway. However, the direct rainfall will only be part of the discharge after the cumulative rain depth for that specific storm reaches the maximum infiltration capacity of the soil, f_{max} calculated from Equation 3-5. The additional rain after that point is assumed as overland flow (L/s) which is calculated by:

$$Q_{overlandflow} = i(t) * A_s \tag{3-6}$$

The swale area, A_s for SHA is 0.312 ha and for MDE is 0.431 ha. Since the rainfall is continuous and the rain gauge reading is collected every 2 minutes, it is hard to calculate the instantaneous rainfall flow at a specific moment. Therefore, $Q_{overlandflow}$ is calculated by using a moving average flow where the rainfall (i(t)) is combined into 10 minutes intervals. In other words, the i(t) is the average rainfall intensity for every 10 minutes. By this way, it also helps to smooth the hydrograph.

Typically, there is a lag time between the peak of the rain and the peak flow of the swale. This is because the rainfall and the highway runoff need time to travel through the swale before it reaches the weir, and from a few observations of the storms, it takes about 10 minutes for the water to travel through the swale and reach the weir. In other words, the travel time is assumed to be 10 minutes. Therefore, the $Q_{overlandflow}$ is lagged for 10 minutes before being subtracted from the flow calculated by the weir from Equation 3-1. The result is called the total grass swale discharge, Q_{swale}:

$$Q_{swale} = Q_{weir} - Q_{overlandflow} \tag{3-7}$$

This method only allows comparison of inflow and outflow with respect to time but it does not allow any instantaneous analysis of infiltration. Besides, the threshold line for infiltration capacity obtained is only valid for the duration of storms that are covered in this study (up to 12 hours). For simplification purposes, Q_{swale} will be referred as Effective Flow in the discussion later.

3.6.3 *Total storm volume*

The total storm volume for the direct runoff and the swales are calculated by integrating the flow over the storm duration:

$$V_{direct} = \int_0^{T_d} Q_{weir}(t)dt \tag{3-8}$$

$$V_{swale} = \int_0^{T_d} Q_{swale}(t)dt \tag{3-9}$$

Where V represents the total volume (L) and T_d represent the duration of the storm event.

3.7 Pollutant Data Evaluation and Calculations

The mass balance around the grass swale is important in order to evaluate the water quality of the highway runoff. The mass balance includes pollutant concentration as a function of time (Figure 3-7, Equation 3-4):

$$R(t)C_{road}(t) + D(t)C_{rain}(t) - I(t)C_{swale}(t) + T(t) = Q(t)C_{swale}(t) \tag{3-10}$$

The term T(t) represents the grass swale treatment term that includes the sum of processes that occurs within the grass swale, such as sedimentation, filtration, absorption and resuspention of sediments or pollutants. A positive T(t) indicates an export of pollutants but a negative T(t) indicates removal of pollutants. For simplification, the pollutant concentration from the rainfall is assumed to be negligible compared to the pollutant from the roadway surface. Equation 3-10 is therefore simplified to:

$$R(t)C_{road}(t) - I(t)C_{swale}(t) + T(t) = Q(t)C_{swale}(t) \tag{3-11}$$

3.7.1 *Total mass load*

The total mass in the flow that is leaving the sampling points is calculated as:

$$M = \int_0^{T_d} Q_{weir} C dt \tag{3-12}$$

Where C represent the pollutant concentration either in swale flow or from the roadway. By taking the integral for each term in Equation 3-12, the total mass measured leaving the swale is:

$$M_{swale} = M_{road} - M_{\text{infiltration}} + M_{treatment} \tag{3-13}$$

3.7.2 *Event Mean Concentration (EMC)*

Event mean concentration is a statistical parameter representing the flow-weighted average of a desired water quality parameter during a single storm event (Wanielista and Yousef 1993). The concept behind this parameter is as if all runoff from the drainage area were collected in a large tank during a storm, the pollutant concentration in this tank would correspond to the EMC. In this study, sequential discrete samples are collected; the EMCs values are determined by calculating the cumulative mass of pollutant and dividing it by the volume of runoff (area under the hydrograph):

$$EMC = \frac{\int_0^{Td} C Q_{weir} dt}{\int_o^{Td} Q_{weir} dt} \tag{3-14}$$

Pollutant concentrations among various events are compared by using the EMC since it represents a single mean concentration. Both data from the current research and the previous research by Stagge (2006) will be compared using this parameter in order to see the benefits of having check dams on the swales.

3.7.3 *Effective Event Mean Concentration (E-EMC)*

Normalization of the event mean concentration is done in order to take into account the dilution effect of the rainfall onto the highway runoff. It is simply done by dividing the mass of the swale with the total volume of the swale after eliminating the excess rainfall:

$$E-EMC=\frac{Mass_{swale}}{Volume_{swale}-Volume_{rainfall}}=\frac{\int_0^{Td}Q_{weir}(t)C_{swale}dt}{\int_0^{Td}Q_{swale}(t)dt} \qquad (3\text{-}15)$$

Both EMC and E-EMC are important because EMC shows the actual field-based pollutant concentration that will impact the receiving water body while E-EMC describes the true removal capability of the swale by taking into consideration the dilution effects.

Since the direct channel has no impervious area, no dilution took place. Therefore, swale E-EMCs can be compared to the direct channel EMCs for water quality comparison purposes. Differences between the two represent the treatment process, T(t) of the swale.

3.8 Statistical Analysis

Statistical analyses are very important to clarify three hypotheses that are made for the study which are:

1st Hypothesis: A grass swale with check dams is making a statistically significant improvement on the hydrology or the water quality.

2nd Hypothesis: The inclusion of grass pretreatment area prior to the grass swale is making a statistically significant difference in the hydrology or the water quality.

3rd Hypothesis: Either grass swale with check dams is making a statistically significant improvement on the hydrology or the water quality compared to grass swales without check dams (Stagge 2006).

All data collected from the direct concrete channel are considered input and all data collected from the SHA and MDE swales are considered output. Direct comparisons are made since the highway drainage areas of the three sampling points are identical and all rainfall that falls directly on the swales is eliminated from the calculation. Comparisons are made between input and output in order to clarify whether the data collected fulfill the three hypotheses mentioned above.

3.8.1 *Overall Statistical Analysis Procedure*

Two tests are used to clarify the hypotheses: Dixon-Thompson Test and Mann-Whitney U Test. These tests are considered paired tests, where the values for each input and output for each storm event are paired in order to see the performance of the swales. Similar with Stagge (2006), all data collected from each storm events are considered as random populations and the data that can be compared in these tests consist of total mass, EMC, E-EMC, peak flow and total volume. Each of the tests will be further explain in Sections 3.7.2 – 3.7.4.

Table 3-4 summaries the list of tests performed to the paired variables, the purpose of each test and the hypothesis of each test.

Table 3-4. Summary of the statistical tests used to identify outliers and significant different between two populations.

Step	Test & Purpose	Hypothesis
1	***Dixon-Thompson Test*** - Identify and possibly remove outliers for both A_{CD} and B_{CD} (McCuen 2003)	H_o: All points are from the same population. H_a: The most extreme point is not from the same population.
2	**Wilcoxon-Mann-Whitney Signed-Ranks Test** - Determine if both data came from the same population. (Siegal and Castellan1988)	H_o: $\mu_{SHA\text{-}CD} = \mu_{DIRECT}$ H_a: $\mu_{SHA\text{-}CD} \neq \mu_{DIRECT}$ H_o: $\mu_{MDE\text{-}CD} = \mu_{DIRECT}$ H_a: $\mu_{MDE\text{-}CD} \neq \mu_{DIRECT}$ H_o: $\mu_{SHA\text{-}CD} = \mu_{MDE\text{-}CD}$ H_a: $\mu_{SHA\text{-}CD} \neq \mu_{MDE\text{-}CD}$ H_o: $\mu_{SHA\text{-}CD} = \mu_{SHA}$ H_a: $\mu_{SHA\text{-}CD} \neq \mu_{SHA}$ H_o: $\mu_{MDE\text{-}CD} = \mu_{MDE}$ H_a: $\mu_{MDE\text{-}CD} \neq \mu_{MDE}$

The first step is important for justification of the assumptions used for the second test. The information will be helpful if decisions need to be made on which test is more applicable in case of disagreement in the analyses. The second step compares the performance between the swales with check dams and also between the swales without any check dams from Stagge (2006). Further explanation on why these tests are chosen can be found in Stagge (2006).

3.8.2 *Dixon-Thompson Test for outliers*

The Dixon-Thompson test is used for detecting outliers on the extreme; either the highest or the lowest value. This test is suitable when the sample size (n) is between 3 to 25 observations. The data is ranked in ascending order, and then based on the sample size the tau (τ) statistic for the highest value or the lowest value is computed. The equations used to compute the tau statistic are tabulated in Table 3.5.

Table 3.5 Equations for calculating outliers in Dixon-Thompson Test (McCuen 2003).

Sample size, n	Highest Value Outliers Test	Lowest Value Outliers Test
3 to 7	$\tau = \frac{X_n - X_{n-1}}{X_n - X_1}$	$\tau = \frac{X_2 - X_1}{X_n - X_1}$
8 to 10	$\tau = \frac{X_n - X_{n-1}}{X_n - X_2}$	$\tau = \frac{X_2 - X_1}{X_{n-1} - X_1}$
11 to 13	$\tau = \frac{X_n - X_{n-2}}{X_n - X_2}$	$\tau = \frac{X_3 - X_1}{X_{n-1} - X_1}$
14 to 25	$\tau = \frac{X_n - X_{n-2}}{X_n - X_3}$	$\tau = \frac{X_3 - X_1}{X_{n-2} - X_1}$

The tau is then compared to a critical value (α) at 5% level of significance in McCuen (2003). If the tau is less than the critical value, the null hypothesis is not rejected and that point is not considered as an outlier. If the tau is more than the critical value, the null hypothesis is rejected and that point is considered as a candidate outlier. However, the outlier candidate can only be removed from the data set in this study if there is some physical reason for the abnormally high or low value, such as an abnormally intense storm. If the point is considered as an outlier, it is then removed from the data set.

3.8.3 *Wilcoxon-Mann-Whitney U Test*

Wilcoxon-Mann-Whitney U Test is a nonparametric test that was used in order to evaluate the significant difference between two populations. Table 3.4 list five main cases that are being evaluated. Below are the steps for the test:

1) Determine the value of *m*, *n and N*. The number of cases in the smaller group is *m* (denoted X); the number of cases in the larger group is *n* (denoted Y); total cases is *N*. Alpha (α) is set to be 5%.
2) Data from both groups are combined and sorted from lowest to largest, being careful that the identity of the data is retained and then these data are ranked in increasing order (1 to the score that is algebraically lowest). An average of the tied ranks is assigned for any tied observations.
3) Determine the sum of ranks in group X, W_x.
4) For large samples, m>10, n>10, the sampling distribution W_x approaches a normal distribution, with mean, variance and significant z value calculated as :

$$Mean = \frac{m(N+1)}{2} \qquad (3\text{-}16)$$

$$Variance = \frac{mn(N+1)}{12} \qquad (3\text{-}17)$$

$$z = \frac{W_x \pm 0.5 - Mean}{\sqrt{Variance}} \qquad (3\text{-}18)$$

5) If m<10 and n<10, the probabilities associated with the significant value, W_x is listed in the table in Siegal and Castellan (1988).

The critical value for the standard normal distribution (z) is found in the statistic table for a 5% level of significance. If the z calculated is larger than the critical z, the null hypothesis is rejected; both data came from different populations and therefore it implies that the grass, the pretreatment area, or the check dams are either successfully improving the hydrology and water quality parameter of the runoff or making the hydrology and water quality worse.

The statistical data such as the mean and the median for the direct and the swales will determines the significant difference of the swales for better or for worse.

3.9 Swale Performance Plots

Two types of plots are frequently used in this study: time based plots and probability plots. The time based plots are used for plotting rainfall, flow rates and constituent concentrations. These plots provide a better understanding of each specific storm event since the plots show delays in peak flow, delay of peak concentrations and differences in performance among the three sampling points.

On the other hand, probability plots are used to compare the distribution of the input (Direct) and the output (MDE-CD Swale and SHA-CD Swales). Comparisons are made between the data for current study and the data by Stagge (2006). Probability plots for peak flows and each pollutant were created by ranking the average value for each event from largest to smallest. The plotting position for each value on the probability scale, *p* was determined as:

$$P = \frac{i - \alpha}{(n + 1 - 2\alpha)} \tag{3-19}$$

where *i* represents the smallest number in sample of size *n* and α represents a constant that describes the plotting position function, selected as α =3/8 (Cunnane 1978). Therefore, for this study, the plotting position function for the probability plots is:

$$P = \frac{i - 0.375}{N + 0.25} \tag{3-20}$$

The best fit line for the data can be drawn and these lines are compared in order to draw conclusions for the swales performance. The x-axis will represent the probability and the y-axis will represent either flow or constituent concentration. All complete flow captured events, are plotted separately along the horizontal axis and therefore those data will not be considered in the best fit line.

Chapter 4

Results and Discussion

4.1 Field Sampling Description

Twenty four storm events were sampled and analyzed throughout the research duration, August 2006 to July 2008. One of the events (2/25/2007) was a snow event and therefore no rainfall data were collected. Among those 24 storms, 10 storms were considered completely captured where no flow output was measured from the swales. Tables 4-1 summarize all storm events.

Table 4-1. Rainfall depth and storm duration for Rt. 32 storm events. Storms with complete capture are shown in bold.

Date	***Total Rainfall (cm)***	***Duration (hr)***
4/4/2007	1.02	5.3
5/12/2007	**0.43**	**6.3**
5/16/2007	1.83	1.7
6/3/2007	2.26	10.3
7/4/2007	1.65	6.0
9/11/2007	**0.51**	**2.5**
10/19/2007	**1.17**	**11.0**
10/24/2007	**0.69**	**11.5**
11/13/2007	**0.23**	**1.3**
12/2/2007	1.24	11.5
12/14/2007	2.06	8.3
1/10/2008	**0.23**	**6.5**
2/1/2008	2.24	12.0
3/4/2008	1.73	10.0
3/16/2008	1.02	6.6
4/3/2008	1.52	8.5
4/26/2008	1.07	6
5/16/2008	1.8	6.9
6/3/2008	1.4	8.2
6/10/2008	**0.51**	**0.17**
6/16/2008	**0.91**	**3.3**
6/30/2008	**0.2**	**0.67**
7/5/2008	**0.1**	**0.17**

In some cases, there were issues in getting a full complete pollutant data set due to technical problems on site and problems with laboratory equipment. Problems that occurred on site include check dam grass dying, check dam mowing, and a broken weir. In August 2007, the housing of the portable sampler for the SHA swale was destroyed in an accident and the new housing was installed on site in September 2007. Since this was the second accident at the site (the first time was when Stagge (2006) was working on the site), both samplers (SHA swale and MDE swale) were installed closer to the southbound lanes of Route 32 rather than the northbound lanes. Nonetheless, this did not affect sampling data. In April 2008, the batteries for the SHA and MDE swales failed to pump water from the weir and thus, pollutant data are unavailable for the SHA swale on 4/3/2008 and the MDE swale on 4/26/2008. After replacing the batteries, no further sampling problems arose. Regarding the check dams, on 6/3/2007, the check dams were accidently mowed by State Highway Administration highway workers, and new check dams were installed on 7/1/2007.

Besides these field issues, full sets of pollutant data were not obtained for certain storms due to technical problems with lab instrumentation. The Dionex ion chromatograph malfunctioned for sample analysis for the storms that occurred between 12/2/2008 and 4/3/2008. Due to that, nitrate analyses could not be done since samples must be analyzed within a week. Samples for chloride on the other hand, can be stored for a long time before being analyzed.

4.2 Hydrology Comparison

4.2.1 Storm Event Characterization

Storm trends in Maryland were analyzed by Kreeb (2003) at 15 stations within the state. Kreeb (2003) rainfall volume and duration data were collected from 10,352 storm events. Table 4-2 represents the frequency of storm events that were collected from those 15 stations.

Table 4-2. Frequency of storm events for 15 storm station in Maryland (Kreeb 2003).

	Rainfall Depth (cm)					
Event Duration	0.0254 - 0.254	0.255 – 0.635	0.636 - 1.27	1.28 - 2.54	> 2.54	***Sum(%)***
0 - 2 hr	0.2857	0.0214	0.0167	0.0043	0.0008	32.89
2 - 3 hr	0.0164	0.0257	0.0221	0.0089	0.0025	7.56
3 - 4 hr	0.0085	0.0223	0.0198	0.0083	0.0038	6.27
4 - 7 hr	0.0099	0.0351	0.0475	0.0221	0.0087	12.33
7 - 13 hr	0.0058	0.0337	0.0629	0.0528	0.0266	18.18
13- 24 hr	0.0024	0.007	0.0397	0.0611	0.0515	16.17
> 24 hr	0	0.0009	0.0043	0.0172	0.0435	6.59
Sum (%)	32.87	14.61	21.3	17.47	13.74	100

From Table 4-2, 33% of storms in Maryland are expected to have duration between 0 - 2 hours and only 6% of storms have 3 – 4 hours duration. Moreover, 33% of storm depths are between 0.0254 – 0.254 cm and only 14% of storms are more than 2.54 cm deep. This information is important for our research since it can be use as a bench mark in order to see whether the storm events sampled are a representative of storms that occurred in Maryland. Results of the frequency of storm events that were sampled on site are tabulated in Table 4-3. The data from Table 4-2 and 4-3 were further compared in

Figures 4-1 and 4-2. Figure 4-1 compares the frequency of storms vis-a-vis the rainfall depth (cm) and Figure 4-2 compares the frequencies of storms vis-a-vis the duration (hr).

Table 4-3. Frequency of storm events for 23 storm events sampled at Rt 32, Maryland.

	Rainfall Depth (cm)					
Event Duration	0.0254 - 0.254	0.255 - 0.635	0.636 - 1.27	1.28 - 2.54	> 2.54	***Sum (%)***
0 - 2 hr	0.1304	0.0435	0	0.0435	0	21.74
2 - 3 hr	0	0.0435	0	0	0	4.35
3 - 4 hr	0	0	0.0435	0	0	4.35
4 - 7 hr	0.0435	0.0435	0.1304	0.0870	0	30.43
7 - 13 hr	0	0	0.1304	0.2609	0	39.13
13- 24 hr	0	0	0	0	0	0
> 24 hr	0	0	0	0	0	0
Sum (%)	17.39	13.04	30.43	39.13	0	100

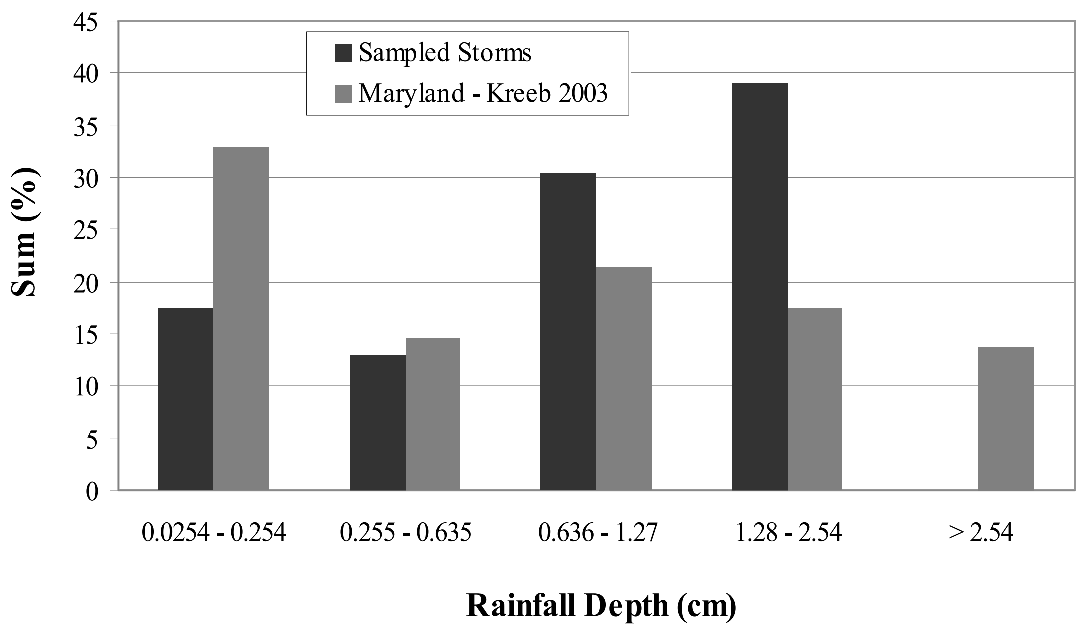

Figure 4-1 Rainfall Depth Distribution for Maryland (Kreeb 2003) and monitored Rt. 32 Storm Events.

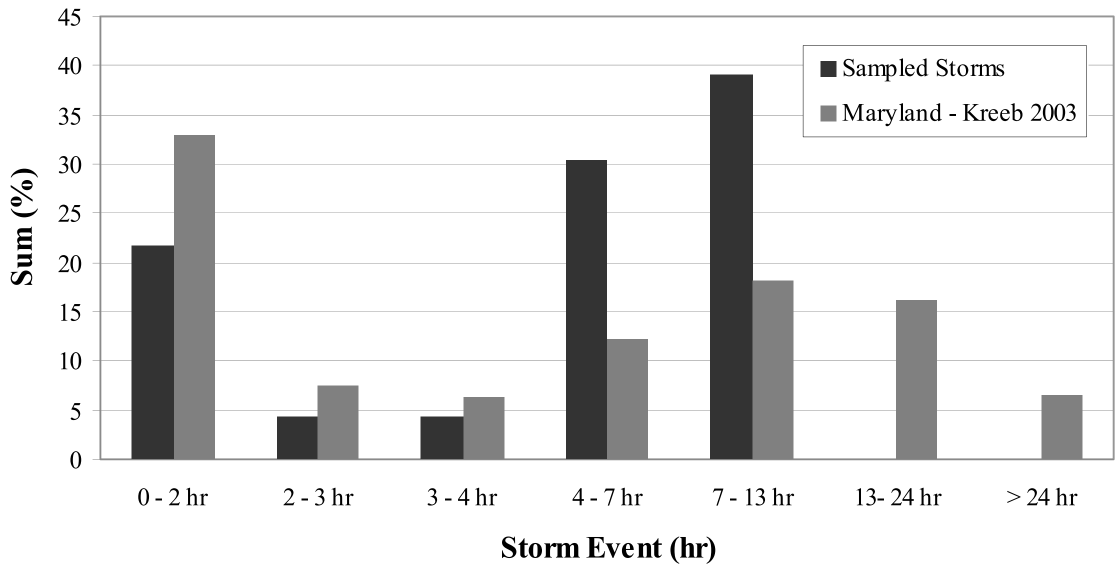

Figure 4-2. Storm duration distribution for Maryland (Kreeb 2003) and monitored Rt. 32 storm events.

From Figures 4-1 and 4-2, no specific trends are obtained but it is clearly seen that all storms sampled at Rt. 32, are less than 2.54 cm and the storm duration is not more than 13 hours. Compared to the Kreeb (2003) data, storms sampled on site were dominated by rainfall between 1.28 – 1.54 cm and 7 - 13 hours duration; both 39%. The results do not match well due to the fewer number of storm events sampled compared to the large number storm events sampled by Kreeb.

The rainfall for the 24 events ranged from 2.3 cm (0.9 inch) to as low as 0.1 cm (0.04 inch). Out of these 24 events, 10 were considered complete captured events. A complete captured event tended to occur when the rain was less than 1.2 cm (0.46 inch). This threshold is similar to the finding by Yu et al. (2001) on 275 m long swale in Virginia where complete captured events occurred for storms less than approximately 1.27 cm (0.5 inch). The swale studied by Yu et al. also has two check dams but it is much longer compared to the SHA-CD swale (198 m) and MDE swale (137 m). This shows that the length of the swale does not help to increase the capacity to infiltrate more water.

A graph of total rainfall depth at different rainfall durations is drawn from data listed in Table 4-1 (Figure 4-3). For this graph, complete captured storms and storms with discharge flow are clearly distinguished. Therefore a relationship between total rainfall and storm duration for the complete captured events can be obtained by linear regression between these two variables.

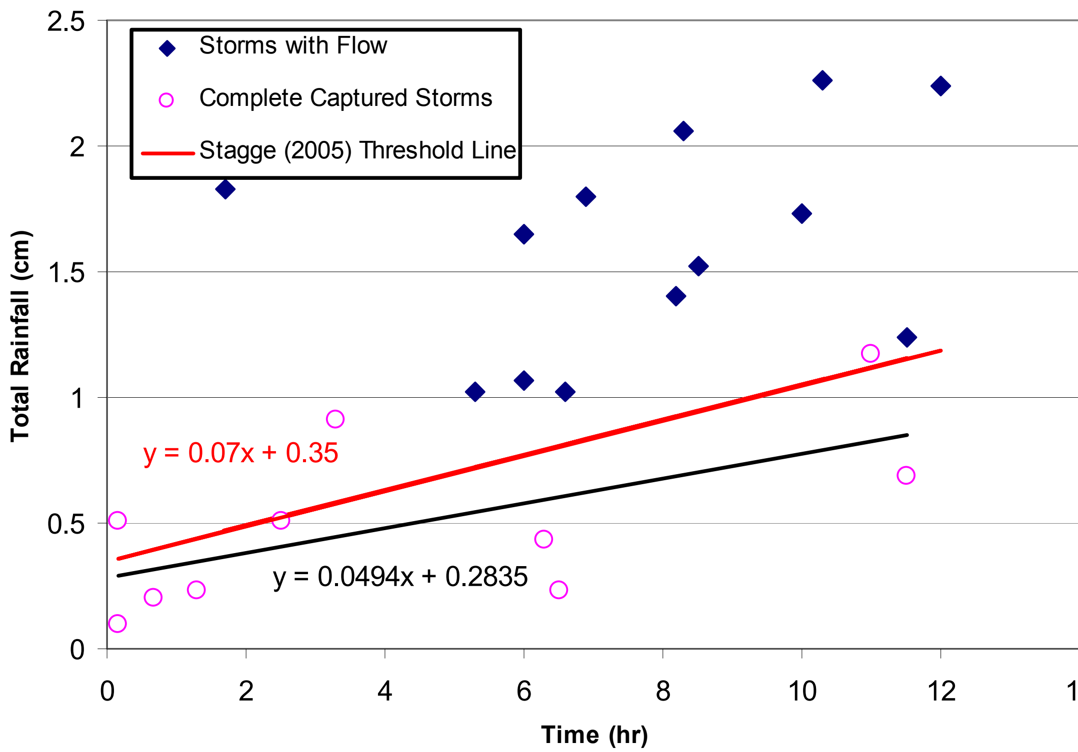

Figure 4-3. Total Rainfall Depth versus Duration. Plot showing completely captured storm events as empty circle (○) and storms with discharge as filled diamond (♦).

The best fit for the linear regression is:

$$Y = 0.0494X + 0.2835 \tag{4-1}$$

where Y represents the total rainfall depth (cm) and X represents the duration of the storm (hr). Therefore, for each storm, Y represents the threshold amount of how much rainfall that will infiltrate into the swale. In other words, Y represents the maximum infiltration capacity of the soil, f_{max}. Table 4-4 summarizes the f_{max} for each of the storm events. The water that infiltrates into the ground may increase the water table and eventually reappear as surface flow. Therefore, any rainfall above the threshold was considered as overland flow which eventually will be part of the swale flow that needs to be excluded from the swale discharge.

Table 4-4. Maximum infiltration capacity (f_{max}) for each storm events. Complete captured events are in bold.

Date	Maximum Infiltration Capacity (cm)
4/4/2007	0.55
5/12/2007	**0.59**
5/16/2007	0.37
6/3/2007	0.79
7/4/2007	0.58
9/11/2007	**0.41**
10/19/2007	**0.83**
10/24/2007	**0.85**
11/13/2007	**0.35**
12/2/2007	0.85
12/14/2007	0.70
1/10/2008	**0.60**
2/1/2008	0.88
3/4/2008	0.78
3/16/2008	0.61
4/3/2008	0.70
4/26/2008	0.58
5/16/2008	0.62
6/3/2008	0.69
6/10/2008	**0.29**
6/16/2008	**0.45**
6/30/2008	**0.32**
7/5/2008	**0.29**

In comparison, Stagge (2006) found, the threshold line for infiltration capacity was:

$$Y = 0.07X + 0.35 \tag{4-2}$$

All units and variables are defined similar with the current study but the duration storms that are covered in this study are up to 30 hours compared to 12 hours for the current study. The maximum infiltration capacity of the soil, f_{max} will be higher in this case. For example, for a 6-hr event, the f_{max} obtained will be 0.75 cm for the previous study and 0.58 cm for the current study. Having a higher infiltration capacity will allow more water to infiltrate and eventually helps to reduce the runoff volume. Besides that, this also shows that the maximum infiltration capacity depends on the duration storms covered by the study.

4.2.2 Flow with respect to time

Hydrographs were created to observe the effectiveness of the grass swales in reducing the peak flow of each event and the time delay between both initial flow and flow from both swales. The hyetograph is incorporated onto the hydrograph. A hyetograph from the April 4, 2007 event is shown in Figure 4-4.

From the hydrograph, it can be seen that the direct channel flow mirrors the rainfall hyetograph (Figure 4-4). High peaks in effective flow for the direct channel correspond to high peaks in rainfall. The effective flow used in the graph is the flow after excluding the overland flow from the calculated flow at the weir (Equation 3-7). Further explanation regarding the effective flow is presented in Section 3.6.2. In most of the events, significant runoff flows reduction was noted through the swales.

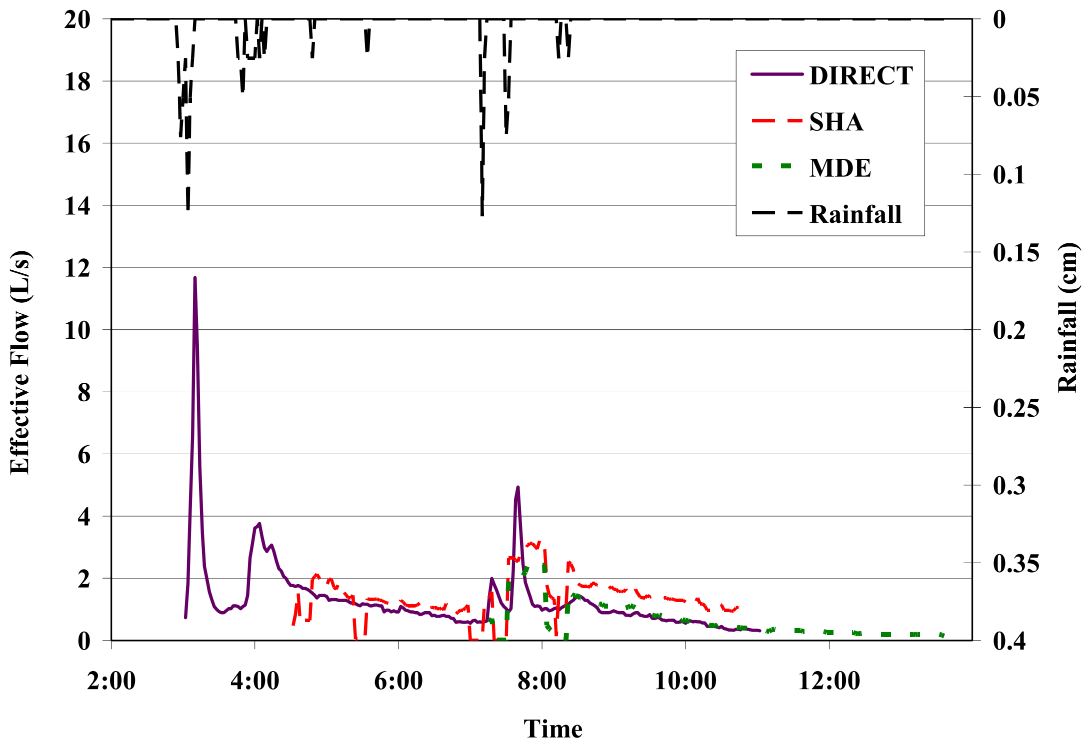

Figure 4-4. Effective Flow for 4/4/07 Storm Event at Rt. 32 Swales

In the event of 4 April 2007 (Figure 4-4), the peak flow from the direct channel was 11.7 L/s and was reduced to 2.6 L/s (MDE) and 3.2 L/s (SHA). Comparing both swales, runoff from the SHA swale for this particular event reached the outlet earlier, apparently due to less contact time in the swale. The peak flow for the MDE swale and the SHA swale was delayed for about 4.5 hours and 1.8 hours, respectively. However, having a secondary peak in the middle of the event can complicate the performance analysis, since it could affect the infiltration capacities of the swales.

Another type of flow behavior exhibited during storms is complete capture events. This phenomenon occurs when the rainfall intensity is small and not enough to produce flow through the swales, but flow still occurs through the direct channel, as demonstrated in Figure 4-5. In this event, the rainfall was 0.91 cm (0.36 inch) and lasted for about 3.3 hours.

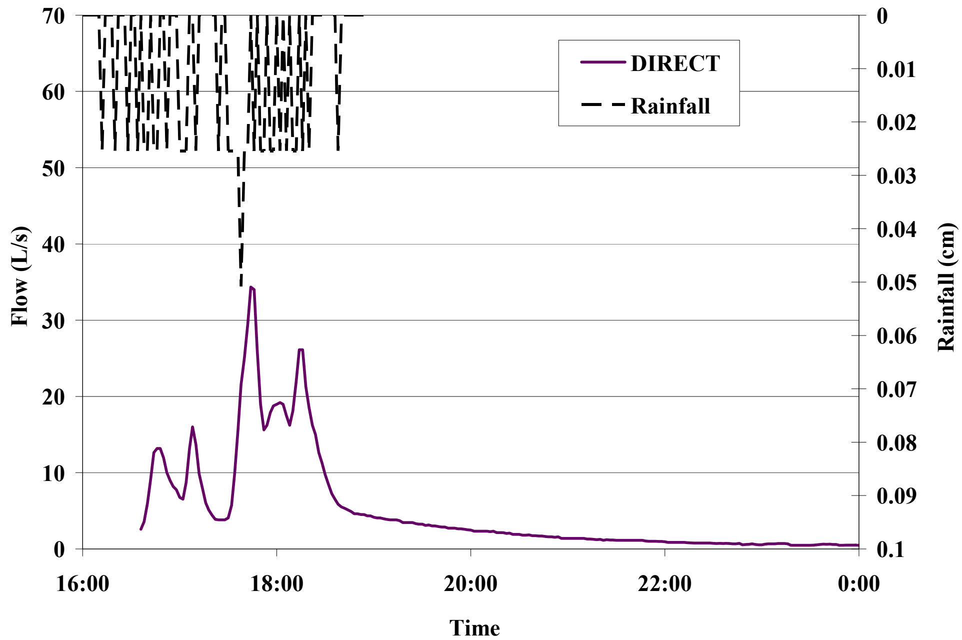

Figure 4-5. Direct Flow for 6/16/08 Storm Event at Rt. 32 Swales (Complete - Capture).

The second largest rain event out of the 23 events occurred on 12/14/07 (Figure 4-6), which was 2.1 cm (0.81 inch) and lasted for about 9 hours. In this event, the SHA swale did not function as expected. It did not reduce the flow but instead it had more flow than the direct and a higher peak discharge. A few secondary peaks in the middle of the event, starting around 1:00 am seemed to contribute to this phenomenon. By comparing this event to the event on 4/4/07 (Figure 4-4), similar phenomena are actually occurring. Around 8 am on 4/4/07, a second peak occurred and from that point, the SHA swale had more flow than the direct. Flows from the surrounding area may contribute to the swale flow at high event intensity. Furthermore, in both events, the MDE swale did not help much to reduce the flow.

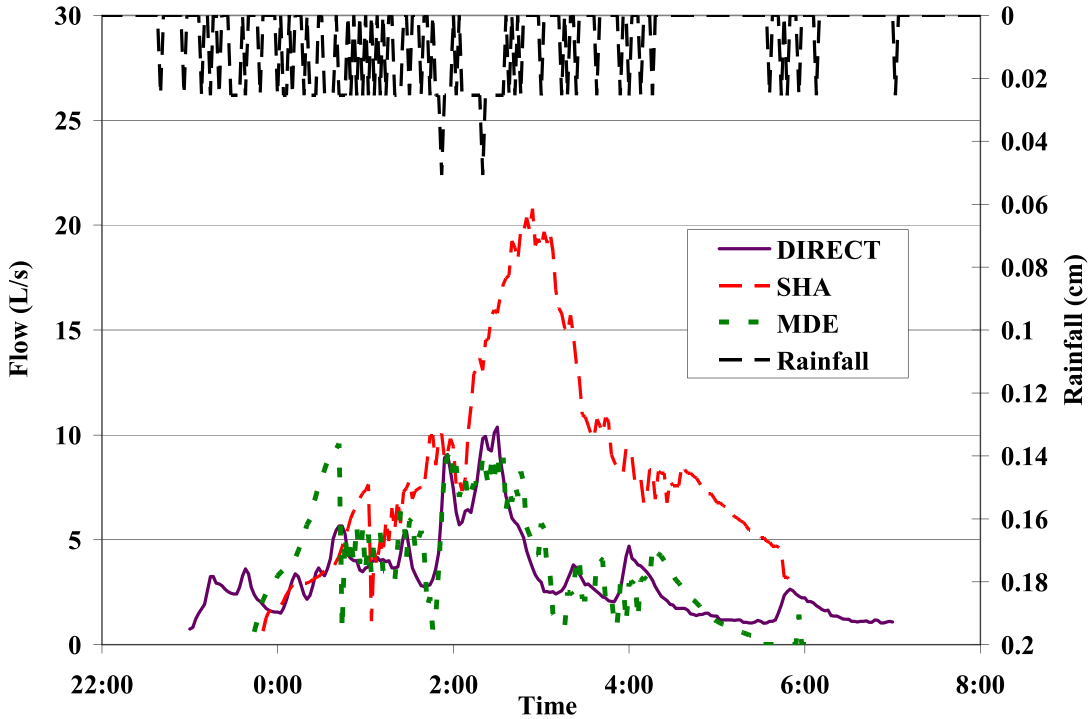

Figure 4-6. Effective Flow for 12/14/07 Storm Event at Rt. 32 Swales.

In the event of snow, the grass swales did not perform as they would for rain. The output produced more flow than the input because when the snow started to accumulate, the ground was freezing. When the rain started, the snow that covered the swales melted, flowing through the swale together with the runoff. Figure 4-7 shows this phenomenon. This phenomenon agrees with the findings of Soderlund (1972), where due to the swale being covered by snow, flow resistance and filtering effects are much lower compared to the rest of the seasons. Therefore, water tends to just flow on the swale instead of infiltrating into the soil.

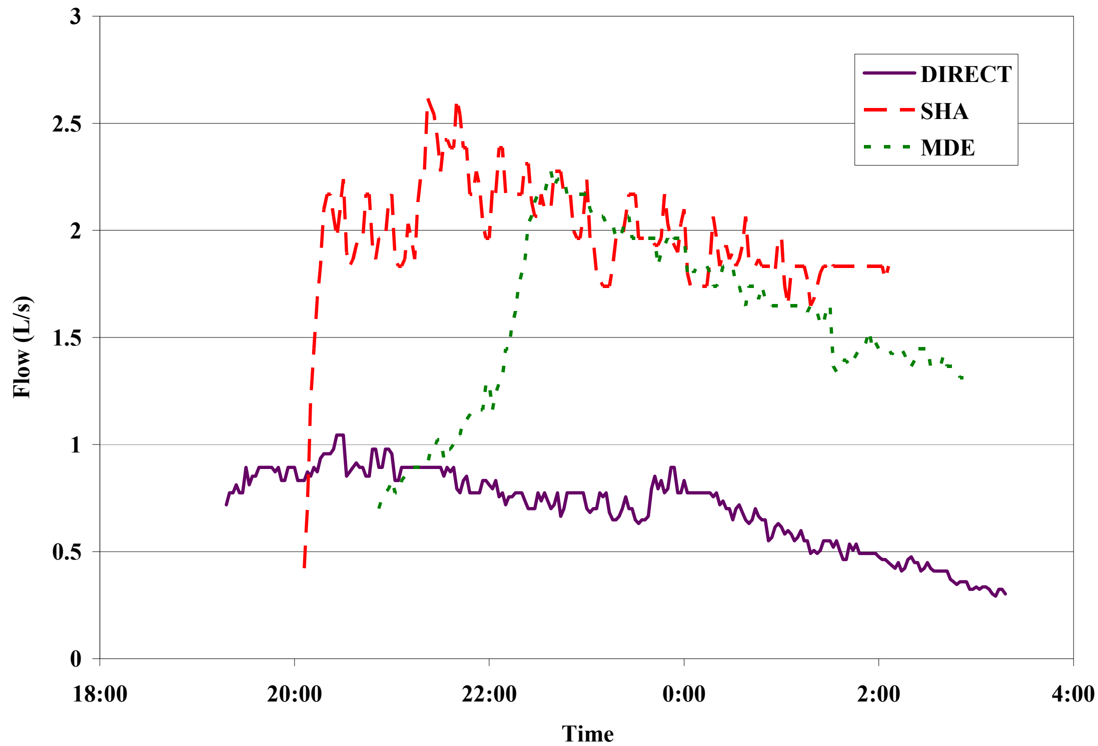

Figure 4-7. Flow for 2/25/07 Rain/Snowmelt Event at Rt. 32 Swales

4.2.3 Peak Flows and Lag Time

In order to have a better understanding on the overall performance of the swales, specifically looking at the hydrology aspect, effective peak flow probability plots were synthesized by ranking the effective peak flows observed from each monitoring point from largest to smallest (Figure 4-8). Table 4-5 summarizes the effective peak flows for all storm events.

Table 4-5. Summary of effective peak flow, effective volume and lag time for each storm events.

	Peak Flow (L/s)			Effective Volume (L)			Lag Time (hr)	
Storm event	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**SHA**	**MDE**
2/25/2007	1.05	3.20	3.00	20020	42600	34100	0.82	1.58
4/4/2007	11.67	2.60	2.28	33800	29300	14700	1.83	4.50
5/12/2007	3.70			11400				
5/16/2007	55.00	9.00	8.90	32800	31600	14300	0.15	0.20
6/3/2007	22.00	10.00	6.70	53200	27900	14000	5.40	5.50
7/4/2007	52.00	24.00	11.00	41500	27200	34300	0.47	0.47
9/11/2007	8.00			7830				
10/19/2007	26.00			25600				
10/24/2007	8.00			25400				
11/13/2007	1.10			3460				
12/2/2007	23.00	7.00	10.00	67700	27500	21200	5.37	5.60
12/14/2007	10.00	21.00	10.00	86700	183000	85300	0.83	1.07
1/10/2008	1.00			1580				
2/1/2008	18.00	12.00	9.00	97200	142000	75400	0.67	0.70
3/4/2008	30.00	13.00	12.00	55800	114000	42500	1.10	1.30
3/16/2008	8.00	3.00	3.00	36300	23900	6100	0.90	1.30
4/3/2008	6.00		3.00	63000		9420		4.97
4/26/2008	5.40	0.60		25000	6410		2.17	
5/16/2008	32.00	14.00	9.00	317000	82500	29200	1.50	1.68
6/3/2008	37.00	3.00	2.00	51700	9350	2670	3.17	5.72
6/10/2008	40.00			7110				
6/16/2008	9.00			29100				
6/30/2008	4.00			5910				
7/5/2008	1.00			820				

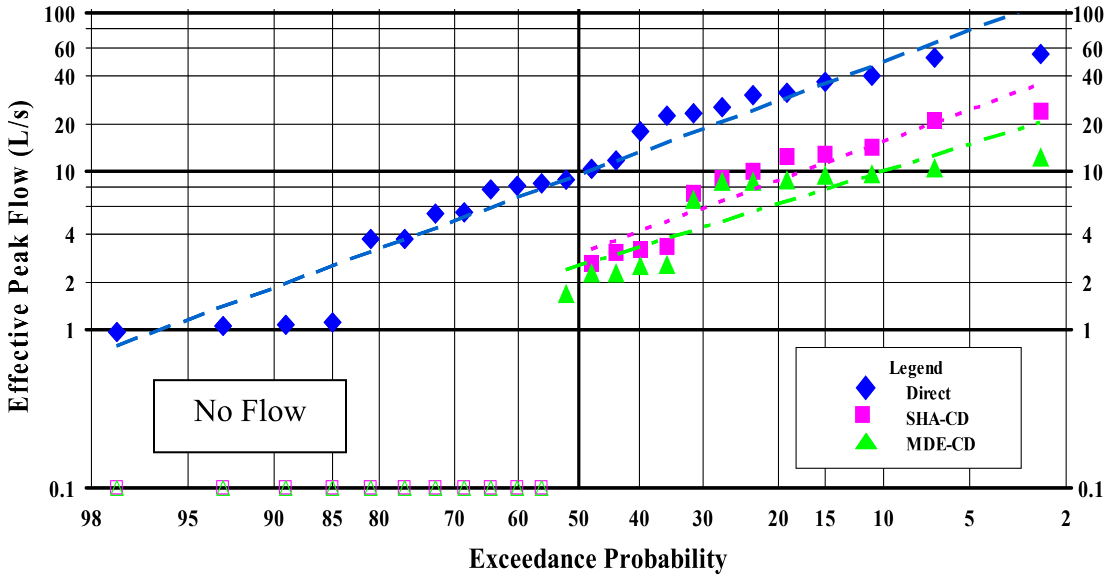

Figure 4-8. Probability plot for Effective Peak Flow at Rt. 32 Swales

The lag time listed in Table 4-5 is the time difference between the starting point of the direct flow and at the swales. Having a longer lag time shows that the swales are actually slowing down the runoff and this allows more filtration and infiltration to occur within the swale. The average time for the SHA swale to start receiving flows at the weir is about 2 hours and the average time for the MDE swale is about 3 hours. The difference is not statistically significant in performance for both swales. Having check dams helps to retain water longer on the swales.

Furthermore, Figure 4-8 shows that the effective peak flow median values for the Direct, SHA and MDE are about 9.5 L/s, 1.6 L/s and 2.0 L/s, respectively. Each point on the plot was obtained from the effective peak flow for the swales and the direct for every storm event. There is a reduction of the median effective peak flow between the direct and the swales but statistically there are no significant improvements between the reduction of peak flow between the direct and the swales. There is also no significant difference in performance between the two swales. This might be due to the nature of the statistic test where zero values (complete-captured events) are not incorporated in the calculations.

The average peak reduction by the swales is between 61% for SHA-CD swale and 68 % for MDE-CD swale. The Stagge (2006) study showed a lower percentage of peak reduction, 50 – 53%. This shows that the check dams on the swales do provide extra time to allow the runoff to infiltrate into the soil and further reduce the peak flow. Besides that, having a pre-treatment area allows the peak to spread out and further reduce the peak flows.

In most cases, the swales do not help much in reducing the total volume of the storm but the swales definitely help to reduce the effective peak flow, which helps protect the downstream water body. This phenomenon can be seen in Figure 4-9 where all flows for 6/3/07 storm were ranked from highest to lowest with 6 minutes increments. The total rainfall for this event was 2.26 cm that lasted for 10 hours. The graph shows that if the stormwater is not treated by the swales, the maximum flow that will enter the river/stream will be about 17 L/s but with check dams swale (SHA-CD), the river/stream will only be impacted with 10 L/s. Even better, the check dams swale with the pre-treatment area (MDE-CD) was able to reduce the flow to about 6 L/s.

From the literature, in order to reduce the erosion in a water body such as a river, a maximum flow velocity of 1.2 – 1.5 m/s (2-yr storm event) is recommended because that is considered a non-erosive flow (Claytor and Schuler 1996). Since this is a velocity, the area or size of the water body would eventually determine whether the flow that enters the river would erode the river bank or not. For example, a reduced peak flow of

17 L/s might not harm the larger river but might still be harmful for the smaller river. Therefore, whether or not the reduction of peak flow could help to reduce the erosion in the water body downstream is dependent on the size of the water body downstream.

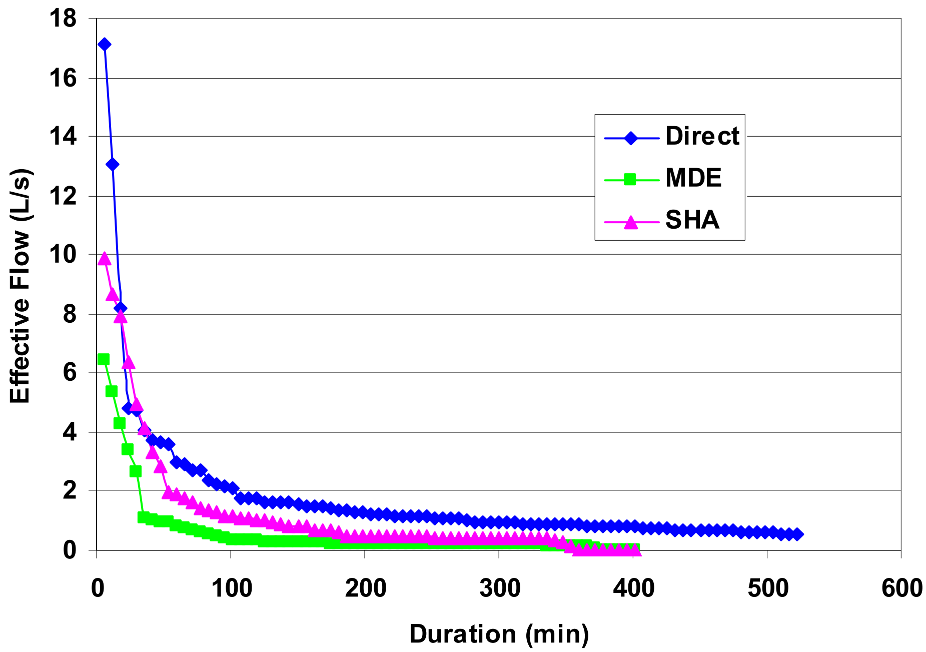

Figure 4-9. Effective Flow for storm sampled on 6/3/07 at Rt. 32 versus Storm Duration

Moreover, the combinations of all flow data for 23 rainfall events are plotted against the storm duration in increments of 6 min in Figure 4-10. It further clarifies that throughout the research project, the swales did help to reduce the effective peak flows and the results show that the swale with a pretreatment area (MDE) performs better than the swale without pretreatment (SHA). The peak flows for Direct, SHA and MDE are 51 L/s, 20 L/s and 11 L/s, respectively. Having extra area to infiltrate the water clearly helps in reducing the peak flows and indirectly reducing the volume. Lower peak flow eventually helps to reduce river bank erosion.

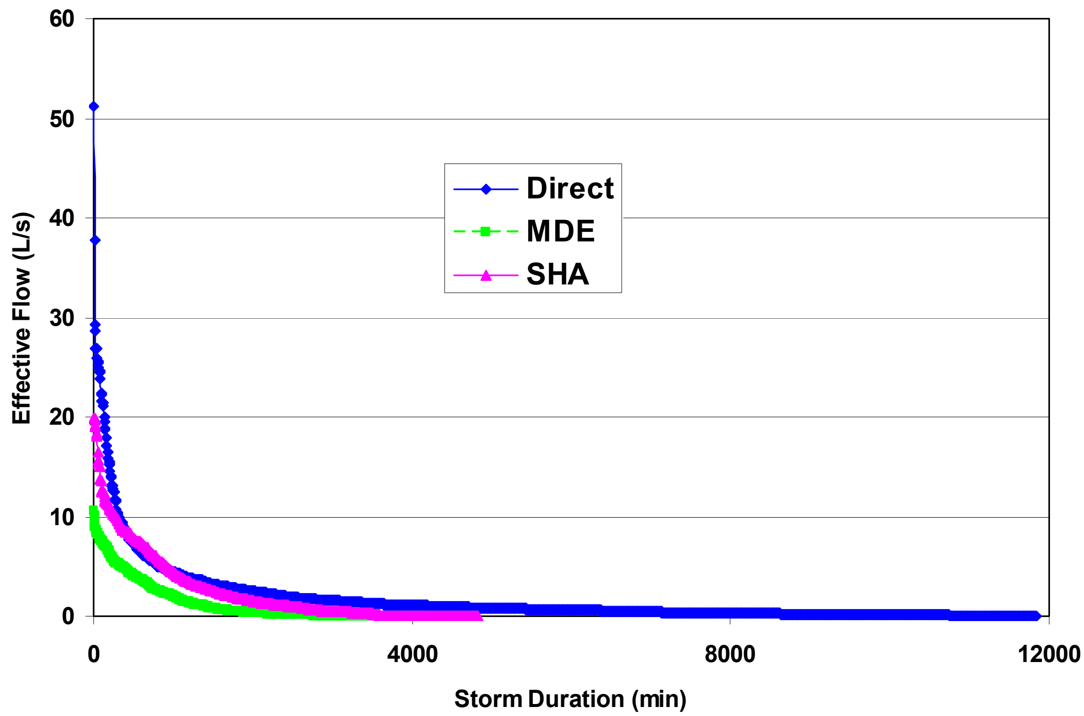

Figure 4-10. Cumulative Effective Flow for all 24 events sampled at Rt. 32 versus Storm Duration

4.2.4 Total volume

Total volume for each event is calculated using Equations 3.9 and 3.10. Table 4-5 provides the effective volume for all 24 events. The effective volume is basically the total volume leaving the swale after removing the excess rainfall that becomes overland flow. From the probability plot of total volume (Figure 4-11), it is shown that the swales do not help significantly reduce the volume.

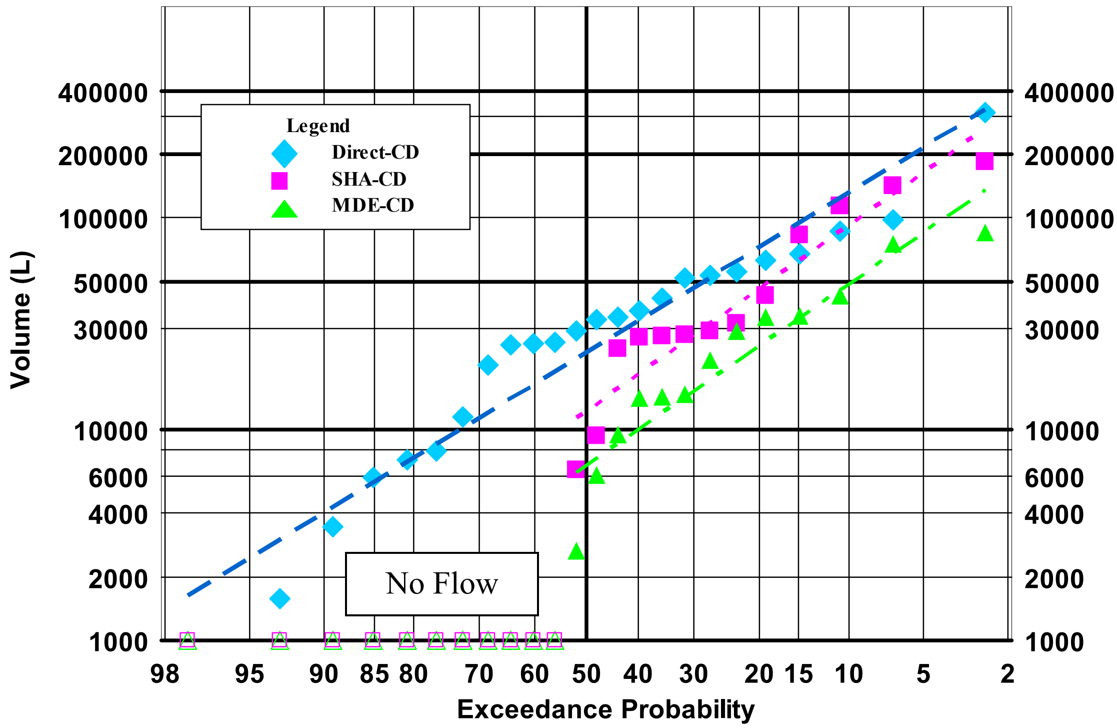

Figure 4-11. Total Volume for each sampling point at Rt. 32 for 24 events.

The median volume for the Direct is about 31000 L, SHA-CD swale is 29000 L and MDE-CD swale is 21000 L. The SHA-CD swale is only capable of reducing 6% of the median volume, but MDE-CD is capable of reducing 32% of the median volume. Having extra area to infiltrate the water helps in reducing the volume but the difference is not statistically significant.

There were four storm events that produced more volume through the swales than the direct runoff (2/25/2007, 12/14/2007, 2/1/2008 and 3/4/2008). The first event (2/25/2007) was due to the snow melt on the swales, but the three other events are basically long duration rainfall events (more than 8 hours) with rainfall more than 1.7 cm (0.7 inch). An example of one of the other three events is given in Figure 4-12. This is the second largest storm event with 2.1 cm (0.8 inch) total rainfall that occurred for 8.3 hours.

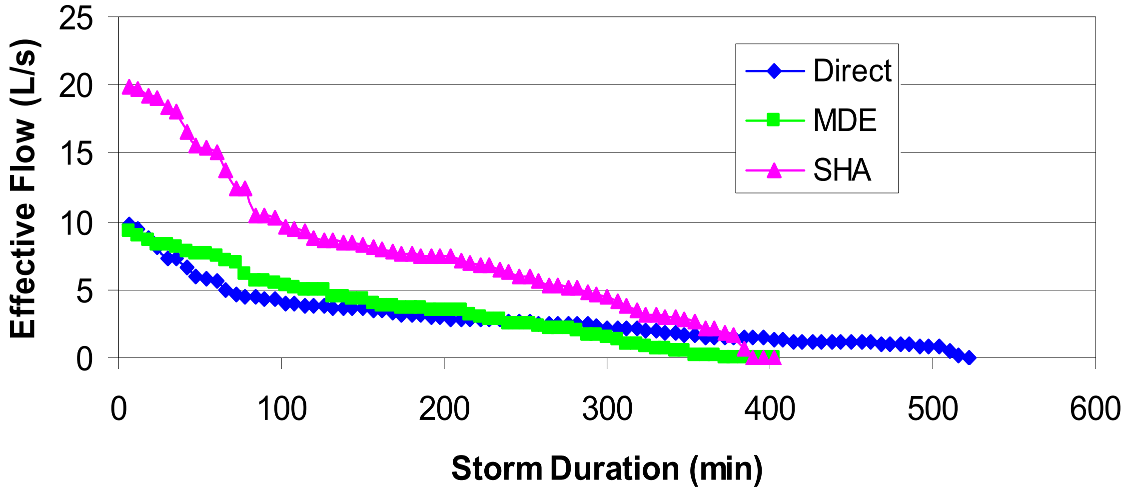

Figure 4–12 Cumulative Effective Flow versus Storm Duration at Rt. 32 (12/14/07)

Furthermore, the phenomenon in Figure 4–12 shows that the swales might have obtained more input from the surrounding areas or there might be some portion of the storm that has high intensity within a short period. Therefore, the water just flows through the swale instead of infiltrating into the swale. The fact that the largest storm event with 2.6 cm (0.9 inch) total rainfall that occurred for about 10.3 hours did not produce more volume through the swales than the direct input might be due to the fact that it occurred in the middle of summer; the soil was probably dry and able to infiltrate/absorb more runoff since the antecedent dry period is longer. Having big storms back to back could also contribute to higher water table and therefore less runoff could infiltrate into the ground.

Comparing to the reduction of total volume with Stagge (2006), without check dams, the reduction of total volume was 46% for SHA-CD and 54% for MDE-CD but with check dams installed, the reduction is 28% for SHA-CD and 64% for MDE-CD. The SHA-CD did not show any improvement of the hydrology because the check dams were not fully matured to act as check dams. As seasons change, the check dam dries up and is not able to retain water longer on the swales.

Overall, although statistically the MDE-CD and SHA-CD do not show any significant improvement in hydrology, the MDE-CD swale clearly shows a better performance in lag time, reducing mean peak flows, total peak flows and volume compare to SHA-CD. Besides that, the MDE-CD reduces more total volume compared to MDE (without check dams). This shows that the swale with the pretreatment area performed better when check dams are incorporated in the system and it is beneficial for stormwater volume reduction. It is not showing statistically just because the zero data for complete capture events are excluded.

4.3 Pollutant Observations and Outliers

Ten pollutants were analyzed for all storms. Each storm has different pollutant concentration shapes with time, but the patterns are similar. Higher concentrations tend to occur at the beginning of the storm and when high intensity of rainfall occurred within a short time. The differences are due to variability in input flows and input pollutant concentrations. This phenomenon can be clearly seen in Figure 4-13 and Figure 4-14 where two of the pollutants analyzed on 12/2/07 show high concentrations at the beginning of the storm event and another peak at around 12:00 am when rainfall starts to peak again.

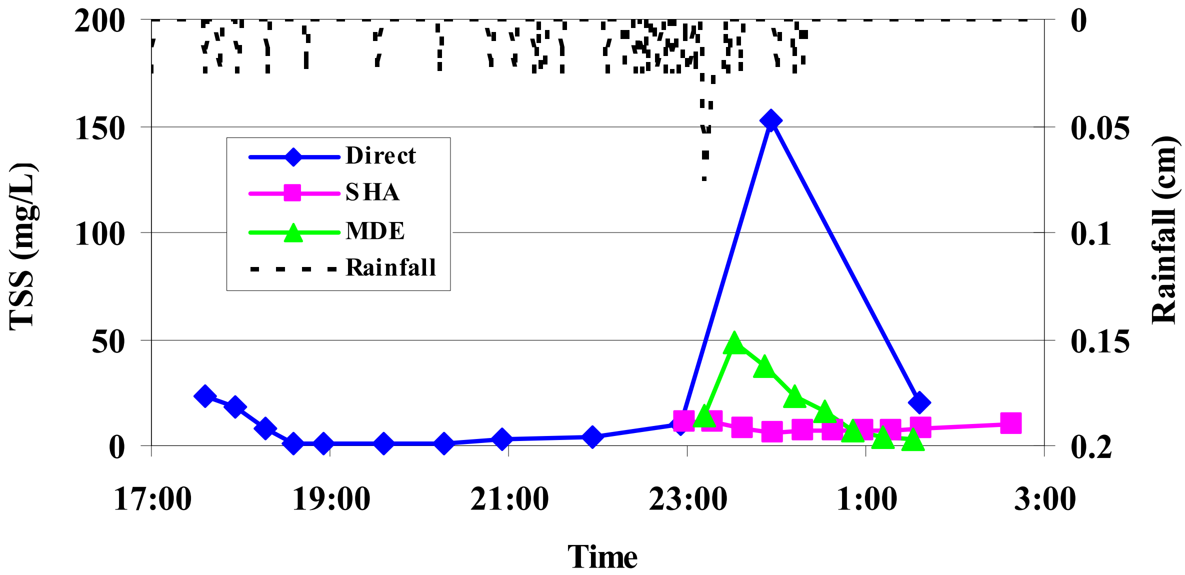

Figure 4-13. TSS Concentrations (12/2/07) at Rt. 32 Swales

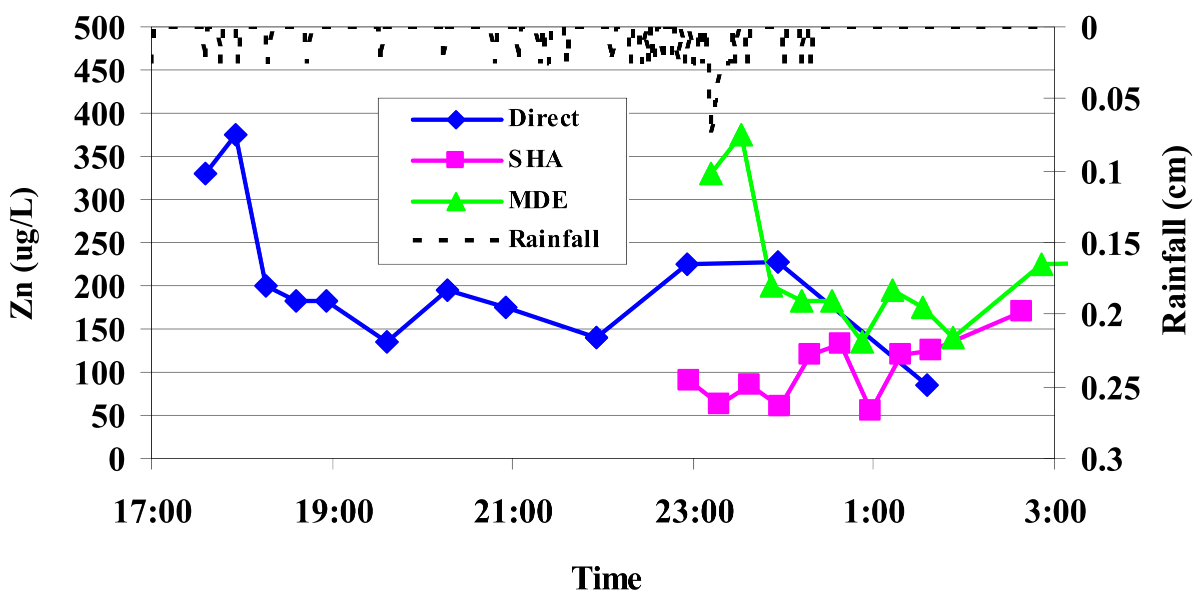

Figure 4-14. Zinc Concentrations (12/2/07) at Rt. 32 Swales

In order to analyze these data, parameters such as the Effective Event Mean Concentration (E-EMC) and total mass pollutant removal are used to quantify and compare the effects of having grass swales with check dams to treat highway runoff. Furthermore, the Event Mean Concentration (EMC) is used to quantify and compare the performance of grass swales with check dams and without check dams (Stagge 2006). Comparison is not done by using Effective Event Mean Concentration because Stagge (2006) had used a different way to incorporate the effect of rainfall dilution in the runoff, which he defines as Normalized Event Mean Concentration (N-EMC). N-EMC and E-EMC use similar concepts where total mass leaving the swale is divided by total volume leaving the swale without rainfall on the swale. The difference between the two is the way total volume is calculated. Total volume for N-EMC is calculated as total volume of runoff leaving the swale minus the total volume of rainfall landing on the swale area during the storm event. On the other hand, the total volume for E-EMC is calculated as total volume of runoff leaving the swale minus the total saturated excess overland flow. The saturated excess overland flow only occurs after the rainfall reaches the maximum infiltration capacity of the soil (Equation 3-5).

The E-EMC's for each pollutant are determined using Equation 3-17. This equation takes into account the dilution effect of the rainfall by dividing the pollutant mass discharge of the swale with the total volume of the swale after eliminating the excess rainfall. Table 4-6 in Appendix A summarizes the E-EMCs for each pollutant for each storm event. Table 4-7 in Appendix B summarizes the EMC for each pollutant for each storm event. Appendix C summarizes the flow and concentration data with respect to time for all storms event.Both EMC and E-EMC are important because EMC shows the actual field-based pollutant concentration that will impact the receiving water body while E-EMC describes the true removal capability of the swale by taking into consideration the dilution effects.

The entire E-EMC data set is further checked using the Dixon-Thompson test in order to find any outliers at the extreme ends (highest and lowest values). Extreme events can create problems in data analysis. For example, an extremely large value can cause the sample mean and standard deviation to be much larger than the population values. However, statistically proven outliers from the sample should not be eliminated unless there is a physical reason that supports the decision to be eliminated. Table 4-8 lists all statistically proven outliers found in the study. These outliers are only at the higher end and no outliers are detected at the lower ends. Besides that, no outliers are detected for cadmium since most of the data are below the detection limits.

Since the storm events are considered random, data may naturally have unusual high values. For example, high values for chloride on 2/25/2007 were due to a snow event and on 4/26/2008, there was an unusual high pollutant load occurred on the SHA swale since this swale possesses high end outliers for all pollutant except for chloride and TKN. Therefore, if the value was actually measured, then such a value should not be discarded from the sample (Davis and McCuen 2005). None of the statistically proven outliers were discarded since there is no specific reason that shows that those concentrations were wrong. Since these high values are kept for further calculation, a nonparametric statistical method is more suitable for the data analysis rather than parametric statistical method. Therefore, a nonparametric test (Mann Whitney U Test) is used as a statistical tool to evaluate the significant improvement of having grass swales with check dams in improving the stormwater runoff at Rt. 32.

Table 4-8. Statistically proven outliers using Dixon-Thompson Test for 24 events at Rt. 32

Constituent	Event Date	Outliers	Source
TSS	7/4/2007	350 mg/L	*MDE*
	9/11/2007	600 mg/L	*Direct*
	4/26/2007	180 mg/L	*SHA*
Nitrate	4/26/2008	7.20 mg-N/L	*SHA*
Nitrite	5/12/2007	0.35 mg-N/L	*Direct*
	4/26/2008	0.38 mg-N/L	*SHA*
TKN	4/26/2008	4.10 mg/L	*Direct*
	6/3/2008	13 mg/L	*SHA*
	6/3/2008	19 mg/L	*MDE*
TP	7/4/2007	1.06 mg-P/L	*MDE*
	3/4/2008	0.63 mg-P/L	*Direct*
	4/26/2008	3.40 mg-P/L	*SHA*
Cl	2/25/2007	7400 mg/L	*Direct*
	2/25/2007	5000 mg/L	*SHA*
	4/4/2007	6100 mg/L	*MDE*
Pb	10/19/2007	560 μg/L	*Direct*
	4/26/2008	500 μg/L	*SHA*
Cu	3/16/2008	240 μg/L	*MDE*
	4/26/2008	500 μg/L	*SHA*
Zn	5/1/6/2007	2070 μg/L	*Direct*
	4/26/2008	850 μg/L	*SHA*

All E-EMC values were then used to construct the probability plots. All complete captured storm events resulted pollutant loads equal to zero and for these cases, a symbols with no fill is indicated on the plots. On most of the plots the water quality target for each constituent is drawn as a dashed line along the y-axis.

Another important parameter is the total mass pollutant removal. It represents the total pollutant load throughout the sampling duration and the differences between the Direct total pollutant load and the swales total pollutant load will represent the effect of swales. This parameter will be more useful than E-EMC when dealing with complete capture events. In Equation 3-13, the total mass formula involves integrating mass and concentration together over time. Therefore, zero flow results in zero mass. In other words, all storms are legitimate to be included in calculations of total mass reduction and this is useful for knowledge about long-term pollutant loadings.

Finally, the most popular way of quantifying the effects of pollutant removal by grass swales is by using the percentage of pollutant concentration reduction. However, the results may be misleading since this parameter is highly dependent on the input concentrations.

4.4 Mann Whitney U Test and Pollutant Removal

The Mann Whitney U Test is a nonparametric test that is used to test for a significant difference between two populations. The Mann Whitney U Test was used to test for five main effects:

1) To test for a significant difference in hydrologic and water quality parameters between the Direct and SHA-CD swales.

2) To test for a significant difference in hydrologic and water quality parameters between the Direct and MDE-CD swales.

3) To test for a significant difference in hydrologic and water quality parameters between the SHA-CD and MDE-CD swales.

4) To test for a significant difference in hydrologic and water quality parameters between the SHA-CD and SHA swales (without check dams).

5) To test for a significant difference in hydrologic and water quality parameters between the MDE-CD and MDE swales (without check dams).

A significance level of 5% was chosen, and Table 4-10, summarizes the findings from the tests. From the table, P (critical) represents the 5% probability of rejecting the null hypothesis and P (calculated) is the calculated rejection probability. The cross (X) indicates that the rejected probability is more than the critical probability and the null hypothesis is accepted (there is no difference between both populations); it is also in bold. The check (√) indicates that the calculated rejected probability is less than the critical probability, the null hypothesis is rejected and the difference between those two populations is significant.

Next, in order to know whether a result designates a significant removal or significant export, other statistical parameters such as the mass, mean and median % removal were examined. The E-EMC varies over a wide range for each pollutant. The difference between the input and output E-EMC represents the ability of the grass swale and check dams to reduce the pollutant levels. The median and percent removals based on the median for each pollutant are presented in Table 4-10. The overall mass pollutant removals for each pollutant at the Rt. 32 Swales are presented in Table 4 -11.

Table 4-9. Wilcoxon Mann Whitney U Test (5% level of significant) for all pollutants.

		P(calculated)	P(critical)	Significant difference in population means (mg/L)
TSS	**Direct / SHA - CD**	**0.0202**	**0.05**	**√ (μ_{DIRECT} = 91 mg/L, μ_{SHA-CD}= 41 mg/L)**
	Direct / MDE-CD	0.2912	0.05	X (μ_{DIRECT} = 91 mg/L, μ_{MDE-CD}=108 mg/L)
	SHA-CD / MDE-CD	**0.0294**	**0.05**	**√ (μ_{SHA-CD} = 41 mg/L, μ_{MDE-CD}=108 mg/L)**
	SHA / SHA -CD	0.2451	0.05	X (μ_{SHA} = 14 mg/L, μ_{SHA-CD}= 20 mg/L)
	MDE / MDE - CD	**0.0039**	**0.05**	**√ (μ_{MDE} = 15 mg/L, μ_{MDE-CD}= 51 mg/L)**
Nitrate	Direct / SHA - CD	0.3372	0.05	X (μ_{DIRECT} = 1 mg/L, μ_{SHA-CD}= 2 mg/L)
	Direct / MDE-CD	0.3594	0.05	X (μ_{DIRECT} = 1 mg/L, μ_{MDE-CD}=1 mg/L)
	SHA-CD / MDE-CD	0.2778	0.05	X (μ_{SHA-CD} = 2 mg/L, μ_{MDE-CD}=1 mg/L)
	SHA / SHA -CD	**0.0179**	**0.05**	**√ (μ_{SHA} = 4 mg/L, μ_{SHA-CD}= 0 mg/L)**
	MDE / MDE - CD	**0.0317**	**0.05**	**√ (μ_{MDE} = 3 mg/L, μ_{MDE-CD}= 0 mg/L)**
Nitrite	Direct / SHA - CD	0.123	0.05	X (μ_{DIRECT} = 0.09 mg/L, μ_{SHA-CD}= 0.08 mg/L)
	Direct / MDE-CD	**0.0019**	**0.05**	**√ (μ_{DIRECT} = 0.09 mg/L, μ_{MDE-CD}= 0.08 mg/L)**
	SHA-CD / MDE-CD	0.1685	0.05	X (μ_{SHA-CD} = 0.08 mg/L, μ_{MDE-CD}= 0.08 mg/L)
	SHA / SHA -CD	**0.0188**	**0.05**	**√ (μ_{SHA} = 0.07 mg/L, μ_{SHA-CD}= 0.03 mg/L)**
	MDE / MDE - CD	0.0985	0.05	X (μ_{MDE} = 0.05 mg/L, μ_{MDE-CD}= 0.04 mg/L)
TKN	**Direct / SHA - CD**	**0.0084**	**0.05**	**√ (μ_{DIRECT} = 0.93 mg/L, μ_{SHA-CD}= 2.72 mg/L)**
	Direct / MDE-CD	0.0749	0.05	X (μ_{DIRECT} = 0.93 mg/L, μ_{MDE-CD}= 2.69 mg/L)
	SHA-CD / MDE-CD	0.2296	0.05	X (μ_{SHA-CD} = 2.72 mg/L, μ_{MDE-CD}= 2.69 mg/L)
	SHA / SHA -CD	**0.0188**	**0.05**	**√ (μ_{SHA} = 2.07 mg/L, μ_{SHA-CD}= 1.63 mg/L)**
	MDE / MDE - CD	**0.0143**	**0.05**	**√ (μ_{MDE} = 1.76 mg/L, μ_{MDE-CD}= 1.26 mg/L)**
TP	**Direct / SHA - CD**	**0**	**0.05**	**√ (μ_{DIRECT} = 0.21 mg/L, μ_{SHA-CD}= 0.82 mg/L)**
	Direct / MDE-CD	0.2946	0.05	X (μ_{DIRECT} = 0.21 mg/L, μ_{MDE-CD}= 0.46 mg/L)
	SHA-CD / MDE-CD	0.1292	0.05	X (μ_{SHA-CD} = 0.82 mg/L, μ_{MDE-CD}= 0.46 mg/L)
	SHA / SHA -CD	0.2236	0.05	X (μ_{SHA} = 0.49 mg/L, μ_{SHA-CD}= 0.43 mg/L)
	MDE / MDE - CD	0.0548	0.05	X (μ_{MDE} = 0.38 mg/L, μ_{MDE-CD}= 0.25 mg/L)
Chloride	**Direct / SHA - CD**	**0.018**	**0.05**	**√ (μ_{DIRECT} = 469 mg/L, μ_{SHA-CD}= 1010 mg/L)**
	Direct / MDE-CD	**0.0005**	**0.05**	**√ (μ_{DIRECT} = 469 mg/L, μ_{MDE-CD}=1214 mg/L)**
	SHA-CD / MDE-CD	0.2119	0.05	X (μ_{SHA-CD} = 1010 mg/L, μ_{MDE-CD}=1214 mg/L)
	SHA / SHA -CD	0.0694	0.05	X (μ_{SHA} = 141 mg/L, μ_{SHA-CD}= 840 mg/L)
	MDE / MDE - CD	0.3264	0.05	X (μ_{MDE} = 246 mg/L, μ_{MDE-CD}= 940 mg/L)
Lead	Direct / SHA - CD	0.409	0.05	X (μ_{DIRECT} = 69 mg/L, μ_{SHA-CD}= 64 mg/L)
	Direct / MDE-CD	0.1446	0.05	X (μ_{DIRECT} = 69 mg/L, μ_{MDE-CD}= 38 mg/L)
	SHA-CD / MDE-CD	0.0869	0.05	X (μ_{SHA-CD} = 64 mg/L, μ_{MDE-CD}=38 mg/L)
	SHA / SHA -CD	0.3859	0.05	X (μ_{SHA} = 11 mg/L, μ_{SHA-CD}= 20 mg/L)
	MDE / MDE - CD	0.1038	0.05	X (μ_{MDE} = 11 mg/L, μ_{MDE-CD}= 19 mg/L)

Table 4-9. Wilcoxon Mann Whitney Test (5% level of significant) cont'd

		P(calculated)	P(critical)	Sig Significant difference in population means
Copper	Direct / SHA - CD	0.3336	0.05	X (μ_{DIRECT} = 66 mg/L, μ_{SHA-CD}= 77 mg/L)
	Direct / MDE-CD	0.2266	0.05	X (μ_{DIRECT} = 66 mg/L, μ_{MDE-CD}=66 mg/L)
	SHA-CD / MDE-CD	0.0749	0.05	X (μ_{SHA-CD} = 77 mg/L, μ_{MDE-CD}=66 mg/L)
	SHA / SHA -CD	0.3859	0.05	X (μ_{SHA} = 30 mg/L, μ_{SHA-CD}= 21 mg/L)
	MDE / MDE - CD	0.0934	0.05	X (μ_{MDE} = 29 mg/L, μ_{MDE-CD}= 18 mg/L)
Zinc	**Direct / SHA - CD**	0	0.05	**√ (μ_{DIRECT} = 360 mg/L, μ_{SHA-CD}= 233 mg/L)**
	Direct / MDE-CD	0	0.05	**√ (μ_{DIRECT} = 360 mg/L, μ_{MDE-CD}=184 mg/L)**
	SHA-CD / MDE-CD	0	0.05	**√ (μ_{SHA-CD} = 233 mg/L, μ_{MDE-CD}=184 mg/L)**
	SHA / SHA -CD	0.0026	0.05	**√ (μ_{SHA} = 124 mg/L, μ_{SHA-CD}= 113 mg/L)**
	MDE / MDE - CD	0.0019	0.05	**√ (μ_{MDE} = 111 mg/L, μ_{MDE-CD}= 97 mg/L)**

Table 4-10. Median and percent removal based on E-EMC median for each pollutant at the Rt. 32 Swales.

	TSS (mg/L)			Nitrate (mg/L)			Nitrite (mg/L)		
	Direct	SHA	MDE	Direct	SHA	MDE	Direct	SHA	MDE
Median	60	5	9	0.7	0	0	0.06	0.01	0.02
% Removal		92	85		100	100		83	67

	TKN (mg/L)			TP (mg/L)			Cl (mg/L)		
	Direct	SHA	MDE	Direct	SHA	MDE	Direct	SHA	MDE
Median	0.55	0.42	0.20	0.22	0.25	0.2	20.00	50	100
% Removal		24	63		-14	9		-150	-400

	Lead (ug/L)			Copper (ug/L)			Zinc (ug/L)		
	Direct	SHA	MDE	Direct	SHA	MDE	Direct	SHA	MDE
Median	20	8	15	50	8	13	248	75	76
% Removal		60	25		84	74		70	69

	Cadmium (ug/L)		
	Direct	SHA	MDE
Median	<2	<2	<2
% Removal		-	-

Table 4-11. Overall mass pollutant removal for each pollutant at the Rt. 32 Swales.

	TSS (g)			Nitrate (g)			Nitrite (g)		
	Direct	SHA	MDE	Direct	SHA	MDE	Direct	SHA	MDE
Total Mass	68000	26000	42000	370	30	17	47	21	14
% Removal		62	38		92	95		55	70

	TKN (g)			TP (g)			Cl (g)		
	Direct	SHA	MDE	Direct	SHA	MDE	Direct	SHA	MDE
Total Mass	470	1000	260	210	220	130	290000	460000	300000
% Removal		-113	45		-5	38		-59	-3

	Lead (mg)			Copper (mg)			Zinc (mg)		
	Direct	SHA	MDE	Direct	SHA	MDE	Direct	SHA	MDE
Total Mass	51000	11000	9000	53000	23000	16000	280000	93000	59000
% Removal		78	82		57	70		67	79

	Cadmium (mg)		
	Direct	SHA	MDE
Total Mass	1200	690	380
% Removal		43	68

Characteristics of each storm event vary and therefore, the use of fractional mean E-EMC percent removal in quantifying the effectiveness of the swales has several drawbacks because it is not giving an accurate assessment of the functionality of the site. For example, a high percent pollutant removal does not necessarily indicate an effective treatment practice because this parameter also depends on the input, and vice versa. However, having a negative percent removal shows that the swale is exporting the pollutant into the runoff. This phenomenon can be seen for total phosphorus and chloride for the mean E-EMC percent removal for both swales and TKN, total phosphorus, and chloride for the mass percent removal specifically only for the SHA-CD swale. The swale performance for each constituent will be discussed in the following sections.

4.5 Total Suspended Solids (TSS)

The water quality goal for TSS is selected to be 30 mg/L since that is the minimum USA National Standards for secondary wastewater treatment (Metcalf and Eddy Inc., 2004). Log-normal probability analyses were made. Figure 4-15 shows that the inflow concentration will theoretically exceed 30 mg/L during 75% of the storm events but with check dam swales, the MDE swale exceeded 30 mg/L TSS during only 35% of storm events and the SHA exceeded 30 mg/L TSS only during 25% of storm events. Summary statistics for the E-EMC from Table 4-10 shows a clear difference between the median values for direct (60 mg/L), SHA (5 mg/L) ,and MDE (9 mg/L). The percent removals for SHA-CD swale is 92% but that for MDE-CD swale is only 85%. Statistically, only effluent TSS from the SHA-CD swale was determined to be different from the Direct and also statistically; there is a significant difference between the performances of both swales (Table 4-9).

Since there is a significant difference between both swales, and SHA-CD performs better, the pretreatment area adjacent to the MDE swale is actually exporting more TSS into the runoff, possibly due to sediment mobilized from the extra area of the pretreatment area. Although only SHA-CD is considered significantly different, the removals of both swales are similar with previous findings such as 79-98% (Backstrom 2003), 65%-98% (Schueler 1994), and 85-87% (Barrett et al. 1998). All those findings are from grass swales without check dams.

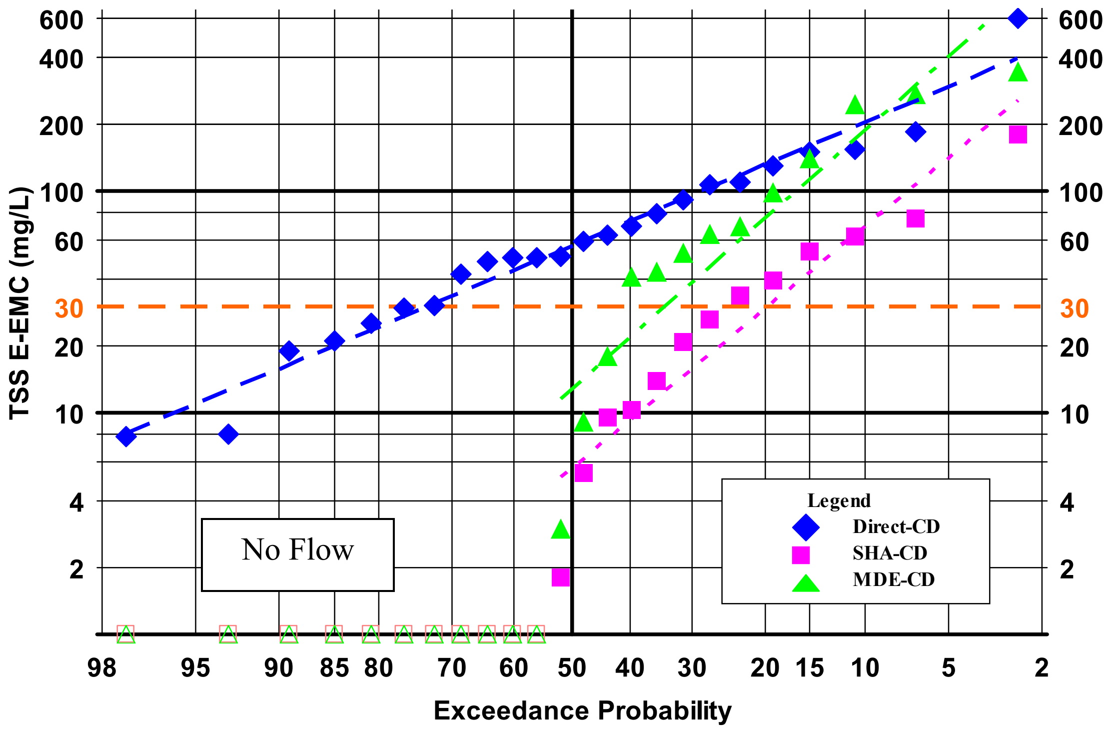

Figure 4-15. Probability plot for TSS E-EMCs at Rt. 32 Swales.

4.5.1 Total Suspended Solids (TSS) Comparison.

According to Yu et al. (2001), the mass removal at the swale outlet with check dams is higher compared to the outlet without any check dams. In the same study in Taiwan, a 30-m grass swale with one check dam in the middle produced 70% TSS mass removal at a constant flow of 4 x 10^{-3} m^3/s and 86% TSS mass removal at a constant flow of 0.9 x 10^{-3} m^3/s. At another site in Virginia, a 275 m length grass swale with two check dams produced about 94% TSS mass removal.

In the current research that includes 24 storm events, Direct, SHA-CD and MDE-CD discharged 68 kg, 26 kg and 42 kg of TSS respectively (including complete captured events). This shows that a significant amount of TSS is conveyed by the extra pretreatment area of the MDE-CD swale. The total mass removal percentage for SHA-CD is 62% but, for MDE-CD it is only 38%. These values are smaller than those reported in the literature, due to not having a constant flow if compared to the Taiwan swale and due to a shorter swale compared to the Virginia swale (198 m for SHA-CD and 137 m for MDE-CD swale). In order to provide a better comparison, current findings are compared to the previous study by Stagge (2006) by using the probability plot in Figure 4-16.

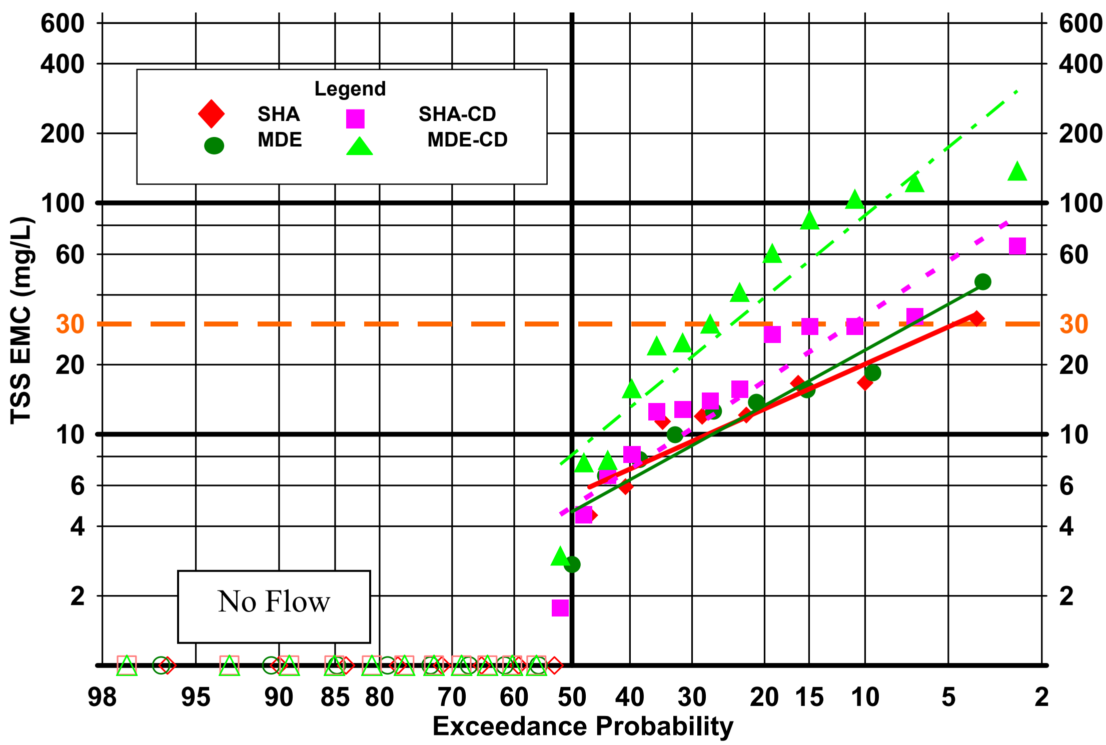

Figure 4-16. Probability plot for TSS EMCs at Rt. 32 Swales
(Current study - SHA-CD and MDE-CD vs Stagge (2006) - SHA and MDE).

In the previous study, (without the check dams), both swales behaved similarly for TSS removal (Figure 4-14). However, in the current study (with check dams), there is a statistically significant difference between both swales. There is also significant difference between the performance of the MDE swale and the MDE-CD swale. No significant difference was found between the performance of the SHA swale and the SHA-CD swale. The MDE swale performs better without any check dams. It exceeded the water quality target only for 5% of storm events, but with the check dams it exceeded for about 25% of storm events. Besides that, previously, the total suspended solid mass was significantly reduced by the swales: 84% SHA and 73% MDE. Compared to the current finding, the total suspended solid mass was reduced only 62% for SHA-CD and only 38% for MDE-CD.

In short, grass swales with check dams are capable of both reducing the total mass and the E-EMC for total suspended solids. This shows that the swales are dependent on sedimentation, filtration and infiltration process. The addition of a pretreatment area does not significantly improve the swale performance, in fact appears to degrade performance. Inclusion of check dams also does not help to significantly improve the performance of SHA-CD swale compared to SHA swale. Inclusion of check dams and pretreatment area on the swales do not appears to be necessary since the performance is worse in treating TSS.

4.6 Nutrients (Total Phosphorus (TP), Nitrite, Nitrate, TKN)

Nitrogen and phosphorus are two nutrients that are a major concern in stormwater runoff. Excess nitrogen in water bodies causes accelerated algal production and high amounts of phosphorus in runoff can produce problems at water treatment plants since it may interfere with the coagulation process (USEPA 2006). The effluent water quality goal for phosphorus is set to be 0.1 mg-P/L and 1 mg-N/L for nitrite by the National

Water Quality Criteria (WQC) (USEPA 2006). For nitrate, on the other hand, the excellent water quality criterion in the Potomac River Basin is 0.2 mg-N/L (Davis and McCuen 2005). WQC was not used as the guideline for nitrate because the target is 10 mg-N/L which is too high for surface water. A TKN criterion was not reported in the WQC.

4.6.1 Total Phosphorus (TP)

Unfortunately, from the phosphorus probability plot (Figure 4-17), it is clearly shown that the swales are not helping towards meeting the goal and worse, all swales discharges exceeded the goal. Both swales tend to export phosphorus into the runoff. The SHA swale with check dams tends to export more phosphorus than the MDE swale with check dams. Statistically, the difference between the Direct and the SHA-CD swale is significant but neither performance between the direct and the MDE-CD swale nor between the SHA-CD swale and MDE-CD swale is significant. The mean E-EMC values for each sampling set: Direct, SHA-CD and MDE-CD are 0.22, 0.25 and 0.20 mg/L, respectively. The mean E-EMC removal of total phosphorus was found to be -14% for SHA and 9% for MDE. The removal is low compared to 31 to 61% by Barrett et al. (1998) and over 99% by Krecher et al. (1983) due to high infiltration rates.

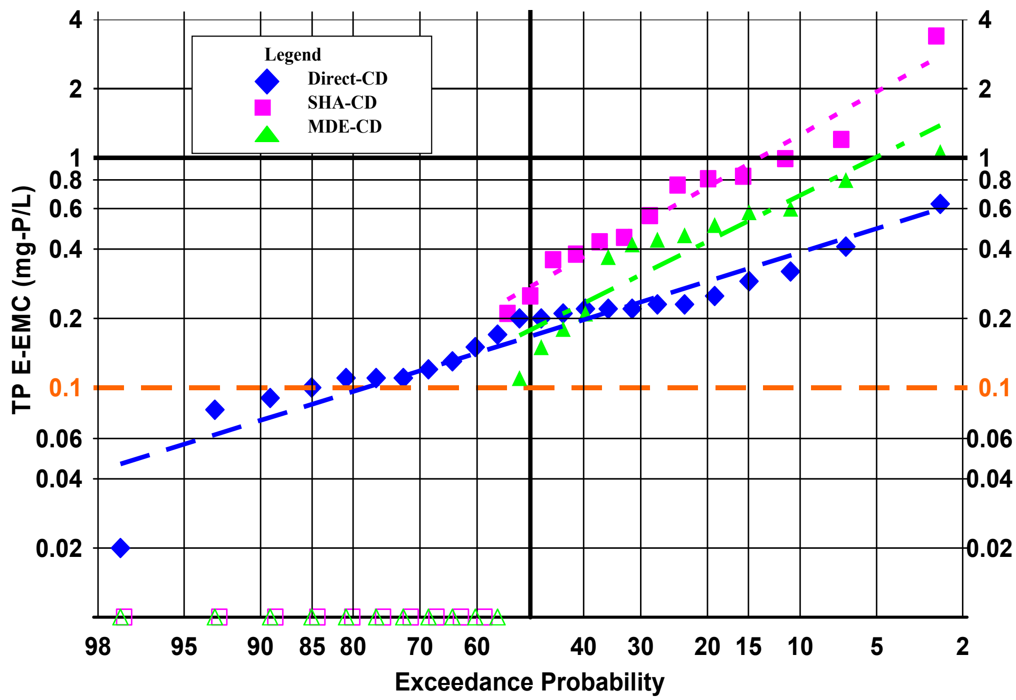

Figure 4-17. Probability plot for TP E-EMCs at Rt. 32 Swales.

In terms of total pollutant mass, the total phosphorus input loading is 213 g; output for SHA-CD is 224 g and MDE-CD 128 g. The total pollutant mass percent removal is -5% (SHA-CD) and 40% (MDE-CD). Statistically, the SHA-CD swale significantly exports phosphorus and having an extra pretreatment area does not help to significantly improve phosphorus reduction. Since most phosphorus is considered as particulate bound, phosphorus removal is highly depends on physical processes such as infiltration, deposition and filtration (Barrett et al. 1998, Rose et al., 2003). Therefore, phosphorus might have been accumulating in the SHA-CD swale and leaches from time to time to cause the export of phosphorus. Length of the swale might not be the cause of the export since Yu et al. (2001) managed to obtain mass removal of about 99% for a 275 m long check dams swale and about 80% mass removal for a 30 m long check dams swale.

4.6.1.1 Total Phosphorus Comparison

Figure 4-18 and statistical data from Table 4-9 shows that addition of check dams on the swale does not show any significant improvement to the water quality for phosphorus content. 50% of storm events will still exceed the water quality target of 0.1 mg-P/L.

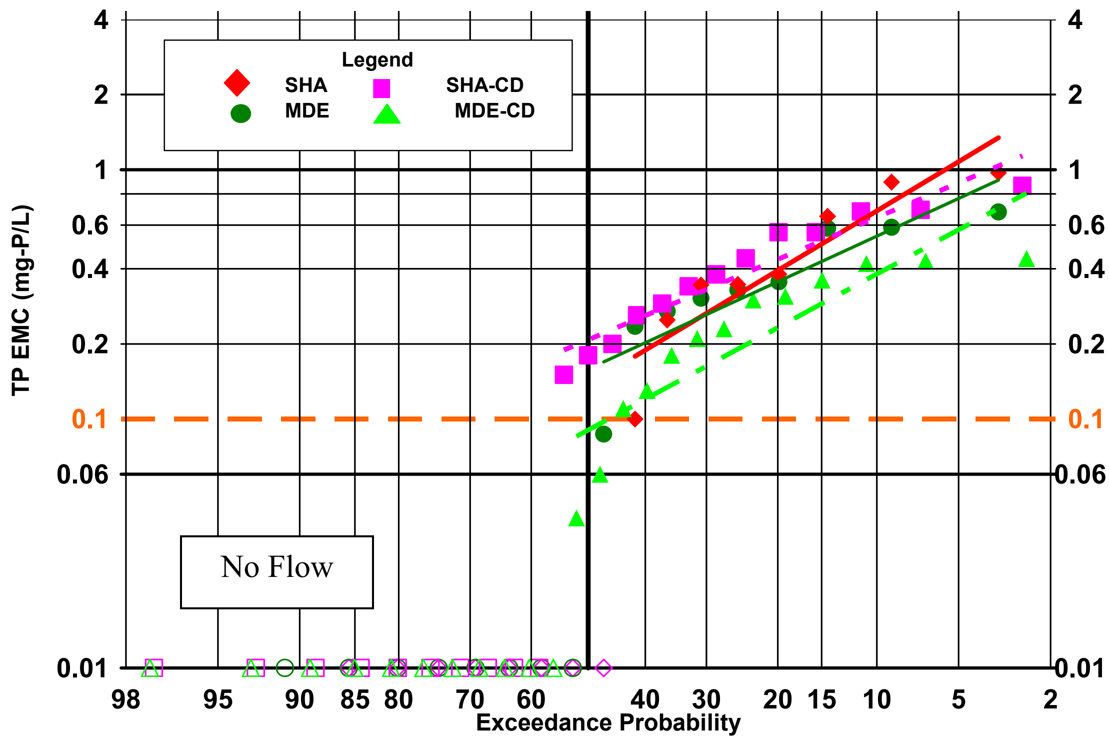

Figure 4-18 Probability plot for TP EMCs at Rt. 32 Swales.
(Current study vs Stagge (2006))

4.6.2 Nitrate, Nitrite and TKN

The probability plots shows that most of the effluent data for nitrate exceeds the selected target limit of 0.2 mg-N/L (Figure 4-19) but all of the effluent data for nitrite meet the selected target limit (Figure 4-20). There is no statistical significant difference between the Direct and the swales for nitrite but there is a significant difference between the Direct and MDE-CD swale for nitrate. However, without grass swales, about 95% of the storm events exceeded the target limits for nitrate but with grass swales, less than 30% of the storm events exceeded the target limits for nitrate. The total mass pollutant loading for nitrite are 47 g (Direct), 21 g (SHA-CD) and 14 g (MDE-CD). The total mass pollutant loading for nitrate are 371 g (Direct), 30 g (SHA-CD) and 17 g (MDE-CD). The MDE-CD swale reduces the total mass of nitrite by about 71% and 95% for nitrate.

In the nitrogen cycle, under aerobic conditions, nitrite becomes an electron donor in the biodecompostion reactions of soil organic matter. In other words, nitrite is easily rapidly oxidized to nitrate under aerobic condition. Therefore, having an extra pretreatment area might allow extra time for aerobic conditions to occur in the soil and therefore could enhance the removal of nitrite.

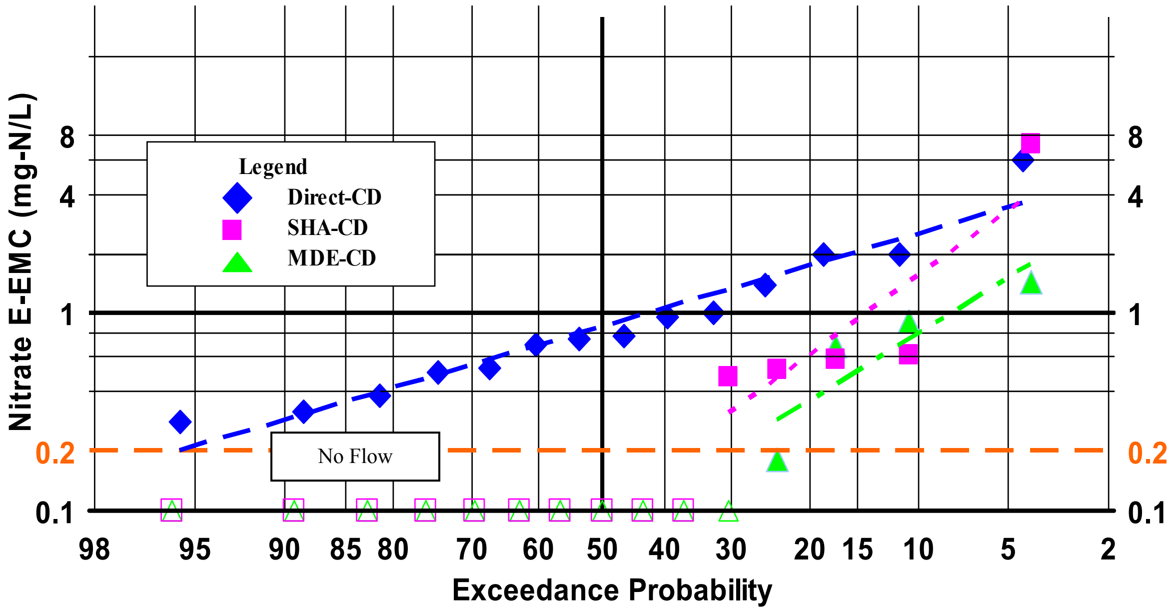

Figure 4-19. Probability plot for Nitrate E-EMCs at Rt. 32 Swales

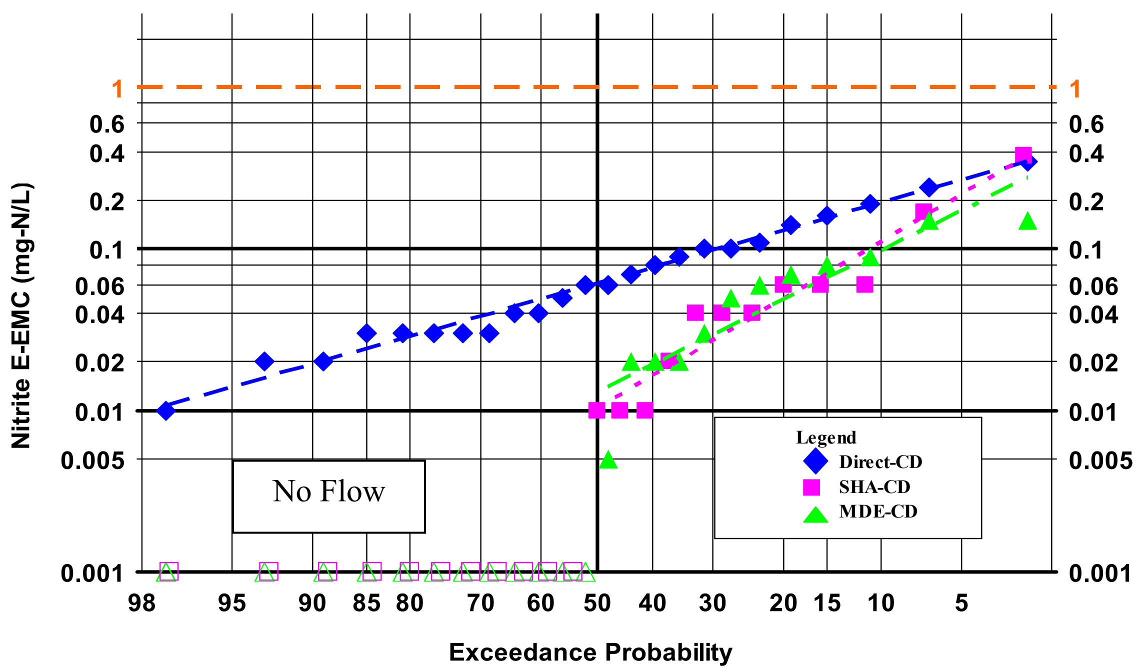

Figure 4-20. Probability plot for Nitrite E-EMCs at Rt. 32 Swales

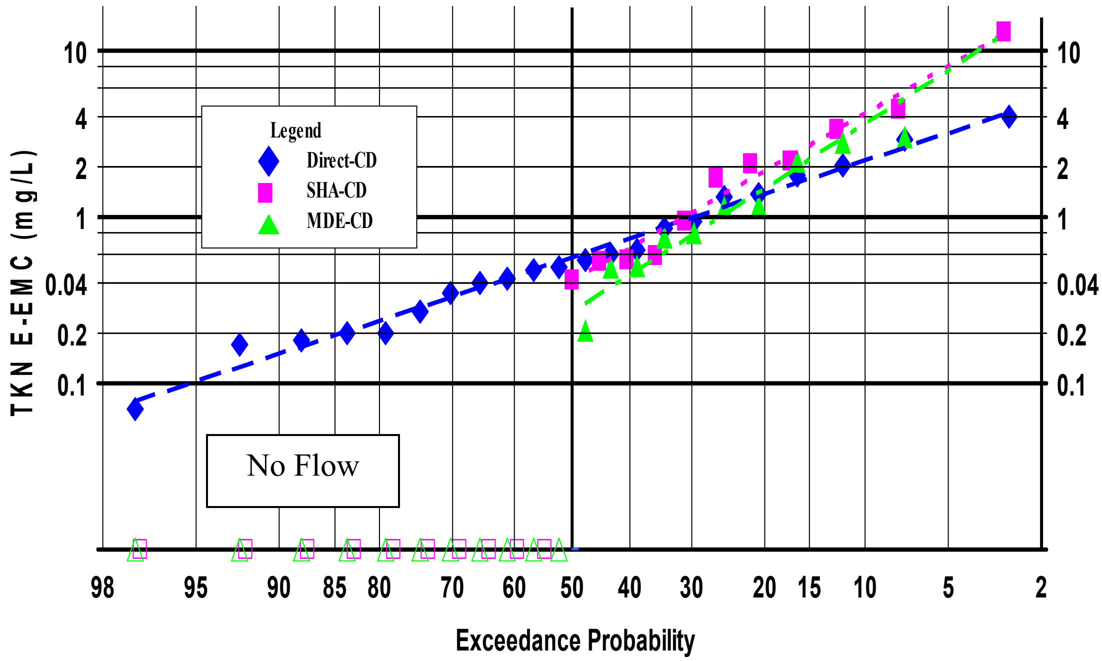

Figure 4-21. Probability plot for TKN E-EMCs at Rt. 32 Swales.

For TKN, the median E-EMC % removal in Table 4-10 shows that SHA-CD swale is able to remove 24% of TKN and MDE-CD swale is able to remove 63% of the TKN. However, looking at the overall total mass pollutant removal, the SHA-CD swale is actually exporting 562 g of TKN (-119%) and MDE-CD helps to reduce the TKN by 206 g (44%). Statistically, only SHA-CD shows significant TKN being reduced by the swale. In this case the median E-EMC % removal and the total mass pollutant % removal for SHA-CD swale provide different conclusions but we can clearly see from the probability plot (Figure 4-21) that the SHA-CD swale is exporting TKN. This might happen due to the fact that SHA-CD is longer than MDE-CD and therefore, more nitrogen from the grass is contributing to the additional mass in the runoff. Literally, total mass of nitrogen is a combination of TKN, nitrite (NO_2^-) and nitrate (NO_3^-). The total mass of nitrogen obtained from Direct, SHA-CD, and MDE-CD are 886 g, 1081 g, and 293 g respectively. An increase or decrease any of the component will effect the mass of total nitrogen. Since SHA-CD exported TKN, it also has the highest total mass nitrogen loading compare to the Direct and MDE-CD swale.

Literature reports mixed results for nutrients removal by grass swale. In some cases, swales tend to export the nutrients into the runoff due to a few factors such as fertilization, mowing, and changing of season. For example, Barrett et al. (1998) reports nitrogen removal ranging from 11 to -7% but Krecher et al. (1983) measured removal rates over 99% for total phosphorus, TKN and total nitrate due to high infiltration rates. Forms of nutrients fluctuate readily with different oxidation characteristics, sediment loads and within the overall environment itself (NCHRP 2006). Since there is no significant difference between the MDE-CD swale and the SHA-CD swale, having an extra pretreatment area is not necessary.

4.6.2.1 Nutrients (Total Phosphorus (TP), Nitrite, Nitrate, TKN) Comparison

All swales with check dams show significant differences compared to the swales without any check dams (Stagge 2006), except for the comparison between MDE and MDE-CD swale for nitrite. Most of the trend lines for the swale with check dams are lower than the line for the swale without any check dams (Figures 4-22 to 4-24). That shows that check dams helped both swales to reduce nutrients concentrations. On the other hand, having an extra pretreatment area for the MDE swale does not show any significant benefits.

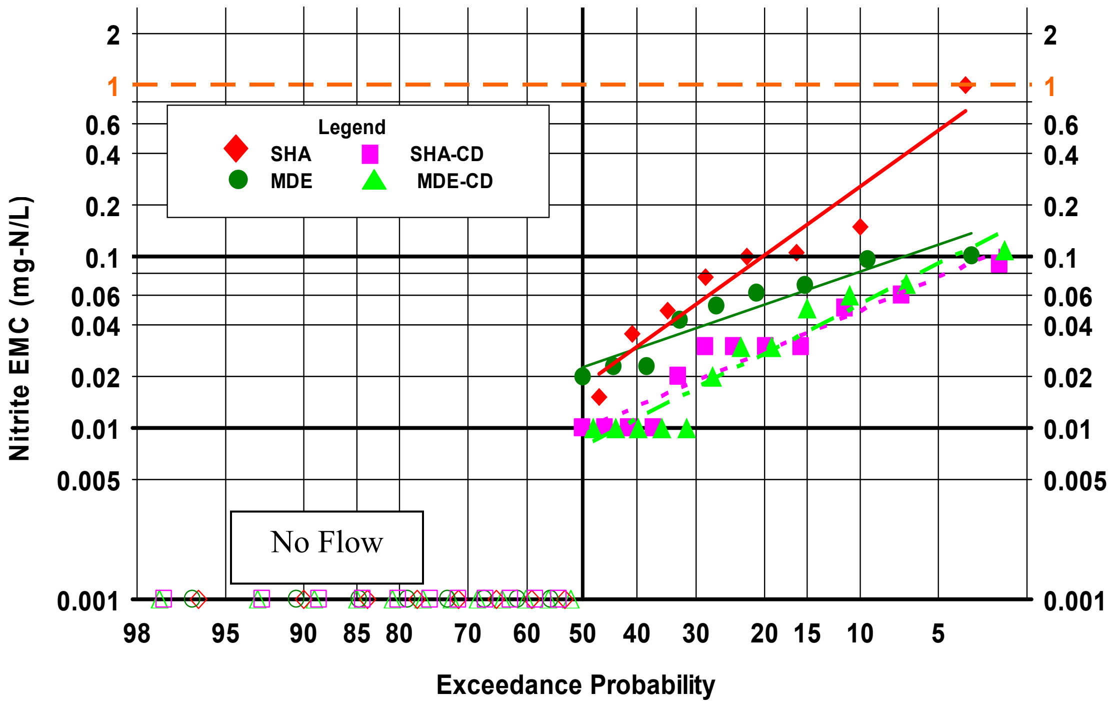

Figure 4-22. Probability plot for Nitrite EMCs at Rt. 32 Swales. (Current study vs Stagge (2006))

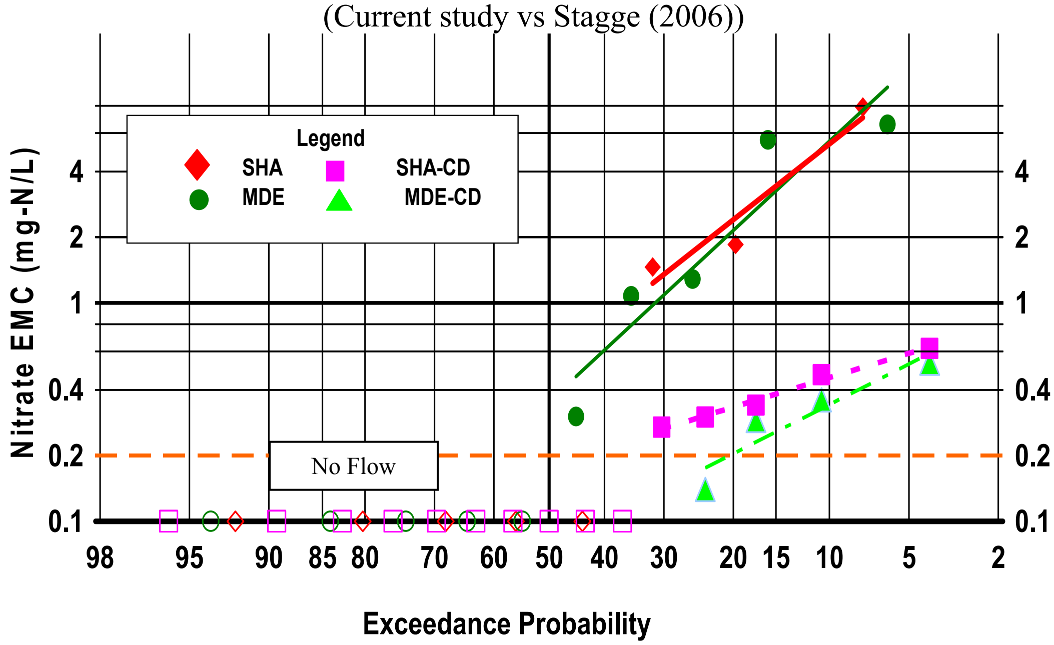

Figure 4-23. Probability plot for Nitrate EMCs at Rt. 32 Swales. (Current study vs Stagge (2006))

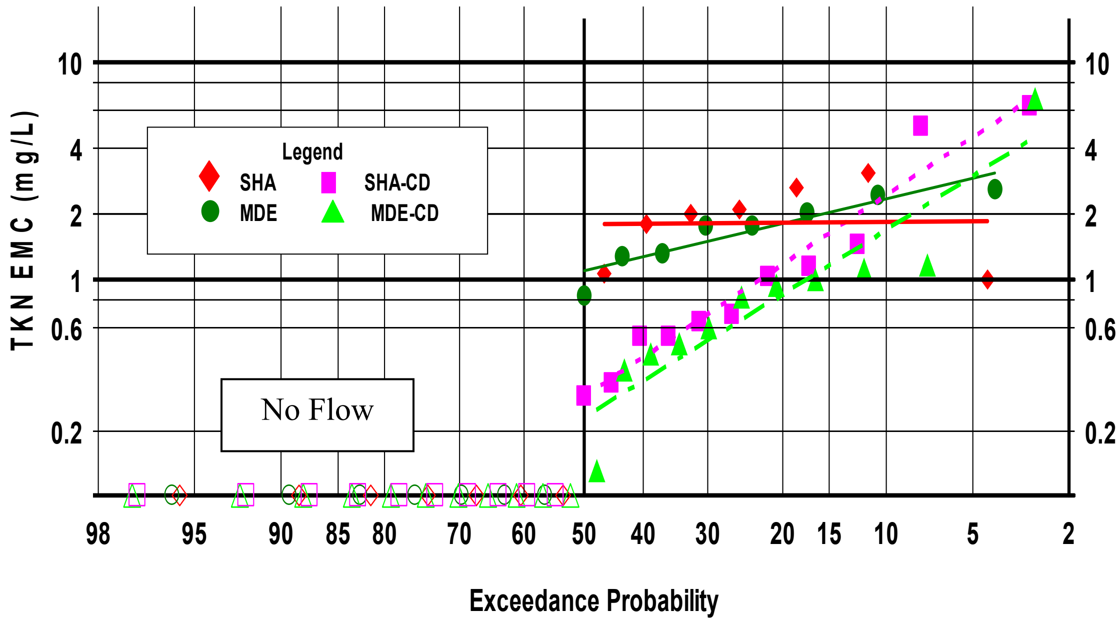

Figure 4-24. Probability plot for TKN EMCs at Rt. 32 Swales.
(Current study vs Stagge (2006))

This finding agrees with Yu et al (2001), who examined a grass swale with check dams and without check dams but having equal length and different slopes. The study with flow rate 4 x 10^{-3} m^3/s shows % mass removal for total nitrogen and total phosphorus to be 21% and 77 % for the grass swale with check dams compared to 20% and 50% for that swale without any check dams. With that, it appears that the addition of check dams on grass swales could attenuate the runoff flow, increase the detention time and further enhance infiltration.

Comparing to Stagge (2006), the removal for nitrate, nitrite and TKN in the current study is higher (Table 4-10). Stagge (2006) had a significant N-EMC removals of nitrite (56-66%) and exhibited variable removal capabilities ranging from -1% to 60% for nitrate, TKN and total phosphorus.

4.7 Chloride

According to the World Health Organization (WHO) guideline for drinking water, the levels of chloride in water supplies should not exceed 250 mg/L (Radojevic and Bashkin 2006). Therefore the effluent water quality goal is set to be 250 mg/L (Figure 4-25)

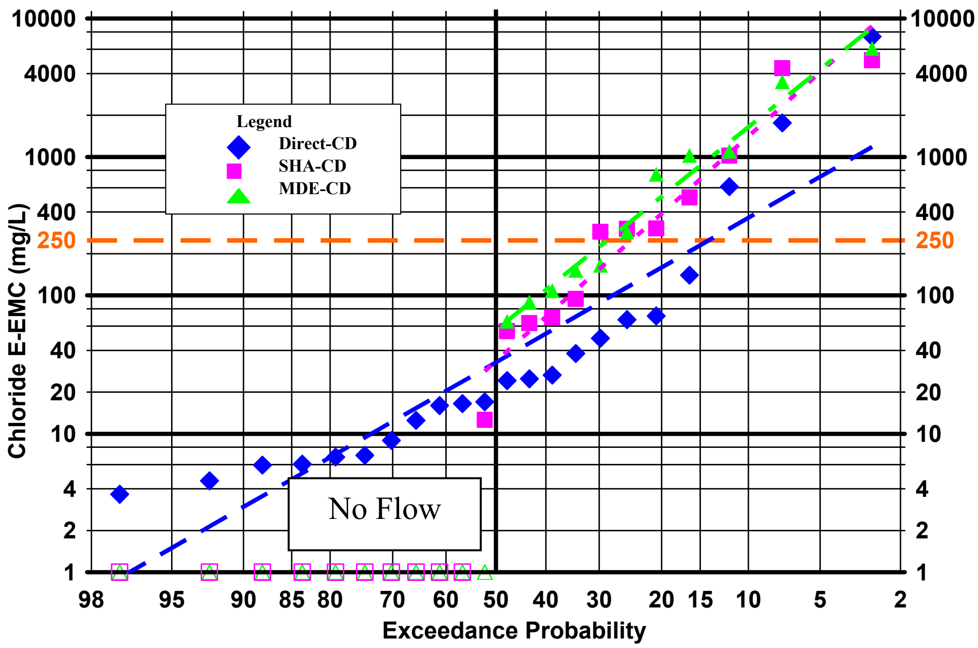

Figure 4-25. Probability plot for Chloride E-EMCs at Rt. 32 Swales.

From the plot, it is clearly seen that there is a significant export of chloride by the swales. However, no significant difference between swales was noted. The significant chloride export apparently comes from the application of de-icing reagents on the highway during snow seasons. Throughout time, the salt slowly dilutes out in every storm event. The total mass pollutant load for chloride is 29 kg (Direct), 46 kg (SHA) and 30 kg (MDE). Therefore the total mass % removal will be -60% (SHA-CD) and -4% (MDE-CD). The negative sign indicates export. Referring to the water quality target, the swales tend to exceed the target for about 30% of storm events compared to the direct at only 15% of the storm events.

4.7.1 Chloride Comparison

It seems that the current chloride loading is a lot more than the previous study especially at the higher ends. Statistically, having check dams on the swale does not help to reduce the chloride. Instead, the non-exceedance probabilities to the target value (250 mg/L) for the swales chloride concentrations had increased to 30% compared to only 8% (SHA) and 15 % (MDE).

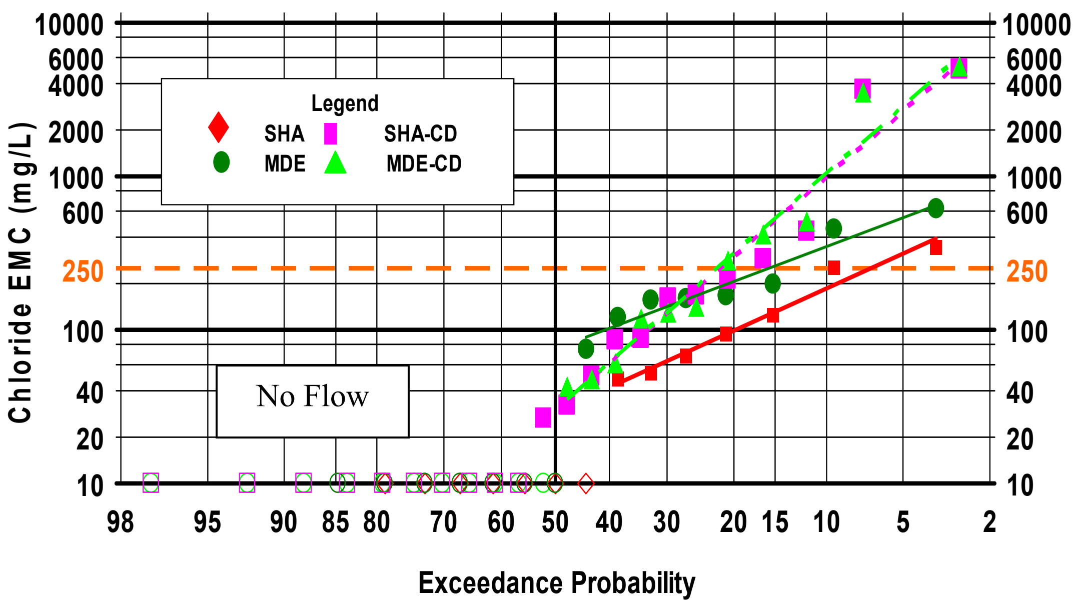

Figure 4-26. Probability plot for Chloride EMCs at Rt. 32 Swales. (Current study vs Stagge (2006))

4.8 Metals (Zinc, Lead, Copper, Cadmium)

Monitoring metal concentrations in the runoff is important because heavy metals have toxic effects on aquatic life and humans. The acute and chronic aquatic toxicity limits established by the Maryland Department of the Environment (MDE 2005) are used as guidelines.

4.8.1 Zinc

Among these four metals, zinc generally has the highest concentration and is found primarily in dissolved form (Dean et al. 2005). The acute toxicity limit for zinc is 120 μg/L (MDE 2005). Figure 4-27 shows that 92% of storm events will produce highway runoff that exceeds the limit. However, after treatment with check-dam swales, only 30% of storm events for SHA-CD swale exceeded the limit of 120 μg/L and only 40% of storm events for MDE-CD swale exceeded 120 μg/L. There are significant statistical improvements in the water quality from the swale and between the swales.

The median E-EMC % removal for the SHA-CD is 70% and for MDE-CD is 69%. In terms of total mass pollutant loading the values are 284 g (Direct), 93 g (SHA-CD) and 59 g (MDE-CD). Therefore, the total mass pollutant % removals are 67% (SHA-CD) and 79% (MDE-CD). The swales performance emphasis should be placed on overall effluent water quality (i.e., total mass pollutant); therefore the MDE-CD swale seems to perform better than the SHA-CD swale since the total mass load reduction is larger. The median E-EMC % removal and total mass pollutant removal for this study falls within previous literature findings such as Barrett et al. (1998, 68-93%), Backstrom (2003, 78-94%) and the total mass load reduction by Backstrom (2003) is about 66%. Zinc is expected to be removed highly since at least 50% of this metal can be effectively removed from runoff by targeting the particulate fraction (Sansalone et al. 1997).

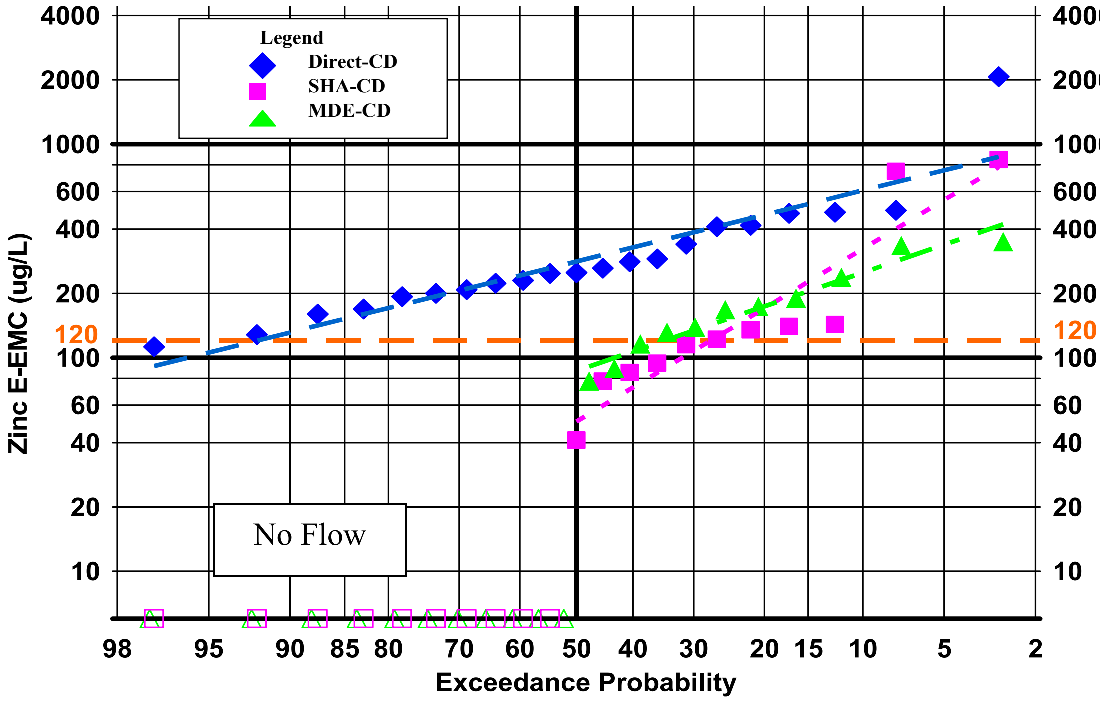

Figure 4-27. Probability plot for Zinc E-EMCs at Rt. 32 Swales.

4.8.1.1 Zinc Comparison

Statistically, there is a significant difference between the performance of grass swales with check dams and without any check dams but it is not clearly seen in Figure 4-28. The current and previous studies still exceed the water quality target for about 20% of storm events. However, there is a big difference in terms of significant removals based on the zinc E-EMC. Previously without check dams, it was reduced by 30%-40%, but with installation of check dams, the removal is 79%-81%.

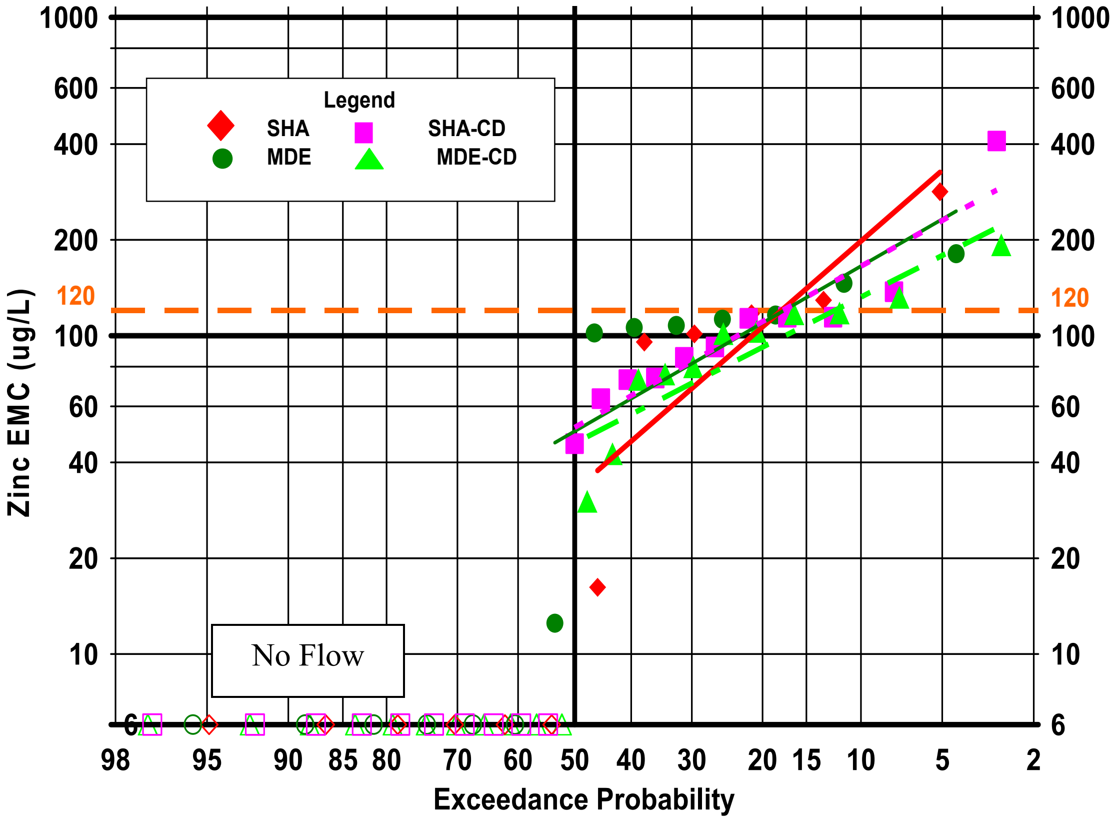

Figure 4-28. Probability plot for Zinc EMCs at Rt. 32 Swales.
(Current study vs Stagge (2006))

4.8.2 Lead

The acute toxicity limit for lead is 65 µg/L (MDE 2005) and 20% of storm events exceeded this limit (Figure 4-29). With treatment from the check dam swales, the limit is exceeded for only about 12% of storm events for SHA-CD and only about 7% of storm events for MDE-CD. Although there is a slight different in the performance, it is not significantly different statistically. The total mass pollutant load for lead is: 51 g (Direct), 11 g (SHA-CD) and 9 g (MDE-CD).

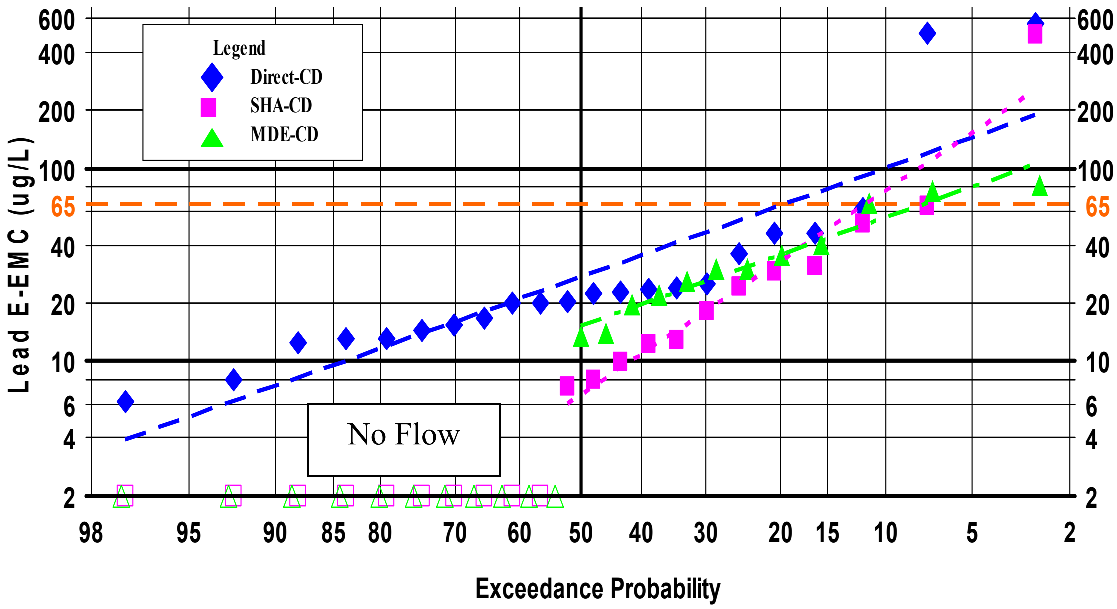

Figure 4-29. Probability plot for Lead E-EMCs at Rt. 32 Swales.

4.8.2.1 Lead Comparison

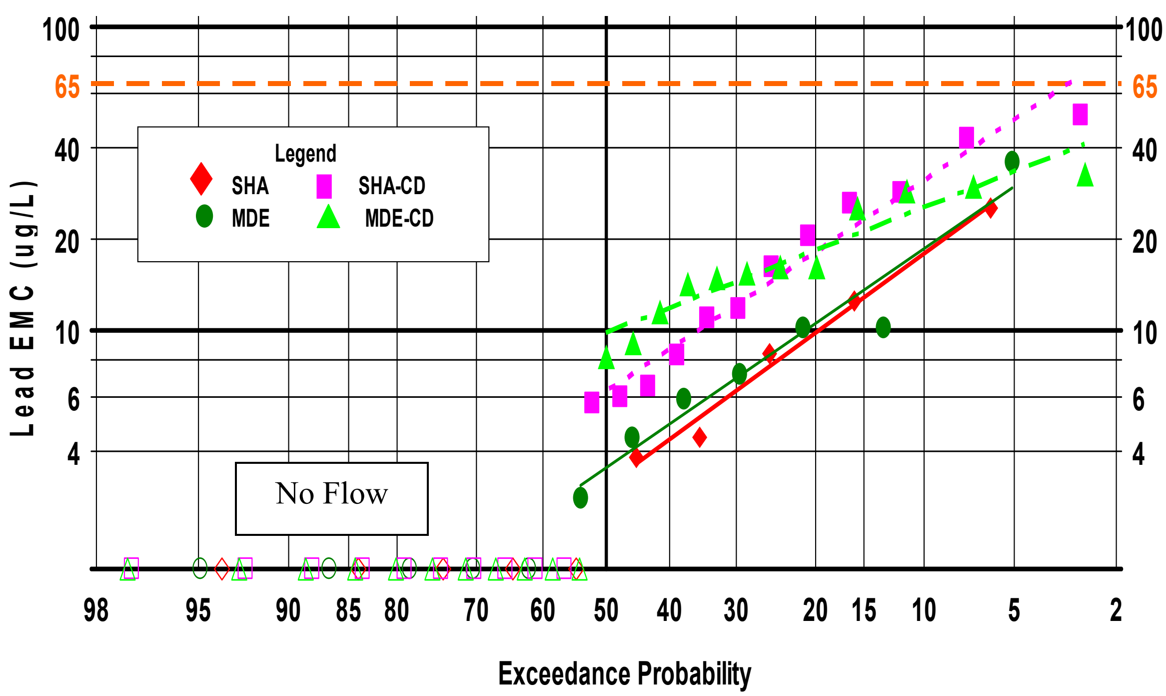

Figure 4-30. Probability plot for Lead EMCs at Rt. 32 Swales.
(Current study vs Stagge (2006))

None of the data from the current study or the previous study exceed the acute toxicity limit of 65 µg/L. Although the performance of the swales with check dams look worst than without any check dams since the trend line appears above the previous study trend line, indeed no statistically significance difference was found.

4.8.3 Copper and Cadmium

The results for copper (Figure 4-31) shows that both swales help to reduce the number of storm events that will exceed the copper acute toxicity limit of 13 µg/L (MDE 2005), from 90% of the storm events to about 45%-50% storm events. This fact does not confirm that it helps to improve the water quality since statistically, there are no difference found between the direct and the swales. The reduction was also mainly due to no-flow event.

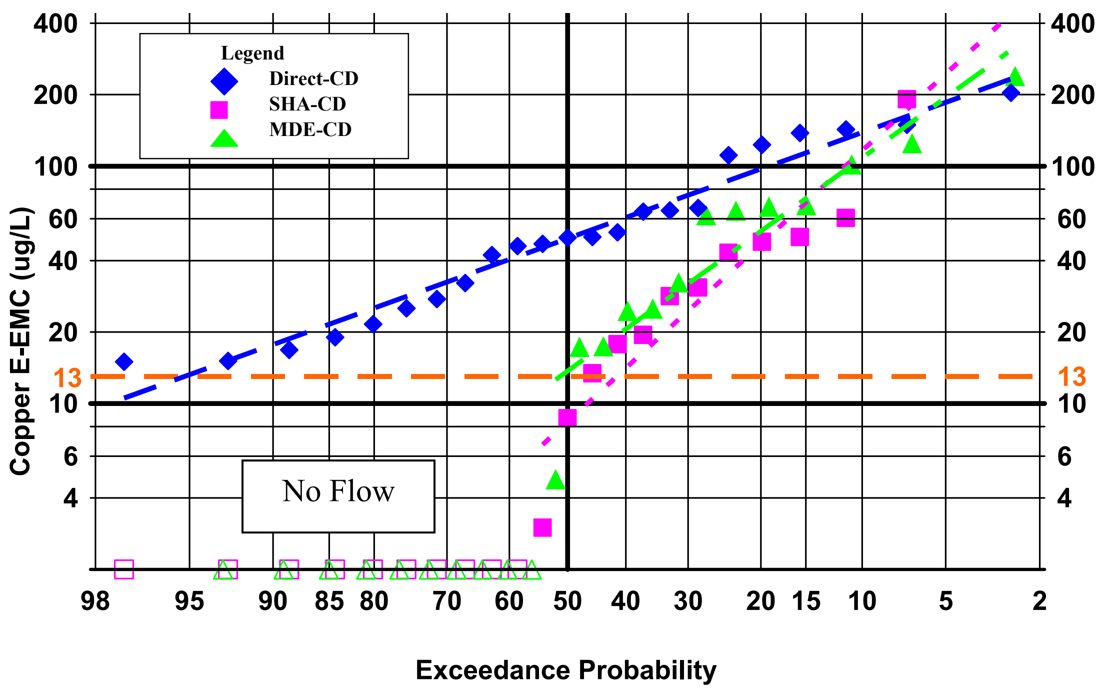

Figure 4-31. Probability plot for Copper E-EMCs at Rt. 32 Swales.

The acute toxicity limit for cadmium is 2 µg/L (MDE 2005). Most of the data are below the detection limit and therefore, no statistical analysis can be done. There are a few occasion where the swale produce high amount of cadmium for uncertain reasons (Figure 4-32).

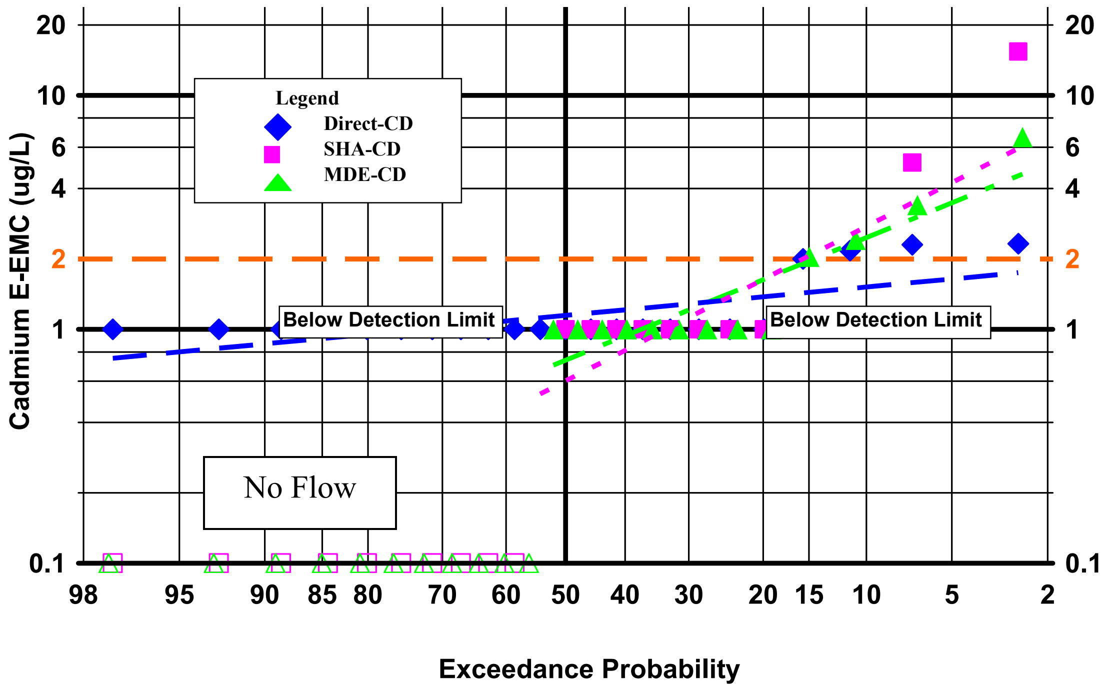

Figure 4-32. Probability plot for Cadmium E-EMCs at Rt. 32 Swales.

4.8.3.1 Copper and Cadmium Comparison

Check dams do not help to reduce the amount of copper in the stormwater runoff since it still exceeded the acute toxicity limit for about 40% of the storm events (Figure 4-33). Cadmium comparison could not be done since all data from the previous study in below detection limits (Figure 4-34).

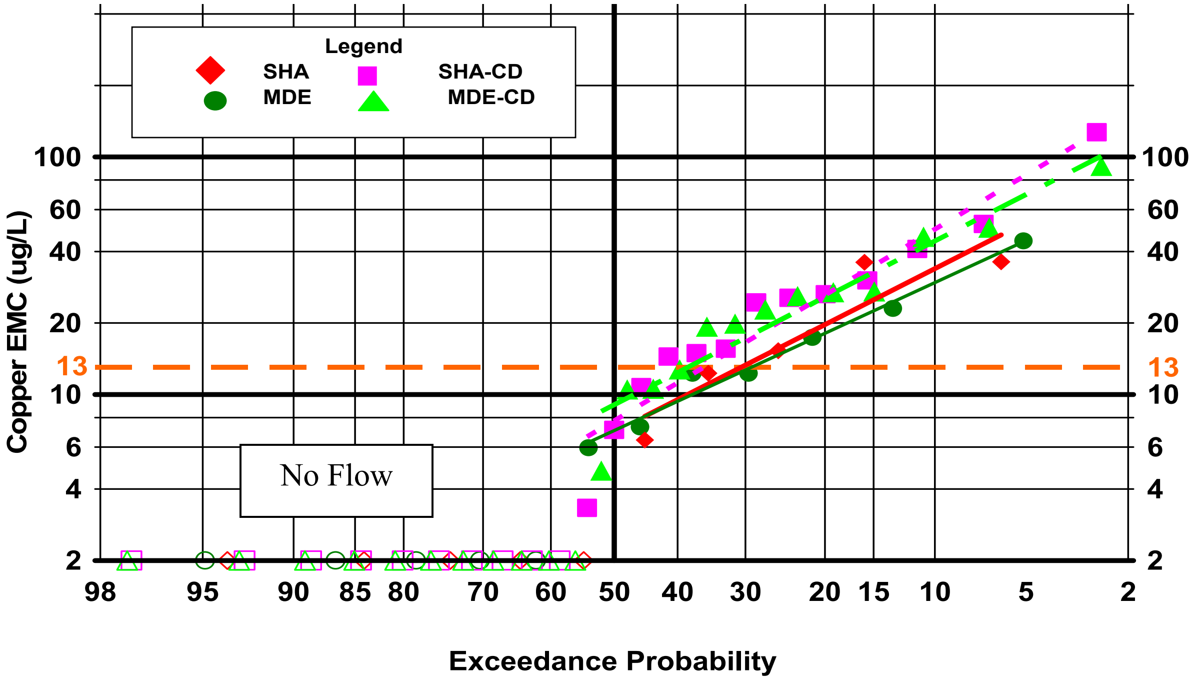

Figure 4-33. Probability plot for Copper EMCs at Rt. 32 Swales.

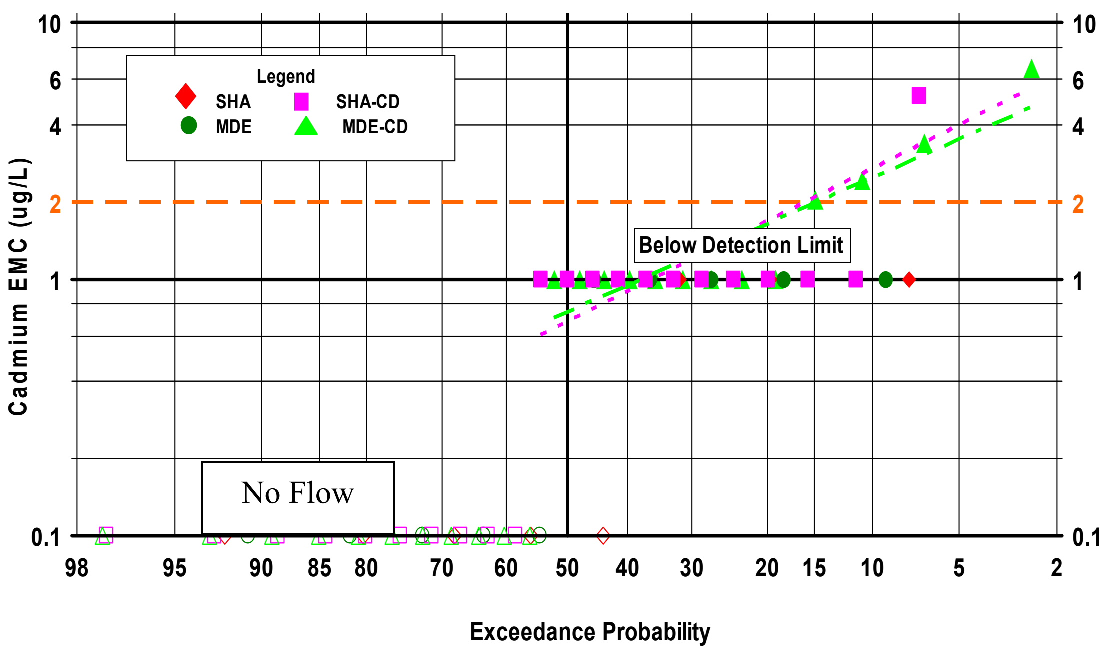

Figure 4-34. Probability plot for Cadmium EMCs at Rt. 32 Swales.
(Current study vs Stagge (2006))

In short, the only metal that shows statistically significant improvement when compared to the Direct is zinc. This might be due to high suspended solids and organic content within the grass. Zinc is easier to be removed compared to copper because copper has a high affinity to bound to organic complexes and zinc is mainly in dissolved form.

On the other hand, all pollutants show positive mass removals, lead (78% SHA-CD, 82% MDE-CD), copper (56% SHA-CD, 70% MDE-CD) and zinc (67% SHA-CD, 79% MDE-CD). Mass removal is significant compared to the concentration reduction. It implies that the swale infiltration mechanism helps to reduce metals better by infiltration of the runoff rather than filtering the metals. This makes sense since most of the metal exists in dissolved form except for lead. Besides that, no significant metal removal was noted by having check dams on the swales.

Chapter 5

CONCLUSION

The Maryland State Highway Administration (SHA) promotes the use of Low Impact Development (LID) technologies for addressing complex stormwater management challenges specifically dealing with highway runoff. This research was supported specifically to examine the hydrologic and water quality benefits of having grass swales with additional pre-treatment area and the incorporation of check dams for managing highway runoff. Stagge (2006) examining the same aspects, but without check dams on the swales. Since both research projects were conducted at the same site, it allows direct comparison of any improvement that resulted from having check dams installed.

The research site was constructed in the median of a four-lane (two in each direction) limited access highway, Maryland Route 32 near Savage, Maryland. The site consists of two swales (MDE-CD and SHA-CD) with different designs but nearly identical contributing roadway drainage area. The only condition that is different than the previous study by Stagge (2006) is that two vegetated check dams are installed within each of the swales. The vegetated check dams were constructed of Panicum Virgatum 'Heavy Metal', a sturdy plant that will remain standing either in heavy rain or snow. The swale that has the pre-treatment area adjacent to the roadway is known as MDE-CD (swale area: 0.431 ha, length: 137 m) and the second swale without the pre-treatment area is known as SHA-CD (swale area: 0.312 ha, length: 198 m). Both swales drain to an inlet where water flow and quality measurements were made. A comparison of the input and output was done by having the direct runoff as the input and flow from the swales as the output. The direct runoff water flow and quality measurements were made from a concrete channel that collects runoff sample directly from the highway. Ten target pollutants were total suspended solids (TSS), nitrate-N, nitrite-N, total Kjeldahl nitrogen (TKN), total phosphorus (TP), chloride (Cl), copper (Cu), lead (Pb), zinc (Zn), and cadmium (Cd).

In total, 24 storm events were analyzed over a period of about two years. Among those 24 storms, 10 were completely captured where no flow output was measured from the swales. To evaluate the performance of the swale, two hypotheses are made. First, the pretreatment area prior to the grass swale is helping by slowing down the runoff velocities, providing more infiltration into underlying soils and filtering out sediment and other pollutions. Second, by having check dams within the grass swales, temporary ponding areas within the swales will be created, runoff velocity will be reduced and the retention time will be increased, and eventually more infiltration through the soil and filtration through the grass swale will occur.

In order to clarify those hypotheses, several hydrologic criteria including the peak flow, lag time, and total effective volume were used to determine the effects of using grass swales with check dams for treating the highway runoff. For water quality purposes, the pollutant were evaluated using the overall total mass loading on the swales and the effective event mean concentration (E-EMC), which allows a comparison between the flow-weighted mean concentrations without the dilution effects of excess rainfall on the grass swale area.

It appears that the average time for the SHA-CD swale to start delivering flows to the weir is about 2 hours after the Direct starts to sample and the average time for the MDE-CD swale is about 3 hours after the Direct starts to sample. Having check dams helps to detain water longer on the swales and will further enhance the filtration and infiltration processes. Furthermore, the overall average peak reduction by the swales is between 61-68% and compares to the Stagge (2006) study; he had a lower percentage of peak reduction of 50-53%. This shows that the check dams on the swales do slow down the runoff and further reduce the peak flow. Throughout the study, the highest peak flow obtained for the Direct is 51 L/s and the highest peak flow obtained for SHA-CD and MDE-CD were 20 L/s and 11 L/s, respectively. Having extra surface area helps to reduce the peak flow and reduce the mean volume. The MDE-CD swale mean volume is 4400 L while the Direct and the SHA-CD swale mean volumes are 31000 L and 7900 L, respectively.

Comparing to the reduction of total volume with Stagge (2006) without check dams, the reduction of total volume was between 46-54%; but with check dams installed, the reduction was actually lower than before, 28-64 %. Many factors could contribute to the fact that SHA-CD did not perform as well as MDE-CD and as well as the swale without check dams. This might be due to the fact that the check dams installed on the SHA-CD was not fully matured to act as a useful check dams. As seasons change, it dries up and not be able to detain water longer on the swales. Generally, this study shows that swales are not designed to detain the runoff but just to slow down the runoff using the vegetation. Data from the MDE-CD swale show that the pretreatment area is beneficial for stormwater volume and peak reduction and increase in lag time.

Considering the water quality benefits, most of the overall mass pollutant loadings exhibit positive reduction, but mixed results are obtained for the mean E-EMCs. Reduction of E-EMCs were more difficult to prove statistically because this comparison only includes those storms with measurable flow, while overall mass reduction allows comparison that includes all complete captured storm events. Therefore, the overall mass reduction can give a better sense of the performance of the swales and more weight is placed on this criterion.

The overall mass loading reduction for TSS shows that the SHA-CD swale is able to reduce 62% of the mass and MDE-CD swale is able to reduce 38% of the mass. This suggests that the swales are capable of filtering out the suspended solids from the highway runoff. Compared with the mean E-EMCs, only SHA-CD shows a statistical difference compared to the Direct. This suggests that the filtration capacity of the SHA-CD swale is better than that of the MDE-CD due to longer swale. The extra area of MDE-CD does not help to significantly reduce the TSS.

For nutrients, the SHA-CD swale showed positive overall mass loading reductions for nitrate (92%) and nitrite (54%), but a negative overall mass loading reduction for TKN (-120%) and TP (-5%). The MDE-CD swale on the other hand, showed positive overall mass loading reductions for all nutrients: nitrate (95%), nitrite (71%), TKN (44%) and TP (40%). Statistically, compared to the Direct, the E-EMC data showed that the MDE-CD swale exported nitrite (-2%) and TKN (-240%), while the SHA-CD exported TKN (-148%) and TP (-172%). The variability in nutrient removals suggests that the grass swales efficiencies are affected by several factors such as seasonal effects, the release of organic matter, mowing, different oxidation characteristics and the input of sediment loads. These factors contributed to the removal efficiency due to the nature of the nutrients itself. For example, phosphorus, which highly depends on physical processes (due to being particulate bound) such as infiltration, deposition and filtration will be easily removed if the TSS is high because it will tend to bond on the surface of the TSS and then be filtered by the grass.

Chloride showed a significant increase in the swales E-EMC compared to the direct (SHA-CD: -388% and MDE-CD: -633%). Also overall mass loading increase was noted for both swales (SHA-CD:-61% and MDE-CD:-4%). This clearly shows a significant chloride export from the swales apparently due to the application of de-icing reagents during the snow seasons. The salts accumulated in the swales during the winter season are slowly leached out in every event.

Metals were all significantly removed by the swales in terms of the overall total mass. Lead showed the highest removal (SHA-CD: 78% and MDE-CD: 82%) followed by zinc (SHA-CD: 67% and MDE-CD: 79%) and copper (SHA-CD: 56% and MDE-Cd: 70%). The reduction of cadmium could not be obtained since most of the cadmium concentrations were below the detection limit. However, only zinc appears to show a significant decrease from the swales E-EMC compared with the Direct (SHA-CD: 57% and MDE-CD: 79%). From the literature, both zinc and copper are mostly in dissolved form, but zinc had a higher tendency to be removed compared to copper because copper has a high affinity to bind to organic complexes. Lead on the other hand, is mostly particulate bound and therefore the removal is the highest since the vegetation and the suspended solids are capable of adsorbing the metal from the runoff, therefore reducing the concentration.

The swale data did not show any significant improvements in water quality by including check dams. No consistent significant difference was obtained. Looking at the overall total mass reduction, it seems that the MDE-CD swale tends to have higher % reduction compared to SHA-CD, except for TSS. This shows that the pre-treatment area was helpful in reducing the total mass of the pollutants and the length of the swale did not affect the removal efficiencies. Although the SHA-CD swale is longer than MDE-CD swale it does not have a significantly impact the removal capability. Yu et al. (2001) showed that the removal rate of pollutants reaches a plateau when swales are longer than approximately 75 m, regardless of slope. The inconsistency obtained for the reduction of the mean E-EMC concentrations indicates that the total mass reduction provides a better indication because it is a total value and not an average value. Since the swales are capable of reducing the total pollutant mass, it can be concluded that the infiltration mechanism works better to improve highway runoff rather than the filtration mechanism since it does not significantly reduce the concentration of the pollutants.

In conclusion, the first hypothesis of this study was confirmed: the pretreatment area prior to the grass swale helps by reducing the runoff velocity, providing more time for filtration, sedimentation and absorption of the pollutants, and increasing the infiltration capacity into underlying soils. However, the second hypothesis is not confirmed since no significant difference in the performance of swales with check dams was found in comparison to those without check dams. Considering the hydrologic aspects, check dams reduced the average peak flow but not the total volume compared to the swale without check dams.

Overall, this study shows that the grass swale is a beneficial technology that helps to manage highway runoff. However, improvements could be made through further research:

1) From the experimental aspect, a larger set of data could provide better understanding of the functioning of swales. A better distribution of storm events sampled could also provide a better understanding in terms of hydrology and water quality for high/low/moderate intensity storms. Furthermore, a better understanding about metal speciation could also help since this would allow a better understanding of the removal mechanisms in grass swales.
2) The performance of different kinds of check dams (vegetated check dams vis-a-vis riprap or wood logs) is another issue that needs study. Vegetated check dams have a disadvantage of being effected by seasons, mowing and the maturity of the plants. But having check dams made from rocks or wood logs could ensure better performance for all seasons and more water can be detained to increase the infiltration and filtration time within the swales. The effects of the number of check dams installed also need to be studied.
3) The design of the swales could be improved by maintaining shallow slopes, having soils that promote infiltration, and having denser grass/thicker vegetation since it is known that filtration and sedimentation are the main mechanisms of the swales. Additionally, having a layer of soil that has high organic matter could also help to increase the performance for particulate bound pollutants, but it needs to be carefully designed because it might

increase the nutrients in the swale. The grass for the pre-treatment area should also be fully developed so that less debris/washout from the extra area affects the water quality.

4) Infiltration rates on site should be measured (e.g., with a double-ring infiltrometer). Since the infiltration capacity was deduced from the linear regression, having the actual measurements on site would help to clarify the method that was used in this research. Additionally, checks for the soil parameters (grain size distribution, hydraulic conductivity, bulk density) could also help to maintain the performance of the swale.

APPENDIX A

E-EMC for All Storm events

	TSS (mg/L)			Nitrate (mg-N/L)			Nitrite (mg-N/L)			TKN (mg/L)			TP (mg/L)		
Storm event	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**
2/25/2007	8	2	3	NA	NA	NA	0.09	0.06	0.05	0.40	0.54	0.50	0.32	0.56	0.44
4/4/2007	130	5	9	NA	NA	NA	0.05	0.06	0.09	1.40	1.80	1.00	0.40	0.45	0.37
5/12/2007	40	NF	NF	6.00	NF	NF	0.40	NF	NF	1.80	NF	NF	0.15	NF	NF
5/16/2007	180	50	280	NA	NA	NA	0.10	0.20	0.20	2.00	2.10	3.10	0.13	0.81	0.80
6/3/2007	70	10	50	1.00	0.50	0.20	0.03	0.04	0.00	0.40	0.60	0.80	0.22	0.76	0.46
7/4/2007	110	60	350	1.40	0.60	0.90	0.02	0.04	0.07	0.60	2.10	2.80	0.22	1.20	1.10
9/11/2007	600	NF	NF	2.00	NF	NF	0.24	NF	NF	0.35	NF	NF	0.23	NF	NF
10/19/2007	60	NF	NF	2.00	NF	NF	0.04	NF	NF	0.20	NF	NF	0.22	NF	NF
10/24/2007	50	NF	NF	1.00	NF	NF	0.10	NF	NF	0.17	NF	NF	0.41	NF	NF
11/13/2007	8	NF	NF	0.50	NF	NF	0.14	NF	NF	0.55	NF	NF	0.17	NF	NF
12/2/2007	50	10	40	NA	NA	NA	0.03	0.00	0.20	0.50	0.40	0.50	<0.1	0.25	0.58
12/14/2007	80	40	140	NA	NA	NA	0.02	0.01	0.02	NA	NA	NA	0.29	0.83	0.18
1/10/2008	20	NF	NF	NA	NF	NF	0.19	NF	NF	0.48	NF	NF	0.23	NF	NF
2/1/2008	90	30	100	NA	NA	NA	0.03	0.04	0.02	0.27	4.40	0.21	0.25	0.43	0.21
3/4/2008	150	80	250	NA	NA	NA	0.06	0.01	0.02	0.20	0.55	0.81	0.63	1.00	0.42
3/16/2008	60	20	60	NA	NA	NA	0.04	0.02	0.08	0.90	1.00	2.20	0.21	0.36	0.60
4/3/2008	30	NA	70	NA	NA	NA	0.01	NA	0.03	0.07	NA	1.20	0.20	NA	0.51
4/26/2008	50	180	NF	0.80	7.00	NF	0.08	0.38	NF	4.10	3.40	NF	0.12	3.39	NF
5/16/2008	30	10	20	0.30	0.50	0.70	0.03	0.01	0.00	NA	NA	NA	<0.1	0.21	0.11
6/3/2008	30	30	40	0.70	0.60	1.40	0.03	0.06	0.06	0.60	13.00	19.00	<0.1	0.38	0.15
6/10/2008	150	NF	NF	0.40	NF	NF	0.07	NF	NF	1.00	NF	0.11	0.11	NF	NF
6/16/2008	20	NF	NF	0.30	NF	NF	0.06	NF	NF	0.20	NF	NF	0.11	NF	NF
6/30/2008	110	NF	NF	0.50	NF	NF	0.11	NF	NF	1.30	NF	NF	0.10	NF	NF
7/5/2008	50	NF	NF	0.70	NF	NF	0.16	NF	NF	3.00	NF	NF	0.11	NF	NF

**NA = Data Not Available, NF = No Flow

	Cl (mg/L)			Lead (ug/L)			Copper (ug/L)			Zinc (ug/L)			Cadmium (ug/L)		
Storm event	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**
2/25/2007	7400	5000	3500	20	8	14	15	3	5	160	140	190	2.00	<2.0	<2.0
4/4/2007	610	4400	6100	61	31	30	32	18	25	420	140	90	<2.0	<2.0	<2.0
5/12/2007	140	NF	NF	24	NF	NF	65	NF	NF	290	NF	NF	2.30	NF	NF
5/16/2007	20	300	750	500	52	76	140	48	69	2000	750	350	2.30	5.20	6.60
6/3/2007	70	90	150	46	18	20	25	28	25	NA	NA	NA	<2.0	<2.0	<2.0
7/4/2007	50	70	110	16	12	41	42	31	68	NA	NA	NA	<2.0	<2.0	<2.0
9/11/2007	20	NF	NF	NA	NF	NF	NA	NF	NF	NA	NF	NF	NA	NF	NF
10/19/2007	20	NF	NF	560	NF	NF	50	NF	NF	490	NF	NF	<2.0	NF	NF
10/24/2007	30	NF	NF	13	NF	NF	47	NF	NF	200	NF	NF	<2.0	NF	NF
11/13/2007	40	NF	NF	8	NF	NF	19	NF	NF	230	NF	NF	<2.0	NF	NF
12/2/2007	7	60	70	17	64	22	15	13	18	190	120	140	<2.0	<2.0	<2.0
12/14/2007	NA	NA	NA	6	8	14	17	9	17	250	80	130	<2.0	<2.0	<2.0
1/10/2008	9	NF	NF	46	NF	NF	46	NF	NF	340	NF	NF	<2.0	NF	NF
2/1/2008	70	290	290	NA	NA	NA	50	20	32	410	140	170	<2.0	<2.0	<2.0
3/4/2008	1800	500	1000	23	13	66	150	61	100	480	85	240	<2.0	<2.0	2.40
3/16/2008	30	300	1100	14	10	30	64	190	240	260	40	78	<2.0	<2.0	<2.0
4/3/2008	NA	NA	NA	13	NA	26	120	NA	130	220	NA	340	<2.0	NA	3.40
4/26/2008	20	1000	NF	24	500	NF	53	480	NF	210	850	NF	<2.0	5.40	NF
5/16/2008	10	10	90	23	29	36	28	43	65	130	120	170	<2.0	2.00	<2.0
6/3/2008	5	60	170	12	24	81	22	50	62	110	90	120	<2.0	<2.0	2.00
6/10/2008	6	NF	NF	20	NF	NF	111	NF	NF	280	NF	NF	2.20	NF	NF
6/16/2008	6	NF	NF	20	NF	NF	67	NF	NF	250	NF	NF	<2.0	NF	NF
6/30/2008	4	NF	NF	25	NF	NF	200	NF	NF	470	NF	NF	<2.0	NF	NF
7/5/2008	7	NF	NF	35	NF	NF	140	NF	NF	170	NF	NF	<2.0	NF	NF

**NA = Data Not Available, NF = No Flow

Appendix B

EMC for All Storm Events

	TSS (mg/L)			Nitrate (mg-N/L)			Nitrite (mg-N/L)			TKN (mg/L)			TP (mg/L)		
Storm event	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**
2/25/2007	8	2	3	NA	NA	NA	0.09	0.06	0.05	0.40	0.54	0.50	0.32	0.56	0.44
4/4/2007	130	5	8	NA	NA	NA	0.05	0.05	0.07	1.40	1.45	1.00	0.40	0.38	0.31
5/12/2007	40	NF	NF	6.00	NF	NF	0.40	NF	NF	1.80	NF	NF	0.15	NF	NF
5/16/2007	180	30	100	NA	NA	NA	0.10	0.09	0.06	2.00	1.15	1.16	0.13	0.44	0.30
6/3/2007	70	10	40	1.00	0.50	0.20	0.03	0.03	0.00	0.40	0.54	0.60	0.22	0.69	0.36
7/4/2007	110	30	140	1.40	0.60	0.90	0.02	0.02	0.03	0.60	1.03	1.11	0.22	0.56	0.42
9/11/2007	600	NF	NF	2.00	NF	NF	0.24	NF	NF	0.35	NF	NF	0.23	NF	NF
10/19/2007	63	NF	NF	2.00	NF	NF	0.04	NF	NF	0.20	NF	NF	0.22	NF	NF
10/24/2007	48	NF	NF	1.00	NF	NF	0.10	NF	NF	0.17	NF	NF	0.41	NF	NF
11/13/2007	8	NF	NF	0.50	NF	NF	0.14	NF	NF	0.55	NF	NF	0.17	NF	NF
12/2/2007	50	10	30	NA	NA	NA	0.03	0.00	0.11	0.50	0.33	0.38	<0.1	0.20	0.43
12/14/2007	80	30	90	NA	NA	NA	0.02	0.01	0.01	NA	NA	NA	0.29	0.68	0.11
1/10/2008	21	NF	NF	NA	NF	NF	0.19	NF	NF	0.48	NF	NF	0.23	NF	NF
2/1/2008	90	30	60	NA	NA	NA	0.03	0.03	0.01	0.27	5.02	0.13	0.25	0.34	0.13
3/4/2008	150	70	120	NA	NA	NA	0.06	0.01	0.01	0.20	0.63	0.93	0.63	0.86	0.21
3/16/2008	60	10	30	NA	NA	NA	0.04	0.01	0.03	0.90	0.69	0.83	0.21	0.26	0.23
4/3/2008	30	NA	24	NA	NA	NA	0.01	NA	0.01	0.07	NA	0.45	0.20	NA	0.18
4/26/2008	50	20	NF	0.80	0.62	NF	0.08	0.03	NF	4.10	0.29	NF	0.12	0.29	NF
5/16/2008	30	7	8	0.30	0.34	0.29	0.03	0.01	0.00	NA	NA	NA	<0.1	0.15	<0.1
6/3/2008	30	10	20	0.70	0.30	0.53	0.03	0.03	0.02	0.60	6.27	6.77	<0.1	0.18	<0.1
6/10/2008	150	NF	NF	0.40	NF	NF	0.07	NF	NF	1.00	NF	NF	0.11	NF	NF
6/16/2008	20	NF	NF	0.30	NF	NF	0.06	NF	NF	0.20	NF	NF	0.11	NF	NF
6/30/2008	110	NF	NF	0.50	NF	NF	0.11	NF	NF	1.30	NF	NF	0.10	NF	NF
7/5/2008	50	NF	NF	0.70	NF	NF	0.16	NF	NF	3.00	NF	NF	0.11	NF	NF

**NA = Data Not Available, NF = No Flow

	Cl (mg/L)			**Lead (ug/L)**			**Copper (ug/L)**			**Zinc (ug/L)**			**Cadmium (ug/L)**		
Storm event	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**	**Direct**	**SHA**	**MDE**
2/25/2007	7400	5000	3500	20	8	14	15	3	5	160	140	190	2.0	<2.0	<2.0
4/4/2007	610	3800	5200	61	26	25	32	15	11	420	113	76	<2.0	<2.0	<2.0
5/12/2007	140	NF	NF	24	NF	NF	65	NF	NF	290	NF	NF	2.3	NF	NF
5/16/2007	20	170	280	500	28	29	140	26	26	2000	410	130	2.3	2.8	2.5
6/3/2007	70	90	120	46	16	15	25	26	19	NA	NA	NA	<2.0	<2.0	<2.0
7/4/2007	50	30	40	16	6	16	42	14	27	NA	NA	NA	<2.0	<2.0	<2.0
9/11/2007	20	NF	NF	NA	NF	NF	NA	NF	NF	NA	NF	NF	NA	NF	NF
10/19/2007	20	NF	NF	560	NF	NF	50	NF	NF	490	NF	NF	<2.0	NF	NF
10/24/2007	30	NF	NF	13	NF	NF	47	NF	NF	200	NF	NF	<2.0	NF	NF
11/13/2007	40	NF	NF	8	NF	NF	19	NF	NF	230	NF	NF	<2.0	NF	NF
12/2/2007	7	50	50	17	51	16	15	11	13	190	92	100	<2.0	<2.0	<2.0
12/14/2007	NA	NA	NA	6	6	8	17	7	11	250	63	80	<2.0	<2.0	<2.0
1/10/2008	9	NF	NF	46	NF	NF	46	NF	NF	340	NF	NF	<2.0	NF	NF
2/1/2008	70	290	140	NA	NA	NA	50	16	20	410	114	103	<2.0	<2.0	<2.0
3/4/2008	1800	440	510	23	11	33	150	52	51	480	74	120	<2.0	<2.0	<2.0
3/16/2008	30	210	420	14	7	12	64	130	92	260	30	30	<2.0	<2.0	<2.0
4/3/2008	NA	NA	NA	13	NA	9	120	NA	46	220	NA	117	<2.0	NA	<2.0
4/26/2008	20	90	NF	24	43	NF	53	41	NF	210	73	NF	<2.0	<2.0	NF
5/16/2008	10	9	40	23	21	15	28	30	27	130	85	73	<2.0	2.00	<2.0
6/3/2008	5	30	60	12	12	30	22	24	23	110	46	43	<2.0	<2.0	2.00
6/10/2008	6	NF	NF	20	NF	NF	110	NF	NF	280	NF	NF	2.20	NF	NF
6/16/2008	6	NF	NF	20	NF	NF	67	NF	NF	250	NF	NF	<2.0	NF	NF
6/30/2008	4	NF	NF	25	NF	NF	200	NF	NF	470	NF	NF	<2.0	NF	NF
7/5/2008	7	NF	NF	35	NF	NF	140	NF	NF	170	NF	NF	<2.0	NF	NF

**NA = Data Not Available, NF = No Flow

Appendix C

Flow and Concentration Data with Respect to Time for All Storms Event

2/25/2007

DIRECT

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	**Nitrite-N**	***Nitrate-N***	**TKN-N**	**TP**	**TSS**	**Chloride**	**Zinc**	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(ug/L)*	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	2/25/07 19:18	0.71	0.18	NA	1.12	0.24	9	7100	260	20	9	3
3,4	2/25/07 19:38	0.87	0.16	NA	-	0.24	2	28400	140	13	18	4
5,6	2/25/07 19:58	0.86	0.13	NA	-	0.24	10	11500	180	13	31	4
7,8	2/25/07 20:18	0.94	0.06	NA	1.12	0.25	11	8100	190	14	13	3
9,10	2/25/07 20:38	0.92	0.10	NA	0.84	0.34	15	8050	140	19	10	3
11,12	2/25/07 21:18	0.89	0.08	NA	-	0.37	9	7900	130	16	10	2
13,14	2/25/07 21:58	0.79	0.08	NA	0.70	0.50	5	2100	200	13	8	2
15,16	2/25/07 22:38	0.74	0.08	NA	-	0.41	8	5750	260	12	3	2
17,18	2/25/07 23:38	0.75	0.08	NA	0.70	0.29	8	5750	140	12	32	2
19,20	2/26/07 0:38	0.67	0.08	NA	-	0.29	8	5800	130	22	72	8
21,22	2/26/07 1:38	0.49	0.09	NA	0.70	0.24	5	5500	150	12	6	1
23,24	2/26/07 3:18	0.34	0.07	NA	-	0.24	2	5700	120	10	8	2

MDE

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	**Nitrite-N**	***Nitrate-N***	**TKN-N**	**TP**	**TSS**	**Chloride**	**Zinc**	**Copper**	**Lead**	**Cadmium**
Bottles	*Date& Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(ug/L)*	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	2/25/07 20:52	0.74	0.04	NA	0.70	0.40	7	-	130	4.3	45.9	0.04
3,4	2/25/07 21:12	0.86	0.03	NA	-	0.42	3	-	91	6.2	1.7	0.15
5,6	2/25/07 21:32	0.98	0.03	NA	0.70	0.48	6	-	130	5.2	31	0.31
7,8	2/25/07 21:52	1.16	0.03	NA	-	0.45	2	-	100	6.1	1.0	0.34
9,10	2/25/07 22:12	1.50	0.04	NA	-	0.47	2	-	89	4.0	2.2	0.50
11,12	2/25/07 22:32	2.14	0.07	NA	-	0.34	1	-	130	3.4	36	0.47
13,14	2/25/07 22:52	2.18	0.05	NA	1.12	0.44	1	8050	93	7.8	48	0.53
15,16	2/25/07 23:12	2.03	0.05	NA	-	0.39	13	1550	120	4.9	46	0.54
17,18	2/25/07 23:32	1.96	0.05	NA	0.84	0.35	1	7050	370	5.6	5.0	0.76
19,20	2/26/07 0:32	1.75	0.05	NA	-	0.37	2	1850	370	5.5	6.8	0.74
21,22	2/26/07 1:32	1.51	0.05	NA	1.12	0.55	3	7200	130	3.1	0.6	0.70
23,24	2/26/07 2:52	1.36	0.04	NA	0.56	0.58	1	1550	81	3.4	11	0.54

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	**Nitrite-N**	***Nitrate-N***	**TKN-N**	**TP**	**TSS**	**Chloride**	**Zinc**	**Copper**	**Lead**	**Cadmium**
Bottles	*Date& Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(ug/L)*	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	2/25/07 20:07	0.70	0.02	NA	0.70	0.55	5.71	4100	130	5.56	10.31	0.65
3,4	2/25/07 20:27	2.02	0.03	NA	-	0.47	3.43	1600	128	1.30	2.24	0.20
5,6	2/25/07 20:47	1.98	0.06	NA	1.12	0.66	3.57	5650	253	2.28	2.63	0.56
7,8	2/25/07 21:07	1.97	0.07	NA	-	0.67	3.29	5650	72	1.74	3.30	1.33
9,10	2/25/07 21:27	2.39	0.07	NA	-	0.52	2.43	6000	181	0.74	6.99	1.05
11,12	2/25/07 21:47	2.32	0.07	NA	-	0.58	1.00	5900	81	0.27	34.54	1.12
13,14	2/25/07 22:07	2.16	0.07	NA	1.26	0.43	3.14	5300	143	1.53	8.96	0.92
15,16	2/25/07 22:27	2.16	0.08	NA	-	0.53	1.00	5300	116	2.16	1.19	1.24
17,18	2/25/07 22:47	2.09	0.07	NA	1.12	0.63	1.00	5250	162	8.45	19.03	1.28
19,20	2/25/07 23:47	1.94	0.06	NA	-	0.58	1.29	5250	111	4.77	6.50	0.87
21,22	2/26/07 0:47	1.85	0.05	NA	0.84	0.52	1.00	5150	162	1.44	3.89	1.59
23,24	2/26/07 2:07	1.83	0.05	NA	0.98	0.55	1.14	3450	106	5.94	3.36	0.91

4/4/2007

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	4/4/07 3:02	3.13	0.064	40.00	6.16	3.17	1000	751	2700	140	150	3.2
3,4	4/4/07 3:22	2.69	0.057	20.00	-	0.68	390	412	380	38	45	0.39
5,6	4/4/07 3:42	1.02	0.052	20.00	5.32	0.47	83	790	360	36	27	0.20
7,8	4/4/07 4:02	0.94	0.052	23.00	-	0.24	94	473	280	28	43	0.15
9,10	4/4/07 4:22	2.32	0.034	24.00	2.52	0.16	49	508	250	22	140	0.04
11,12	4/4/07 5:02	1.32	0.048	11.50	-	0.12	40	536	240	25	130	0.04
13,14	4/4/07 5:42	1.07	0.045	7.50	1.54	0.11	37	684	160	26	42	0.02
15,16	4/4/07 6:22	0.83	0.045	9.50	-	0.30	23	656	140	22	18	0.01
17,18	4/4/07 7:22	1.44	0.053	9.50	1.54	0.25	16	456	500	41	73	0.41
19,20	4/4/07 8:22	1.12	0.071	10.50	-	0.18	150	698	290	31	23	0.23
21,22	4/4/07 9:22	0.74	0.062	10.00	1.68	0.20	17	716	250	21	23	0.05
23,24	4/4/07 11:02	0.37	0.060	11.00	1.4	0.18	11	885	240	18	16	0.10

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	**Chloride**	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	4/4/07 7:37	0.71	0.078	-	3.08	0.50	4	3100	72	22	3	0.26
3,4	4/4/07 7:57	1.89	0.081	-	-	0.50	16	2500	56	9	5	0.07
5,6	4/4/07 8:17	2.43	0.086	-	1.82	0.29	13	6300	86	19	7	0.19
7,8	4/4/07 8:37	1.82	0.081	-	-	0.31	13	6400	123	12	6	0.15
9,10	4/4/07 8:57	1.32	0.088	-	2.1	0.26	9	6900	57	14	11	0.12
11,12	4/4/07 9:17	1.15	0.088	-	-	0.24	7	6100	86	13	5	0.10
13,14	4/4/07 9:37	1.03	0.076	-	1.96	0.30	4	5000	38	10	7	0.12
15,16	4/4/07 9:57	0.81	0.074	-	-	0.24	3	8200	36	3	110	0.04
17,18	4/4/07 10:17	0.58	0.062	-	1.4	0.24	0	5100	91	8	3	0.12
19,20	4/4/07 11:17	0.38	0.041	-	-	0.28	1	3400	77	9	170	0.16
21,22	4/4/07 12:17	0.27	0.033	-	1.4	0.25	1	3800	70	13	3	0.09
23,24	4/4/07 13:37	0.19	0.028	-	1.4	0.27	1	3400	75	8	2	0.12

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	**Chloride**	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	4/4/07 4:52	0.80	0.041	9.00	3.5	0.47	11	3400	150	29	4	0.26
3,4	4/4/07 5:12	1.94	0.029	9.00	-	0.54	4	3300	130	25	4	0.11
5,6	4/4/07 5:32	1.65	0.034	12.50	2.8	0.43	3	2500	120	20	3	0.32
7,8	4/4/07 5:52	1.36	0.031	10.50	-	0.47	1	2500	70	17	14	0.30
9,10	4/4/07 6:12	1.23	0.084	11.50	2.8	0.52	3	8200	130	17	11	0.20
11,12	4/4/07 6:32	1.15	0.028	10.50	-	0.44	1	6900	190	16	2	0.19
13,14	4/4/07 6:52	1.05	0.041	-	1.82	0.37	44	4100	75	18	16	0.19
15,16	4/4/07 7:12	1.03	0.043	-	-	0.47	1	3300	95	15	2	0.15
17,18	4/4/07 7:32	2.03	0.034	-	2.52	0.44	3	5900	120	13	5	0.12
19,20	4/4/07 8:32	2.55	0.038	-	-	0.33	3	2600	110	16	100	0.16
21,22	4/4/07 9:32	1.52	0.093	-	2.52	0.30	3	2800	140	11	3	0.20
23,24	4/4/07 10:52	1.11	0.040	-	1.82	0.28	3	3100	45	9	1	0.02

5/12/2007 (Complete Captured Event)

DIRECT

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	5/12/07 22:12	0.76	0.32	1.89	4.06	0.12	406	76	1100	260	44	3.92
3,4	5/12/07 22:32	0.72	1.52	1.91	-	0.16	49	55	670	130	18	1.50
5,6	5/12/07 22:52	0.24	1.41	1.73	3.92	0.15	20	55	360	75	11	1.42
7,8	5/12/07 23:12	0.94	0.18	10.00	-	0.17	19	190	380	72	12	1.38
9,10	5/12/07 23:32	0.32	0.32	11.00	5.32	0.13	12	86	320	59	10	1.07
11,12	5/13/07 0:12	0.25	0.21	11.50	-	0.16	22	140	250	59	8	1.84
13,14	5/13/07 0:52	0.17	0.17	12.50	3.22	0.17	17	190	160	48	20	1.50
15,16	5/13/07 1:32	0.11	0.15	11.00	-	0.17	14	190	150	46	9	4.38
17,18	5/13/07 2:32	0.06	0.20	14.00	4.06	0.14	13	180	180	38	71	1.42
19,20	5/13/07 3:32	0.72	0.21	3.60	-	0.17	19	190	210	45	57	2.97
21,22	5/13/07 4:32	0.59	0.18	2.61	1.68	0.15	54	120	220	54	9	3.48
23,24	5/13/07 6:12	0.35	0.16	2.72	1.82	0.12	7	150	110	38	7	1.06

5/16/2007

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	5/16/07 16:36	17.48	0.210	-	5	0.125	600	20	3300	280	150	3.08
3,4	5/16/07 16:56	9.42	0.076	-	-	0.133	88	8	2700	130	1200	3.95
5,6	5/16/07 17:16	2.63	0.045	-	0.9	0.155	95	9	1500	84	100	0.77
7,8	5/16/07 17:36	0.94	0.057	-	-	0.120	19	37	680	140	37	0.60
9,10	5/16/07 17:56	1.47	0.060	-	3.5	0.123	110	32	480	34	26	0.05
11,12	5/16/07 18:36	1.01	0.067	-	5.6	0.155	29	29	220	51	19	0.04
13,14	5/16/07 19:16	0.68	0.067	-	0.7	0.135	22	26	200	33	18	0.01

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	5/16/07 16:48	5.21	0.040	-	2	0.268	99	270	190	25	33	4
3,4	5/16/07 17:08	18.89	0.036	-	-	0.221	160	280	110	31	40	2
5,6	5/16/07 17:28	6.69	0.090	-	1.8	0.409	69	310	130	23	18	3
7,8	5/16/07 17:48	2.33	0.060	-	2.2	0.401	37	300	120	22	15	3
9,10	5/16/07 18:08	1.01	0.093	-	2	0.391	30	290	90	22	14	4

SHA

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	5/16/07 16:45	11.12	0.031	-	2.8	0.243	110	230	340	22	11	4.0
3,4	5/16/07 17:05	17.15	0.034	-	-	0.381	24	110	170	29	8	4.4
5,6	5/16/07 17:25	8.90	0.062	-	1.9	0.434	13	140	900	30	31	2.9
7,8	5/16/07 17:45	5.43	0.103	-	-	0.524	8	170	700	26	140	2.5
9,10	5/16/07 18:05	3.43	0.186	-	2.3	0.622	2	210	150	24	7	0.25
11,12	5/16/07 18:25	2.40	0.243	-	-	0.582	12	240	150	23	7	0.35
13,14	5/16/07 18:45	1.78	0.259	-	2.6	0.902	17	240	240	36	7	0.38
15,16	5/16/07 19:05	1.36	0.291	-	-	0.562	12	240	170	22	4	0.37
17,18	5/16/07 19:25	1.01	0.324	-	2.4	0.544	8	280	140	25	7	0.2

6/3/2007

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/3/07 12:34	0.94	0.210	1.260	0.2	0.144	32	164	-	46	10	0.14
3,4	6/3/07 12:54	2.48	0.085	0.560	-	0.169	100	50	-	39	10	0.57
5,6	6/3/07 13:14	1.46	0.087	2.130	1.6	0.273	22	68	-	30	7	0.22
7,8	6/3/07 13:34	0.94	0.055	2.500	-	0.164	11	100	-	24	98	0.20
9,10	6/3/07 13:54	0.70	0.053	2.500	1.3	0.387	9	150	-	28	4	0.24
11,12	6/3/07 14:34	1.64	0.040	0.930	-	0.152	7	65	-	21	11	0.17
13,14	6/3/07 15:14	1.22	0.032	0.930	2.2	0.164	4	82	-	26	28	0.33
15,16	6/3/07 15:54	0.81	0.022	1.120	-	0.172	2	82	-	21	5	0.04
17,18	6/3/07 16:54	1.17	0.033	1.920	0.5	0.157	4	73	-	19	13	0.14
19,20	6/3/07 17:54	6.33	0.013	0.360	-	0.237	190	55	-	33	130	0.50
21,22	6/3/07 18:54	1.37	0.012	0.430	0.5	0.280	64	50	-	20	21	0.12
23,24	6/3/07 20:34	0.89	0.013	0.510	0.4	0.177	23	50	-	14	16	0.11

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/3/07 18:04	1.29	0.007	0.190	1.4	0.475	86	210	-	19	6	0.25
3,4	6/3/07 18:24	5.46	0.005	0.180	-	0.326	63	100	-	20	11	0.39
5,6	6/3/07 18:44	3.10	0.003	0.200	1	0.298	36	79	-	17	36	0.09
7,8	6/3/07 19:04	1.56	0.003	0.010	-	0.331	28	110	-	18	6	0.17
9,10	6/3/07 19:24	0.88	0.005	0.190	0.7	0.288	15	110	-	21	8	0.18
11,12	6/3/07 19:44	0.52	0.003	0.160	-	0.457	17	130	-	21	7	0.11
13,14	6/3/07 20:04	0.33	0.002	0.170	1.1	0.392	11	140	-	19	6	0.12
15,16	6/3/07 20:24	0.22	0.003	0.010	-	0.366	21	130	-	25	9	0.17
17,18	6/3/07 20:44	0.16	0.003	0.160	2.4	0.404	13	110	-	16	25	0.21
19,20	6/3/07 21:44	0.18	0.003	0.010	-	0.508	11	130	-	17	6	0.07
21,22	6/3/07 22:44	0.23	0.003	0.010	1.1	0.460	14	160	-	23	8	0.06
23,24	6/4/07 0:04	0.26	0.003	0.010	1	0.462	10	200	-	28	27	0.27

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/3/07 17:58	4.43	0.000	0.400	0.2	0.594	44	50	-	21	20	0.09
3,4	6/3/07 18:18	7.55	0.012	0.620	-	0.584	14	68	-	20	28	0.14
5,6	6/3/07 18:38	3.77	0.027	0.640	0.5	0.670	8	85	-	21	25	0.17
7,8	6/3/07 18:58	2.21	0.028	0.560	-	0.803	8	88	-	19	11	0.10
9,10	6/3/07 19:18	1.56	0.082	0.440	1.8	0.690	4	85	-	52	5	0.18
11,12	6/3/07 19:38	1.13	0.073	0.390	-	0.682	9	99	-	25	10	0.10
13,14	6/3/07 19:58	1.04	0.077	0.350	1.9	0.786	9	110	-	27	6	0.05
15,16	6/3/07 20:18	0.85	0.057	0.320	-	0.738	4	97	-	26	5	0.05
17,18	6/3/07 20:38	0.73	0.062	0.280	1.7	0.601	4	120	-	34	5	0.1
19,20	6/3/07 21:38	0.54	0.057	0.230	-	0.806	5	110	-	31	5	1.5
21,22	6/3/07 22:38	0.43	0.045	0.240	1.5	0.925	3	120	-	38	7	0.13
23,24	6/3/07 23:58	0.42	0.032	0.170	1.8	0.766	2	110	-	23	5	0.15

7/4/2007

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	7/4/07 19:34	2.31	0.028	1.75	1.2	0.13	150	50	-	63	22	1.08
3,4	7/4/07 19:54	20.01	0.020	1.7	-	0.29	130	51	-	63	25	1.53
5,6	7/4/07 20:14	7.48	0.023	1.56	1.3	0.18	110	51	-	23	7	1.25
7,8	7/4/07 20:34	0.94	0.023	0.45	-	0.18	75	57	-	21	9	0.49
9,10	7/4/07 20:54	1.40	0.020	0.4	0.8	0.22	30	51	-	13	5	0.22
11,12	7/4/07 21:34	0.84	0.017	0.30	0.6	0.25	34	26	-	12	4	0.13
13,14	7/4/07 22:14	0.62	0.017	0.27	0.9	0.21	18	46	-	12	4	0.29

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	7/4/07 20:02	11.34	0.018	0.56	1.5	0.47	100	59	-	29	18	0.37
3,4	7/4/07 20:22	16.94	0.027	0.32	1.2	0.35	220	36	-	27	17	0.28
5,6	7/4/07 20:42	4.46	0.032	0.30	0.7	0.51	65	43	-	28	14	0.26
7,8	7/4/07 21:02	1.48	0.043	0.20	0.8	0.49	31	40	-	17	12	0.15

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	7/4/07 20:02	10.32	0.012	0.32	1	0.46	73	24	-	19	8	0.20
3,4	7/4/07 20:22	10.93	0.017	0.30	1	0.53	24	30	-	14	7	0.17
5,6	7/4/07 20:42	3.91	0.028	0.22	1.1	0.64	7	40	-	13	4	0.13
7,8	7/4/07 21:02	1.73	0.033	0.22	1.2	0.72	7	43	-	13	3	0.11
9,10	7/4/07 21:22	0.96	0.037	0.21	0.9	0.83	11	44	-	12	1	0.10

9/11/2007 (Complete Captured Event)

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	9/11/07 0:10	1.97	0.49	2.85	0.84	0.28	380	23	-	-	-	-
3,4	9/11/07 0:30	2.74	0.19	0.76	0.28	0.24	930	5	-	-	-	-
5,6	9/11/07 0:50	0.93	0.35	2.51	0.28	0.24	640	20	-	-	-	-
7,8	9/11/07 1:10	0.90	0.14	1.98	0.28	0.18	380	17	-	-	-	-
9,10	9/11/07 1:30	0.64	0.17	3.06	0.14	0.22	440	34	-	-	-	-

10/19/2007 (Complete Captured Event)

DIRECT

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	10/19/07 20:32	8.79	0.11	1.54	0.42	0.26	240	13	1400	190	3800	0.69
3,4	10/19/07 20:52	3.58	0.07	1.34	-	0.27	51	13	450	40	23	0.43
5,6	10/19/07 21:12	1.27	0.04	1.48	0.70	0.22	20	21	100	8	3	0.01
7,8	10/19/07 21:32	0.94	0.03	1.58	-	0.20	26	20	230	22	6	0.17
9,10	10/19/07 21:52	1.32	0.02	1.55	0.42	0.24	37	21	200	16	5	0.13
11,12	10/19/07 22:32	2.56	0.02	1.56	-	0.19	47	16	190	15	4	0.07
13,14	10/19/07 23:12	1.15	0.02	1.48	0.14	0.17	16	25	190	14	4	0.11
15,16	10/19/07 23:52	0.71	0.01	1.40	0.14	0.20	10	22	1400	100	110	0.15

10/24/2007 (Complete Captured Event)

DIRECT

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	10/24/07 4:04	0.51	0.47	2.00	0.56	0.53	50	14	410	35	14	0.31
3,4	10/24/07 4:24	0.37	0.38	1.74	-	0.51	29	17	240	28	4	0.13
5,6	10/24/07 4:44	0.21	0.31	1.45	0.42	0.53	34	20	190	49	140	0.17
7,8	10/24/07 5:04	0.94	0.30	1.39	-	0.55	39	19	200	16	2	0.06
9,10	10/24/07 5:24	1.12	0.23	1.22	0.42	0.51	26	10	310	328	7	0.20
11,12	10/24/07 6:04	1.37	0.06	0.86	-	0.44	84	18	210	16	4	0.68
13,14	10/24/07 6:44	2.11	0.07	1.42	0.28	0.33	44	32	230	23	4	0.38
15,16	10/24/07 7:24	0.69	0.07	0.77	-	0.37	49	30	160	19	3	0.12
17,18	10/24/07 8:24	0.63	0.09	0.96	0.28	0.42	53	19	180	16	4	0.10
19,20	10/24/07 9:24	1.17	0.10	0.61	-	0.41	63	18	190	20	8	0.11
21,22	10/24/07 10:24	0.63	0.06	1.49	0.28	0.40	26	37	170	35	42	0.20
23,24	10/24/07 12:04	0.44	0.04	1.23	0.14	0.36	24	43	140	18	24	0.09

11/13/2007 (Complete Captured Event)

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	11/13/07 8:18	0.72	0.18	0.45	0.84	0.14	19	46	320	23	11	1.70
3,4	11/13/07 8:38	0.67	0.25	0.62	0.42	0.17	11	45	240	24	9	1.46
5,6	11/13/07 8:58	0.92	0.14	0.42	0.7	0.17	7	27	280	22	8	1.98
7,8	11/13/07 9:18	0.94	0.07	0.5	0.56	0.26	4	54	200	11	8	1.37

12/02/2007

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	12/2/07 17:36	0.80	0.091	-	0.28	0.203	23	10	330	37	11	0.70
3,4	12/2/07 17:56	1.17	0.066	-	-	0.231	19	4	380	27	14	0.75
5,6	12/2/07 18:16	0.82	0.083	-	1.4	0.201	9	4	200	20	43	0.67
7,8	12/2/07 18:36	0.94	0.041	-	-	0.208	1	1	180	24	6	0.41
9,10	12/2/07 18:56	0.68	0.043	-	0.42	0.188	1	22	180	15	20	0.59
11,12	12/2/07 19:36	0.52	0.052	-	-	0.148	1	31	140	16	7	0.45
13,14	12/2/07 20:16	0.55	0.052	-	1.54	0.128	1	29	200	15	5	0.37
15,16	12/2/07 20:56	0.93	0.053	-	-	0.213	3	18	170	15	4	0.35
17,18	12/2/07 21:56	1.43	0.033	-	0.28	0.178	4	15	140	16	40	0.49
19,20	12/2/07 22:56	7.53	0.024	-	-	0.133	10	1	230	15	12	0.63
21,22	12/2/07 23:56	4.40	0.022	-	1.26	0.218	150	2	230	15	15	0.47
23,24	12/3/07 1:36	1.26	0.017	-	0.28	0.143	20	6	85	10	9	0.32

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	12/2/07 23:12	1.57	0.021	-	1.54	0.131	14	76	84	11	4	0.42
3,4	12/2/07 23:32	8.87	0.138	-	-	1.310	49	67	92	15	15	0.85
5,6	12/2/07 23:52	6.94	0.138	-	0.56	0.093	37	30	120	14	20	0.70
7,8	12/3/07 0:12	3.13	0.103	-	-	0.103	23	32	100	13	17	0.70
9,10	12/3/07 0:32	1.84	0.052	-	0.28	0.087	16	35	140	15	32	0.73
11,12	12/3/07 0:52	1.30	0.103	-	-	0.100	7	43	56	8	11	0.45
13,14	12/3/07 1:12	0.92	0.121	-	0.7	0.071	4	51	130	9	6	0.46
15,16	12/3/07 1:32	0.43	0.086	-	0.56	0.087	3	47	55	11	17	0.73

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	12/2/07 22:58	0.86	0.017	-	1.4	0.253	11	190	89	14	12	0.37
3,4	12/2/07 23:18	4.66	0.009	-	-	0.183	11.	92	62	11	12	0.37
5,6	12/2/07 23:38	6.75	0.005	-	0.28	0.206	9	51	86	13	210	0.55
7,8	12/2/07 23:58	4.00	0.002	-	-	0.231	6	15	61	10	12	0.37
9,10	12/3/07 0:18	3.02	0.005	-	0.98	0.183	7	33	120	9	8	0.46
11,12	12/3/07 0:38	2.47	0.003	-	-	0.196	7	20	130	10	12	0.43
13,14	12/3/07 0:58	1.91	0.005	-	0.28	0.186	7	33	56	11	37	0.55
15,16	12/3/07 1:18	1.39	0.003	-	-	0.188	7	39	120	11	19	0.55
17,18	12/3/07 1:38	0.99	0.002	-	0.28	0.208	8	43	130	9	9	0.49
19,20	12/3/07 2:38	0.68	0.000	-	1.12	0.196	10	51	170	12	16	0.63

12/15/2007

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	12/15/07 23:00	0.92	0.191	-	0	0.268	54	-	300	33	9	1.20
3,4	12/15/07 23:20	2.70	0.071	-	-	0.303	53	-	390	29	17	1.03
5,6	12/15/07 23:40	2.72	0.022	-	0	0.419	280	-	280	23	15	0.77
7,8	12/16/07 0:00	0.94	0.133	-	-	0.288	31	-	190	16	5	0.82
9,10	12/16/07 0:20	2.98	0.021	-	0	0.261	20	-	200	19	5	0.80
11,12	12/16/07 1:00	3.88	0.009	-	-	0.351	91	-	310	21	6	0.82
13,14	12/16/07 1:40	4.74	0.009	-	0	0.266	41	-	140	10	2	0.38
15,16	12/16/07 2:20	7.30	0.009	-	-	0.191	130	-	350	19	1	0.93
17,18	12/16/07 3:20	2.89	0.007	-	0	0.336	86	-	340	21	17	0.82
19,20	12/16/07 4:20	2.58	0.009	-	-	0.308	69	-	140	10	3	0.26
21,22	12/16/07 5:20	1.55	0.002	-	0	0.168	51	-	140	13	2	0.28
23,24	12/16/07 7:00	1.15	0.009	-	0	0.587	26	-	98	9	2	0.28

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	12/16/07 0:04	1.08	0.036	-	0	0.201	20	-	63	10	4	0.37
3,4	12/16/07 0:24	3.53	0.031	-	-	0.117	20	-	23	8	2	0.34
5,6	12/16/07 0:44	6.37	0.022	-	0	0.100	37	-	46	10	10	0.53
7,8	12/16/07 1:04	9.43	0.019	-	-	0.138	66	-	94	10	14	0.39
9,10	12/16/07 1:24	9.03	0.010	-	0	0.116	91	-	69	15	18	0.38
11,12	12/16/07 1:44	8.31	0.017	-	-	0.091	70	-	57	12	12	0.31
13,14	12/16/07 2:04	11.09	0.010	-	0	0.137	79	-	45	13	11	0.35
15,16	12/16/07 2:24	16.24	0.012	-	0	0.169	90	-	130	13	15	0.39
17,18	12/16/07 2:44	12.79	0.009	-	-	0.085	230	-	87	12	15	0.35
19,20	12/16/07 3:44	4.64	0.002	-	-	0.090	31	-	84	7	6	0.30
21,22	12/16/07 4:44	3.27	0.007	-	-	0.096	19	-	94	6	3	0.23
23,24	12/16/07 6:04	0.89	0.002	-	-	0.078	10	-	69	6	4	0.22

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	12/15/07 23:50	0.77	0.047	-	0	0.298	14	-	96	12	4	0.29
3,4	12/16/07 0:10	2.55	0.033	-	-	0.479	50	-	93	15	6	0.42
5,6	12/16/07 0:30	3.32	0.026	-	0	0.379	57	-	89	14	5	0.331
7,8	12/16/07 0:30	5.83	0.022	-	-	0.531	110	-	113	16	9	0.405
9,10	12/16/07 0:50	8.30	0.016	-	0	1.183	56	-	66	11	6	0.272
11,12	12/16/07 1:10	10.52	0.007	-	-	0.506	43	-	42	8	5	0.227
13,14	12/16/07 1:30	11.65	0.009	-	0	2.454	34	-	39	8	6	0.218
15,16	12/16/07 1:50	16.03	0.009	-	-	1.840	31	-	93	7	6	0.261
17,18	12/16/07 2:10	23.46	0.007	-	0	0.461	33	-	72	7	6	0.189
19,20	12/16/07 2:30	14.06	0.003	-	0	0.286	29	-	51	6	5	0.267
21,22	12/16/07 3:30	8.32	0.003	-	-	0.278	17	-	57	6	9	0.237
23,24	12/16/07 4:30	4.90	0.002	-	-	0.389	11	-	59	3	4	0.21

1/10/2008 (Complete Captured Event)

DIRECT

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	1/10/08 20:00	0.63	0.32	-	0.42	0.40	46	10	440	52	-	0.40
3,4	1/10/08 20:20	0.64	0.18	-	0.7	0.24	21	14	420	53	-	0.82
5,6	1/10/08 20:40	0.36	0.13	-	0.28	0.09	3	2	200	42	-	0.30

2/1/2008

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	2/1/08 5:40	1.04	0.074	-	0.28	0.30	49	7	490	52	-	0.91
3,4	2/1/08 6:00	5.10	0.047	-	-	0.16	340	4	1700	140	-	3.11
5,6	2/1/08 6:20	5.40	0.022	-	2.1	0.16	240	120	510	60	-	1.32
7,8	2/1/08 6:40	0.94	0.034	-	-	0.11	94	170	460	52	-	0.63
9,10	2/1/08 7:00	4.32	0.034	-	1.4	0.25	83	150	510	63	-	0.72
11,12	2/1/08 7:40	5.33	0.028	-	-	0.33	77	120	360	48	-	0.43
13,14	2/1/08 8:20	5.45	0.028	-	0.42	0.21	99	120	400	50	-	0.78
15,16	2/1/08 9:00	3.78	0.028	-	-	0.47	44	100	280	47	-	0.49
17,18	2/1/08 10:00	2.61	0.038	-	0	0.12	51	37	290	42	-	0.42
19,20	2/1/08 11:00	1.41	0.029	-	-	0.23	33	3	200	30	-	0.28
21,22	2/1/08 12:00	1.12	0.034	-	-	0.25	16	3	170	27	-	0.27
23,24	2/1/08 13:40	6.00	0.022	-	0	0.20	130	12	380	47	-	0.68

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	2/1/08 6:22	0.78	0.060	-	0.14	0.156	130	1000	140	42	-	0.45
3,4	2/1/08 6:42	6.18	0.038	-		0.074	140	640	140	36	-	0.54
5,6	2/1/08 7:02	6.93	0.033	-	0.14	0.139	100	500	120	31	-	0.37
7,8	2/1/08 7:22	8.41	0.021	-		0.108	90	250	80	17	-	0.09
9,10	2/1/08 7:42	8.45	0.014	-	0.28	0.093	73	150	110	29	-	0.19
11,12	2/1/08 8:02	12.08	0.005	-		0.127	81	130	110	26	-	0.22
13,14	2/1/08 8:22	12.04	0.009	-	0.42	0.149	76	72	110	19	-	0.12
15,16	2/1/08 8:42	10.52	0.009	-		0.105	54	80	100	20	-	0.14
17,18	2/1/08 9:02	7.75	0.009	-	0.28	0.269	34	52	87	13	-	0.05
19,20	2/1/08 10:02	4.66	0.002	-		0.091	14	93	100	10	-	0.06
21,22	2/1/08 11:02	2.12	0.005	-		0.075	17	100	95	12	-	0.05
23,24	2/1/08 12:22	0.21	0.000	-	0.14	0.064	6	80	81	11	-	0.05

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	2/1/08 6:20	1.16	0.074	-	1.82	0.283	79	2500	130	36	-	0.48
3,4	2/1/08 6:40	3.38	0.062	-	-	0.564	50	710	150	17	-	0.11
5,6	2/1/08 7:00	4.19	0.062	-	1.26	0.336	34	680	150	28	-	0.29
7,8	2/1/08 7:20	6.10	0.047	-	-	0.293	44	510	140	22	-	0.22
9,10	2/1/08 7:40	7.72	0.045	-	3.36	0.283	44	400	140	21	-	0.16
11,12	2/1/08 8:00	11.22	0.038	-	-	0.221	46	250	140	18	-	0.17
13,14	2/1/08 8:20	14.04	0.036	-	1.4	0.564	41	140	120	19	-	0.21
15,16	2/1/08 8:40	15.09	0.026	-	-	0.218	36	110	90	13	-	0.10
17,18	2/1/08 9:00	13.37	0.029	-	19.04	0.253	21	89	130	14	-	0.12
19,20	2/1/08 10:00	9.78	0.021	-	-	0.416	21	230	94	12	-	0.09
21,22	2/1/08 11:00	6.22	0.022	-	-	0.369	9	160	96	16	-	0.20
23,24	2/1/08 12:20	3.64	0.021	-	16.94	0.331	4	130	100	9	-	0.09

3/4/2008

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	3/4/08 21:56	1.19	0.321	-	3.92	2.264	150	540	1600	160	66	4.12
3,4	3/4/08 22:16	1.98	0.171	-	-	0.632	270	2600	1000	200	51	3.69
5,6	3/4/08 22:36	3.27	0.036	-	1.4	6.217	210	200	1000	110	31	2.60
7,8	3/4/08 22:56	0.94	0.071	-	-	0.760	170	2700	750	110	38	2.17
9,10	3/4/08 23:16	3.42	0.052	-	0.84	0.198	93	3000	360	58	17	0.97
11,12	3/4/08 23:56	0.79	0.059	-	-	0.143	60	3100	200	60	43	0.49
13,14	3/5/08 0:36	0.93	0.059	-	-	0.148	46	3400	230	100	10	1.35
15,16	3/5/08 1:16	4.88	0.093	-	18.2	0.221	250	3300	520	130	30	2.21
17,18	3/5/08 2:16	3.76	0.022	-	-	0.396	150	640	550	240	17	2.57
19,20	3/5/08 3:16	1.30	0.026	-	19.6	0.431	180	140	350	210	15	1.33

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	3/4/08 23:14	1.67	0.019	-	0.56	0.209	73	990	270	28	26	0.76
3,4	3/4/08 23:34	4.33	0.017	-	-	0.102	67	1000	110	29	41	0.70
5,6	3/4/08 23:54	2.34	0.016	-	3.08	0.409	37	2100	97	30	41	0.83
7,8	3/5/08 0:14	0.84	0.010	-	-	0.686	26	2000	120	38	12	0.70
9,10	3/5/08 0:34	0.10	0.005	-	15.4	0.159	14	1000	54	29	22	0.55
11,12	3/5/08 0:54	0.29	0.000	-	-	0.000	0	1000	0	75	32	1.00
13,14	3/5/08 1:14	13.20	0.003	-	-	0.830	390	610	230	83	67	1.59
15,16	3/5/08 1:34	8.98	0.022	-	1.96	0.187	240	400	150	63	48	1.44
17,18	3/5/08 1:54	6.21	0.010	-	-	0.096	80	340	99	40	24	1.14
19,20	3/5/08 2:54	8.46	0.003	-	-	0.070	71	240	100	46	24	1.30
21,22	3/5/08 3:54	0.78	0.002	-	0.56	0.070	27	290	75	46	13	1.00

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	3/4/08 23:02	1.09	0.052	-	2.8	0.286	87	1000	150	41	15	0.81
3,4	3/4/08 23:22	3.43	0.034	-	-	0.659	63	920	87	35	10	1.25
5,6	3/4/08 23:42	2.68	0.028	-	1.4	2.765	30	1200	90	49	7	3.03
7,8	3/4/08 23:42	1.79	0.022	-	-	0.892	20	1200	76	44	10	0.61
9,10	3/5/08 0:02	1.50	0.029	-	0.7	0.303	16	1500	66	35	7	0.66
11,12	3/5/08 0:22	1.20	0.014	-	-	2.061	17	1700	62	24	4	0.56
13,14	3/5/08 0:42	4.33	0.017	-	-	3.978	190	1400	80	31	13	0.76
15,16	3/5/08 1:02	9.99	0.010	-	1.4	1.274	130	630	100	29	11	0.77
17,18	3/5/08 1:22	9.69	0.012	-	-	0.732	73	320	80	34	10	2.73
19,20	3/5/08 1:42	12.64	0.003	-	1.68	0.361	66	220	70	20	17	0.65
21,22	3/5/08 2:42	6.47	0.000	-	1.54	0.366	34	210	61	120	7	1.56
23,24	3/5/08 3:42	2.35	0.000	-	-	1.394	27	350	58	79	4	0.92

3/16/2008

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	3/16/08 2:48	2.63	0.081	-	7.7	0.266	430	93	1700	260	78	4.19
3,4	3/16/08 3:08	4.05	0.024	-	-	0.323	99	28	310	94	17	0.75
5,6	3/16/08 3:28	3.65	0.021	-	1.68	0.123	28	20	170	66	8	0.61
7,8	3/16/08 3:48	0.94	0.021	-	-	0.098	37	95	170	62	4	0.60
9,10	3/16/08 4:08	2.85	0.029	-	1.26	0.135	11	26	270	97	17	0.96
11,12	3/16/08 4:48	2.97	0.041	-	-	0.266	20	10	160	72	14	0.54
13,14	3/16/08 5:28	1.72	0.041	-	0.9	0.155	36	7	110	16	8	0.49
15,16	3/16/08 6:08	0.90	0.041	-	-	0.201	51	23	120	18	9	0.64
17,18	3/16/08 7:08	0.62	0.040	-	0.8	0.291	41	30	110	37	14	0.69
19,20	3/16/08 8:08	0.60	0.038	-	1	0.213	27	25	110	21	11	0.48

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	3/16/08 4:06	0.71	0.040	-	0.7	0.102	55	900	54	29	16	0.67
3,4	3/16/08 4:26	2.34	0.028	-	-	0.194	29	530	46	99	10	0.90
5,6	3/16/08 4:46	2.13	0.026	-	2.1	0.083	26	500	26	95	8	0.80
7,8	3/16/08 5:06	2.40	0.028	-	-	0.664	22	390	32	160	25	0.51
9,10	3/16/08 5:26	2.99	0.033	-	1.54	0.128	24	320	31	130	10	0.51
11,12	3/16/08 5:46	1.99	0.041	-	-	0.096	19	330	18	100	12	0.59
13,14	3/16/08 6:06	0.90	0.034	-	1.82	0.264	19	320	15	34	6	0.60

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	3/16/08 3:42	0.84	0.021	-	1.4	0.328	55	800	66	560	26	0.8
3,4	3/16/08 4:02	2.74	0.024	-	-	0.343	28	320	40	81	8.	0.7
5,6	3/16/08 4:22	2.79	0.002	-	1.82	0.268	17	200	33	89	4	0.6
7,8	3/16/08 4:22	2.08	0.005	-	-	0.306	11	220	23	130	8	0.6
9,10	3/16/08 4:42	2.71	0.002	-	1.82	0.271	15	290	51	130	6	0.7
11,12	3/16/08 5:02	3.43	0.009	-	-	0.281	19	190	15	100	5	0.3
13,14	3/16/08 5:22	3.26	0.019	-	1.12	0.278	12	170	23	200	7	0.5
15,16	3/16/08 5:42	2.79	0.019	-	-	0.231	13	140	30	270	9	0.6
17,18	3/16/08 6:02	2.00	0.021	-	-	0.226	9	140	40	92	8	0.6
19,20	3/16/08 6:22	1.12	0.017	-	1.4	0.221	7	200	14	56	5	0.5

4/3/2008

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	4/3/08 16:50	0.81	0.103	-	0.28	0.440	76	-	450	38	19	2.5
3,4	4/3/08 17:10	1.74	0.074	-	-	0.140	59	-	400	50	19	4.8
5,6	4/3/08 17:30	1.73	0.050	-	0.42	0.310	41	-	340	500	17	3.8
7,8	4/3/08 17:50	0.94	0.050	-	-	0.240	21	-	240	600	7	1.5
9,10	4/3/08 18:10	1.13	0.021	-	1.4	0.200	9	-	240	23	8	1.7
11,12	4/3/08 18:50	1.73	0.022	-		0.270	9	-	170	14	9	2.3
13,14	4/3/08 19:30	1.74	0.022	-	-	0.100	15	-	180	4	10	1.4
15,16	4/3/08 20:10	1.83	0.017	-	3.92	0.130	14	-	220	28	11	3.6
17,18	4/3/08 21:10	2.16	0.014	-	-	0.260	10	-	200	31	10	0.7
19,20	4/3/08 22:10	3.71	0.002	-	-	0.160	28	-	270	370	12	0.6
21,22	4/3/08 23:10	3.17	0.002	-	-	0.270	48	-	190	30	22	0.9
23,24	4/4/08 0:50	1.65	0.002	-	-	0.130	47	-	200	81	8	0.7

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	4/3/08 21:48	0.70	0.019	-	4.2	0.090	30	-	100	20	8	3.9
3,4	4/3/08 22:08	2.24	0.017	-		0.100	29	-	110	24	10	1.0
5,6	4/3/08 22:28	3.02	0.016	-	0.56	0.230	27	-	60	41	11	2.0
7,8	4/3/08 22:48	3.83	0.010	-		0.100	30	-	96	34	11	1.6
9,10	4/3/08 23:08	4.12	0.005	-	0.98	0.080	28	-	170	39	10	0.7
11,12	4/3/08 23:28	3.08	0.000	-		0.200	29	-	120	38	12	0.9
13,14	4/3/08 23:48	2.10	0.003	-		0.670	20	-	140	160	10	1.3
15,16	4/4/08 0:08	1.41	0.022	-	0.42	0.130	14	-	190	19	7	0.6
17,18	4/4/08 0:28	0.43	0.010	-		0.140	15	-	240	37	23	1.0

SHA

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	1/0/00 0:00	0.00										
3,4	1/0/00 0:00	0.00										
5,6	1/0/00 0:00	0.00										
7,8	1/0/00 0:00	0.00										
9,10	1/0/00 0:00	0.00										
11,12	1/0/00 0:00	0.00										
13,14	1/0/00 0:00	0.00										
15,16	1/0/00 0:00	0.00										
17,18	1/0/00 0:00	0.00										
19,20	1/0/00 0:00	0.00										
21,22	1/0/00 0:00	0.00										
23,24	1/0/00 0:00	0.00										

4/26/2008

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	4/26/08 22:52	0.84	0.834	2.13	12.18	0.22	250	87	960	270	68	2.3
3,4	4/26/08 23:12	1.17	0.226	1.18	-	0.16	93	60	350	110	35	2.0
5,6	4/26/08 23:32	3.59	0.119	0.39	0.28	0.11	140	6	390	160	27	1.3
7,8	4/26/08 23:52	0.94	0.038	0.50	-	0.08	110	3	300	43	34	3.1
9,10	4/27/08 0:12	2.33	0.034	0.35	0.28	0.08	37	12	180	26	6	1.1
11,12	4/27/08 0:52	1.35	0.034	0.85	-	0.13	15	11	140	24	16	2.6
13,14	4/27/08 1:32	1.04	0.034	0.86	7.70	0.11	18	18	130	23	8	0.6
15,16	4/27/08 2:12	0.63	0.038	1.17	-	0.22	13	45	110	20	19	0.8
17,18	4/27/08 3:12	0.41	0.062	1.04	17.36	0.14	10	46	76	21	40	1.9
19,20	4/27/08 4:12	0.64	0.045	0.66	-	0.08	4	35	150	29	50	1.0
21,22	4/27/08 5:12	0.32	0.047	0.99	25.2	0.12	3	29	90	20	20	1.7

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	1/0/00 0:00	0.00										
3,4	1/0/00 0:00	0.00										
5,6	1/0/00 0:00	0.00										
7,8	1/0/00 0:00	0.00										
9,10	1/0/00 0:00	0.00										
11,12	1/0/00 0:00	0.00										
13,14	1/0/00 0:00	0.00										
15,16	1/0/00 0:00	0.00										
17,18	1/0/00 0:00	0.00										
19,20	1/0/00 0:00	0.00										
21,22	1/0/00 0:00	0.00										
23,24	1/0/00 0:00	0.00										

SHA

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	4/27/08 0:02	1.01	0.031	0.530	0.7	0.286	29	130	84	43	33	1.9
3,4	4/27/08 0:22	2.27	0.036	1.080	-	0.326	17	100	86	42	99	2.1
5,6	4/27/08 0:42	1.45	0.036	0.400	0.28	0.313	12	75	70	50	12	0.8
7,8	4/27/08 0:42	0.76	0.028	0.310	-	0.251	11	56	59	39	11	0.8
9,10	4/27/08 1:02	0.33	0.022	0.390	1.54	0.226	8	71	48	11	3	0.01

5/16/2008

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	5/16/08 3:04	1.04	0.172	1.72	-	0.068	24	29	180	65	14	1.3
3,4	5/16/08 3:24	3.10	0.188	0.77	-	0.058	39	20	220	59	39	1.1
5,6	5/16/08 3:44	9.91	0.072	0.63	-	0.065	46	30	270	54	16	2.9
7,8	5/16/08 4:04	0.94	0.043	0.65	-	0.080	6	33	100	20	15	1.2
9,10	5/16/08 4:24	24.46	0.019	0.420	-	0.045	66	20	220	42	14	1.8
11,12	5/16/08 5:04	24.16	0.033	0.340	-	0.070	20	6	130	31	25	0.9
13,14	5/16/08 5:44	21.00	0.033	0.270	-	0.065	29	5	120	21	21	0.8
15,16	5/16/08 6:24	10.84	0.016	0.190	-	0.065	11	2	80	17	24	0.9
17,18	5/16/08 7:24	14.92	0.026	0.310	-	0.090	29	13	140	24	13	0.8
19,20	5/16/08 8:24	6.89	0.026	0.180	-	0.273	3	20	75	27	43	2.3
21,22	5/16/08 9:24	6.04	0.041	0.250	-	0.065	9	18	110	28	16	1.1
23,24	5/16/08 11:04	2.37	0.017	0.220	-	0.068	40	17	68	20	37	1.0

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	5/16/08 4:44	1.27	0.000	0.260	-	0.051	24	34	68	24	73	0.7
3,4	5/16/08 5:04	7.06	0.000	0.222	-	0.032	13	56	55	23	25	0.4
5,6	5/16/08 5:24	10.49	0.000	0.310	-	0.046	9	41	84	33	9	0.2
7,8	5/16/08 5:44	13.65	0.000	0.180	-	0.056	11	33	94	24	17	0.2
9,10	5/16/08 6:04	8.61	0.000	0.340	-	0.037	6	31	54	28	10	0.2
11,12	5/16/08 6:24	3.25	0.000	0.440	-	0.040	4	27	75	15	11	0.1
13,14	5/16/08 6:44	1.14	0.000	0.420	-	0.175	2	15	48	28	19	0.1
15,16	5/16/08 7:04	1.33	0.000	0.290	-	0.016	4	24	68	38	17	0.1
17,18	5/16/08 7:24	4.47	0.000	0.360	-	0.030	1	48	44	22	8	0.1
19,20	5/16/08 8:24	0.98	0.000	0.270	-	0.039	1	46	111	46	12	0.1

SHA

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	5/16/08 4:34	1.30	0.034	0.260	-	0.113	21	35	110	33	13	0.5
3,4	5/16/08 4:54	4.43	0.017	0.260	-	0.170	12	24	70	57	16	0.4
5,6	5/16/08 5:14	5.81	0.026	0.310	-	0.193	9	14	150	33	6	1.5
7,8	5/16/08 5:14	12.74	0.014	0.210	-	0.135	13	10	100	26	31	2.2
9,10	5/16/08 5:34	15.27	0.009	0.230	-	0.125	14	10	60	40	14	0.6
11,12	5/16/08 5:54	11.59	0.000	0.210	-	0.196	6	6	10	21	11	1.0
13,14	5/16/08 6:14	7.14	0.000	0.200	-	0.196	4	7	90	22	11	1.1
15,16	5/16/08 6:34	4.84	0.000	0.440	-	0.125	5	9	78	52	60	1.2
17,18	5/16/08 6:54	6.40	0.000	0.780	-	0.170	2	1	63	23	21	0.7
19,20	5/16/08 7:14	5.16	0.000	0.220	-	0.103	0.1	10	68	25	22	1
21,22	5/16/08 8:14	1.52	0.000	0.540	-	0.133	2	4	70	26	23	1
23,24	5/16/08 9:14	1.09	0.000	0.500	-	0.103	2	9	72	49	21	1

6/03/2008

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/3/08 20:02	0.56	0.531	1.26	4.48	0.17	180	6	470	110	30	1.2
3,4	6/3/08 20:22	0.52	0.257	1.36	-	0.17	26	6	314	98	11	0.3
5,6	6/3/08 20:42	0.21	0.198	1.04	4.06	0.17	8	6	199	63	10	0.5
7,8	6/3/08 21:02	0.94	0.300	1.70	-	0.11	10	4	202	100	15	0.6
9,10	6/3/08 21:22	0.60	0.091	0.86	1.54	0.07	1	14	192	35	6	0.7
11,12	6/3/08 22:02	0.24	0.004	0.81	-	0.09	5	7	97	25	11	0.8
13,14	6/3/08 22:42	5.56	0.004	0.68	-	0.09	97	9	73	26	11	0.5
15,16	6/3/08 23:22	3.18	0.033	0.72	-	0.06	22	5	159	29	18	2.2
17,18	6/4/08 0:22	0.85	0.021	1.35	1.82	0.10	19	2	111	20	13	0.2
19,20	6/4/08 1:22	2.75	0.034	0.50	-	0.07	12	1	117	14	9	0.5
21,22	6/4/08 2:22	2.01	0.016	0.45	0.7	0.05	23	1	87	6	16	0.6
23,24	6/4/08 4:02	0.73	0.010	0.50	1.82	0.07	3	9	55	2	5	0.1

MDE

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/4/08 1:42	0.67	0.009	0.500	1.68	0.062	15	43	47	25	72	0.2
3,4	6/4/08 2:02	1.89	0.038	0.540	-	0.057	44	67	37	21	12	1.9
5,6	6/4/08 2:22	2.08	0.022	0.530	21	0.063	6	54	44	28	47	0.4
7,8	6/4/08 2:42	1.43	0.009	0.610	-	0.047	2	81	49	18	12	0.2
9,10	6/4/08 3:02	0.33	0.012	0.370	1.4	0.045	2	47	40	22	22	0.4

SHA

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/3/08 23:12	1.25	0.022	0.410	0	0.223	30	20	60	36	15	0.3
3,4	6/3/08 23:32	3.35	0.033	0.390	-	0.175	11	20	49	26	11	0.2
5,6	6/3/08 23:52	1.29	0.034	0.370	0	0.223	12	19	53	25	17	0.5
7,8	6/3/08 23:52	0.26	0.034	0.280	-	0.218	7	46	45	29	14	0.7
9,10	6/4/08 0:12	0.00	0.036	0.360	2.38	0.286	10	25	45	25	20	0.8
11,12	6/4/08 0:32	0.00	0.017	0.200	-	0.251	0	20	40	20	20	0.8
13,14	6/4/08 0:52	0.00	0.017	0.100	-	0.226	0	21	51	24	22	0.7
15,16	6/4/08 1:12	1.31	0.021	0.360	-	0.218	48	28	65	26	22	0.6
17,18	6/4/08 1:32	2.57	0.029	0.370	22.26	0.196	9	45	48	25	10	0.3
19,20	6/4/08 1:52	1.35	0.028	0.200	3.36	0.183	6	23	40	25	10	0.2

6/10/2008 (Complete Captured Event)

DIRECT

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/10/08 20:44	8.72	0.078	0.57	2.24	0.14	360	3	540	200	41	3.0
3,4	6/10/08 21:04	1.13	0.059	0.25	-	0.09	10	8	110	48	6	1.8
5,6	6/10/08 21:24	0.44	0.055	0.26	0.28	0.08	7	11	77	56	4	0.35

6/16/2008 (Complete Captured Event)

DIRECT

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/16/08 16:36	1.15	0.34	0.61	2.94	0.08	42	26	310	98	19	0.52
3,4	6/16/08 16:56	2.53	0.09	0.33	-	0.06	31	2	410	81	21	0.75
5,6	6/16/08 17:16	2.16	0.08	0.22	0.28	0.07	17	3	290	150	6	0.60
7,8	6/16/08 17:36	4.38	0.06	0.22	-	0.08	36	1	260	49	18	0.92
9,10	6/16/08 17:56	5.19	0.03	0.20	-	0.07	20	1	340	96	22	0.68
11,12	6/16/08 18:36	1.69	0.03	0.31	0.42	0.22	6.6	0	160	18	12	1.20
13,14	6/16/08 19:16	0.94	0.02	0.40	-	0.08	7.7	18	89	31	61	0.15
15,16	6/16/08 19:56	0.64	0.03	0.35	0.70	0.17	4.7	17	110	27	14	1.5

6/30/2008 (Complete Captured Event)

DIRECT

			Nitrogen			*Phosphorus*	*Solids*		*Metals*			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	6/30/08 21:48	0.78	0.366	0.58	2.1	0.10	290	1	860	390	45	2.6
3,4	6/30/08 22:08	2.76	0.076	0.78	1.4	0.10	95	3	480	170	25	1.5
5,6	6/30/08 22:28	1.16	0.045	0.29	1.12	0.10	44	3	390	170	23	0.8
7,8	6/30/08 22:48	0.62	0.043	0.37	0.7	0.11	57	12	210	170	8	0.7

7/5/2008 (Complete Captured Event)

DIRECT

			Nitrogen			Phosphorus	Solids		Metals			
		Ave. Flow	***Nitrite-N***	***Nitrate-N***	***TKN-N***	***TP***	***TSS***	***Chloride***	***Zinc***	**Copper**	**Lead**	**Cadmium**
Bottles	*Date & Time*	*(L/s)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	(ug/L)	*(ug/L)*	*(ug/L)*	*(ug/L)*
1,2	7/5/08 3:10	0.42	0.241	1.10	5.88	0.17	81	7	200	250	69	0.40
3,4	7/5/08 3:30	0.47	0.153	0.66	1.96	0.10	48	9	210	11o	26	0.20

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