Evaluation of Permeable Friction Course (PFC), Roadside Filter Strips, Dry Swales, and Wetland Swales for Treatment of Highway Stormwater Runoff

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16. Abstract

Stormwater runoff from roadways is a source of surface water pollution in North Carolina. The North Carolina Department of Transportation (NCDOT) is required to implement stormwater control measures (SCMs) in the linear environment. NCDOT has specific interest in evaluating pollutant loads from interstate highways and potential stormwater treatment measures. The research presented herein focuses on monitoring of highway runoff at four sites along Interstate 40 (I-40) in Johnston, Sampson, and Duplin counties. This entire stretch of I-40 had a permeable overlay [known as a permeable friction course (PFC)] applied in November, 1998. The overlay is porous, and allows water to pass through the surface of the pavement, reducing splash during rainfall and allowing for improved vehicle traction (Barrett et al. 2006). Drainage from the PFC was monitored at all four sites to determine highway pollutant concentrations and loads. Roadside filter strips are nearly ubiquitous on highways, as they are constructed to make grade and to hydraulically connect the roadway to the roadside swale. Two roadside filter strips (21.5 ft in width) were evaluated in this study. Finally, four linear roadside swales were monitored to determine their hydrologic and water quality benefits. Two of these swales were dry swales, meaning that they drained inter-event. The other two swales had wetland characteristics, including hydrophytic vegetation, hydric soils, and wetland hydrology.

Data collection began in September 2008 and continued through May 2010. Runoff from the highway and the downslope edge of the filter strip was collected in separate slot drains. The drainage was conveyed to a weir and stage recorder, which enabled flow measurement. An outlet structure using a compound weir was installed in each swale and a similar weir and stage recorder was used for flow measurement. Flow-proportional, composite water quality samples were obtained at ten different locations, four at the edge-of-pavement, two at the downslope end of the filter strips, and four at the swale outlets. Monitored water quality parameters included total Kjeldahl nitrogen (TKN), nitrate- and nitrite-nitrogen ($NO_{2,3}$-N), ammonium nitrogen (NH_4-N), organic N (Org-N), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS).

Results showed that PFC sequestered and/or reduced the generation of TSS from the highway surface. Median effluent TSS concentrations were 8 mg/L, 8 mg/L, 9 mg/L, and 17 mg/L, lower than previous studies on standard asphalt highways (Barrett et al. 1998; Sansalone et al. 1998; Kayhanian et al. 2003). Other sediment-bound pollutant (such as phosphorus) concentrations, were reduced to what appeared to be at- or near-irreducible levels. Due to these findings, the authors support further use of PFC on highways throughout North Carolina. The roadside filter strips were shown to increase sediment and sediment-bound pollutant concentrations, due to relatively high slopes, fair vegetative cover, and clean influent. The wetland swales produced lower mean effluent concentrations (by approximately 0.4 mg/L) of TN when compared to the dry swales. Similar trends were not observed for TP and TSS. Therefore, there is the potential for greater nitrogen removal credit for wetland swales. Load reductions of pollutants were generally poor to fair for the roadside filter strips due to substantial measured soil compaction. In fact, TP and TSS loads *increased* through both filter strips studied. Pollutant loads were generally lowest at the swale outlets, except at site D, where a head cut in the swale caused substantial increases in TP and TSS loads vis-à-vis the edge-of-pavement.

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Preface

This final report has been written to satisfy NCDOT research contract 2007-21: "Research of Hydrologic and Water Quality Performance of 2 Linear Wetlands in Eastern NC and House Creek Interchange Retrofits." This report will focus on the hydrologic and water quality performance of a permeable friction course (PFC) overlay on Interstate-40, roadside filter strips, and dry and wetland swales. The final report for the House Creek interchange retrofits was submitted to NCDOT in November 2008. The authors wish to thank NCDOT for funding this project and for their support and aid throughout the project. Two other publications have been submitted to the ASCE *Journal of Environmental Engineering* based upon this research: (1) "Water quality of drainage from permeable friction course" by Eck et al. and (2) "Field evaluation of stormwater control measures for treatment of highway runoff in North Carolina," by Winston et al (2011).

Executive Summary

Stormwater runoff from roadways is a source of surface water pollution in North Carolina. The North Carolina Department of Transportation (NCDOT) is required to implement stormwater control measures (SCMs) in the linear environment. NCDOT has specific interest in evaluating pollutant loads from interstate highways and potential stormwater treatment measures. The research presented herein focuses on monitoring of highway runoff at four sites along Interstate 40 (I-40) in Johnston, Sampson, and Duplin counties. This entire stretch of I-40 had a permeable overlay [known as a permeable friction course (PFC)] applied in November, 1998. The overlay is porous, and allows water to pass through the surface of the pavement, reducing splash during rainfall and allowing for improved vehicle traction (Barrett et al. 2006). Drainage from the PFC was monitored at all four sites to determine highway pollutant concentrations and loads. Roadside filter strips are nearly ubiquitous on highways, as they are constructed to make grade and to hydraulically connect the roadway to the roadside swale. Two roadside filter strips (21.5 ft in width) were evaluated in this study. Finally, four linear roadside swales were monitored to determine their hydrologic and water quality benefits. Two of these swales were dry swales, meaning that they drained inter-event. The other two swales had wetland characteristics, including hydrophytic vegetation, hydric soils, and wetland hydrology.

Data collection began in September 2008 and continued through May 2010. Runoff from the highway and the downslope edge of the filter strip was collected in separate slot drains. The drainage was conveyed to a weir and stage recorder, which enabled flow measurement. An outlet structure using a compound weir was installed in each swale and a similar weir and stage recorder was used for flow measurement. Flow-proportional, composite water quality samples were obtained at ten different locations, four at the edge-of-pavement, two at the downslope end of the filter strips, and four at the swale outlets. Monitored water quality parameters included total Kjeldahl nitrogen (TKN), nitrate- and nitrite-nitrogen ($NO_{2,3}$-N), ammonium nitrogen (NH_4-N), organic N (Org-N), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS).

Results showed that PFC sequestered and/or reduced the generation of TSS from the highway surface. Median effluent TSS concentrations were 8 mg/L, 8 mg/L, 9 mg/L, and 17 mg/L, lower than previous studies on standard asphalt highways (Barrett et al. 1998; Sansalone et al. 1998; Kayhanian et al. 2003). Other sediment-bound pollutant (such as phosphorus) concentrations, were reduced to what appeared to be at- or near-irreducible levels. Due to these findings, the authors support further use of PFC on highways throughout North Carolina. The roadside filter strips were shown to increase sediment and sediment-bound pollutant concentrations, due to relatively high slopes, fair vegetative cover, and clean influent. The wetland swales produced lower mean effluent concentrations (by approximately 0.4 mg/L) of TN when compared to the dry swales. Similar trends were not observed for TP and TSS. Therefore, there is the potential for greater nitrogen removal credit for wetland swales. Load reductions of pollutants were generally poor to fair for the roadside filter strips due to substantial measured soil compaction. In fact, TP and TSS loads *increased* through both filter strips studied. Pollutant loads were generally lowest at the swale outlets, except at site D, where a head cut in the swale caused substantial increases in TP and TSS loads vis-à-vis the edge-of-pavement.

Introduction

Roadway runoff has been identified as one of several potential pollutant sources that are detrimental to surface water quality (USEPA 2009). Pollutant production and transport are unique in the highway environment, and are due to anthropogenic sources from traffic-related activities. Previous data have been collected on runoff quality from highways across the U.S. (FHWA 1990; Sansalone and Buchberger 1997; Barrett et al. 1998; Kayhanian et al. 2007). Pollutants of concern that have been identified for the highway land use include heavy metals, sediment, nutrients, and hydrocarbons. For instance, one study of highway runoff in Charlotte, NC found mean TN, TP, TSS, copper (Cu), and lead (Pb) concentrations of 2.24 mg/L, 0.43 mg/L 283 mg/L, 24.2 μg/L and 21.0 μg/L, respectively (Wu et al. 1998). For treatment of highway runoff, engineers typically employ a roadside filter strip and a drainage swale to convey stormwater from the pavement surface. However, the North Carolina Department of Transportation (NCDOT) is constantly attempting to be innovative in its development of new designs for SCMs. This project was originally designed to study three SCMs: roadside filter strips, dry swales, and swales that were allowed to develop wetland hydrology, hydrophytic vegetation, and hydric soils. However, due to a fortuitous application of permeable friction course (PFC) on I-40 between Raleigh and Wilmington, NC, the goals of this project were amended to include studying runoff quality from a highway with a PFC-overlay. A literature review on four SCMs (PFC overlays, filter strips, dry swales, and wet swales) that are used to treat highway runoff is presented below.

Permeable Friction Course

A typical highway is paved using hot mix asphalt (HMA), which is impervious and translates nearly all rainfall into surface runoff. The aggregate gradation used to mix HMA contains a large percentage of fines (Table 1), which can generate TSS as the pavement wears. One SCM that has never before been studied in North Carolina is permeable friction course (PFC), which is a layer of porous asphalt (usually 1.25-2.0 in (30-50 mm) thick) that is overlain onto a traditional impermeable HMA. Instead of running off, rainfall moves vertically through the PFC layer until it meets the impermeable asphalt. Stormwater then flows laterally through the PFC, and sheet flows into the roadside filter strip. Because the PFC mix contains much fewer fine particles than HMA (Table 1), it should generate proportionally less TSS as it wears. Also, sedimentation probably occurs in the void space of the PFC.

Table 1. Aggregate gradation and binder content for permeable friction course (PFC) and hot mix asphalt (HMA) in North Carolina.

Sieve Designations	**Total Percent Passing**	
	PFC Design Mix	**HMA Design Mix**
19.0 mm	100	100
12.5 mm	80-100	100
9.5 mm	35-60	90-100
4.75 mm	1-20	90
2.36 mm	1-10	32-67
.075 mm	1-4	4-8
Design Requirements		
Asphalt Binder	PG 64-22	PG 76-22
Asphalt Binder (% Range)	5-8	4-10
Mixing Temperature Range	93.3-135 °C	168.3 °C

Source: NCDOT (2006).

Because it removes water from the surface of the road, PFC reduces splashing (which improves visibility while driving) and hydroplaning (NCHRP 2009). It also reduces road noise during dry weather periods – one of the reasons for its original use. In addition to its safety benefits, PFC has also been shown to reduce concentrations of pollutants commonly observed in highway runoff. A study in the Netherlands compared runoff water quality from permeable overlays and conventional pavement surfaces (Berbee et al. 1999). In most cases, impermeable asphalt effluent concentrations were higher than those derived from pavement with permeable overlays. In particular, median TSS concentrations were 194 mg/L and 17 mg/L for the impermeable and permeable asphalts, respectively, a 91% difference. Median TKN was also reduced from 2.5 mg/L to 0.4 mg/L. Median total Pb, total zinc (Zn), and total Cu concentrations were between 67%-92% lower for the pavement with a permeable overlay.

Researchers in France (Pagotto et al., 2000), Germany (Stotz and Krauth 1994), and Texas (Barrett et al. 2006; Barrett 2008) studied highway research sites where a porous asphalt was applied onto a conventional asphalt. In Germany, the filterable solids and polycyclic aromatic hydrocarbons (PAH) loads were reduced by 60% and 96%, respectively, when compared to a nearby impermeable highway site. Similar results were found in France, where monitoring before and after installation of PFC showed that mean TSS levels dropped from 46 mg/L to 8.7 mg/L, an 81% difference. Concentrations of total Cu, Pb, cadmium (Cd), and Zn also decreased by 35-78%. In Texas, a 94% reduction in TSS concentration, a 43% reduction in TKN concentration, and reductions in heavy metal concentrations were observed when comparing a PFC site to a conventional pavement site in a side-by-side test.

Literature on the service life of PFC layers is sparse, but is expected to range from 8-10 years (NCHRP, 2009). After this time, the PFC layer degrades and requires replacement. One prior study has investigated the water quality benefits of PFC over its lifetime (Eck et al. 2011). The authors found that sediment, and therefore sediment-bound (such as phosphorus and heavy metals) pollutant concentrations, were effectively reduced throughout the pavement life. Therefore, PFC layers that are replaced at the end of their structural life should provide consistent water quality benefits.

Apart from their stormwater benefits, PFC overlays are typically installed for their traffic safety benefits. Because of its porous structure, PFC allows the road surface to drain efficiently, reducing the chance for hydroplaning. Also, PFC has been shown to reduce traffic noise. Another benefit is reduced splash created by tires during rainfall; this may also help to reduce wash-off of pollutants from the wheel wells of cars and trucks. Figure 1 shows a section of I-35 without PFC (left) and a section of I-35 with PFC during a rainstorm in San Antonio, Texas (right).

Figure 1. Splash reduction through application of a PFC.
Source: Texas DOT construction division.

Roadside Filter Strips

Roadside filter strips were tested in two locations in Virginia for removal of stormwater pollutants (Kaighn and Yu 1996). Trapping of particulate pollutants in the 9.8 ft wide filter strips was excellent; average TSS concentration reductions were 64% and 66%. Chemical oxygen demand (COD) and Zn concentrations were also reduced, while TP concentration reductions were mixed (-21% and 71%). A similar finding was made in a study of filter strips in North Carolina (Winston et al. 2011), wherein one site with high influent particle-bound phosphorus concentrations reduced TP concentrations and another with high influent orthophosphorus concentrations failed to significantly reduce TP concentrations. Kaighn and Yu (1996) contended that highway filter strips were responsible for substantial particulate pollutant removal and that swales received effectively cleaner runoff, reducing their performance when using the concentration reduction metric. Barrett et al. (1998) came to a similar conclusion in a study of highway runoff in Texas; the authors suggested that the length and slope of the filter strip were more important in pollutant removal than the length of the swale, indicating that a majority of the pollutant removal was occurring in the filter strip.

Filter strips with an associated flow spreading device have been shown to be very effective at removal of particulate pollutants (Winston et al. 2011; Line and Hunt 2009; Yu et al. 1993), with TSS concentration reductions of at least 50% in all cases. It is imperative that filter strips receive diffuse flow for sedimentation to occur; this is often the case with highway runoff, where the edge-of-pavement acts as a flow-spreader. Also, it is important that lateral slopes (those parallel to the edge-of-pavement) are relatively near zero so that the flow remains diffuse; this is also the case in areas with low slopes, such as the North Carolina coastal plain. Design variables that may be important for VFS functionality include slope (both longitudinal and lateral), density of vegetation, type of vegetation, infiltration rate of underlying soil, compaction of filter strip soils, and catchment area to filter strip area ratio.

Swales

The traditional drainage swale is used to remove water from the highway environment after passing through the filter strip; however, this conveyance may also have ancillary water quality benefits. Two swales studied in Virginia (Kaighn and Yu 1996) showed low to moderate reduction (49% and 30%) of TSS concentrations, and low reduction (0% and 33%) of TP concentrations. A grassed swale in Brisbane, Australia reduced pollutant loads of TN, TP, and TSS by an average of 56%, 46%, and 69%, respectively (Deletic and Fletcher 2006). Two swales studied by Barrett et al. (1998) in Texas demonstrated high load reductions (>90%) for TSS, and moderate load reductions for TKN (~50%) and TP (~50%). Previous research (Barrett et al. 1998; Yousef et al. 1985; Yu et al. 2001) has shown that pollutant removal generally increases as a function of swale length. Further, the addition of check dams has a stilling effect on the water, and generally increases retention time and therefore pollutant removal (Yu et al. 2001, Kaighn and Yu 1996). Similar to highway filter strips, the major pollutant treatment mechanism in swales is sedimentation. Design variables that have been suggested as important to pollutant removal include: swale length, longitudinal slope, presence of check dams, cross sectional shape, vegetative density, grass stiffness, soil infiltration rate, design flow depth, and design flow rate.

In areas with low slopes and high water tables (such as Eastern North Carolina), wetland conditions, such as ponded water and emergent vegetation, often predominate in roadside swales.

However, no scientific literature on wetland swale performance for water quality exists. It stands to reason that the anoxic zones, differences in nutrient uptake, and greater vegetative height (and potentially stiffness) of a wetland swale might produce lower effluent concentrations than a dry swale. Stormwater wetlands are commonly used to treat runoff for nitrogen, phosphorus, sediment, and other pollutants (Line et al. 2008; Lenhart and Hunt 2011; Wadzuk et al. 2010; Min and Wise 2010, Hathaway and Hunt 2010). Should wetland swales perform better than standard dry swales, the potential exists for them to receive greater pollutant treatment credit from regulatory agencies. This is important in the highway environment, as options for stormwater treatment in this linear system are limited.

Research Goals

The goals of this research were threefold: (1) Examine the quality and quantity of drainage from asphalt overlayed with PFC at four sites along I-40; (2) Examine the impact that roadside filter strips have on highway runoff; and (3) Examine the impact of dry swales and wet swales on highway runoff.

Description of Sites

To determine the quality and quantity of highway runoff and effluent quality from roadside filter strips and swales, monitoring was undertaken at four sites in Eastern North Carolina (Figure 2). The sites are located along the eastbound lanes of I-40. The first site (site A) was located near mile marker 330 and the second site (site B) was located between mile markers 332 and 333; both of these sites are in Johnston County. The third site (site C) was located between mile marker 352 and 353 in Sampson County. The final site (site D) was located in Duplin County near mile marker 360. Each site was located near the intersection of I-40 and an overpass (site A – Stricklands Crossroads Road; site B – Five Points Road; site C – Giddensville Road; site D – McGowen Road). In this way, the section of swale was hydraulically separated, allowing for simpler calculation of the watershed areas. At all four sites, both edge-of-pavement and swale outlet water quantity measurements and water quality samples were taken. At sites A and D, 21.5 ft VFSs were studied to determine their pollutant removal potential. A representative monitoring schematic is presented in Figure 3.

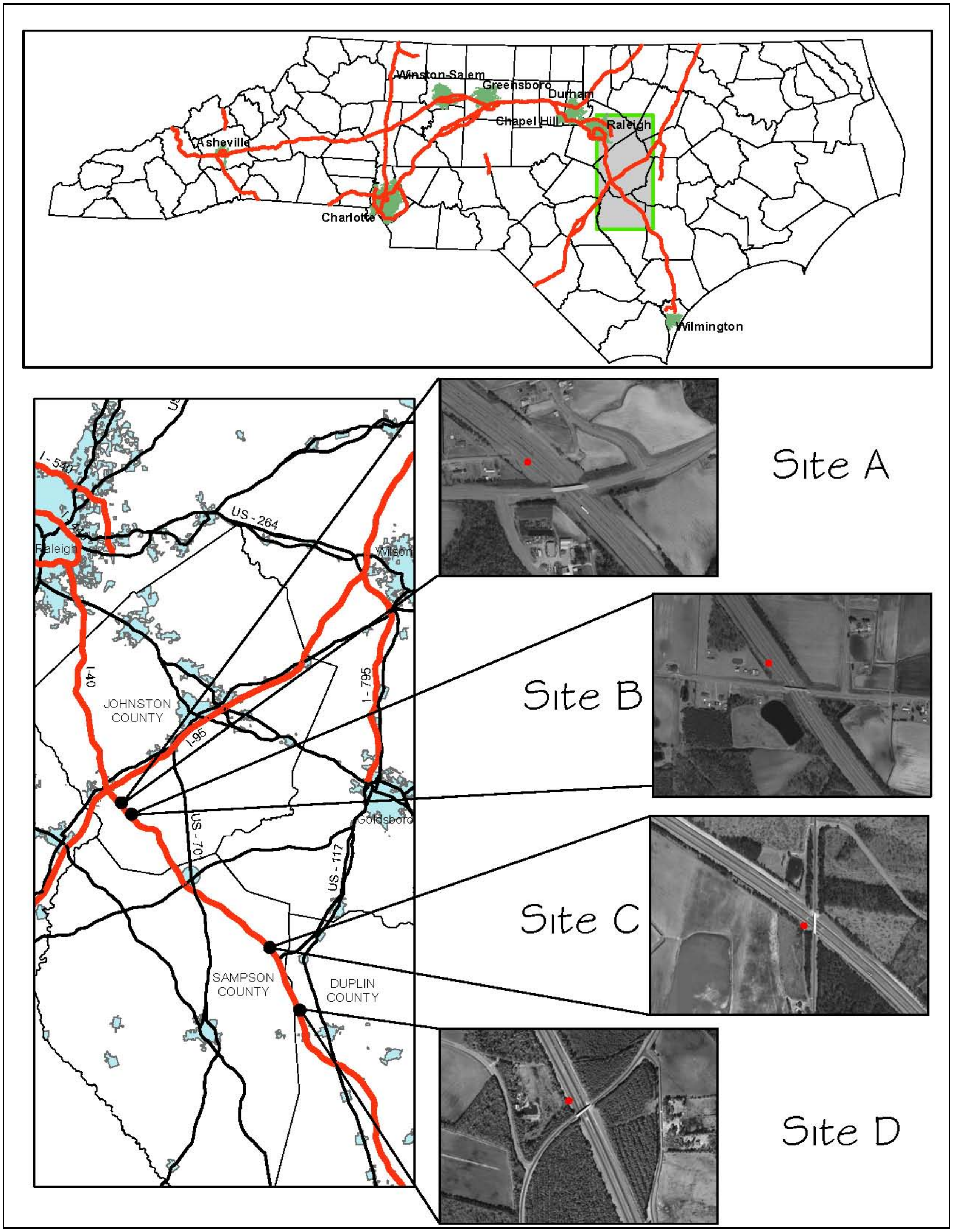

Figure 2. Location of Interstate 40 research sites.

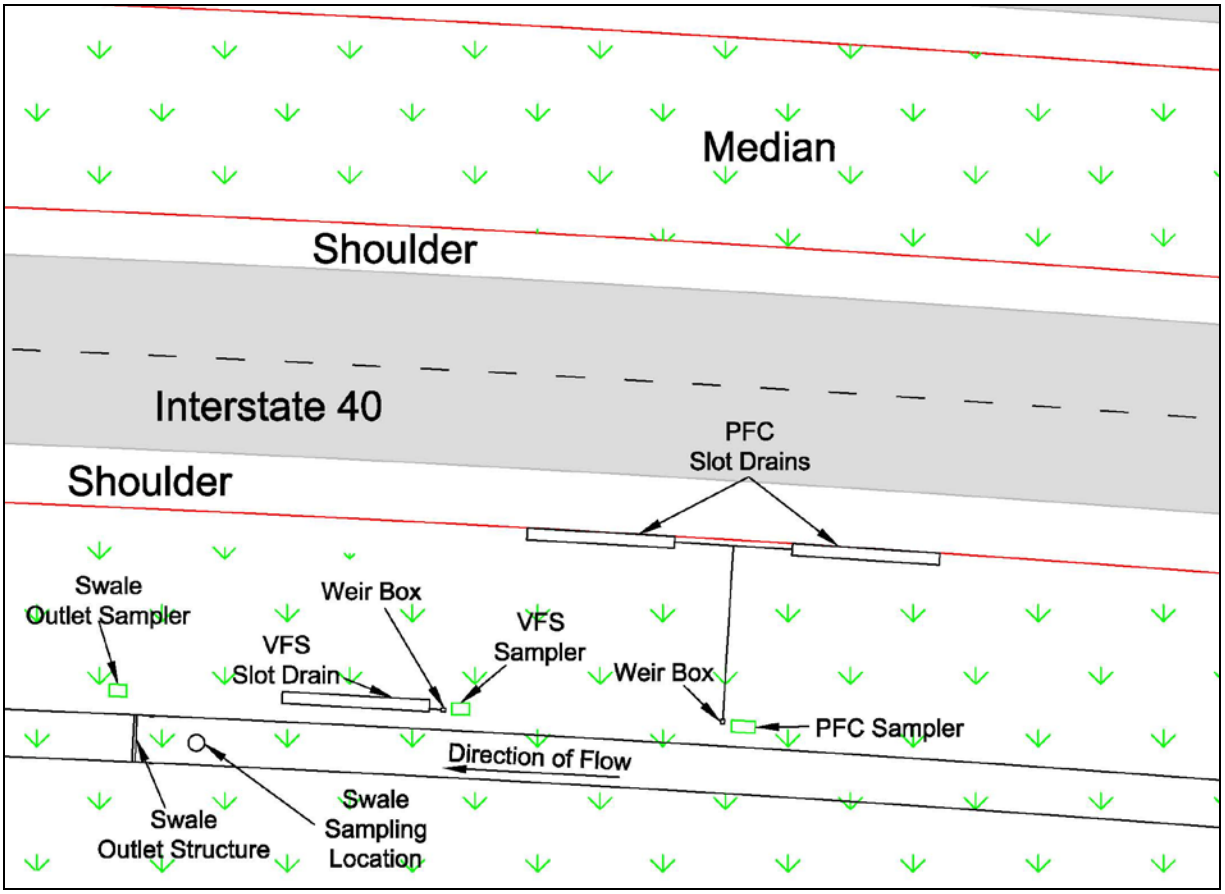

Figure 3. Monitoring schematic for I-40 research sites.

An open graded asphalt friction course (OGAFC), a type of PFC, was applied to this stretch of I-40 in November, 1999 (Figure 4). Upon reaching its design life, it was replaced in March-April 2010. The PFC overlay on I-40 was 1.5 in (4 cm) thick.

Figure 4. Cross sectional view of PFC overlay on I-40.

Along the monitored section of I-40, the highway was a four lane, divided roadway with associated emergency lanes. The watershed for edge-of-pavement sampling included a travel lane and an emergency lane. Slot drains were installed at the edge of the pavement to capture all runoff from the PFC-overlayed highway (Figure 5). Two slot drains were installed at each site in asphalt set 1 ft (30 cm) from the edge of the existing pavement; the opening of each slot drain measured 20 ft (6.1 m) long by 2 in (5.1 cm) wide. Total watershed size was 860 ft^2 (80 m^2) and watershed imperviousness was 100%. Stormflow from the roadway was conveyed from the slot drains to 4 in (10.2 cm) diameter PVC pipes. The outflow from both slot drains was combined into one 6 in (15.2 cm) diameter pipe and then conveyed downslope to a weir box (Figure 5).

Figure 5. Edge-of-pavement slot drain (left) and weir box (right).

At sites A and D, the existing vegetative filter strip (VFS) along the highway edge was monitored for pollutant removal. VFS characteristics are given below in Table 2. The watersheds were approximately 430 ft^2 (40 m^2) of roadway, and VFS area was approximately 410 ft^2 (38 m^2). This resulted in a catchment area to filter strip area ratio slightly greater than 1. VFS slopes were 18.1% and 15.8% for sites A and D, respectively, which was considered extremely high compared to other VFS studies in North Carolina (Line and Hunt 2009; Hunt et al. 2010; Winston et al. 2011). Vegetation in both filter strips was volunteer warm season grasses. Vegetative cover was fair will be quantified in the results section of this document.

Table 2. Characteristics of the highway filter strips along I-40.

VFS Characteristics		
Attribute	**Site A**	**Site D**
Watershed Area (ft^2)	439	423
Watershed Imperviousness (%)	100	100
VFS Width (ft)	21.3	21.8
VFS Length (ft)	19.1	19.1
VFS Area (ft^2)	407	416
Catchment Area to Filter Strip Area Ratio	1.08	1.02
VFS Slope (%)	18.1	15.8
VFS Vegetation	Volunteer Warm Season Grasses	Volunteer Warm Season Grasses

Outlet structures were placed approximately 21.5 ft (6.6 m) from the edge-of-pavement which constrained the width of the VFS (Figure 6). The outlet structure was a single slot drain (as described previously) installed flush with the ground surface. The outlet structure drained to a 4 in (100 mm) diameter PVC pipe, which conveyed flow to a weir box (Figure 6).

Figure 6. Filter strip slot drain (left) and weir box (right).

A linear drainage swale was monitored at each of the four sites along I-40 (Table 3). Watershed area varied from 1.19 to 1.53 ac (0.48-0.62 ha) and catchment imperviousness ranged from 23% to 43%. Catchment area and imperviousness were calculated from total station surveys. The catchments consisted only of highway land use. Swale length was calculated from the overpass to the installed monitoring outlet structure and varied from 500 ft (152 m) to 800 ft (238 m). Average swale width was 71-77 ft (22-24 m), except for site D, which had a width of 52.1 ft (15.9 m). Swale cross sectional shape was triangular. The major difference between the swales was the hydrologic characteristics; sites A and D were dry (ephemeral) swales, while sites B and C had wetland hydrology, hydrophytic vegetation, and hydric soils (Figure 7). One of the major goals of this project was to determine if swales with wetland characteristics can improve nutrient removal vis-à-vis a dry swale.

Table 3. Characteristics of the swales along I-40.

Swale Characteristics				
Attribute	**Site A**	**Site B**	**Site C**	**Site D**
Watershed Area (ac)	1.32	1.53	1.19	1.32
Watershed Imperviousness (%)	23.1	30.1	27.9	43.3
Length (ft)	600	708	498	782
Avg Width (ft)	76.6	77.6	71.3	52.1
Avg Longitudinal Slope (%)	0.28	0.63	0.63	0.62
Right Bank Side Slope	1 : 8	1 :6.25	1 : 6	1 : 6
Left Bank Side Slope	1 : 5.75	1 : 5.7	1 : 6.25	1 :6.5
Shape	Triangular	Triangular	Triangular	Triangular
Vegetation	Warm Season Grasses, Weeds	*Typha spp.* (Cattail), *Juncus spp.* (Common Rush), *Scirpus cyperinus* (Woolgrass), Tall Grasses	*Typha spp.* (Cattail), *Juncus spp.* (Common Rush), *Carex spp.* (Sedges)	Warm Season Grasses, Weeds
Hydrologic Condition	Dry	Wetland	Wetland	Dry

Figure 7. Wetland swale at site B (left) and traditional dry swale at site D (right).

Materials and Methods

Hydrologic and Water Quality Data

Edge-of-pavement runoff and filter strip runoff were captured in separate slot drains, which drained to weir boxes. The weir boxes housed 30^{o} v-notch weirs and ISCO 730 bubbler modules were used to measure the depth of flow over the weirs. Flow rate was calculated using the standard 30^{o} v-notch weir equation (Grant and Dawson 2001):

$$Q = 0.676 \times H^{2.5} \quad \text{(eq. 1)}$$

Where Q is flow rate (cfs) and H is head (ft). The ISCO 730 bubbler modules triggered ISCO 6712 automatic samplers to take flow-weighted, composite samples during each storm event. Sampling intake strainers were located in the weir boxes in an area of well-mixed flow.

An outlet structure was placed in the center of each swale to allow for collection of hydrologic and water quality data. The outlet structure was constructed of 2 in (5 cm) by 12 in (30 cm) lumber that was pushed into place with an excavator bucket (Figure 8). The lumber was glued together to create a watertight seal. The top of each weir was approximately 20 ft (6.1 m) long, with a 30° v-notch weir installed in the center (Figure 8). An ISCO 730 bubbler module was used to measure flow depth 6 ft (1.8 m) upstream of the weir invert. This flow depth was converted to flow rate using a derived (based on v-notch and broad crested weir equations), step-wise, function given in equation 2a and 2b (Grant and Dawson 2001).

$$Q = 0.676 \times H^{2.5} \text{ when H < 1 ft} \quad \text{(eq. 2a)}$$

$$Q = 0.676 + 66.6 \times H^{1.5} \text{ when H > 1 ft} \quad \text{(eq. 2b)}$$

Where Q is flow rate (cfs) and H is head (ft). The step-wise function calculates flow through the 30° weir (Eq. 2a) and then over the broad-crested (Eq. 2b). These calculated flow rates were utilized by an ISCO 6712 to take flow-weighted, composite stormwater samples from a well-mixed location in the center of the swale (Figure 8). During the winter months, a high water table in the swales caused submergence of the weir, invalidating the weir equations given above. While water quality samples were still taken, flow volumes and therefore loads were unable to be calculated for these storm events. These storms were characterized by a stage greater than 0.1 ft (30 mm) above the weir invert for more than 1 day after rainfall ceased.

Figure 8. Weir installation (top left), v-notch weir location (top right), and sample intake (bottom) for the swale outlet monitoring stations.

Rainfall measurements were obtained at each of the four sites. A Hobo™ tipping bucket rain gage was used to measure rainfall intensity, while a plastic manual rain gage measured rainfall depth for each storm event (Figure 9). All hydrology and rainfall data were analyzed using Flowlink™ software.

Figure 9. Rain gage installation.

Water quality and hydrology data were collected from September 2008 through May 2010. Storm events were characterized by a minimum 6 hr antecedent dry period and a minimum rainfall depth of 0.1 in (2.5 mm). Over the 21 month monitoring period, 76, 79, 78, and 78 events met these criteria at sites A-D, respectively. Of these, 24, 23, 20, and 20 storm events (again at sites A-D, respectively) were sampled for water quality. The storms sampled for water quality represented between 32-45% of the total rainfall, and had median rainfall depths ranging from 0.85 in (21.6 mm) at site A to 1.0 in (2.54 mm) at site D. The median monitored water quality storm event was between the 70th and 80th percentile storm rainfall depth calculated from 30 years of rainfall data in nearby Fayetteville, NC (Bean 2005).

A summary of rainfall depths, sample collection type (nutrients, sediment, or both nutrients and sediment), and sample collection location (edge-of-pavement [EOP] outlet, vegetative filter strip [VFS] outlet, and/or swale outlet) is presented in Appendices A and D.

Pollutant loads were calculated for each storm for which water quality samples were collected. They were determined by multiplying the pollutant event mean concentration (EMC) by observed runoff volume at each monitoring location.

Vegetation and Soil Data

To further detail the vegetated SCMs that were studied, soil samples were collected from all filter strips and swales. Samples were taken from two randomly chosen locations for each SCM. Samples were obtained at two depths at each location, one near the surface (2-6" deep) and one at deeper depths (6-10" deep). Samples were transported to the laboratory, and analyzed for chemical composition and particle size distribution using the hydrometer method (Gee and Bauder 1986). Soil chemical composition was determined by the North Carolina Division of Agriculture Soil Testing laboratory (Raleigh, NC) and particle size distribution was completed in a research laboratory on NC State University campus. Compaction of soils in the filter strips was also measured at two locations in each filter strip using a cone penetrometer (Figure 10). A Spectrum Field Scout SC-900 hand cone penetrometer was used to measure compaction. Similar to Pitt et al. (2008), a soil was considered compacted if the cone index exceeded 300 psi (2,070 kpa) in the top 3 in (7.6 cm) of the soil profile.

Figure 10. Measurement of soil compaction with a cone penetrometer.

Vegetative cover in the VFSs was analyzed based on aerial photographs collected on July 30, 2010. Photographs of the filter strips were taken and digitally pieced together to represent the entire filter strip. The analysis of vegetative cover was performed by importing the photographs into AutoCAD and drawing polygons around areas with bare soil (Figure 11). A ratio of areas with bare soil versus the total picture area was then taken to calculate vegetative cover. Vegetation type was visually determined twice during the study for both the filter strips and the swales (August 2009 and July 2010).

Figure 11. Example of vegetative cover analysis.

Laboratory Analysis

Water quality samples were collected from samplers during an approximately 3 hr round-trip from Raleigh, NC. Sample collection took place within 24 hours of the end of the rain event. The composite samples were dispensed into 125 mL pre-acidified plastic bottles for nutrient analysis and a 1000 mL plastic bottle for TSS analysis. Upon collection, all samples were immediately placed on ice and chilled to <4°C. Samples were delivered to the NC State Center for Applied Aquatic Ecology laboratory and were analyzed using EPA (U.S. EPA 1993) and Standard methods (APHA 1998) (Table 4). Laboratory analysis was performed for TKN, NH_4-

N, NO_{2-3}-N, TP, and TSS. TN was calculated by summing TKN and NO_{2-3}-N. Organic N (Org-N) was calculated by subtracting the NH_4-N concentration from the TKN concentration.

Table 4. Nutrient and sediment analysis techniques and reporting limits.

Constituent	Laboratory Testing Methods	Preservation	Laboratory Reporting Limit (mg/L)
NH_4-N	Std Method 4500 NH3 H (APHA, 1998)	H_2SO_4 (<2 pH), <4°C	0.007
TKN	EPA Method 351.1 (US EPA, 1993)	H_2SO_4 (<2 pH), <4°C	0.14
NO_{2-3}-N	Std Method 4500 NO3 F (APHA, 1998)	H_2SO_4 (<2 pH), <4°C	0.0056
TN	Calculated as NO_{2-3} + TKN	Not applicable	0.15
Org-N	Calculated as TKN – NH_4	Not applicable	0.15
TP	Std Method 4500 P F (APHA, 1998)	H_2SO_4 (<2 pH), <4°C	0.01
TSS	Std Method 2540 D (APHA, 1998)	<4°C	1

Statistical Analysis

The water quality and hydrology data were statistically analyzed to compare among and within monitoring sites. Non-parametric tests were favored to avoid assumptions regarding the distribution of the data. Comparisons of two groups used the Mann-Whitney test if samples were independent or the Wilcoxon signed rank test if samples were paired. Comparisons between multiple groups were conducted using the Kruskal-Wallis *k*-sample test. If significant differences were found, further exploration was completed using Mann-Whitney tests among all possible pairs of groups. A criterion of 95% confidence (α=0.05) was used for this research. Statistical analyses were performed using the SAS software version 9.1.3 (SAS Institute 2006). A value of one-half the detection limit was substituted for concentration data that were below the detection limit (Antweiler and Taylor 2008).

Results and Discussion

Vegetative and Soils Analyses

Results of the chemical soil analysis are presented in Table 5. Sample IDs are presented as swale or filter strip, sampling location number (1 or 2), and surface (S) or deep (D) sampling location.

Soil pH in all of the swale samples was near 5, while that for the filter strips was somewhat higher, approximately 7 at site A and 6 at site D. Percentage of humic matter in the soil was generally less than 1%, with the surface samples having a greater percentage of humic matter than the deeper samples (as expected). Cation exchange capacity (CEC) values were low at all sampling locations with average values of 5.2, 3.6, 2.6 and 3.7 meq/100 cm^3, at sites A-D, respectively. Percent base saturation was high at all of the sites, with average values of 82%, 39%, 52%, and 58% at sites A-D, respectively. Since the base saturation is high and the CEC is low, the soil has little ability to adsorb cations, such as Fe^{2+} and Al^{3+}. Since labile P often sorbs to soil particles by cation bridging, this mechanism is not expected to be present for P removal in the filter strips or swales. P-index, a measure of the amount of phosphorus in the soil, was low, with average values of 3, 11, 15, and 10 at sites A-D, respectively.

Table 5. Soil sampling results for the filter strips and swales.

Site A									
Sample ID	Soil Type	pH	HM%	W/V	CEC	BS%	P-I	Zn-I	Cu-I
Swale 1S	MIN	5.3	0.22	0.98	4.7	53	2	84	14
Swale 1D	MIN	5.6	0.04	1.18	3.6	81	2	8	11
Swale 2S	MIN	5.2	0.41	0.57	7.2	50	4	195	15
Swale 2D	MIN	5.5	0.04	1.14	3.8	74	3	22	11
FS 1S	MIN	7.4	0.04	1.1	5.5	100	4	45	60
FS 1D	MIN	6.6	0.04	1.11	4.9	100	2	5	15
FS 25	MIN	7.5	0.09	1.09	6.8	100	3	83	46
FS 2D	MIN	7.4	0.13	1.07	5.3	100	6	38	34
Site B									
Sample ID	Soil Type	pH	HM%	W/V	CEC	BS%	P-I	Zn-I	Cu-I
Swale 1S	MIN	4.8	0.22	0.92	4.2	38	15	117	12
Swale 1D	MIN	4.9	0.27	1.16	3.5	31	17	7	10
Swale 2S	MIN	4.9	0.09	1.03	3.6	44	7	28	12
Swale 2D	MIN	4.9	0.04	1.17	3.1	42	5	7	8
Site C									
Sample ID	Soil Type	pH	HM%	W/V	CEC	BS%	P-I	Zn-I	Cu-I
Swale 1S	MIN	5	0.51	1.21	1.9	42	26	20	5
Swale 1D	MIN	5	0.09	1.36	3	87	11	7	5
Swale 2S	MIN	4.8	0.41	1.2	2.7	48	22	227	11
Swale 2D	MIN	5.1	0.09	1.27	2.8	32	0	39	7
Site D									
Sample ID	Soil Type	pH	HM%	W/V	CEC	BS%	P-I	Zn-I	Cu-I
Swale 1S	MIN	4.9	0.6	1.1	3	30	23	101	13
Swale 1D	MIN	4.9	0.32	1.09	2.3	35	15	33	11
Swale 2S	MIN	4.9	0.46	1.17	2.9	38	16	120	18
Swale 2D	MIN	4.8	0.32	1.24	2.3	39	6	53	20
FS 1S	MIN	6.1	1.43	1.16	7	79	13	275	53
FS 2S	MIN	5.9	0.32	1.25	4.2	76	5	114	42
FS 1D	MIN	5.9	0.66	1.18	5	80	1	99	19
FS 2D	MIN	6.4	0.18	1.29	3	90	3	30	19

MIN – mineral soil class, %HM - % humic matter, W/V – weight per volume ratio, CEC – cation exchange capacity expressed in meq/100 cm3 , BS% - percentage of CEC occupied by the basic cations calcium (Ca), magnesium (Mg), and potassium (K), P-I – phosphorus (P) index, Zn-I – zinc (Zn) index, Cu-I – copper (Cu) index (Hardy, 2003).

Two soil samples, each composited over a depth of 2-10 inches, were taken from each of the filter strips and swales at the four research sites and were transported to the laboratory for particle size distribution (PSD) testing. Results of the PSD tests are presented in Table 6. The soil textures present in the filter strips ranged from loamy sand to sandy clay loam. The swales had similar soil textures, ranging from sand at site D to sandy clay loam at sites A, B, and C. Generally, these soil textures should allow infiltration to occur in both the filter strips and the swales, were they to be relatively uncompacted.

Table 6. Particle size distribution test results.

Sample Location	Sample Number	Percent Clay	Percent Sand	Percent Silt	USDA Soil Type
Filter Strip Site A	1	21.5	69.8	8.7	sandy loam
	2	19.8	69.5	10.7	loamy sand
Swale Site A	1	29.5	61.3	9.2	sandy loam
	2	21.6	62.5	15.9	sandy clay loam
Swale Site B	1	22.3	69.0	8.7	sandy clay loam
	2	26.4	65.2	8.4	sandy loam
Swale Site C	1	6.4	91.4	2.2	sandy clay loam
	2	16.0	68.9	15.1	sandy clay loam
Filter Strip Site D	1	16.9	69.9	13.2	sandy clay loam
	2	9.5	81.7	8.8	sandy loam
Swale Site D	1	13.0	70.4	16.6	sand
	2	11.3	74.8	13.9	sandy loam

Hydrology

Tables A.1-A.4 of Appendix A show all the rainfall data recorded at the four sites during the monitoring period, including storms that were not sampled for pollutants. Rainfall depth, rainfall duration, average rainfall intensity, peak 5-minute rainfall intensity, and antecedent dry period are presented for each storm event in these tables.

Tables B.1-B.4 of Appendix B present all of the flow volume data collected throughout the study at the edge-of-pavement, the filter strip outlets, and the swale outlets. It should be noted that flow data were not able to be obtained at the outlet of the swale at site C, as the weir was submerged constantly throughout most of the monitoring period, attributed to a high water table and wetland conditions that kept the swale full of water year-round. Also, there were periods in the winter where a high water table prevented flow data collection at all four sites.

Tables C.1-C.4 of Appendix C displays the peak flow rate data that were collected at each of the ten monitoring points throughout the study. Again, high water table effects prevented collection of some peak flow rate data in each of the swales. Hydrologic data are further utilized to predict pollutant loads.

Water Quality

Effluent Concentrations

Permeable Friction Course Results

The PFC layer appeared to trap and/or contribute very few sediment particles and their associated pollutants, with resulting mean TSS effluent concentrations of 13, 31, 9, and 14 mg/L from sites A-D, respectively. These concentrations were well below mean TSS concentrations from standard asphalt highways, which often range from 100-200 mg/L (Barrett et al. 1998; Sansalone et al. 1998; Kayhanian et al. 2003). However, effluent concentrations from the PFC-overlayed highway were similar to prior studies of PFC in Texas (8 mg/L), France (13 mg/L), and the Netherlands (17 mg/L) for sediment-bound pollutants (Table 7) (Berbee et al. 1999; Pagotto et al. 2000; Barrett et al. 2006). For phosphorus, a pollutant that is often sediment bound, concentrations were also low from the PFC, with mean values between 0.08-0.13 mg/L (Figure 12). Nitrogen concentrations were on the high end of those reported in the literature for highways and parking lots in North Carolina (Passeport and Hunt 2009; Wu et al. 1998), from 1.48 mg/L to 2.60 mg/L for the four sites. This may be the result of atmospheric nitrogen deposition due to hog farming in eastern North Carolina (Aneja et al. 2000). TSS at site B had a substantial difference between mean and median concentrations due to an outlier of 178 mg/L TSS observed on January 29, 2009, following a heavy snow event the week prior. This increased concentration was likely due to application of sand on the roadway surface.

Table 7. Effluent concentrations (mg/L) from the permeable friction course.

Sampling Location	TKN	NO_{2-3}-N	TN	NH_4N	Org N	TP	TSS
Mean Concentrations ±Standard Deviation							
Site A PFC	0.97 ±0.62	0.51 ±0.29	1.48 ±0.84	0.41 ±0.28	0.56 ±0.47	0.08 ±0.07	13 ±9
Site B PFC	1.26 ±1.02	0.41 ±0.14	1.66 ±1.06	0.46 ±0.32	0.79 ±0.77	0.11 ±0.11	31 ±39
Site C PFC	1.32 ±1.12	0.71 ±0.29	2.03 ±1.29	0.62 ±0.52	0.71 ±0.71	0.10 ±0.06	9 ±4
Site D PFC	1.27 ±0.87	1.32 ±0.85	2.60 ±1.19	0.55 ±0.57	0.72 ±0.44	0.13 ±0.07	14 ±14
Median Concentrations							
Site A PFC	0.82	0.394	1.295	0.39	0.346	0.053	9
Site B PFC	0.968	0.397	1.47	0.344	0.561	0.081	17
Site C PFC	1.009	0.759	1.725	0.4625	0.4285	0.083	8
Site D PFC	1.0855	1.063	2.367	0.344	0.563	0.1	8.4

Kruskal-Wallis tests were performed to determine if significant differences existed between the highway runoff at the four research sites. For TN, TP, and TSS, significant differences were found, with p-values of 0.0088, 0.0198, and 0.0428, respectively. To determine which sites significantly differed, Mann-Whitney tests were performed between all possible pairs of sites. For TN, significant differences existed for effluent concentrations between sites A and D and sites B and D. Sites A and D produced significantly different TP concentrations. For TSS, sites B and C and sites B and D produced significantly different effluent concentrations. All other comparisons between sites were not significantly different. While some differences were statistically observed between sites, the PFC at the four sites separated by 30 mile (48 km) produced relatively similar (in magnitude) TP and TSS effluent concentrations (Table 7). Kruskal Wallis tests were utilized to determine if statistical differences still existed between the four sites for TSS concentrations after removal of a 178 mg/L outlier at site B; statistical differences for TSS concentrations were still found between sites B and C.

Roadside Filter Strip Results

In general, relatively high concentrations of all pollutants analyzed exited the roadside filter strips when compared against edge-of-pavement concentrations (Table 8). TP and TSS EMCs exceeded those from other filter strip studies in North Carolina (Winston et al. 2011; Line and Hunt 2009). A Mann-Whitney test showed that TN and TSS concentrations leaving the filter strips were not significantly different between sites A and D (Figure 12). The concentration of

TP leaving the site D filter strip was found to be significantly higher than that from site A (Figure 12).

The poor performance of the filter strips in this study was potentially due to the design and maintenance of these systems. Fair vegetative cover existed in both of the filter strips (75% and 90% for sites A and D, respectively). Barrett et al. (2004) found that performance of roadside VFSs declined rapidly when vegetative cover fell below 80%. The roadside filter strips had slopes of 18.1% at site A and 15.8% at site D, much higher than recommended slopes (NCDENR 2007; U.S. EPA 2008) for removal of sediment bound pollutants in filter strips. Also, the VFSs received runoff from the PFC that was at or near "irreducible" concentrations for TSS and particulate-bound pollutants (Strecker et al. 2001). The combination of these factors may have resulted in poor performance of the filter strip for nutrient and sediment removal.

Table 8. Effluent concentrations (mg/L) from the roadside filter strips.

Sampling Location	TKN	$NO_{2\text{-}3}$-N	TN	NH_4N	Org N	TP	TSS
Mean Concentrations ±Standard Deviation							
Site A VFS	1.60 ±1.12	0.42 ±0.42	2.02 ±1.43	0.31 ±0.37	1.29 ±0.98	0.27 ±0.19	26 ±27
Site D VFS	1.83 ±0.89	0.43 ±0.34	2.26 ±1.14	0.28 ±0.26	1.55 ±0.74	0.36 ±0.19	36 ±42
Median Concentrations							
Site A VFS	1.12	0.39	1.45	0.17	0.94	0.20	17
Site D VFS	1.47	0.34	1.91	0.13	1.34	0.28	24

Efficiency ratios have often been used as a metric to determine how well an SCM removes pollutants; this metric is highly reliant on influent concentration, where low influent concentrations often produce poor efficiency ratios (Strecker et al. 2001; Lenhart and Hunt, 2011). When compared with the edge-of-pavement water quality, the filter strips usually caused an increase in pollutant concentration (Table 9). This was likely due to the fact that most of the particle-bound pollutants were presumably removed in the PFC layer; therefore, benefits from the major pollutant removal mechanism (sedimentation) that filter strips employ were minimized. In fact, the filter strip at site A significantly *increased* concentrations of all constituents studied except $NO_{2\text{-}3}$-N and NH_4-N. For both filter strips, TP and TSS concentrations increased by more than 100% from the edge-of-pavement. $NO_{2\text{-}3}$-N efficiency ratios were 0.18 and 0.68 across the filter strips; this positive performance has not been observed elsewhere in the filter strip literature.

Table 9. Efficiency ratios for filter strips.

Analyte	Site A		Site D	
	Efficiency Ratio	p-value	Efficiency Ratio	p-value
TKN	-0.65	**0.0029**	-0.44	**0.0141**
$NO_{2\text{-}3}$-N	0.18	0.1891	0.68	**0.0004**
TN	-0.37	**0.0253**	0.13	0.213
NH_4-N	0.25	**0.0427**	0.50	**0.0202**
Org N	-1.32	**0.0036**	-1.16	**<0.0001**
TP	-2.27	**0.0005**	-1.73	**<0.0001**
TSS	-1.08	**0.0013**	-1.56	**0.0027**

Dry and Wet Swale Results

Dry swales have been shown to mitigate high concentrations of pollutants associated with storm events and produce lower, more consistent effluent concentrations than untreated road runoff (Bäckström 2003; Deletic and Fletcher 2006). However, the authors are not aware of previous peer-reviewed studies on wetland swales that have been published. Effluent concentrations and standard deviations of pollutant concentrations for the dry swales (sites A and D) and wetland swales (sites B and C) are presented in Table 10. Effluent concentrations of nitrogen (specifically TKN, TN, Org-N, and NH_4-N) were typically lower for wetland swales than they were for dry swales. Effluent concentrations for TP and TSS were similar for wetland swales and dry swales. The only exception to this was the TSS concentration for the dry swale at site D, presumably due to a head cut that was actively eroding in the swale during the study (Figures 12-13, and Table 10). Since phosphorus is often sediment-bound, it is not surprising that the swale at site D also had the highest TP effluent concentrations.

Table 10. Effluent concentrations (mg/L) from the dry and wetland swales.

Mean Concentrations ±Standard Deviation							
Sampling Location	**TKN**	**NO_{2-3}-N**	**TN**	**NH_4N**	**Org N**	**TP**	**TSS**
Site A Swale	1.24 ±0.61	0.41 ±0.42	1.65 ±0.65	0.14 ±0.14	1.11 ±0.50	0.11 ±0.07	25 ±26
Site B Swale	1.12 ±0.50	0.16 ±0.24	1.22 ±0.52	0.07 ±0.04	1.05 ±0.50	0.12 ±0.04	24 ±14
Site C Swale	0.90 ±0.35	0.25 ±0.31	1.15 ±0.59	0.09 ±0.08	0.81 ±0.32	0.08 ±0.04	20 ±19
Site D Swale	1.40 ±0.70	0.21 ±0.17	1.62 ±0.74	0.14 ±0.12	1.26 ±0.32	0.19 ±0.10	70 ±62
Median Concentrations							
Site A Swale	1.13	0.30	1.63	0.09	1.06	0.09	15
Site B Swale	0.91	0.08	1.03	0.06	0.86	0.13	21
Site C Swale	0.81	0.16	1.02	0.06	0.74	0.08	14
Site D Swale	1.26	0.17	1.50	0.11	1.06	0.17	47

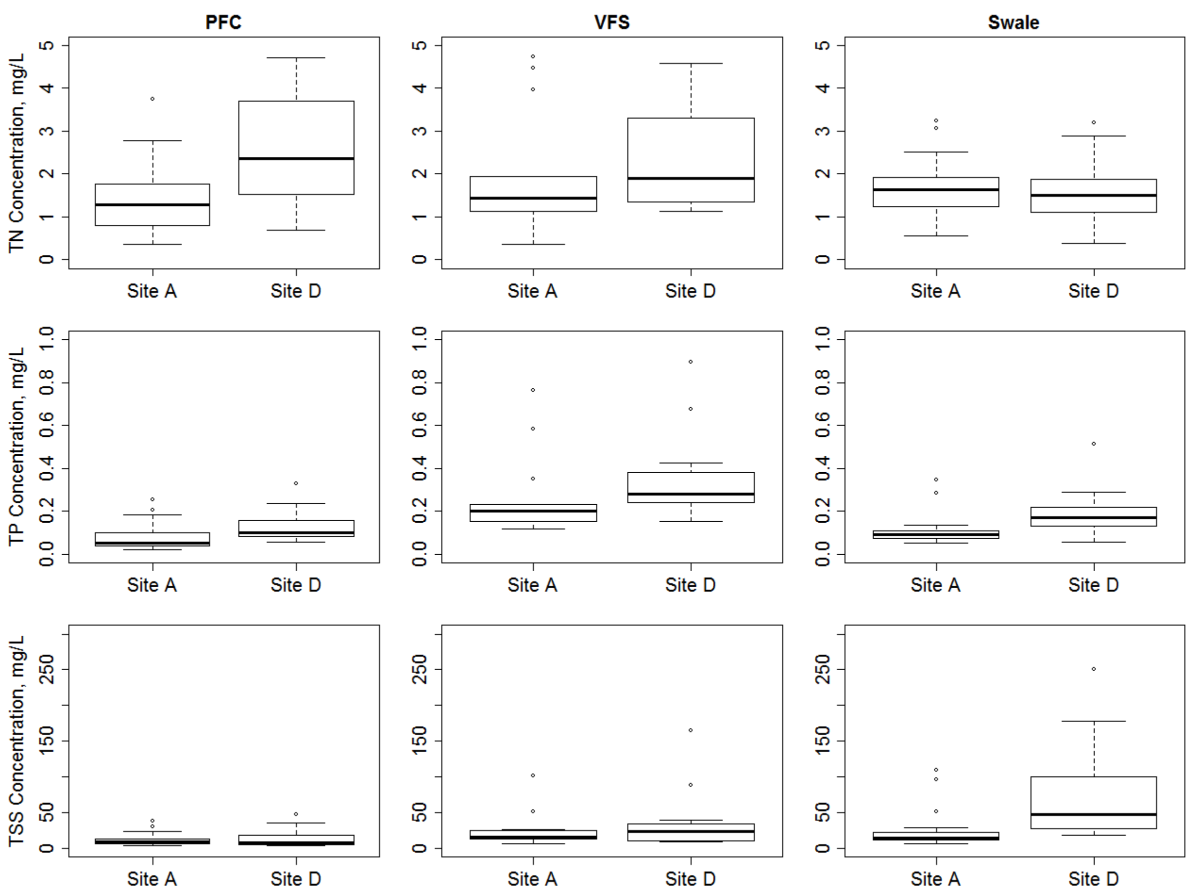

Figure 12. Boxplots of TN, TP, and TSS for the PFC, VFS, and swale sampling locations at sites A and D.

Figure 13. Head cut in dry swale at site D.

To compare effluent concentrations, a Kruskal-Wallis test was performed for the four sites. For TN, TP, and TSS, significant differences were found, with p-values of 0.0029, <0.0001, and <0.0001, respectively. For TN, there were no significant differences among effluent concentrations when comparing the dry swales to each other and the wetland swales to each other. All combinations of a wetland swale versus a dry swale were significantly different. Thus, the two dry swales produced effluent nitrogen concentrations that were statistically higher than those from wetland swales (Figure 14). This was probably due to the larger number of unit processes (denitrification, filtration, and potentially greater plant uptake) employed by a wetland swale as compared to those of a dry, grassed swale. Similar trends were not found for TP or TSS. For these pollutants, all other swales differed (significantly) from site D, likely due to erosion from the head cut. The effluent TP and TSS concentrations from the other three swales (sites A-C) were not significantly different.

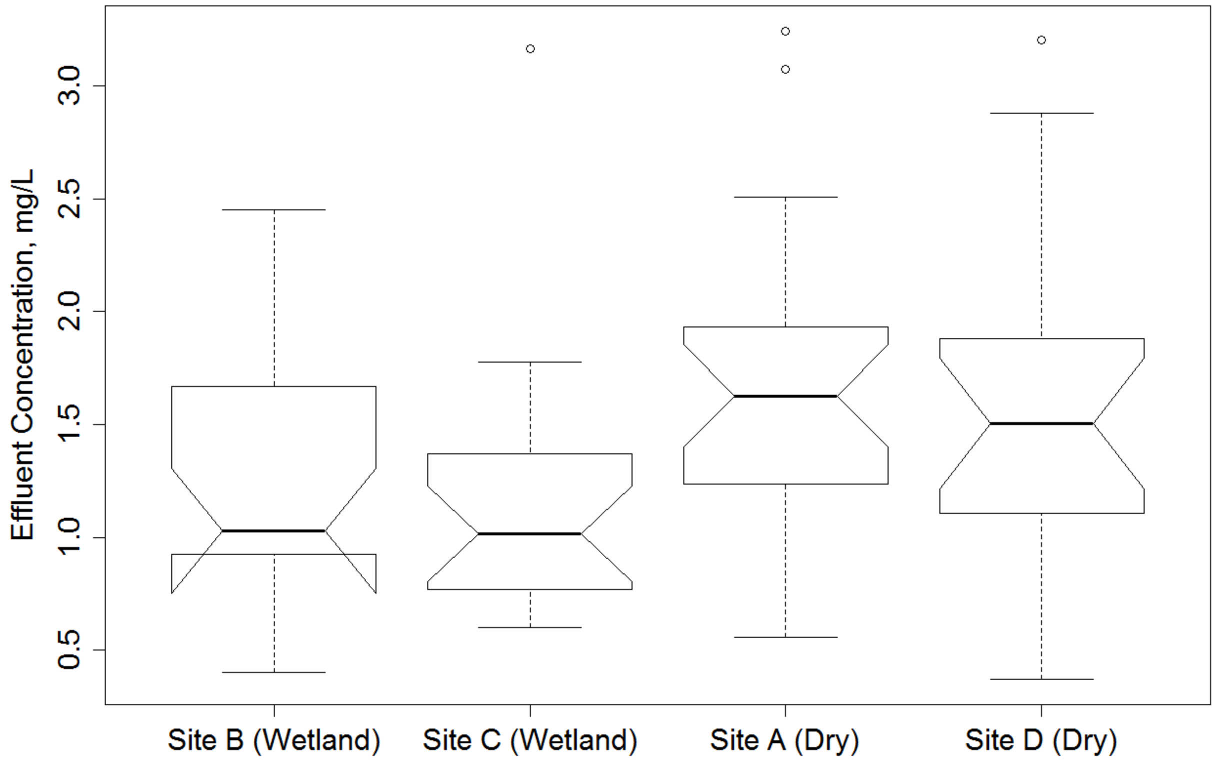

Figure 14. Boxplots of TN for the wetland swale and dry swale outlets.

Efficiency ratios (ERs) from the edge-of-pavement to the swale outlet and from the filter strip outlet to the swale outlet are presented in Table 11. Nitrate reductions were significant and substantial from the edge of pavement to the outlet of the swale at all four sites. Interestingly, the dry swale at site D reduced nitrate concentrations to 50% of the concentration at the outlet of the filter strip. Nitrate concentration and load reductions were also observed in two dry swales in Texas (Barrett et al. 1998). TN concentrations were significantly reduced from the edge-of-pavement to the swale outlet at sites C and D, but similar results were not found at sites A and B. NH_4-N concentrations were significantly decreased by all four swales when compared against edge-of-pavement and VFS outlet concentrations. Organic nitrogen concentrations were reduced (non-significantly) from the filter strip outlet to the swale outlet at sites A and D. However, edge-of-pavement organic nitrogen concentrations were always significantly lower than those at the swale outlet. Perhaps this result is due to the addition of decaying plant matter as the stormwater passes through the filter strip and swale. Mean TP concentrations *increased* from the edge-of-pavement to the swale outlet at sites A, B, and D, and were reduced by 18% at site C. It is speculated that because of the low TSS concentrations emitted from the PFC-overlayed highway, TSS efficiency ratios for the filter strip-swale treatment systems were often negative (Table 11). In fact, TSS concentrations increased by 100% or more (all statistically significant) at sites A, C, and D. The filter strip-swale SCMs were able to reduce TSS by 24% at site B (not statistically significant).

Table 11. Efficiency ratios for the swale compared to edge-of-pavement and filter strip outlet concentrations.

Analyte	Site A (Dry)				Site B (Wetland)		Site C (Wetland)		Site D (Dry)			
	PFC-Swale ER	p-value	FS-Swale ER	p-value	PFC-Swale ER	p-value	PFC-Swale ER	p-value	PFC-Swale ER	p-value	FS-Swale ER	p-value
TKN	-0.28	**0.0026**	0.22	0.9707	0.11	0.1141	0.32	0.1949	-0.10	0.1700	0.23	**0.0362**
$NO_{2\text{-}3}$-N	0.19	**0.0099**	0.02	0.9739	0.60	**<0.0001**	0.65	**<0.0001**	0.84	**<0.0001**	0.50	**0.0392**
TN	-0.12	**0.0183**	0.18	0.6246	0.27	0.2570	0.43	**0.0003**	0.38	**0.0008**	0.29	**0.0252**
NH_4N	0.67	**<0.0001**	0.56	**0.0259**	0.85	**<0.0001**	0.85	**<0.0001**	0.74	**0.0003**	0.49	**0.0317**
Org N	-1.32	**0.0004**	0.14	0.9869	-0.32	**0.0162**	-0.15	**0.0172**	-0.75	**0.0017**	0.19	0.1532
TP	-0.32	0.1020	0.6	**0.0023**	-0.06	0.0893	0.18	0.2010	-0.48	**0.0057**	0.46	**<0.0001**
TSS	-0.96	**0.0002**	0.06	0.2139	0.24	0.2668	-1.15	**0.0060**	-4.00	**0.0002**	-0.95	**0.0386**

Another metric that can be used to assess stormwater SCM performance is the use of a target effluent concentration. McNett et al. (2010) characterized water quality levels by correlating in-stream pollutant concentrations to benthic macroinvertebrate health. In the Piedmont of North Carolina, “good” water quality concentrations for TN and TP were 0.99 mg/L and 0.11 mg/L, respectively. “Good” water quality supported intolerant benthic macroinvertebrates, such as mayflies (*Ephemeroptera*) and caddisflies (*Tricoptera*). These target values are shown in Figures 15-18 as horizontal lines. Target concentrations for TSS were based on those from the Sustainable Sites Initiative (ASLA et al., 2009); in this case a target TSS concentration of 25 mg/L is used in Figure 16.

Mean TN concentrations from the PFC, VFSs, and swales were all above the target water quality concentration of 0.99 mg/L (Figures 15-18). This suggests that these four SCMs (PFC, VFS, dry swales, and wet swales) cannot produce nitrogen concentrations that consistently meet this metric. Mean TP concentrations from the edge of I-40 were 0.08 mg/L, 0.11 mg/L, 0.10 mg/L, and 0.13 mg/L (Figures 15-18); thus, at three of the four research sites, the pavement runoff produced concentrations that were below the target TP concentration. In both cases, the filter strips increased mean TP concentrations above the target. Three of the four swales did meet the water quality target. The swale at site D produced mean TP effluent concentrations of 0.19 mg/L, probably due to the head cut in the swale that was actively eroding during the study period (Figure 13).

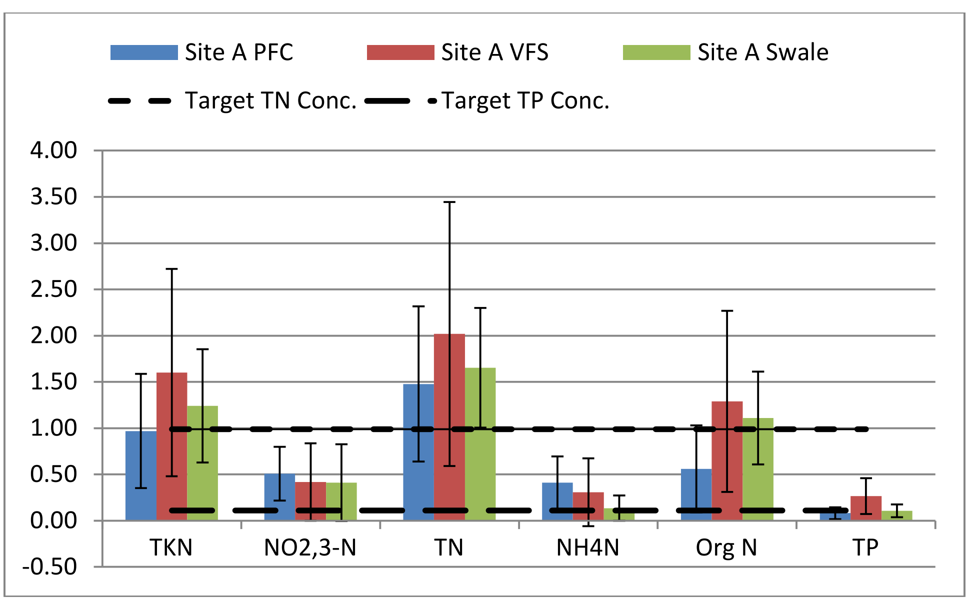

Figure 15. Average nutrient concentrations (mg/L) with standard deviations for site A.

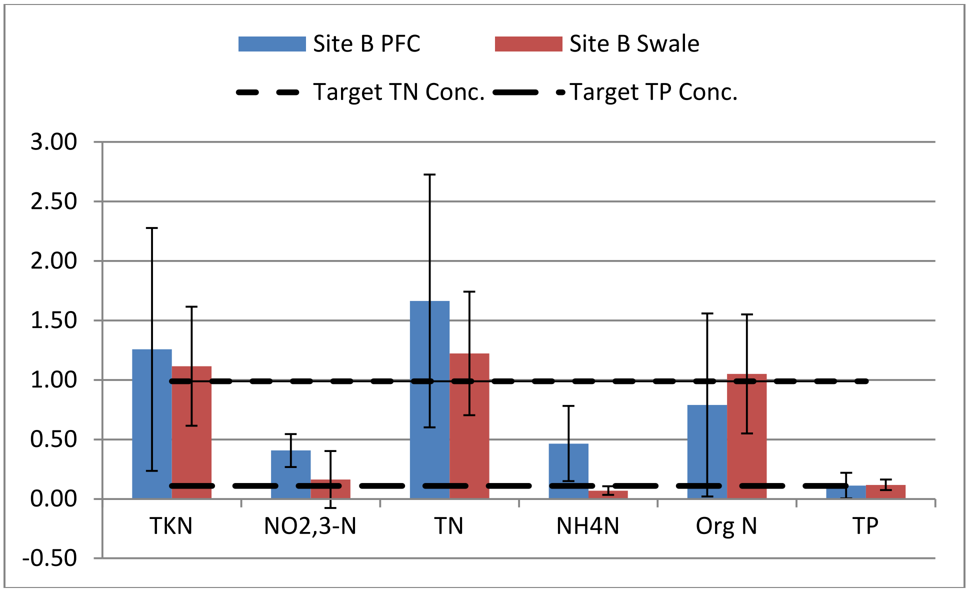

Figure 16. Average nutrient concentrations (mg/L) with standard deviations for site B.

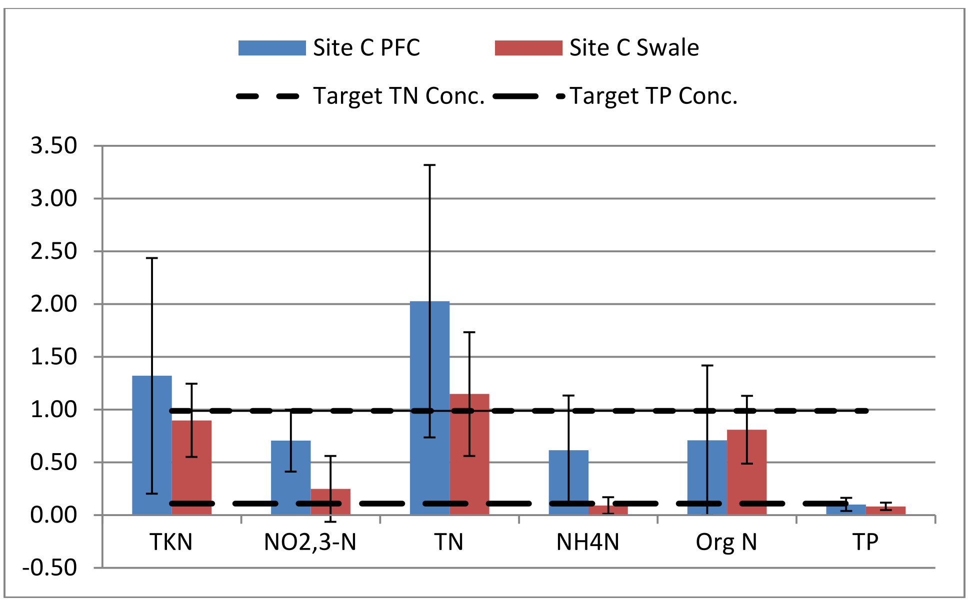

Figure 17. Average nutrient concentrations (mg/L) with standard deviations for site C.

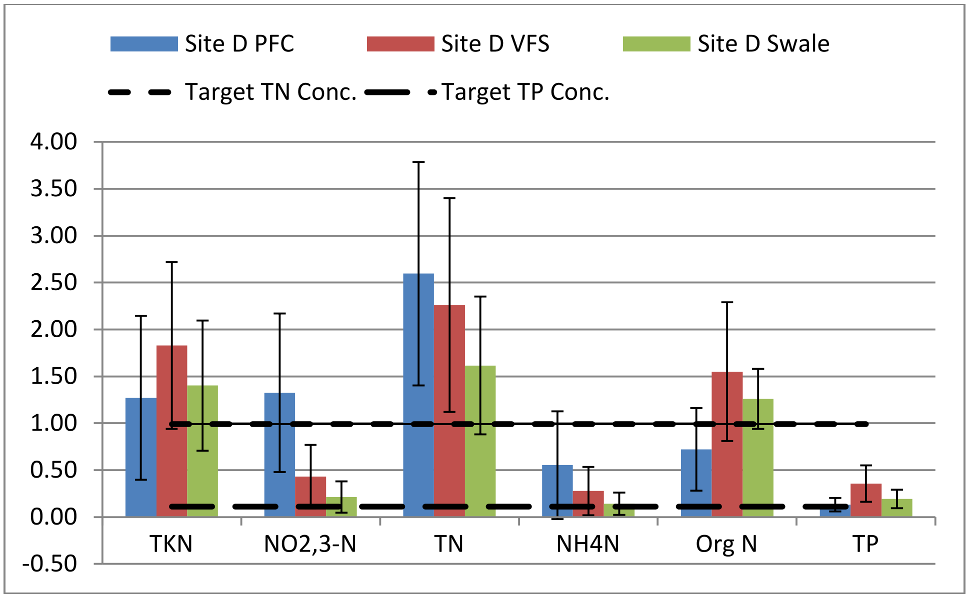

Figure 18. Average nutrient concentrations (mg/L) with standard deviations for site D.

Mean total suspended solids concentrations for the four sites and a total of ten SCMs are presented in Figure 19. At three of the four edge-of-pavement sampling locations, mean TSS EMCs were less than the 25 mg/L threshold. At site A, the 25 mg/L concentration was only exceeded during two of 24 sampled storm events, and it was never exceeded for any of the 20 sampled storm events at site C. The roadside filter strips generally caused an increase in sediment concentration presumably due to fair vegetative cover. The swales at sites A, B, and C produced mean effluent TSS concentrations between 20-25 mg/L. The swale at site D produced mean effluent concentrations of 70 mg/L due to the head cut. A 300% difference in TSS concentration when comparing site D to sites A-C shows the importance of maintenance of SCMs (in this case preventing the formation of a head cut) in the linear environment.

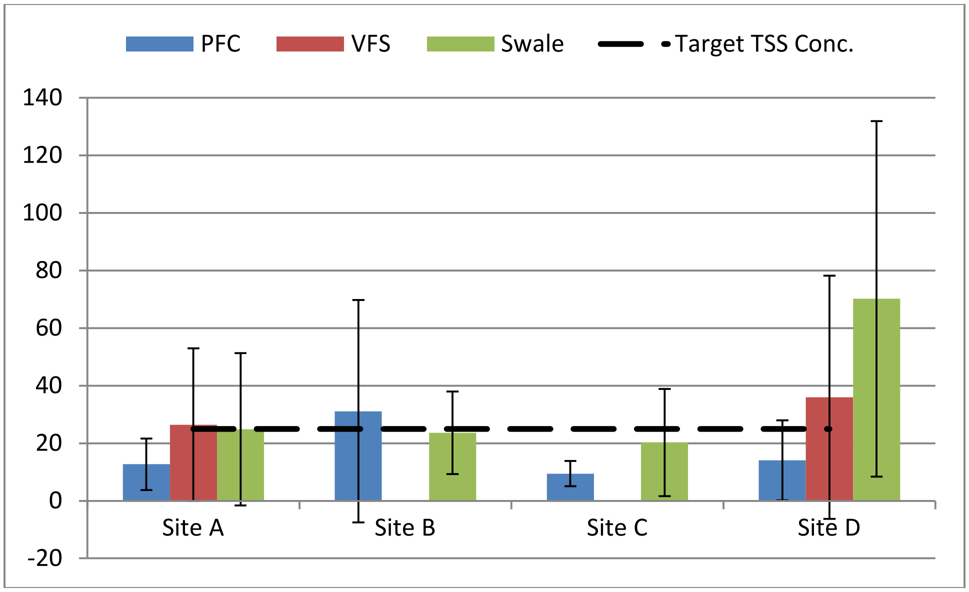

Figure 19. Average TSS concentrations (mg/L) from the PFC, VFSs, and swales.

It is clear from Figures 15-20 that the runoff coming from the highway was quite clean relative to target concentrations for TP and TSS. At three of four sites, TP and TSS concentrations were already less than target concentrations as the runoff left the highway. When analyzing the pollutant concentrations based on this metric, the filter strips' and swales' inability to effectively reduce the TP and TSS concentrations in the runoff was not necessarily a sign of inadequately functioning SCMs. One must consider the idea of irreducible concentrations, which has been suggested by Strecker et al. (2001) and Lenhart and Hunt (2011), among others. If runoff quality from the highway reaches an irreducible concentration, then an SCM cannot further reduce this concentration. This was probably the case for TP and TSS, where mean effluent concentrations from the highway were below 0.10 mg/L and 14 mg/L, respectively, at three of the four research sites.

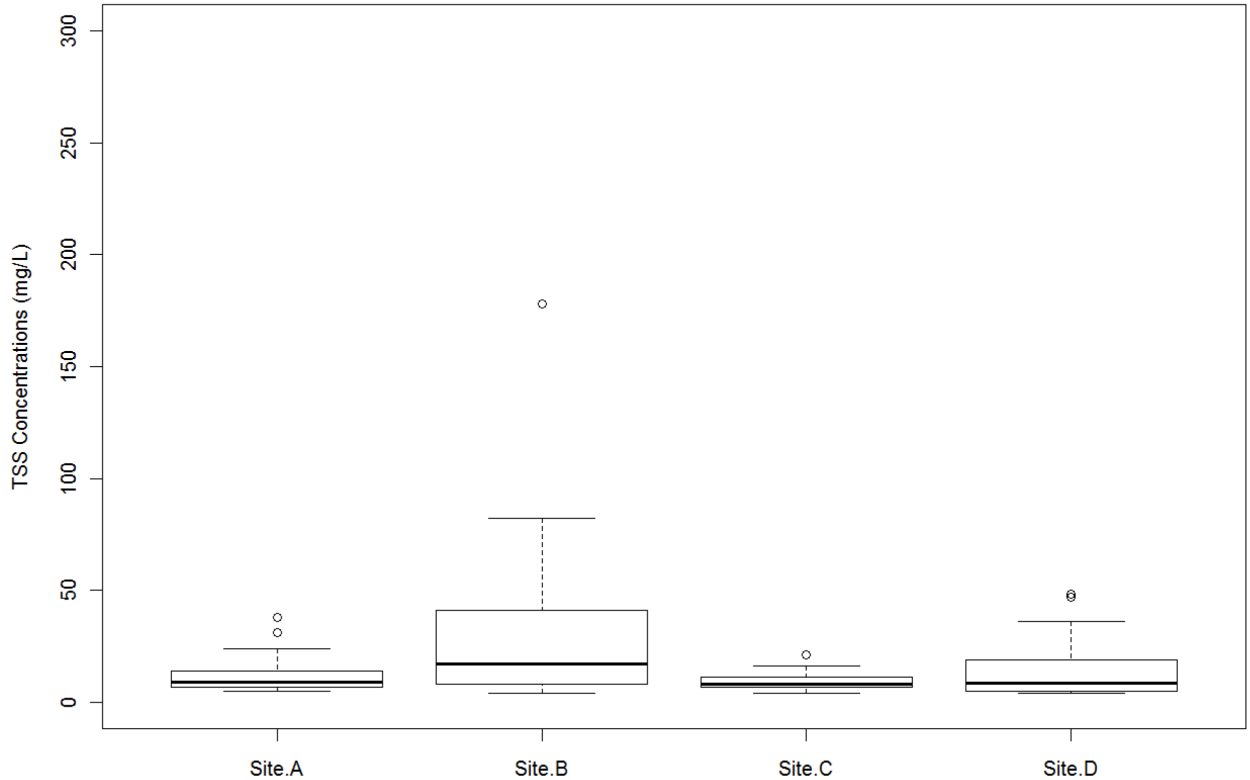

Figure 20. Boxplots of TSS concentration (mg/L) by site at the edge-of-pavement.

Pollutant Loads

Pollutant loads normalized by watershed area for nitrogen species, TP, and TSS are presented in Table 12 for the PFC, roadside VFSs, and the dry swales (sites A and D) and wetland swales (sites B and C). Data were not presented for VFSs at sites B and C, as they were not studied. Also, flow data were not reliable for the swale outlet at site C due to the presence of a nearly year-round high water table causing submergence of the weir, which prevented pollutant loads from being calculated.

Normalized pollutant loads were generally either lowest at the edge-of-pavement or at the swale outlet. Pollutant load reductions were generally due to reduction in concentration when they occurred, rather than infiltration in the filter strip or the swale. For instance, the NH_4 load reduction at site B was 95% from the edge-of-pavement to the outlet of the swale, but only 17% of the 95% reduction was due to infiltration in the vegetated right-of-way.

Load reductions across the filter strips were mixed, with the majority of nitrogen species' loads reduced, while most TP and TSS loads increased through the filter strips. While particle size distribution tests showed that the underlying soils were relatively sandy (USDA soil type was either sand, sandy loam, loamy sand, or sandy clay loam), infiltration was probably minimized due to compaction of the soils during construction of the highway. Even in a relatively permeable hydrologic soil group A or B soil, compaction from construction activities can substantially limit infiltration (Pitt et al. 2008; Brown and Hunt 2010). Soil compaction was tested at two locations in each VFS. Soil was considered compacted at one test location at site A and both test locations at site D (Figure 21), with cone indices above the threshold of 300 psi (2,070 kpa) in the top 3 in (7.6 cm) (Pitt et al. 2008). At site A, the penetrometer would not advance past a 5 in (13 cm) and 8 in (20 cm) depth at the two test sites due to extremely compacted soil layers. These filter strip results were contrasted to those from the wetland swale at site D (Figure 21), where the cone index never exceeded 300 psi (2,070 kpa) in the top 3 in (7.6 cm), perhaps due to the saturation of the soil. It is postulated that soil compaction in the roadside filter strips limited infiltration, thereby reducing their effectiveness for pollutant load reduction.

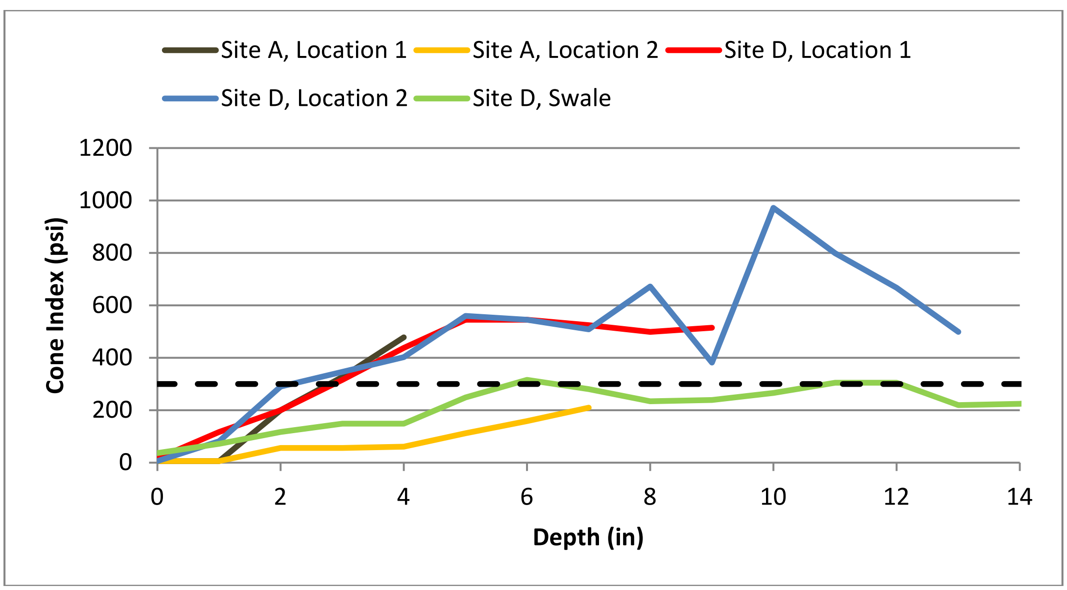

Figure 21. Soil compaction in the filter strips.

Pollutant loads appear to be further reduced (beyond levels produced by the VFSs) by the swales, with the mass of nitrogen species and TP being reduced from the edge-of-pavement. For all pollutant forms measured, the swale at site D had the highest nutrient and sediment load (except $NO_{2,3}$-N) of any of the swales, probably due to the head cut that was actively eroding in the swale. Loads at site C could not be calculated; based upon site B, it appeared that wetland swales may yield smaller loads of most nitrogen constituents. This is logical because of the greater number of pollutant removal mechanisms in a wetland swale. Any improvement would not be due to increased infiltration in the wetland swales. Results for TP and TSS loads for wetland swales were similar to those from dry swales. Again, TP and TSS loads for site D may be an anomaly, as a large head cut in the swale was contributing to the sediment load. The superior performance of the wetland swales is important for regions of the United States and world where high water tables are common; to improve nitrogen control, swales in high water table situations should be designed and maintained so that wetland conditions develop.

Table 12. Pollutant loads normalized by watershed area for the permeable friction course, roadside filter strips, and the dry and wetland swales.

Analyte	Location	Site A	Site B	Site C	Site D
TKN (lb/ac/yr)	PFC	10.84	10.83	15.6	11.33
	VFS	5.10	-	-	30.76
	Swale	4.89	2.84	-	8.59
$NO_{2\text{-}3}$-N (lb/ac/yr)	PFC	5.94	5.10	9.9	14.15
	VFS	1.28	-	-	7.30
	Swale	0.69	2.00	-	1.53
TN (lb/ac/yr)	PFC	16.77	15.93	25.5	25.48
	VFS	6.37	-	-	38.12
	Swale	5.58	3.06	-	10.12
NH_4N (lb/ac/yr)	PFC	4.29	4.65	6.7	5.27
	VFS	0.90	-	-	6.74
	Swale	0.43	0.22	-	1.03
Org N (lb/ac/yr)	PFC	6.54	6.18	8.9	6.06
	VFS	4.19	-	-	24.01
	Swale	4.45	2.62	-	7.56
TP (lb/ac/yr)	PFC	0.87	1.01	1.7	1.25
	VFS	1.24	-	-	6.64
	Swale	0.46	0.33	-	1.10
TSS (lb/ac/yr)	PFC	145.3	222.4	170.2	159.2
	VFS	93.8	-	-	335.3
	Swale	72.8	58.8	-	239.6

Conclusions

Data were presented on pollutant concentrations and loads from ten monitoring locations along I-40 in Eastern North Carolina. The following conclusions can be drawn from this study:

1. Pollutant concentrations and loads of sediment-bound pollutants and TSS at the edge of the PFC-overlayed highway were extremely low. Median effluent concentrations were 8 mg/L, 9 mg/L, 9 mg/L, and 17 mg/L from the highway, which was equivalent to effluent concentrations produced by bioretention (Hunt et al. 2008; Brown and Hunt 2011) and permeable pavement (Bean et al. 2007), two SCMs currently recommended for use world-wide. Because of its excellent performance for sediment bound pollutants, the authors have encouraged further use of PFC throughout North Carolina.

2. Significantly and substantially (~0.4 mg/L difference) lower TN concentrations were observed from the wetland swales when compared to traditional dry swales. Differences in effluent concentrations were not observed for TP or TSS. Where appropriate, swales should be intentionally designed with wetland characteristics. Moreover, governing agencies should consider awarding greater credit to wetland swales for nitrogen treatment than traditional dry swales.

3. The two roadside VFSs studied both caused significant and substantial (>100%) increases in TP and TSS concentrations from the edge-of-pavement. Three reasons were observed for this: (1) influent concentrations of sediment bound pollutants were at or near irreducible concentrations [a similar result was observed in Barrett et al. (2006)], (2) VFS slopes were high (>15%) and (3) VFS vegetative cover was 75% and 90%. This suggests that maintenance and establishment of ground cover on roadside filter strips is essential for proper performance.

4. The swale at site D produced significantly higher TP and TSS concentrations compared to the other three swales studied. This result was attributed to a head cut in the thalweg of the swale channel, suggesting that maintenance of highway SCMs has substantial impact on their performance.

5. Pollutant load reductions in the highway filter strips were lower than expected, potentially owing to compaction of the in situ soils. This may be unavoidable in the highway environment, as compaction is needed in roadside shoulders to structurally support the roadway.

6. Pollutant loads were generally lowest at the swale outlet, suggesting that further "polishing" of stormwater beyond that of PFC does occur in the vegetated highway shoulder. Pollutant loads were also affected by maintenance-related activities – the lack of vegetation in the VFSs and the head cut in the swale at site D caused increases in TP and TSS loads from the edge-of-pavement.

7. Further research is needed in two areas: (1) the authors believe it would be valuable to examine PFC in cold-weather climates, to determine its long-term functionality when plowing activities are more frequent; (2) an analysis of the unit processes that occur in a wetland swale is needed to determine why they function better than traditional dry swales for nitrogen reduction.

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Appendix A: Rainfall Data.

Table A.1. Rainfall data recorded during monitoring period at site A.

Storm No.	Rainfall (in)	Date	Rainfall (mm)	Storm Event Duration (hrs)	Average Rainfall Intensity (cm/hr)	Peak 5-min Intensity (cm/hr)	ADP (hrs)	Sampled?
1	3.92	6-Sep-08	99.57	ND	ND	ND	ND	Yes
2	1.35	17-Sep-08	34.29	ND	ND	ND	ND	Yes
3	1.43	29-Sep-08	36.32	40.07	0.906	3.05	ND	Yes
4	0.16	1-Oct-08	4.06	11.77	0.345	1.22	101.97	No
5	1.02	18-Oct-08	25.90	17.33	1.495	1.22	405.6	Yes
6	0.3	24-Oct-08	7.62	5.75	1.325	0.61	150.17	No
7	0.79	6-Nov-08	20.07	36.07	0.556	0.61	236.52	Yes
8	0.21	8-Nov-08	5.33	2.7	1.976	2.13	73.32	No
9	3.27	17-Nov-08	83.06	60.72	1.368	8.84	117.18	Yes
10	0.34	24-Nov-08	8.64	3.67	2.353	1.22	219.22	No
11	0.85	2-Dec-08	21.59	33.18	0.651	0.91	103.92	Yes
12	1.02	12-Dec-08	25.91	32.47	0.798	2.74	241.65	Yes
13	0.06	15-Dec-08	1.52	N/A	N/A	N/A	N/A	-
14	0.5	20-Dec-08	12.70	18.37	0.691	2.13	120.7	No
15	0.07	26-Dec-08	1.78	N/A	N/A	N/A	N/A	-
16	0.15	29-Dec-08	3.81	5.03	0.757	1.83	59.05	No
17	0.16	4-Jan-09	4.06	1.93	2.106	1.22	119.9	No
18	0.51	6-Jan-09	12.95	10.52	1.231	1.22	38.12	No
19	0.09	7-Jan-09	2.29	N/A	N/A	N/A	N/A	-
20	0.39	11-Jan-09	9.91	7.32	1.353	1.52	78.7	No
21	0.37	18-Jan-09	9.40	6.18	1.521	0.61	171.4	No
22	0.05	20-Jan-09	1.27	N/A	N/A	N/A	N/A	-
23	0.11	21-Jan-09	2.79	3.22	0.868	0.30	30.2	No
24	0.34	29-Jan-09	8.64	ND	ND	ND	ND	Yes
25	0.05	2-Feb-09	1.27	N/A	N/A	N/A	N/A	-
26	0.1	4-Feb-09	2.54	4.53	0.561	0.30	29.83	No
27	0.91	19-Feb-09	23.11	27.92	0.828	2.44	329.91	Yes
28	0.08	22-Feb-09	2.03	1	2.032	0.61	71.42	No
29	3.24	5-Mar-09	82.30	46.2	1.781	1.22	212.23	Yes
30	1.23	13-Mar-09	31.24	65.4	0.478	1.83	268.03	Yes
31	0.25	16-Mar-09	6.35	11.95	0.531	0.61	11.88	No
32	0.33	19-Mar-09	8.38	4.42	1.896	0.61	68.52	No
33	0.08	26-Mar-09	2.03	N/A	N/A	N/A	N/A	-
34	0.5	27-Mar-09	12.70	10.52	1.207	3.96	14.76	No

35	0.67	28-Mar-09	17.02	7.22	2.357	2.74	14.58	No
36	0.12	2-Apr-09	3.05	14.37	0.212	0.61	107.07	No
37	0.34	6-Apr-09	8.64	0.68	12.700	3.66	81.92	No
38	2.37	14-Apr-09	60.20	13.33	4.516	15.85	194.93	No
39	0.14	20-Apr-09	3.56	8.48	0.419	2.74	127.07	No
40	0.52	4-May-09	13.21	17.27	0.765	1.83	339.18	No
41	1.08	7-May-09	27.43	16.23	1.690	7.32	38.5	No
42	0.23	9-May-09	5.84	0.25	23.368	4.27	48.1	No
43	0.08	11-May-09	2.03	N/A	N/A	N/A	N/A	-
44	0.21	16-May-09	5.33	0.32	16.669	4.27	122.6	No
45	0.54	17-May-09	13.72	19.75	0.694	1.83	43.82	No
46	0.41	26-May-09	10.41	18.4	0.566	3.96	155.8	Yes
47	0.1	28-May-09	2.54	7.88	0.322	1.83	76.65	No
48	0.45	4-Jun-09	11.43	5.7	2.005	6.10	162.73	Yes
49	0.08	9-Jun-09	2.03	N/A	N/A	N/A	N/A	-
50	0.51	17-Jun-09	12.95	6.43	2.015	3.66	142.97	Yes
51	0.12	18-Jun-09	3.05	4.63	0.658	3.05	44.63	No
52	0.33	14-Jul-09	8.38	19.3	0.434	1.83	597.67	Yes
53	2.59	21-Jul-09	65.79	80.45	0.818	8.53	58.57	Yes
54	1.01	24-Jul-09	25.65	14.42	1.779	4.88	88.6	Yes
55	1.14	28-Jul-09	28.96	2.47	11.723	5.79	81.62	Yes
56	0.06	30-Jul-09	1.52	N/A	N/A	N/A	N/A	-
57	1.63	31-Jul-09	41.40	4.75	8.716	9.75	23.23	No
58	0.71	2-Aug-09	18.03	0.97	18.592	4.27	38.07	No
59	1.75	5-Aug-09	44.45	10.15	4.379	8.84	75.07	No
60	1.16	11-Aug-09	29.46	9.22	3.196	13.11	137.5	No
61	0.09	12-Aug-09	2.29	N/A	N/A	N/A	N/A	-
62	0.27	13-Aug-09	6.86	15.03	0.456	0.91	12.3	No
63	0.37	14-Aug-09	9.40	1.53	6.142	2.44	14.1	No
64	1.18	22-Aug-09	29.97	13.15	2.279	10.97	192.43	No
65	0.16	28-Aug-09	4.06	4.22	0.963	0.91	134.53	No
66	0.32	31-Aug-09	8.13	11.05	0.736	0.91	50.32	Yes
67	0.22	7-Sep-09	5.59	7.75	0.721	0.91	170.83	No
68	0.11	17-Sep-09	2.79	12.8	0.218	0.61	220.37	No
69	0.42	22-Sep-09	10.67	4.15	2.571	4.27	110.03	No
70	0.2	23-Sep-09	5.08	1.72	2.953	0.91	18.25	No
71	0.22	23-Sep-09	5.59	1.28	4.366	2.74	8.35	No
72	0.06	25-Sep-09	1.52	N/A	N/A	N/A	N/A	-
73	0.21	26-Sep-09	5.33	20.43	0.261	2.44	17.35	No
74	0.33	5-Oct-09	8.38	7.88	1.064	0.91	215.78	No

75	0.31	11-Oct-09	7.87	8.43	0.934	1.22	108.13	No
76	0.14	12-Oct-09	3.56	6.08	0.585	0.30	28.07	No
77	0.37	14-Oct-09	9.40	25.75	0.365	0.91	34.73	No
78	0.12	26-Oct-09	3.05	11.52	0.265	0.61	270.73	No
79	0.22	27-Oct-09	5.59	18.53	0.302	1.83	13.98	No
80	0.1	1-Nov-09	2.54	7.65	0.332	1.22	87.08	No
81	3.93	13-Nov-09	99.82	57.53	1.735	1.83	221.4	Yes
82	0.33	20-Nov-09	8.38	6.63	1.264	1.83	132.22	Yes
83	0.67	24-Nov-09	17.02	13.65	1.247	0.91	72.48	Yes
84	0.4	9-Apr-10	10.16	1.97	5.157	4.57	375.48	Yes
85	0.19	21-Apr-10	4.83	9.46	0.510	3.35	293.1	No
86	0.2	24-Apr-10	5.08	7.83	0.649	0.91	76.63	No
87	0.98	18-May-10	24.89	43.23	0.576	0.91	514.28	Yes
88	0.73	24-May-10	18.54	16	1.159	5.79	113.83	Yes

Table A.2. Rainfall data recorded during monitoring period at site B.

Storm No.	Rainfall (in)	Date	Rainfall (mm)	Storm Event Duration (hrs)	Average Rainfall Intensity (cm/hr)	Peak 5-min Intensity (cm/hr)	ADP (hrs)	Sampled?
1	3.92	6-Sep-08	99.57	ND	ND	ND	ND	Yes
2	2.1	17-Sep-08	53.34	ND	ND	ND	ND	Yes
3	1.66	29-Sep-08	42.16	2.28	18.49	3.35	100.28	Yes
4	0.13	1-Oct-08	3.30	12.52	0.26	1.83	20.52	No
5	0.06	9-Oct-08	1.52	N/A	N/A	N/A	N/A	-
6	1.22	18-Oct-08	30.99	15.17	2.04	2.13	188.72	Yes
7	0.35	24-Oct-08	8.89	13.43	0.66	0.61	152.33	No
8	0.89	6-Nov-08	22.61	48.32	0.47	0.61	228.82	Yes
9	0.18	8-Nov-08	4.57	2.72	1.68	1.22	73.98	No
10	0.24	13-Nov-08	6.10	3.55	1.72	0.91	117.22	No
11	2.39	17-Nov-08	60.71	42.9	1.42	6.40	14.88	Yes
12	0.3	24-Nov-08	7.62	7.62	1.00	0.91	218.55	No
13	0.96	2-Dec-08	24.38	10.07	2.42	1.22	99.75	Yes
14	0.89	12-Dec-08	22.61	8.72	2.59	3.35	241.2	Yes
15	0.41	20-Dec-08	10.41	9.23	1.13	0.61	200.43	No
16	0.19	21-Dec-08	4.83	2.17	2.22	3.96	7.53	No
17	0.07	26-Dec-08	1.78	N/A	N/A	N/A	N/A	-
18	0.15	29-Dec-08	3.81	5	0.76	1.83	58.83	No
19	0.13	4-Jan-09	3.30	1.8	1.83	0.91	144.15	No
20	0.57	6-Jan-09	14.48	7.65	1.89	1.22	40.08	No

21	0.09	7-Jan-09	2.29	N/A	N/A	N/A	N/A	-
22	0.36	11-Jan-09	9.14	7.38	1.24	0.91	79.73	No
23	0.39	18-Jan-09	9.91	6.3	1.57	0.61	171.43	No
24	0.05	20-Jan-09	1.27	N/A	N/A	N/A	N/A	-
25	0.12	21-Jan-09	3.05	3.77	0.81	0.30	29.52	No
26	0.28	29-Jan-09	7.11	18.52	0.38	1.22	158.93	Yes
27	0.1	2-Feb-09	2.54	4.67	0.54	0.30	120.52	No
28	0.1	4-Feb-09	2.54	2.95	0.86	0.30	29.17	No
29	0.88	19-Feb-09	22.35	31.5	0.71	3.66	329.68	Yes
30	0.09	22-Feb-09	2.29	N/A	N/A	N/A	N/A	-
31	2.81	5-Mar-09	83.31	48.82	1.71	1.52	137.23	Yes
32	0.3	13-Mar-09	7.62	11.85	0.64	0.61	267.48	No
33	0.73	14-Mar-09	33.53	32.82	1.02	1.22	18.62	Yes
34	0.31	16-Mar-09	7.87	17.53	0.45	0.61	12.03	No
35	0.31	19-Mar-09	7.87	4.37	1.80	0.61	64	No
36	0.07	26-Mar-09	1.52	N/A	N/A	N/A	N/A	-
37	0.55	27-Mar-09	13.97	11.32	1.23	3.96	20.3	No
38	0.65	28-Mar-09	16.51	6.55	2.52	2.74	15.05	No
39	0.1	2-Apr-09	2.54	14.13	0.18	0.30	107.32	No
40	0.7	6-Apr-09	17.78	0.82	21.68	4.88	84.03	No
41	0.08	11-Apr-09	2.03	N/A	N/A	N/A	N/A	-
42	0.73	14-Apr-09	18.54	26.37	0.70	4.27	81.38	No
43	0.17	20-Apr-09	4.32	5.08	0.85	4.88	126.8	No
44	0.2	4-May-09	5.08	2.15	2.36	1.22	342.62	No
45	0.46	5-May-09	11.68	11.73	1.00	3.35	9.07	No
46	1.11	7-May-09	28.19	2.77	10.18	8.23	32.77	No
47	0.47	7-May-09	11.94	15.67	0.76	3.66	7.35	No
48	0.13	9-May-09	3.30	7.33	0.45	3.05	38.73	No
49	0.1	11-May-09	2.54	3.38	0.75	0.91	28.12	No
50	0.08	16-May-09	2.03	N/A	N/A	N/A	N/A	-
51	0.54	17-May-09	13.72	19.65	0.70	2.44	19.6	No
52	0.37	4-Jun-09	9.40	10.57	0.89	4.57	408.58	No
53	0.07	9-Jun-09	1.78	N/A	N/A	N/A	N/A	-
54	0.55	17-Jun-09	13.97	16.2	0.86	3.05	16.2	Yes
55	0.49	14-Jul-09	12.45	8.28	1.50	2.13	646.78	Yes
56	2.45	21-Jul-09	62.23	92.2	0.67	9.45	57.63	Yes
57	1.48	24-Jul-09	37.59	11.93	3.15	9.75	88.9	Yes
58	1.44	28-Jul-09	36.58	2.65	13.80	6.10	83.93	Yes
59	1.3	31-Jul-09	33.02	4.55	7.26	8.53	93.92	No
60	0.91	2-Aug-09	23.11	0.92	25.12	8.84	38.3	No

61	1.43	5-Aug-09	36.32	10.07	3.61	8.53	75.17	No
62	1.1	11-Aug-09	27.94	9.22	3.03	7.62	137.47	No
63	0.13	12-Aug-09	3.30	2.78	1.19	0.61	14.73	No
64	0.23	13-Aug-09	5.84	10.22	0.57	0.91	12.2	No
65	0.3	14-Aug-09	7.62	5.15	1.48	3.35	15.1	No
66	1.19	22-Aug-09	30.23	18.22	1.66	12.19	192.53	No
67	0.29	23-Aug-09	7.37	0.93	7.92	2.44	10.45	No
68	0.21	28-Aug-09	5.33	4.4	1.21	1.52	117.98	No
69	0.37	31-Aug-09	10.41	12.08	0.86	1.22	50.33	Yes
70	0.28	7-Sep-09	7.11	9.18	0.77	1.22	169.5	No
71	0.18	17-Sep-09	4.57	4.12	1.11	0.91	221.35	No
72	0.28	22-Sep-09	7.11	4.28	1.66	1.52	117.48	No
73	0.19	23-Sep-09	4.83	1.6	3.02	0.61	18.1	No
74	0.73	23-Sep-09	18.54	1.23	15.07	14.33	8.45	No
75	0.05	25-Sep-09	1.27	N/A	N/A	N/A	N/A	-
76	0.26	26-Sep-09	6.60	18.9	0.35	2.13	10.77	No
77	0.31	5-Oct-09	7.87	26.12	0.30	0.61	198.92	No
78	0.36	11-Oct-09	9.14	4.65	1.97	1.83	113.9	No
79	0.14	12-Oct-09	3.56	5.75	0.62	0.30	31.55	No
80	0.35	14-Oct-09	8.89	28.77	0.31	0.61	35.53	No
81	0.09	26-Oct-09	2.29	N/A	N/A	N/A	N/A	-
82	0.21	27-Oct-09	5.33	20.12	0.27	1.22	14.53	No
83	0.12	1-Nov-09	3.05	7.85	0.39	1.22	84.15	No
84	3.49	13-Nov-09	88.65	57.58	1.54	1.83	221.2	Yes
85	0.39	20-Nov-09	9.91	6.45	1.54	2.74	132.63	Yes
86	0.56	24-Nov-09	14.22	19.68	0.72	0.91	72.51	Yes
87	0.35	9-Apr-10	9.14	2.3	3.98	3.96	252.23	Yes
88	0.05	21-Apr-10	1.27	N/A	N/A	N/A	N/A	-
89	0.22	24-Apr-10	5.59	7.7	0.73	0.61	75.43	No
90	1.22	18-May-10	30.99	43.95	0.71	2.44	514.38	Yes
91	0.96	24-May-10	24.38	22.82	1.07	6.71	113.3	Yes

Table A.3. Rainfall data recorded during monitoring period at site C.

Storm No.	Rainfall (in)	Date	Rainfall (mm)	Storm Event Duration (hrs)	Average Rainfall Intensity (cm/hr)	Peak 5-min Intensity (cm/hr)	ADP (hrs)	Sampled?
1	3.70	6-Sep-08	93.98	22.47	4.18	6.40	ND	Yes
2	0.75	7-Sep-08	19.05	0.82	23.23	4.88	32.63	No
3	2.41	8-Sep-08	61.21	1.03	59.43	17.98	22.08	No

4	0.43	9-Sep-08	10.92	29.88	0.37	7.01	19.92	No
5	0.76	16-Sep-08	19.30	25	0.77	2.44	124.25	Yes
6	2.34	29-Sep-08	59.44	0.83	71.61	4.88	193.93	Yes
7	0.17	9-Oct-08	4.32	0.5	8.64	1.52	325.9	No
8	0.09	10-Oct-08	2.29	N/A	N/A	N/A	N/A	-
9	1.06	18-Oct-08	26.92	29.07	0.93	1.22	154.22	Yes
10	0.38	24-Oct-08	9.65	19.25	0.50	0.61	138.13	No
11	0.58	4-Nov-08	14.73	25.55	0.58	0.91	221.75	Yes
12	0.05	8-Nov-08	1.27	N/A	N/A	N/A	N/A	-
13	0.25	13-Nov-08	6.35	13.05	0.49	0.91	114.98	No
14	2.25	17-Nov-08	57.15	39.08	1.46	8.84	10.67	Yes
15	0.08	25-Nov-08	2.03	N/A	N/A	N/A	N/A	-
16	0.99	2-Dec-08	25.15	36.58	0.69	0.91	101.35	Yes
17	0.76	12-Dec-08	19.30	28.67	0.67	2.13	245.05	Yes
18	0.22	20-Dec-08	5.59	9.58	0.58	0.61	202.23	No
19	0.17	21-Dec-08	4.32	0.6	7.20	2.13	6.47	No
20	0.05	26-Dec-08	1.27	N/A	N/A	N/A	N/A	-
21	0.05	4-Jan-09	1.27	N/A	N/A	N/A	N/A	-
22	0.47	6-Jan-09	11.94	8.17	1.46	1.52	41.07	No
23	0.08	7-Jan-09	2.03	N/A	N/A	N/A	N/A	-
24	0.23	11-Jan-09	5.84	7.77	0.75	0.61	86.57	No
25	0.15	13-Jan-09	3.81	3.67	1.04	0.61	52.11	No
26	0.34	18-Jan-09	8.64	6.4	1.35	0.61	115.55	No
27	0.08	20-Jan-09	2.03	N/A	N/A	N/A	N/A	-
28	0.05	21-Jan-09	1.27	N/A	N/A	N/A	N/A	-
29	0.28	29-Jan-09	7.11	7	1.02	1.52	172.13	Yes
30	0.06	2-Feb-09	1.52	N/A	N/A	N/A	N/A	-
31	0.85	19-Feb-09	21.59	22.55	0.96	3.35	364.52	Yes
32	2.73	5-Mar-09	69.34	44.78	1.55	3.05	216.2	Yes
33	0.07	13-Mar-09	1.78	N/A	N/A	N/A	N/A	-
34	0.23	16-Mar-09	5.84	19.53	0.30	0.61	35.3	Yes
35	0.39	16-Mar-09	9.91	13.8	0.72	1.22	8.27	No
36	0.1	20-Mar-09	2.54	2.5	1.02	0.30	69.9	No
37	0.06	26-Mar-09	1.52	N/A	N/A	N/A	N/A	-
38	0.56	27-Mar-09	14.22	14.13	1.01	2.74	18.5	No
39	0.86	28-Mar-09	21.84	7.4	2.95	10.06	13.82	No
40	0.26	2-Apr-09	6.60	13.15	0.50	2.44	80.62	No
41	0.15	6-Apr-09	3.81	0.48	7.94	1.52	86.1	No
42	0.14	10-Apr-09	3.56	5.05	0.70	1.52	108.57	No
43	0.86	14-Apr-09	21.84	15.8	1.38	4.57	78.45	No

44	0.06	20-Apr-09	1.52	N/A	N/A	N/A	N/A	-
45	0.14	21-Apr-09	3.56	19.42	0.18	2.44	11.12	No
46	0.36	4-May-09	9.14	2.77	3.30	3.96	306.88	No
47	0.7	5-May-09	17.78	6.17	2.88	1.83	8.78	No
48	0.44	7-May-09	11.18	3.9	2.87	1.52	38.05	No
49	0.13	7-May-09	3.30	3.15	1.05	2.74	14.82	No
50	0.15	11-May-09	3.81	3.73	1.02	1.83	78.33	No
51	0.51	17-May-09	12.95	20.58	0.63	2.74	144.4	No
52	0.22	29-May-09	5.59	3.73	1.50	3.35	277.27	No
53	0.16	4-Jun-09	4.06	1.67	2.43	3.35	139.53	No
54	0.22	10-Jun-09	5.59	10.93	0.51	1.52	115.45	Yes
55	0.71	11-Jun-09	18.03	0.53	34.03	9.75	40.45	No
56	0.83	15-Jun-09	21.08	21.23	0.99	4.88	92.5	Yes
57	0.13	18-Jun-09	3.30	0.85	3.88	0.91	40.32	No
58	0.06	1-Jul-09	1.52	N/A	N/A	N/A	N/A	-
59	0.13	5-Jul-09	3.30	1.97	1.68	3.35	80.65	No
60	0.2	6-Jul-09	5.08	1.18	4.31	2.74	8.78	No
61	0.9	14-Jul-09	22.86	7.45	3.07	2.74	174.03	Yes
62	0.06	16-Jul-09	1.52	N/A	N/A	N/A	N/A	-
63	1	21-Jul-09	25.40	50.63	0.50	6.10	27.38	Yes
64	1.12	24-Jul-09	28.45	13.73	2.07	7.32	88.67	Yes
65	1.67	28-Jul-09	42.42	9.03	4.70	7.62	81.53	Yes
66	0.28	31-Jul-09	7.11	9.42	0.75	2.13	90.13	No
67	0.12	1-Aug-09	3.05	1.58	1.93	2.13	12.25	No
68	1.91	2-Aug-09	48.51	9.45	5.13	10.97	19.87	No
69	0.64	4-Aug-09	16.26	0.47	34.59	8.23	41.45	No
70	0.23	5-Aug-09	5.84	6.35	0.92	3.05	24.8	No
71	1.76	11-Aug-09	44.70	8.75	5.11	8.84	139.45	No
72	0.19	13-Aug-09	4.83	22.07	0.22	0.61	25.53	No
73	4.59	14-Aug-09	116.59	2.6	44.84	14.63	6.75	No
74	1.20	22-Aug-09	30.48	13.72	2.22	8.23	193.02	No
75	0.53	23-Aug-09	13.46	8.73	1.54	6.10	13.48	No
76	0.05	28-Aug-09	1.27	N/A	N/A	N/A	N/A	-
77	1.09	31-Aug-09	27.69	11.02	2.51	5.18	23.07	Yes
78	0.05	7-Sep-09	1.27	N/A	N/A	N/A	N/A	-
79	0.71	22-Sep-09	18.03	13.75	1.31	3.35	345.43	No
80	0.11	23-Sep-09	2.79	1.58	1.77	0.91	10.8	No
81	0.42	25-Sep-09	10.67	0.28	38.10	10.36	58.35	No
82	0.63	26-Sep-09	16.00	5.88	2.72	3.35	26.2	No
83	0.31	5-Oct-09	7.87	24.22	0.33	0.91	197.42	No

84	0.05	10-Oct-09	1.27	N/A	N/A	N/A	N/A	-
85	0.07	11-Oct-09	1.78	N/A	N/A	N/A	N/A	-
86	0.06	12-Oct-09	1.52	N/A	N/A	N/A	N/A	-
87	0.45	14-Oct-09	11.43	23.57	0.48	1.22	38.17	No
88	0.21	26-Oct-09	5.33	15.95	0.33	0.61	268.05	No
89	0.05	31-Oct-09	1.27	N/A	N/A	N/A	N/A	-
90	3.79	13-Nov-09	96.27	61.97	1.55	1.52	237.37	Yes
91	0.47	20-Nov-09	11.94	16.43	0.73	1.52	128.63	Yes
92	0.47	24-Nov-09	11.94	18.38	0.65	0.91	82.3	Yes
93	0.07	9-Apr-10	1.78	N/A	N/A	N/A	N/A	-
94	0.36	21-Apr-10	9.14	22.72	0.40	2.44	289.77	No
95	0.11	24-Apr-10	2.79	7.53	0.37	0.30	68.3	No
96	0.13	4-May-10	3.30	2.92	1.13	0.91	215.35	No
97	2.54	18-May-10	64.52	38.43	1.68	12.80	296	No
98	0.22	19-May-10	5.59	0.67	8.34	2.74	22.23	No
99	0.49	24-May-10	12.70	26.58	0.48	2.44	100.73	Yes

Table A.4. Rainfall data recorded during monitoring period at site D.

Storm No.	Rainfall (in)	Date	Rainfall (mm)	Storm Event Duration (hrs)	Average Rainfall Intensity (cm/hr)	Peak 5-min Intensity (cm/hr)	ADP (hrs)	Sampled?
1	3.70	6-Sep-08	93.98	22.47	4.18	5.79	-	Yes
2	1.76	7-Sep-08	44.70	0.82	54.52	5.49	32.63	No
3	2.42	8-Sep-08	61.47	1.03	59.68	16.46	22.08	No
4	0.36	9-Sep-08	9.14	9.73	0.94	6.71	19.92	No
5	0.76	17-Sep-08	19.30	25	0.77	2.74	144.4	Yes
6	2.34	29-Sep-08	59.44	24.83	2.39	4.88	193.93	Yes
7	0.17	9-Oct-08	4.32	0.5	8.64	1.22	325.9	No
8	0.08	10-Oct-08	2.03	N/A	N/A	N/A	N/A	-
9	0.94	18-Oct-08	23.88	29.07	0.82	1.22	154.22	Yes
10	0.24	24-Oct-08	6.10	11.73	0.52	0.61	138.2	No
11	0.50	6-Nov-08	12.70	30	0.42	0.61	224.58	Yes
12	0.26	13-Nov-08	6.60	15.47	0.43	1.22	203.55	No
13	2.47	17-Nov-08	62.74	37.73	1.66	4.88	10.56	Yes
14	1.01	2-Dec-08	25.65	36.48	0.70	0.91	323.52	Yes
15	1.38	12-Dec-08	35.05	51.7	0.68	3.35	219.7	Yes
16	0.07	15-Dec-08	1.78	N/A	N/A	N/A	N/A	-
17	0.24	20-Dec-08	6.10	10.42	0.59	0.61	121.95	No
18	0.11	21-Dec-08	2.79	1.22	2.29	2.13	8.87	No

19	0.05	25-Dec-08	1.27	N/A	N/A	N/A	N/A	-
20	0.09	29-Dec-08	2.29	N/A	N/A	N/A	N/A	-
21	0.14	4-Jan-09	3.56	0.72	4.94	1.83	0.72	No
22	0.64	6-Jan-09	16.26	11.93	1.36	2.13	9.93	No
23	0.12	7-Jan-09	3.05	4.63	0.66	2.74	16.97	No
24	0.26	11-Jan-09	6.60	7.63	0.87	1.22	87.3	No
25	0.27	13-Jan-09	6.86	7.78	0.88	0.61	47.77	No
26	0.39	18-Jan-09	9.91	6.02	1.65	0.61	6.02	No
27	0.06	20-Jan-09	1.52	N/A	N/A	N/A	N/A	-
28	0.10	21-Jan-09	2.54	4.8	0.53	0.30	4.58	No
29	0.32	29-Jan-09	8.13	4.52	1.80	0.61	170.65	Yes
30	0.08	2-Feb-09	2.03	N/A	N/A	N/A	N/A	-
31	0.95	19-Feb-09	24.13	17.58	1.37	5.49	355.72	Yes
32	2.65	5-Mar-09	67.31	45.65	1.47	1.83	221.05	Yes
33	0.56	16-Mar-09	14.22	21.07	0.68	1.83	316	Yes
34	0.32	16-Mar-09	8.13	14.55	0.56	0.61	7.76	No
35	0.07	20-Mar-09	1.78	N/A	N/A	N/A	N/A	-
36	0.13	26-May-09	3.30	13	0.25	0.61	145.43	No
37	0.61	27-Mar-09	15.49	13.73	1.13	3.66	17.97	No
38	0.47	28-Mar-09	11.94	7.52	1.59	3.05	14.65	No
39	0.18	2-Apr-09	4.57	12.25	0.37	0.61	104.03	No
40	0.18	6-Apr-09	4.57	0.6	7.62	5.18	87.72	No
41	0.24	11-Apr-09	6.10	2.58	2.36	3.96	108.68	No
42	0.63	14-Apr-09	16.00	16.42	0.97	2.74	79.87	No
43	0.06	20-Apr-09	1.52	N/A	N/A	N/A	N/A	-
44	0.14	21-Apr-09	3.56	19.42	0.18	2.44	11.12	No
45	0.36	4-May-09	9.14	2.77	3.30	3.96	306.88	No
46	0.7	5-May-09	17.78	6.17	2.88	1.83	8.78	No
47	0.44	7-May-09	11.18	3.9	2.87	1.52	38.05	No
48	0.13	7-May-09	3.30	3.15	1.05	2.74	14.82	No
49	0.15	11-May-09	3.81	3.73	1.02	1.83	78.33	No
50	0.51	17-May-09	12.95	20.58	0.63	2.74	144.4	No
51	0.12	28-May-09	3.05	8.4	0.36	1.52	1045.62	No
52	0.35	29-May-09	8.89	0.37	24.03	5.79	17.72	No
53	0.85	1-Jun-09	21.59	0.95	22.73	6.71	70.13	No
54	0.08	4-Jun-09	2.03	N/A	N/A	N/A	N/A	-
55	0.28	5-Jun-09	7.11	3.63	1.96	1.52	16.18	No
56	0.67	10-Jun-09	17.02	7.48	2.28	5.79	92.47	Yes
57	0.10	11-Jun-09	2.54	0.47	5.40	2.44	41.53	No
58	0.71	15-Jun-09	18.03	3.42	5.27	3.35	91.18	No

59	0.61	16-Jun-09	15.49	8.18	1.89	3.96	11.2	Yes
60	0.13	1-Jul-09	3.30	0.15	22.01	3.35	365.3	No
61	0.24	6-Jul-09	6.10	2.15	2.84	2.44	99.18	No
62	0.05	9-Jul-09	1.27	N/A	N/A	N/A	N/A	-
63	0.39	14-Jul-09	9.91	8.07	1.23	5.79	88.4	Yes
64	2.12	21-Jul-09	53.85	5.3	10.16	10.36	98.8	Yes
65	1.47	24-Jul-09	37.34	15.03	2.48	10.97	132.9	Yes
66	1.01	28-Jul-09	25.65	5.32	4.82	6.71	81.77	Yes
67	0.08	29-Jul-09	2.03	N/A	N/A	N/A	N/A	-
68	0.28	31-Jul-09	7.11	3.15	2.26	3.96	46.85	No
69	0.94	2-Aug-09	23.88	6.57	3.63	3.96	39.95	No
70	0.12	4-Aug-09	3.05	0.1	30.48	3.35	44.83	No
71	0.43	5-Aug-09	10.92	0.65	16.80	5.49	24.6	No
72	2.72	11-Aug-09	69.09	2.15	32.13	11.28	145.57	No
73	1.39	13-Aug-09	35.31	17.85	1.98	7.62	31.08	No
74	1.44	22-Aug-09	36.58	13.63	2.68	8.53	207.75	No
75	0.99	31-Aug-09	25.15	42.93	0.59	4.57	157.33	Yes
76	0.05	7-Sep-09	1.27	N/A	N/A	N/A	N/A	-
77	0.28	22-Sep-09	7.11	9.2	0.77	1.83	114.08	No
78	0.05	23-Sep-09	1.27	-	-	-	-	-
79	0.14	25-Sep-09	3.56	0.27	13.17	2.44	45.78	No
80	0.24	26-Sep-09	6.10	5.47	1.11	1.22	5.47	No
81	0.24	5-Oct-09	6.10	20.68	0.29	0.30	197.95	No
82	0.07	10-Oct-09	1.78	N/A	N/A	N/A	N/A	-
83	0.07	12-Oct-09	1.78	N/A	N/A	N/A	N/A	-
84	43.70	13-Nov-09	111.00	ND	ND	ND	ND	Yes
85	5.70	20-Nov-09	14.48	ND	ND	ND	ND	Yes
86	6.20	24-Nov-09	15.75	ND	ND	ND	ND	Yes
87	0.50	9-Apr-10	12.70	4.88	2.60	8.84	-	Yes
88	0.21	21-Apr-10	5.33	5.4	0.99	1.22	290.33	No
89	0.10	24-Apr-10	2.54	7.62	0.33	0.61	81.75	No
90	0.14	4-May-10	3.56	1.47	2.42	2.44	216.85	No
91	2.91	18-May-10	73.91	45.53	1.62	10.36	295.43	Yes
92	0.21	19-May-10	5.33	0.93	5.74	3.35	15.72	No
93	1.90	24-May-10	48.26	3.1	15.57	6.10	100.65	Yes

Appendix B: Flow Volume Data.

Table B.1. Flow volume data at Site A.

Flow Volume (cf)

Storm Date	Event Number	Rainfall (in)	NVA IN	NVA FS	NVA OUT	Sampled?
6-Sep-08	1	3.92	48.5	245	15299	Yes
17-Sep-08	2	1.35	100	19	ND	Yes
29-Sep-08	3	1.43	223.5	24	3783	Yes
1-Oct-08	4	0.16	2.6	0	92	No
17-Oct-08	5	1.02	107	0	1781	No
24-Oct-08	6	0.3	21	0	256	No
3-Nov-08	7	0.79	79.4	0	1463	Yes
8-Nov-08	8	0.21	11.6	0	257	No
14-Nov-08	9	3.27	322.9	62	10804	Yes
24-Nov-08	10	0.34	ND	0	HWT	No
30-Nov-08	11	0.85	ND	2	HWT	Yes
12-Dec-08	12	1.02	ND	8	HWT	Yes
15-Dec-08	13	0.06	ND	0	HWT	-
20-Dec-08	14	0.5	64.6	0.4	HWT	No
26-Dec-08	15	0.07	NF	0	HWT	-
29-Dec-08	16	0.15	7.9	0.1	HWT	No
4-Jan-09	17	0.16	6.2	0	HWT	No
6-Jan-09	18	0.51	58.1	0.8	HWT	No
7-Jan-09	19	0.09	2.2	0	HWT	-
11-Jan-09	20	0.39	33.8	0.8	HWT	No
18-Jan-09	21	0.37	20.9	0	HWT	No
20-Jan-09	22	0.05	11.4	0	HWT	-
21-Jan-09	23	0.11	2.1	0	HWT	No
28-Jan-09	24	0.34	25.8	1.5	HWT	Yes
2-Feb-09	25	0.05	0	0	HWT	-
4-Feb-09	26	0.1	3.6	0	HWT	No
18-Feb-09	27	0.91	101.2	2.1	HWT	Yes
22-Feb-09	28	0.08	0	0	HWT	No
28-Feb-09	29	3.24	339.3	13	HWT	Yes
13-Mar-09	30	1.23	ND	0	HWT	Yes
16-Mar-09	31	0.25	ND	1.6	HWT	No
19-Mar-09	32	0.33	ND	0.3	HWT	No
26-Mar-09	33	0.08	ND	0	HWT	-
27-Mar-09	34	0.5	ND	4.4	HWT	No
28-Mar-09	35	0.67	ND	10.3	HWT	No
2-Apr-09	36	0.12	ND	0	0	No
6-Apr-09	37	0.34	ND	1.1	982.5	No
14-Apr-09	38	2.37	ND	212	6680.7	No

20-Apr-09	39	0.14	ND	0	177.6	No
4-May-09	40	0.52	ND	0	333.4	No
7-May-09	41	1.08	ND	33	3986.1	No
9-May-09	42	0.23	ND	2.6	656	No
11-May-09	43	0.08	ND	0	0	-
16-May-09	44	0.21	ND	0	203.7	No
17-May-09	45	0.54	ND	2.6	2386.8	No
26-May-09	46	0.41	21.2	ND	ND	Yes
28-May-09	47	0.1	0	0	ND	No
4-Jun-09	48	0.45	ND	ND	ND	Yes
9-Jun-09	49	0.08	ND	ND	ND	-
16-Jun-09	50	0.51	43.6	2.8	147.7	Yes
18-Jun-09	51	0.12	7.7	0	ND	No
13-Jul-09	52	0.33	21.5	0	ND	Yes
21-Jul-09	53	2.59	50.4	12.8	686.1	Yes
24-Jul-09	54	1.01	99.6	17.6	1903.4	Yes
28-Jul-09	55	1.14	118.6	40.5	3950.6	Yes
30-Jul-09	56	0.06	1.9	0	0	-
31-Jul-09	57	1.63	163.6	113.9	4581	No
2-Aug-09	58	0.71	72.1	24.1	ND	No
5-Aug-09	59	1.75	194	112.5	7158	No
11-Aug-09	60	1.16	109.5	68.2	ND	No
12-Aug-09	61	0.09	0	0	ND	-
13-Aug-09	62	0.27	16.9	0.9	ND	No
14-Aug-09	63	0.37	37.2	4.8	ND	No
22-Aug-09	64	1.18	143.1	46.2	ND	No
28-Aug-09	65	0.16	0	0	0	No
30-Aug-09	66	0.32	7.2	0	ND	Yes
7-Sep-09	67	0.22	2	0	65	No
17-Sep-09	68	0.11	ND	0	0	No
22-Sep-09	69	0.42	22.5	6.5	395	No
23-Sep-09	70	0.2	7.6	1.2	248.2	No
23-Sep-09	71	0.22	14.4	1.8	715.1	No
25-Sep-09	72	0.06	0.4	0	0	-
26-Sep-09	73	0.21	6.6	0	0	No
5-Oct-09	74	0.33	2.5	0	0	No
11-Oct-09	75	0.31	23	0	6	No
12-Oct-09	76	0.14	1.3	0	7.2	No
14-Oct-09	77	0.37	8.4	0	ND	No
26-Oct-09	78	0.12	0	0	ND	No

27-Oct-09	79	0.22	10.6	0	ND	No
1-Nov-09	80	0.1	3.5	0	ND	No
10-Nov-09	81	3.93	506.3	65.4	7468.5	Yes
19-Nov-09	82	0.33	30.9	ND	HWT	Yes
24-Nov-09	83	0.67	ND	ND	HWT	Yes
9-Apr-10	84	0.4	30.4	8.2	1024.8	Yes
21-Apr-10	85	0.19	4.3	0	0	No
24-Apr-10	86	0.2	7.2	0	90.2	No
16-May-10	87	0.98	281.4	20.5	2171.8	Yes
24-May-10	88	0.73	ND	ND	1337.1	Yes

Table B.2. Flow volume data at Site B.

Flow Volume (cf)					
Storm Date	**Event Number**	**Rainfall (in)**	**VA IN**	**VA OUT**	**Sampled?**
6-Sep-08	1	3.92	649.4	792	Yes
17-Sep-08	2	2.1	13.5	ND	Yes
25-Sep-08	3	1.66	185.3	ND	Yes
1-Oct-08	4	0.13	3.8	50.1	No
9-Oct-08	5	0.06	0	0	-
18-Oct-08	6	1.22	137.4	3353.9	No
24-Oct-08	7	0.35	13.3	183.5	No
3-Nov-08	8	0.89	70.9	1783.3	Yes
8-Nov-08	9	0.18	5.1	144.4	No
13-Nov-08	10	0.24	6.8	375	No
14-Nov-08	11	2.39	261.1	13556	Yes
24-Nov-08	12	0.3	10	HWT	No
30-Nov-08	13	0.96	84.8	HWT	Yes
11-Dec-08	14	0.89	142.1	HWT	Yes
20-Dec-08	15	0.41	21.6	HWT	No
21-Dec-08	16	0.19	20.3	HWT	No
26-Dec-08	17	0.07	0.6	HWT	-
29-Dec-08	18	0.15	3.9	HWT	No
4-Jan-09	19	0.13	4.2	HWT	No
6-Jan-09	20	0.57	45.6	HWT	No
7-Jan-09	21	0.09	3.6	HWT	-
11-Jan-09	22	0.36	18.2	HWT	No
18-Jan-09	23	0.39	30.3	HWT	No
20-Jan-09	24	0.05	0	HWT	-

21-Jan-09	25	0.12	0	HWT	No
29-Jan-09	26	0.28	13.9	HWT	Yes
2-Feb-09	27	0.1	0.5	HWT	No
4-Feb-09	28	0.1	1	HWT	No
19-Feb-09	29	0.88	89.9	HWT	Yes
22-Feb-09	30	0.09	0.6	HWT	-
28-Feb-09	31	3.28	328.6	HWT	Yes
13-Mar-09	32	0.3	6.1	HWT	No
14-Mar-09	33	1.32	67	HWT	Yes
16-Mar-09	34	0.31	23	HWT	No
19-Mar-09	35	0.31	22.4	HWT	No
26-Mar-09	36	0.06	0	HWT	-
27-Mar-09	37	0.55	47.1	HWT	No
28-Mar-09	38	0.65	70.2	HWT	No
2-Apr-09	39	0.1	1.3	HWT	No
6-Apr-09	40	0.7	74.7	HWT	No
11-Apr-09	41	0.08	2.2	HWT	-
14-Apr-09	42	0.73	77.9	HWT	No
20-Apr-09	43	0.17	11.2	HWT	No
4-May-09	44	0.2	4.1	HWT	No
5-May-09	45	0.46	47.1	HWT	No
7-May-09	46	1.11	132.6	HWT	No
7-May-09	47	0.47	41.4	HWT	No
9-May-09	48	0.13	9	0	No
11-May-09	49	0.1	1.8	0	No
16-May-09	50	0.08	2.3	0	-
17-May-09	51	0.54	38.5	ND	No
4-Jun-09	52	0.37	ND	ND	No
9-Jun-09	53	0.07	ND	ND	-
16-Jun-09	54	0.55	30.3	ND	Yes
13-Jul-09	55	0.49	17.2	866.5	Yes
20-Jul-09	56	2.45	84.6	2652.7	Yes
23-Jul-09	57	1.48	180.1	2068.4	Yes
27-Jul-09	58	1.44	176.9	0	Yes
31-Jul-09	59	1.3	161.1	3085.2	No
2-Aug-09	60	0.91	105.4	2750.9	No
5-Aug-09	61	1.43	170.9	4094.4	No
11-Aug-09	62	1.1	128.3	2788	No
12-Aug-09	63	0.13	0	0	No
13-Aug-09	64	0.23	7.6	366.1	No

14-Aug-09	65	0.3	20.2	736.3	No
22-Aug-09	66	1.19	125	3199.6	No
23-Aug-09	67	0.29	15	41.4	No
28-Aug-09	68	0.21	2.4	299.4	No
31-Aug-09	69	0.41	13.4	44.6	Yes
7-Sep-09	70	0.28	6.9	0.6	No
17-Sep-09	71	0.18	1.1	2438.2	No
22-Sep-09	72	0.28	10.7	ND	No
23-Sep-09	73	0.19	7.4	ND	No
23-Sep-09	74	0.73	85.1	0	No
25-Sep-09	75	0.05	1.6	247.6	-
26-Sep-09	76	0.26	10.3	1.7	No
5-Oct-09	77	0.31	1.3	130.1	No
11-Oct-09	78	0.36	16.9	HWT	No
12-Oct-09	79	0.14	1	HWT	No
14-Oct-09	80	0.35	14.5	HWT	No
26-Oct-09	81	0.09	4.6	HWT	-
27-Oct-09	82	0.21	14.5	HWT	No
1-Nov-09	83	0.12	8	HWT	No
11-Nov-09	84	3.49	1133.3	HWT	Yes
20-Nov-09	85	0.39	ND	HWT	Yes
24-Nov-09	86	0.56	ND	725.4	Yes
9-Apr-10	87	0.36	18.8	0	Yes
21-Apr-10	88	0.05	ND	0	-
24-Apr-10	89	0.22	ND	ND	No
16-May-10	90	1.22	109.2	874.9	Yes
23-May-10	91	0.96	51.9	HWT	Yes

Table B.3. Flow volume data at Site C.

Flow Volume (cf)					
Storm Date	**Event Number**	**Rainfall (in)**	**VB IN**	**VB OUT**	**Sampled?**
6-Sep-08	1	3.7	594.4	HWT	Yes
7-Sep-08	2	0.75	ND	HWT	No
8-Sep-08	3	2.41	ND	HWT	No
9-Sep-08	4	0.43	5.6	HWT	No
16-Sep-08	5	0.76	22.8	HWT	Yes
25-Sep-08	6	2.34	567.9	HWT	Yes
9-Oct-08	7	0.17	0	HWT	No
10-Oct-08	8	0.09	0	HWT	-

23-Oct-08	9	1.06	50.3	HWT	No
24-Oct-08	10	0.38	7.9	HWT	No
4-Nov-08	11	0.58	21.6	HWT	Yes
8-Nov-08	12	0.05	0	HWT	-
13-Nov-08	13	0.25	0.6	HWT	No
14-Nov-08	14	2.25	273.9	HWT	Yes
25-Nov-08	15	0.08	0	HWT	-
30-Nov-08	16	0.99	59.6	HWT	Yes
11-Dec-08	17	0.76	55.7	HWT	Yes
20-Dec-08	18	0.22	0.7	HWT	No
21-Dec-08	19	0.17	14.4	HWT	No
26-Dec-08	20	0.05	0	HWT	-
4-Jan-09	21	0.05	0	HWT	-
6-Jan-09	22	0.47	38.5	HWT	No
7-Jan-09	23	0.08	1	HWT	-
11-Jan-09	24	0.23	5	HWT	No
13-Jan-09	25	0.15	0	HWT	No
18-Jan-09	26	0.34	13.9	HWT	No
20-Jan-09	27	0.08	0.4	HWT	-
21-Jan-09	28	0.05	0.6	HWT	-
28-Jan-09	29	0.28	9.1	HWT	Yes
2-Feb-09	30	0.06	0	HWT	-
18-Feb-09	31	0.85	70.5	HWT	Yes
28-Feb-09	32	2.73	23.8	HWT	Yes
13-Mar-09	33	0.07	0	HWT	-
16-Mar-09	34	0.23	0.6	HWT	Yes
16-Mar-09	35	0.39	25.6	HWT	No
20-Mar-09	36	0.1	0.4	HWT	No
26-Mar-09	37	0.06	0	HWT	-
27-Mar-09	38	0.56	40.7	HWT	No
28-Mar-09	39	0.86	116.5	HWT	No
2-Apr-09	40	0.26	2.8	HWT	No
6-Apr-09	41	0.15	2.2	HWT	No
10-Apr-09	42	0.14	0.9	HWT	No
14-Apr-09	43	0.86	104	HWT	No
20-Apr-09	44	0.06	0	HWT	-
21-Apr-09	45	0.14	3.1	HWT	No
4-May-09	46	0.36	14.5	HWT	No
5-May-09	47	0.7	78.6	HWT	No
7-May-09	48	0.44	42.4	HWT	No

7-May-09	49	0.13	2.5	HWT	No
11-May-09	50	0.15	3.8	HWT	No
17-May-09	51	0.51	33.6	HWT	No
29-May-09	52	0.22	ND	HWT	No
4-Jun-09	53	0.16	ND	HWT	No
10-Jun-09	54	0.22	ND	HWT	Yes
11-Jun-09	55	0.71	60.3	HWT	No
15-Jun-09	56	0.83	37.1	HWT	Yes
18-Jun-09	57	0.13	0.1	HWT	No
1-Jul-09	58	0.06	0	HWT	-
5-Jul-09	59	0.13	0.2	HWT	No
6-Jul-09	60	0.2	4.6	HWT	No
13-Jul-09	61	0.9	65.8	HWT	Yes
16-Jul-09	62	0.06	0	HWT	-
21-Jul-09	63	1	74.9	HWT	Yes
23-Jul-09	64	1.12	111	HWT	Yes
27-Jul-09	65	1.67	159.7	HWT	Yes
31-Jul-09	66	0.28	8.2	HWT	No
1-Aug-09	67	0.12	0.7	HWT	No
2-Aug-09	68	1.91	216.9	HWT	No
4-Aug-09	69	0.64	55.6	HWT	No
5-Aug-09	70	0.23	7.2	HWT	No
11-Aug-09	71	1.76	183.4	HWT	No
13-Aug-09	72	0.19	0	HWT	No
14-Aug-09	73	4.59	1133	HWT	No
22-Aug-09	74	1.2	93.5	HWT	No
23-Aug-09	75	0.53	43.3	HWT	No
28-Aug-09	76	0.05	0	HWT	-
31-Aug-09	77	1.09	79.1	HWT	Yes
7-Sep-09	78	0.05	0	HWT	-
22-Sep-09	79	0.71	68.5	HWT	No
23-Sep-09	80	0.11	0.8	HWT	No
25-Sep-09	81	0.42	33.2	HWT	No
26-Sep-09	82	0.63	57.4	HWT	No
5-Oct-09	83	0.31	ND	HWT	No
10-Oct-09	84	0.05	0	HWT	-
11-Oct-09	85	0.07	0	HWT	-
12-Oct-09	86	0.06	0	HWT	-
14-Oct-09	87	0.45	ND	HWT	No
26-Oct-09	88	0.21	57.6	HWT	No

31-Oct-09	89	0.05	0	HWT	-
11-Nov-09	90	3.79	1131	HWT	Yes
20-Nov-09	91	0.47	ND	HWT	Yes
24-Nov-09	92	0.47	ND	HWT	Yes
9-Apr-10	93	0.07	ND	HWT	-
21-Apr-10	94	0.36	1.6	HWT	No
24-Apr-10	95	0.11	0.1	HWT	No
4-May-10	96	0.13	0.3	HWT	No
18-May-10	97	2.54	246.3	HWT	No
19-May-10	98	0.22	16.7	HWT	No
24-May-10	99	0.5	9.8	HWT	Yes

Table B.4. Flow volume data for Site D.

Flow Volume (cf)						
Storm Date	Event Number	Rainfall (in)	NVB IN	NVB FS	NVB OUT	Sampled?
6-Sep-08	1	3.7	ND	ND	HWT	Yes
7-Sep-08	2	1.76	ND	ND	HWT	No
8-Sep-08	3	2.42	ND	ND	HWT	No
9-Sep-08	4	0.36	ND	ND	HWT	No
17-Sep-08	5	0.76	ND	ND	HWT	Yes
25-Sep-08	6	2.34	342	ND	HWT	Yes
9-Oct-08	7	0.17	18.6	ND	HWT	No
10-Oct-08	8	0.08	6.7	ND	HWT	-
17-Oct-08	9	0.94	110.4	152.1	HWT	No
24-Oct-08	10	0.24	10.6	ND	HWT	No
3-Nov-08	11	0.5	28.1	11.6	HWT	Yes
13-Nov-08	12	0.26	6.2	0.7	HWT	No
14-Nov-08	13	2.47	335.3	ND	HWT	Yes
2-Dec-08	14	1.01	ND	10.5	HWT	Yes
12-Dec-08	15	1.38	ND	34.8	HWT	Yes
15-Dec-08	16	0.07	5	ND	HWT	-
20-Dec-08	17	0.24	36.2	ND	HWT	No
21-Dec-08	18	0.11	26.3	ND	HWT	No
25-Dec-08	19	0.05	ND	ND	HWT	-
29-Dec-08	20	0.09	ND	ND	HWT	-
4-Jan-09	21	0.14	2.9	ND	HWT	No
6-Jan-09	22	0.64	149.3	ND	HWT	No
7-Jan-09	23	0.12	44	ND	HWT	No

11-Jan-09	24	0.26	13	ND	HWT	No
13-Jan-09	25	0.27	9.7	ND	HWT	No
18-Jan-09	26	0.39	19.4	ND	HWT	No
20-Jan-09	27	0.06	5.2	ND	HWT	-
21-Jan-09	28	0.1	4.1	ND	HWT	No
28-Jan-09	29	0.32	19.4	4.7	HWT	Yes
2-Feb-09	30	0.08	28.1	0	HWT	-
18-Feb-09	31	0.95	159.6	30.2	HWT	Yes
28-Feb-09	32	2.65	363	216.9	HWT	Yes
15-Mar-09	33	0.56	71.3	8.1	HWT	Yes
16-Mar-09	34	0.32	65	4.9	HWT	No
20-Mar-09	35	0.07	0	0	HWT	-
26-May-09	36	0.13	1.1	0	HWT	No
27-Mar-09	37	0.61	101	9.5	HWT	No
28-Mar-09	38	0.47	73.7	19	HWT	No
2-Apr-09	39	0.18	32.5	2	HWT	No
6-Apr-09	40	0.18	28.1	5.4	HWT	No
11-Apr-09	41	0.24	20.5	0.9	HWT	No
14-Apr-09	42	0.63	274.5	11.7	HWT	No
20-Apr-09	43	0.06	0	0	HWT	-
21-Apr-09	44	0.14	ND	ND	HWT	No
4-May-09	45	0.36	45.6	0	0	No
5-May-09	46	0.7	292.4	174.4	1207.3	No
7-May-09	47	0.44	149.9	4.7	112.5	No
7-May-09	48	0.13	0	0	0	No
11-May-09	49	0.15	6.5	0	0	No
17-May-09	50	0.51	200.6	1.7	8.3	No
28-May-09	51	0.12	ND	ND	ND	No
29-May-09	52	0.35	ND	ND	ND	No
1-Jun-09	53	0.85	ND	ND	ND	No
4-Jun-09	54	0.08	ND	ND	ND	-
5-Jun-09	55	0.28	ND	ND	ND	No
10-Jun-09	56	0.67	ND	ND	ND	Yes
11-Jun-09	57	0.1	ND	ND	ND	No
15-Jun-09	58	0.71	91.4	ND	1539.4	No
16-Jun-09	59	0.61	90.8	ND	2720.1	Yes
1-Jul-09	60	0.13	0	ND	0	No
6-Jul-09	61	0.24	0	ND	0	No
9-Jul-09	62	0.05	0	ND	0	-
14-Jul-09	63	0.39	ND	3.8	0	Yes

17-Jul-09	64	2.12	ND	161.5	5360	Yes
23-Jul-09	65	1.47	ND	104	4536.5	Yes
27-Jul-09	66	1.01	135.2	79	3323.6	Yes
29-Jul-09	67	0.08	2.2	0	0	-
31-Jul-09	68	0.28	25.9	0.9	130.2	No
2-Aug-09	69	0.94	124.3	36.8	4439.4	No
4-Aug-09	70	0.12	4.2	0	1225.9	No
5-Aug-09	71	0.43	41.1	12.8	153.8	No
11-Aug-09	72	2.72	461.1	263.4	HWT	No
13-Aug-09	73	1.39	231.2	121.2	HWT	No
22-Aug-09	74	1.44	231.1	118.6	HWT	No
31-Aug-09	75	0.99	144.4	19.2	HWT	Yes
7-Sep-09	76	0.05	0	0	HWT	-
22-Sep-09	77	0.28	14.3	1.7	HWT	No
23-Sep-09	78	0.05	0	0	HWT	-
25-Sep-09	79	0.14	6.3	0	HWT	No
26-Sep-09	80	0.24	ND	1.1	HWT	No
5-Oct-09	81	0.24	ND	0.1	HWT	No
10-Oct-09	82	0.07	0	0	HWT	-
12-Oct-09	83	0.07	0	0	HWT	-
11-Nov-09	84	4.37	2863	125.9	HWT	Yes
20-Nov-09	85	0.57	ND	ND	HWT	Yes
24-Nov-09	86	0.62	ND	ND	HWT	Yes
9-Apr-10	87	0.5	124.1	84	1232.7	Yes
21-Apr-10	88	0.21	14.5	0	ND	No
24-Apr-10	89	0.1	7.7	0	ND	No
4-May-10	90	0.14	3.8	0	0	No
18-May-10	91	2.91	451.8	290.2	3319.8	Yes
19-May-10	92	0.21	ND	ND	0	No
24-May-10	93	1.9	ND	ND	4880.2	Yes

Appendix C: Peak Flow Rate Data.

Table C.1. Peak flow rate data for Site A.

Peak Flow Rate (cfs)						
Storm Date	**Event Number**	**Rainfall (in)**	**NVA IN**	**NVA FS**	**NVA OUT**	**Sampled?**
6-Sep-08	1	3.92	0.043	0.086	0.925	Yes
17-Sep-08	2	1.35	0.055	0.015	ND	Yes
29-Sep-08	3	1.43	0.109	0.011	0.393	Yes
1-Oct-08	4	0.16	0.0018	0	0.0022	No

17-Oct-08	5	1.02	0.009	0	0.087	No
24-Oct-08	6	0.3	0.004	0	0.009	No
3-Nov-08	7	0.79	0.005	0	0.04	Yes
8-Nov-08	8	0.21	0.003	0	0.014	No
14-Nov-08	9	3.27	0.128	0.132	0.61	Yes
24-Nov-08	10	0.34	ND	0	HWT	No
30-Nov-08	11	0.85	ND	0.0002	HWT	Yes
12-Dec-08	12	1.02	ND	0.005	HWT	Yes
15-Dec-08	13	0.06	ND	0	HWT	-
20-Dec-08	14	0.5	0.01	0.00002	HWT	No
26-Dec-08	15	0.07	NF	0.00001	HWT	-
29-Dec-08	16	0.15	0.002	0	HWT	No
4-Jan-09	17	0.16	0.001	0.00003	HWT	No
6-Jan-09	18	0.51	0.0065	0	HWT	No
7-Jan-09	19	0.09	0.0025	0.00005	HWT	-
11-Jan-09	20	0.39	0.004	0	HWT	No
18-Jan-09	21	0.37	0.002	0	HWT	No
20-Jan-09	22	0.05	0.0008	0	HWT	-
21-Jan-09	23	0.11	0.00024	0	HWT	No
28-Jan-09	24	0.34	0.007	0.00007	HWT	Yes
2-Feb-09	25	0.05	0	0	HWT	-
4-Feb-09	26	0.1	0.00035	0	HWT	No
18-Feb-09	27	0.91	0.024	0.002	HWT	Yes
22-Feb-09	28	0.08	0	0	HWT	No
28-Feb-09	29	3.24	0.014	0.002	HWT	Yes
13-Mar-09	30	1.23	ND	0	HWT	Yes
16-Mar-09	31	0.25	ND	0.0004	HWT	No
19-Mar-09	32	0.33	ND	0.00003	HWT	No
26-Mar-09	33	0.08	ND	0	HWT	-
27-Mar-09	34	0.5	ND	0.009	HWT	No
28-Mar-09	35	0.67	ND	0.012	HWT	No
2-Apr-09	36	0.12	ND	0	0	No
6-Apr-09	37	0.34	ND	0.001	0.098	No
14-Apr-09	38	2.37	ND	0.17	0.85	No
20-Apr-09	39	0.14	ND	0	0.006	No
4-May-09	40	0.52	ND	0	0.019	No
7-May-09	41	1.08	ND	0.045	0.492	No
9-May-09	42	0.23	ND	0.005	0.031	No
11-May-09	43	0.08	ND	0	0	-
16-May-09	44	0.21	ND	0	0.008	No

17-May-09	45	0.54	ND	0.0045	0.087	No
26-May-09	46	0.41	0.051	ND	ND	Yes
28-May-09	47	0.1	NF	0	ND	No
4-Jun-09	48	0.45	ND	ND	ND	Yes
9-Jun-09	49	0.08	ND	ND	ND	-
16-Jun-09	50	0.51	0.031	0.0055	0.015	Yes
18-Jun-09	51	0.12	0.034	0	ND	No
13-Jul-09	52	0.33	0.0065	0	ND	Yes
21-Jul-09	53	2.59	0.055	0.029	0.092	Yes
24-Jul-09	54	1.01	0.057	0.03	0.254	Yes
28-Jul-09	55	1.14	0.06	0.046	0.618	Yes
30-Jul-09	56	0.06	0.007	0	0	-
31-Jul-09	57	1.63	0.102	0.115	1.37	No
2-Aug-09	58	0.71	0.045	0.031	ND	No
5-Aug-09	59	1.75	0.077	0.082	0.63	No
11-Aug-09	60	1.16	0.109	0.088	ND	No
12-Aug-09	61	0.09	0	0	ND	-
13-Aug-09	62	0.27	0.006	0.00013	ND	No
14-Aug-09	63	0.37	0.014	0.0037	ND	No
22-Aug-09	64	1.18	0.121	0.122	ND	No
28-Aug-09	65	0.16	0	0	0	No
30-Aug-09	66	0.32	0.0014	0	ND	Yes
7-Sep-09	67	0.22	0.002	0	0.002	No
17-Sep-09	68	0.11	ND	0	0	No
22-Sep-09	69	0.42	0.035	0.018	0.019	No
23-Sep-09	70	0.2	0.0017	0.00016	0.015	No
23-Sep-09	71	0.22	0.013	0.0024	0.049	No
25-Sep-09	72	0.06	0.0011	0	0	-
26-Sep-09	73	0.21	0.013	0	0	No
5-Oct-09	74	0.33	0.0017	0	0	No
11-Oct-09	75	0.31	0.006	0	0.0006	No
12-Oct-09	76	0.14	0.0002	0	0.0005	No
14-Oct-09	77	0.37	0.0019	0	ND	No
26-Oct-09	78	0.12	0	0	ND	No
27-Oct-09	79	0.22	0.018	0	ND	No
1-Nov-09	80	0.1	0.0055	0	ND	No
10-Nov-09	81	3.93	0.018	0.006	0.227	Yes
20-Nov-09	82	0.33	0.016	ND	HWT	Yes
24-Nov-09	83	0.67	ND	ND	HWT	Yes
9-Apr-10	84	0.4	0.048	0.018	0.101	Yes

21-Apr-10	85	0.19	0.007	0	0	No
24-Apr-10	86	0.2	0.0009	0	0.004	No
16-May-10	87	0.98	0.037	0.012	0.146	Yes
24-May-10	88	0.73	ND	ND	0.183	Yes

Table C.2. Peak flow rate data for Site B.

Peak Flow Rate (cfs)					
Storm Date	**Event Number**	**Rainfall (in)**	**VA IN**	**VA OUT**	**Sampled?**
6-Sep-08	1	3.92	0.077	0.178	Yes
17-Sep-08	2	2.1	0.005	ND	Yes
25-Sep-08	3	1.66	0.04	ND	Yes
1-Oct-08	4	0.13	0.008	0.002	No
9-Oct-08	5	0.06	0	0	-
18-Oct-08	6	1.22	0.024	0.136	No
24-Oct-08	7	0.35	0.002	0.01	No
3-Nov-08	8	0.89	0.005	0.053	Yes
8-Nov-08	9	0.18	0.003	0.006	No
13-Nov-08	10	0.24	0.0035	0.016	No
14-Nov-08	11	2.39	0.117	0.643	Yes
24-Nov-08	12	0.3	0.002	HWT	No
2-Dec-08	13	0.96	0.009	HWT	Yes
11-Dec-08	14	0.89	0.043	HWT	Yes
20-Dec-08	15	0.41	0.004	HWT	No
21-Dec-08	16	0.19	0.05	HWT	No
26-Dec-08	17	0.07	0.0014	HWT	-
29-Dec-08	18	0.15	0.008	HWT	No
4-Jan-09	19	0.13	0.005	HWT	No
6-Jan-09	20	0.57	0.009	HWT	No
7-Jan-09	21	0.09	0.011	HWT	-
11-Jan-09	22	0.36	0.0025	HWT	No
18-Jan-09	23	0.39	0.003	HWT	No
20-Jan-09	24	0.05	0	HWT	-
21-Jan-09	25	0.12	0	HWT	No
29-Jan-09	26	0.28	0.002	HWT	Yes
2-Feb-09	27	0.1	0.0018	HWT	No
4-Feb-09	28	0.1	0.0006	HWT	No
19-Feb-09	29	0.88	0.035	HWT	Yes
22-Feb-09	30	0.09	0.0002	HWT	-
5-Mar-09	31	3.28	0.017	HWT	Yes

13-Mar-09	32	0.3	0.0013	HWT	No
14-Mar-09	33	1.32	0.008	HWT	Yes
16-Mar-09	34	0.31	0.002	HWT	No
19-Mar-09	35	0.31	0.0035	HWT	No
26-Mar-09	36	0.06	0	HWT	-
27-Mar-09	37	0.55	0.046	HWT	No
28-Mar-09	38	0.65	0.025	HWT	No
2-Apr-09	39	0.1	0.001	HWT	No
6-Apr-09	40	0.7	0.054	HWT	No
11-Apr-09	41	0.08	0.0035	HWT	-
14-Apr-09	42	0.73	0.027	HWT	No
20-Apr-09	43	0.17	0.048	HWT	No
4-May-09	44	0.2	0.003	HWT	No
5-May-09	45	0.46	0.063	HWT	No
7-May-09	46	1.11	0.111	HWT	No
7-May-09	47	0.47	0.026	HWT	No
9-May-09	48	0.13	0.03	0	No
11-May-09	49	0.1	0.0016	0	No
16-May-09	50	0.08	0.003	0	-
17-May-09	51	0.54	0.029	ND	No
4-Jun-09	52	0.37	ND	ND	No
9-Jun-09	53	0.07	ND	ND	-
16-Jun-09	54	0.55	0.02	ND	Yes
13-Jul-09	55	0.49	0.013	0.13	Yes
20-Jul-09	56	2.45	0.117	0.444	Yes
23-Jul-09	57	1.48	0.171	0.457	Yes
27-Jul-09	58	1.44	0.074	0	Yes
31-Jul-09	59	1.3	0.097	0.582	No
2-Aug-09	60	0.91	0.111	0.437	No
5-Aug-09	61	1.43	0.119	0.455	No
11-Aug-09	62	1.1	0.08	0.514	No
12-Aug-09	63	0.13	0	0	No
13-Aug-09	64	0.23	0.004	0.013	No
14-Aug-09	65	0.3	0.029	0.055	No
22-Aug-09	66	1.19	0.119	0.514	No
23-Aug-09	67	0.29	0.018	0.001	No
28-Aug-09	68	0.21	0.038	0.012	No
31-Aug-09	69	0.41	0.008	0.001	Yes
7-Sep-09	70	0.28	0.004	0.000025	No
17-Sep-09	71	0.18	0.001	0.404	No

22-Sep-09	72	0.28	0.011	ND	No
23-Sep-09	73	0.19	0.005	ND	No
23-Sep-09	74	0.73	0.169	0	No
25-Sep-09	75	0.05	0.007	0.007	-
26-Sep-09	76	0.26	0.016	0.00005	No
5-Oct-09	77	0.31	0.001	0.005	No
11-Oct-09	78	0.36	0.017	HWT	No
12-Oct-09	79	0.14	0.0001	HWT	No
14-Oct-09	80	0.35	0.0053	HWT	No
26-Oct-09	81	0.09	0.00025	HWT	-
27-Oct-09	82	0.21	0.025	HWT	No
1-Nov-09	83	0.12	0.013	HWT	No
11-Nov-09	84	3.49	0.029	HWT	Yes
20-Nov-09	85	0.39	ND	HWT	Yes
24-Nov-09	86	0.56	ND	0.06	Yes
9-Apr-10	87	0.36	0.034	0	Yes
21-Apr-10	88	0.05	ND	0	-
24-Apr-10	89	0.22	ND	ND	No
16-May-10	90	1.22	0.055	0.094	Yes
23-May-10	91	0.96	0.051	HWT	Yes

Table C.3. Peak flow rate data for site C.

Peak Flow Rate (cfs)					
Storm Date	**Event Number**	**Rainfall (in)**	**VB IN**	**VB OUT**	**Sampled?**
6-Sep-08	1	3.7	0.086	HWT	Yes
7-Sep-08	2	0.75	ND	HWT	No
8-Sep-08	3	2.41	ND	HWT	No
9-Sep-08	4	0.43	0.0024	HWT	No
16-Sep-08	5	0.76	0.02	HWT	Yes
25-Sep-08	6	2.34	0.266	HWT	Yes
9-Oct-08	7	0.17	0	HWT	No
10-Oct-08	8	0.09	0	HWT	-
23-Oct-08	9	1.06	0.004	HWT	No
24-Oct-08	10	0.38	0.0014	HWT	No
4-Nov-08	11	0.58	0.0027	HWT	Yes
8-Nov-08	12	0.05	0	HWT	-
13-Nov-08	13	0.25	0.00023	HWT	No
14-Nov-08	14	2.25	0.101	HWT	Yes
25-Nov-08	15	0.08	0	HWT	-

30-Nov-08	16	0.99	0.005	HWT	Yes
11-Dec-08	17	0.76	0.014	HWT	Yes
20-Dec-08	18	0.22	0.00012	HWT	No
21-Dec-08	19	0.17	0.008	HWT	No
26-Dec-08	20	0.05	0	HWT	-
4-Jan-09	21	0.05	0	HWT	-
6-Jan-09	22	0.47	0.011	HWT	No
7-Jan-09	23	0.08	0.00045	HWT	-
11-Jan-09	24	0.23	0.0007	HWT	No
13-Jan-09	25	0.15	0	HWT	No
18-Jan-09	26	0.34	0.0022	HWT	No
20-Jan-09	27	0.08	0.000065	HWT	-
21-Jan-09	28	0.05	0.00018	HWT	-
28-Jan-09	29	0.28	0.0012	HWT	Yes
2-Feb-09	30	0.06	0	HWT	-
19-Feb-09	31	0.85	0.016	HWT	Yes
5-Mar-09	32	2.73	0.0035	HWT	Yes
13-Mar-09	33	0.07	0	HWT	-
16-Mar-09	34	0.23	0.00008	HWT	Yes
16-Mar-09	35	0.39	0.0016	HWT	No
20-Mar-09	36	0.1	0.00004	HWT	No
26-Mar-09	37	0.06	0	HWT	-
27-Mar-09	38	0.56	0.021	HWT	No
28-Mar-09	39	0.86	0.144	HWT	No
2-Apr-09	40	0.26	0.001	HWT	No
6-Apr-09	41	0.15	0.003	HWT	No
10-Apr-09	42	0.14	0.0012	HWT	No
14-Apr-09	43	0.86	0.045	HWT	No
20-Apr-09	44	0.06	0	HWT	-
21-Apr-09	45	0.14	0.0018	HWT	No
4-May-09	46	0.36	0.013	HWT	No
5-May-09	47	0.7	0.035	HWT	No
7-May-09	48	0.44	0.017	HWT	No
7-May-09	49	0.13	0.004	HWT	No
11-May-09	50	0.15	0.0012	HWT	No
17-May-09	51	0.51	0.0055	HWT	No
29-May-09	52	0.22	ND	HWT	No
4-Jun-09	53	0.16	ND	HWT	No
10-Jun-09	54	0.22	ND	HWT	Yes
11-Jun-09	55	0.71	0.098	HWT	No

15-Jun-09	56	0.83	0.051	HWT	Yes
18-Jun-09	57	0.13	0.0002	HWT	No
1-Jul-09	58	0.06	0	HWT	-
5-Jul-09	59	0.13	0.000095	HWT	No
6-Jul-09	60	0.2	0.007	HWT	No
13-Jul-09	61	0.9	0.02	HWT	Yes
16-Jul-09	62	0.06	0	HWT	-
21-Jul-09	63	1	0.061	HWT	Yes
23-Jul-09	64	1.12	0.075	HWT	Yes
27-Jul-09	65	1.67	0.086	HWT	Yes
31-Jul-09	66	0.28	0.015	HWT	No
1-Aug-09	67	0.12	0.0012	HWT	No
2-Aug-09	68	1.91	0.137	HWT	No
4-Aug-09	69	0.64	0.055	HWT	No
5-Aug-09	70	0.23	0.01	HWT	No
11-Aug-09	71	1.76	0.107	HWT	No
13-Aug-09	72	0.19	0	HWT	No
14-Aug-09	73	4.59	0.348	HWT	No
22-Aug-09	74	1.2	0.096	HWT	No
23-Aug-09	75	0.53	0.05	HWT	No
28-Aug-09	76	0.05	0	HWT	-
31-Aug-09	77	1.09	0.043	HWT	Yes
7-Sep-09	78	0.05	0	HWT	-
22-Sep-09	79	0.71	0.03	HWT	No
23-Sep-09	80	0.11	0.00095	HWT	No
25-Sep-09	81	0.42	0.111	HWT	No
26-Sep-09	82	0.63	0.03	HWT	No
5-Oct-09	83	0.31	ND	HWT	No
10-Oct-09	84	0.05	0	HWT	-
11-Oct-09	85	0.07	0	HWT	-
12-Oct-09	86	0.06	0	HWT	-
14-Oct-09	87	0.45	ND	HWT	No
26-Oct-09	88	0.21	0.03	HWT	No
31-Oct-09	89	0.05	0	HWT	-
11-Nov-09	90	3.79	0.027	HWT	Yes
20-Nov-09	91	0.47	ND	HWT	Yes
24-Nov-09	92	0.47	ND	HWT	Yes
9-Apr-10	93	0.07	ND	HWT	-
21-Apr-10	94	0.36	0.004	HWT	No
24-Apr-10	95	0.11	0.00002	HWT	No

4-May-10	96	0.13	0.00019	HWT	No
18-May-10	97	2.54	0.22	HWT	No
19-May-10	98	0.22	0.02	HWT	No
24-May-10	99	0.5	0.005	HWT	Yes

Table C.4. Peak flow rate data for site D.

Peak Flow Rate (cfs)						
Storm Date	**Event Number**	**Rainfall (in)**	**NVB IN**	**NVB FS**	**NVB OUT**	**Sampled?**
6-Sep-08	1	3.7	ND	ND	HWT	Yes
7-Sep-08	2	1.76	ND	ND	HWT	No
8-Sep-08	3	2.42	ND	ND	HWT	No
9-Sep-08	4	0.36	ND	ND	HWT	No
17-Sep-08	5	0.76	ND	ND	HWT	Yes
25-Sep-08	6	2.34	0.071	ND	HWT	Yes
9-Oct-08	7	0.17	0.012	ND	HWT	No
10-Oct-08	8	0.08	0.0004	ND	HWT	-
17-Oct-08	9	0.94	0.011	0.021	HWT	No
24-Oct-08	10	0.24	0.0011	ND	HWT	No
3-Nov-08	11	0.5	0.0055	0.002	HWT	Yes
13-Nov-08	12	0.26	0.001	0.00011	HWT	No
14-Nov-08	13	2.47	0.075	ND	HWT	Yes
2-Dec-08	14	1.01	ND	0.0009	HWT	Yes
12-Dec-08	15	1.38	ND	0.008	HWT	Yes
15-Dec-08	16	0.07	0.003	ND	HWT	-
20-Dec-08	17	0.24	0.008	ND	HWT	No
21-Dec-08	18	0.11	0.003	ND	HWT	No
25-Dec-08	19	0.05	ND	ND	HWT	-
29-Dec-08	20	0.09	ND	ND	HWT	-
4-Jan-09	21	0.14	0.0005	ND	HWT	No
6-Jan-09	22	0.64	0.028	ND	HWT	No
7-Jan-09	23	0.12	0.007	ND	HWT	No
11-Jan-09	24	0.26	0.002	ND	HWT	No
13-Jan-09	25	0.27	0.001	ND	HWT	No
18-Jan-09	26	0.39	0.003	ND	HWT	No
20-Jan-09	27	0.06	0.0002	ND	HWT	-
21-Jan-09	28	0.1	0.0004	ND	HWT	No
28-Jan-09	29	0.32	0.0025	0.0013	HWT	Yes
2-Feb-09	30	0.08	0.005	0	HWT	-

18-Feb-09	31	0.95	0.037	0.027	HWT	Yes
28-Feb-09	32	2.65	0.021	0.02	HWT	Yes
15-Mar-09	33	0.56	0.013	0.006	HWT	Yes
16-Mar-09	34	0.32	0.002	0.0005	HWT	No
20-Mar-09	35	0.07	0	0	HWT	-
26-May-09	36	0.13	0.000045	0	HWT	No
27-Mar-09	37	0.61	0.009	0.002	HWT	No
28-Mar-09	38	0.47	0.036	0.018	HWT	No
2-Apr-09	39	0.18	0.0011	0.00004	HWT	No
6-Apr-09	40	0.18	0.024	0.003	HWT	No
11-Apr-09	41	0.24	0.0033	0.0006	HWT	No
14-Apr-09	42	0.63	0.031	0.009	HWT	No
20-Apr-09	43	0.06	0	0	HWT	-
21-Apr-09	44	0.14	ND	ND	HWT	No
4-May-09	45	0.36	0.01	0	0	No
5-May-09	46	0.7	0.244	0.13	0.373	No
7-May-09	47	0.44	0.021	0.002	0.024	No
7-May-09	48	0.13	0	0	0	No
11-May-09	49	0.15	0.003	0	0	No
17-May-09	50	0.51	0.008	0.0005	0.002	No
28-May-09	51	0.12	ND	ND	ND	No
29-May-09	52	0.35	ND	ND	ND	No
1-Jun-09	53	0.85	ND	ND	ND	No
4-Jun-09	54	0.08	ND	ND	ND	-
5-Jun-09	55	0.28	ND	ND	ND	No
10-Jun-09	56	0.67	ND	ND	ND	Yes
11-Jun-09	57	0.1	ND	ND	ND	No
15-Jun-09	58	0.71	0.038	ND	0.129	No
16-Jun-09	59	0.61	0.034	ND	0.437	Yes
1-Jul-09	60	0.13	0	ND	0	No
6-Jul-09	61	0.24	0	ND	0	No
9-Jul-09	62	0.05	0	ND	0	-
14-Jul-09	63	0.39	ND	0.013	0	Yes
17-Jul-09	64	2.12	ND	0.092	0.65	Yes
23-Jul-09	65	1.47	ND	0.085	0.577	Yes
27-Jul-09	66	1.01	0.071	0.051	0.567	Yes
29-Jul-09	67	0.08	0.0056	0	0	-
31-Jul-09	68	0.28	0.018	0.00085	0.009	No
2-Aug-09	69	0.94	0.066	0.03	0.459	No
4-Aug-09	70	0.12	0.012	0	0.148	No

5-Aug-09	71	0.43	0.039	0.02	0.15	No
11-Aug-09	72	2.72	0.155	0.098	HWT	No
13-Aug-09	73	1.39	0.09	0.054	HWT	No
22-Aug-09	74	1.44	0.005	0.08	HWT	No
31-Aug-09	75	0.99	0.049	0.025	HWT	Yes
7-Sep-09	76	0.05	0	0	HWT	-
22-Sep-09	77	0.28	0.02	0.002	HWT	No
23-Sep-09	78	0.05	0	0	HWT	-
25-Sep-09	79	0.14	0.007	0	HWT	No
26-Sep-09	80	0.24	ND	0.00055	HWT	No
5-Oct-09	81	0.24	ND	0.00002	HWT	No
10-Oct-09	82	0.07	0	0	HWT	-
12-Oct-09	83	0.07	0	0	HWT	-
11-Nov-09	84	4.37	0.071	0.009	HWT	Yes
20-Nov-09	85	0.57	ND	ND	HWT	Yes
24-Nov-09	86	0.62	ND	ND	HWT	Yes
9-Apr-10	87	0.5	0.106	0.111	0.142	Yes
21-Apr-10	88	0.21	0.003	0	ND	No
24-Apr-10	89	0.1	0.0002	0	ND	No
4-May-10	90	0.14	0.013	0	0	No
18-May-10	91	2.91	0.144	0.061	0.252	Yes
19-May-10	92	0.21	ND	ND	0	No
24-May-10	93	1.9	ND	ND	0.618	Yes

Appendix D: Sampled Storm Events.

Table D.1. Summary of sampled storm events at site A.

Date	WQ Storm No.	Site A Rainfall (in)	Constituents Sampled EOP	Constituents Sampled VFS Outlet	Constituents Sampled Swale Outlet
6-Sep-08	1	3.92	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
17-Sep-08	2	1.35	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
29-Sep-08	3	1.43	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
6-Nov-08	4	0.79	Nutrients, TSS	-	Nutrients, TSS
17-Nov-08	5	3.27	Nutrients, TSS	-	Nutrients, TSS
2-Dec-08	6	0.85	Nutrients, TSS	-	Nutrients, TSS
12-Dec-08	7	1.15	Nutrients, TSS	-	Nutrients, TSS
29-Jan-09	8	0.34	Nutrients, TSS	-	Nutrients, TSS
19-Feb-09	9	1.18	Nutrients, TSS	-	Nutrients, TSS
16-Mar-09	11	1.23	Nutrients, TSS	-	-
26-May-09	12	0.41	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
10-Jun-09	13	0.45	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
17-Jun-09	14	0.63	Nutrients, TSS	Nutrients	Nutrients, TSS
14-Jul-09	15	0.33	Nutrients, TSS	-	-
21-Jul-09	16	2.59	-	Nutrients, TSS	Nutrients, TSS
24-Jul-09	17	1.01	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
28-Jul-09	18	1.14	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
31-Aug-09	19	0.32	Nutrients, TSS	-	Nutrients, TSS
13-Nov-09	20	3.93	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
20-Nov-09	21	0.33	Nutrients, TSS	-	Nutrients, TSS
24-Nov-09	22	0.67	Nutrients, TSS	-	Nutrients, TSS
9-Apr-10	23	0.4	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
18-May-10	24	0.98	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
24-May-10	25	0.73	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS

Table D.2. Summary of sampled storm events at site B.

Date	WQ Storm No.	Site B Rainfall (in)	Constituents Sampled EOP	Constituents Sampled Swale Outlet
6-Sep-08	1	3.92	Nutrients, TSS	Nutrients, TSS
17-Sep-08	2	2.1	Nutrients, TSS	Nutrients, TSS
29-Sep-08	3	1.66	Nutrients, TSS	Nutrients, TSS
6-Nov-08	4	0.89	Nutrients, TSS	-
17-Nov-08	5	2.39	Nutrients, TSS	Nutrients, TSS
2-Dec-08	6	0.96	Nutrients, TSS	-
12-Dec-08	7	0.93	Nutrients, TSS	Nutrients, TSS
29-Jan-09	8	0.28	Nutrients, TSS	-
19-Feb-09	9	0.88	Nutrients, TSS	Nutrients, TSS
16-Mar-09	11	1.32	Nutrients, TSS	Nutrients, TSS
17-Jun-09	14	0.61	Nutrients, TSS	Nutrients, TSS
14-Jul-09	15	0.49	Nutrients, TSS	-
21-Jul-09	16	2.45	Nutrients, TSS	Nutrients, TSS
24-Jul-09	17	1.44	Nutrients, TSS	Nutrients, TSS
28-Jul-09	18	1.45	Nutrients, TSS	Nutrients, TSS
31-Aug-09	19	0.37	Nutrients, TSS	Nutrients, TSS
13-Nov-09	20	3.49	Nutrients, TSS	Nutrients, TSS
20-Nov-09	21	0.39	Nutrients, TSS	Nutrients, TSS
24-Nov-09	22	0.56	Nutrients, TSS	Nutrients, TSS
9-Apr-10	23	0.36	Nutrients, TSS	Nutrients, TSS
18-May-10	24	1.22	Nutrients, TSS	Nutrients, TSS
24-May-10	25	0.96	Nutrients, TSS	Nutrients, TSS

Table D.3. Summary of sampled storm events at site C.

Date	WQ Storm No.	Site C Rainfall (in)	Constituents Sampled EOP	Constituents Sampled Swale Outlet
6-Sep-08	1	3.7	Nutrients, TSS	Nutrients, TSS
17-Sep-08	2	0.76	Nutrients, TSS	Nutrients, TSS
29-Sep-08	3	2.34	Nutrients, TSS	Nutrients, TSS
6-Nov-08	4	0.58	Nutrients, TSS	Nutrients, TSS
17-Nov-08	5	2.25	Nutrients, TSS	Nutrients, TSS
2-Dec-08	6	0.99	Nutrients, TSS	Nutrients, TSS
12-Dec-08	7	0.76	Nutrients, TSS	Nutrients, TSS
29-Jan-09	8	0.32	Nutrients, TSS	Nutrients, TSS
19-Feb-09	9	0.85	Nutrients, TSS	Nutrients, TSS
10-Jun-09	13	0.22	Nutrients, TSS	Nutrients, TSS
14-Jul-09	15	0.9	Nutrients, TSS	Nutrients, TSS
21-Jul-09	16	1	Nutrients, TSS	Nutrients, TSS
24-Jul-09	17	1.12	Nutrients, TSS	Nutrients, TSS
28-Jul-09	18	1.67	Nutrients, TSS	Nutrients, TSS
31-Aug-09	19	1.09	Nutrients, TSS	Nutrients, TSS
13-Nov-09	20	3.79	Nutrients, TSS	Nutrients, TSS
20-Nov-09	21	0.47	Nutrients, TSS	Nutrients, TSS
24-Nov-09	22	0.47	Nutrients, TSS	Nutrients, TSS
24-May-10	25	0.49	Nutrients, TSS	Nutrients, TSS

Table D.4. Summary of sampled storm events at site D.

Date	WQ Storm No.	Site D Rainfall (in)	Constituents Sampled EOP	Constituents Sampled VFS Outlet	Constituents Sampled Swale Outlet
29-Sep-08	3	2.34	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
6-Nov-08	4	0.89	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
17-Nov-08	5	2.47	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
2-Dec-08	6	1.01	Nutrients, TSS	-	Nutrients, TSS
12-Dec-08	7	1.38	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
29-Jan-09	8	0.32	Nutrients, TSS	Nutrients	Nutrients, TSS
19-Feb-09	9	0.95	Nutrients, TSS	-	Nutrients, TSS
10-Jun-09	13	0.67	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
17-Jun-09	14	0.61	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
14-Jul-09	15	0.39	Nutrients, TSS	Nutrients, TSS	-
21-Jul-09	16	2.12	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
24-Jul-09	17	1.47	Nutrients, TSS	-	Nutrients, TSS
28-Jul-09	18	1.01	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
31-Aug-09	19	0.99	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
13-Nov-09	20	4.37	Nutrients, TSS	Nutrients, TSS	-
20-Nov-09	21	0.57	Nutrients, TSS	-	Nutrients, TSS
24-Nov-09	22	0.62	Nutrients, TSS	-	Nutrients, TSS
9-Apr-10	23	0.5	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
18-May-10	24	2.91	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS
24-May-10	25	1.9	Nutrients, TSS	Nutrients, TSS	Nutrients, TSS

Appendix E: Nutrient and Sediment Concentrations.

Table E.1. Nutrient and sediment concentrations for the PFC-overlayed highway at site A.

Date Sampled	Sample Location	TKN (mg/L)	NO2-3 (mg/L)	TN (mg/L)	NH4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/6/08	Site A PFC	0.27	0.10	0.37	0.17	0.10	0.02	6
9/17/08	Site A PFC	0.39	0.33	0.71	0.19	0.20	0.02	5
9/29/08	Site A PFC	0.36	0.25	0.61	0.12	0.23	0.03	7
11/6/08	Site A PFC	0.74	0.50	1.24	0.39	0.34	0.05	6
11/17/08	Site A PFC	0.47	0.30	0.77	0.17	0.30	0.04	11
12/2/08	Site A PFC	0.32	0.37	0.69	0.23	0.09	0.02	5
12/12/08	Site A PFC	0.41	0.44	0.84	0.20	0.20	0.04	10
1/29/09	Site A PFC	1.93	0.85	2.78	0.95	0.98	0.18	24
2/19/09	Site A PFC	0.94	0.76	1.69	0.39	0.55	0.21	31
3/16/09	Site A PFC	0.47	0.51	0.98	0.21	0.26	0.06	8
5/26/09	Site A PFC	1.57	0.28	1.85	1.22	0.35	0.05	9
6/10/09	Site A PFC	0.95	0.64	1.59	0.55	0.40	0.06	9
6/17/09	Site A PFC	0.83	0.69	1.51	0.43	0.40	0.10	8
7/14/09	Site A PFC	2.27	1.47	3.74	0.85	1.43	0.16	11
7/24/09	Site A PFC	0.76	0.54	1.30	0.54	0.21	0.04	9
7/28/09	Site A PFC	0.82	0.31	1.13	0.60	0.22	0.03	6
8/31/09	Site A PFC	1.85	0.85	2.70	0.29	1.56	0.25	24
11/13/09	Site A PFC	0.41	0.32	0.73	0.18	0.23	0.04	6
11/20/09	Site A PFC	1.28	0.39	1.67	0.52	0.76	0.09	22
11/24/09	Site A PFC	0.53	0.37	0.90	0.16	0.37	0.04	10
4/9/10	Site A PFC	1.78	0.33	2.12	0.44	1.35	0.14	38
5/18/10	Site A PFC	1.82	0.71	2.52	0.43	1.39	0.10	14
5/24/10	Site A PFC	1.18	0.37	1.55	0.23	0.95	0.09	14

Table E.2. Nutrient and sediment concentrations for the highway filter strips at site A.

Date Sampled	Sample Location	TKN (mg/L)	NO_{2-3} (mg/L)	TN (mg/L)	NH_4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/6/08	Site A FS	0.35	0.03	0.37	0.07	0.27	0.16	7
9/17/08	Site A FS	1.05	0.09	1.14	0.35	0.70	0.21	27
9/29/08	Site A FS	0.68	0.08	0.75	0.08	0.60	0.18	24
5/26/09	Site A FS	1.38	0.29	1.67	0.04	1.35	0.15	12
6/10/09	Site A FS	3.08	0.88	3.96	1.39	1.69	0.76	52
6/17/09	Site A FS	3.14	1.59	4.73	0.60	2.54	0.35	NS
7/21/09	Site A FS	1.06	0.38	1.45	0.50	0.57	0.21	15
7/24/09	Site A FS	1.12	0.28	1.39	0.18	0.94	0.15	21
7/28/09	Site A FS	0.82	0.24	1.06	0.11	0.71	0.12	10
11/13/09	Site A FS	0.78	0.57	1.35	0.11	0.67	0.14	15
4/9/10	Site A FS	4.03	0.45	4.48	0.17	3.86	0.58	102
5/18/10	Site A FS	1.74	0.21	1.95	0.27	1.47	0.23	15
5/24/10	Site A FS	1.59	0.36	1.95	0.13	1.45	0.20	18

Table E.3. Nutrient and sediment concentrations for the dry swale at site A.

Date Sampled	Sample Location	TKN (mg/L)	NO_{2-3} (mg/L)	TN (mg/L)	NH_4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/6/08	Site A Swale	0.55	0.01	0.56	0.06	0.49	0.06	7
9/17/08	Site A Swale	0.90	0.12	1.01	0.12	0.77	0.08	17
9/29/08	Site A Swale	0.70	0.05	0.75	0.03	0.66	0.07	9
11/6/08	Site A Swale	1.14	0.07	1.21	0.11	1.03	0.09	15
11/17/08	Site A Swale	0.92	0.14	1.06	0.07	0.85	0.09	19
12/2/08	Site A Swale	0.62	0.78	1.40	0.02	0.59	0.05	11
12/12/08	Site A Swale	0.79	0.48	1.27	0.04	0.75	0.07	22
1/29/09	Site A Swale	0.57	1.94	2.51	0.07	0.50	0.05	12
2/19/09	Site A Swale	1.13	0.79	1.92	0.07	1.06	0.09	52
3/16/09	Site A Swale	0.84	0.60	1.43	0.09	0.74	0.11	13
5/26/09	Site A Swale	2.91	0.17	3.07	0.49	2.42	0.35	110
6/10/09	Site A Swale	1.56	0.52	2.08	0.28	1.28	0.09	23
6/17/09	Site A Swale	1.13	0.57	1.70	0.06	1.07	0.10	11
7/21/09	Site A Swale	1.44	0.51	1.95	0.38	1.06	0.06	7
7/24/09	Site A Swale	1.30	0.21	1.51	0.10	1.20	0.10	14
7/28/09	Site A Swale	0.96	0.20	1.16	0.10	0.86	0.08	11
8/31/09	Site A Swale	1.64	0.05	1.69	0.05	1.59	0.08	29
11/13/09	Site A Swale	1.23	0.30	1.53	0.05	1.18	0.13	14
11/20/09	Site A Swale	1.29	0.65	1.95	0.09	1.21	0.11	22
11/24/09	Site A Swale	1.04	0.61	1.65	0.07	0.97	0.12	19
4/9/10	Site A Swale	2.86	0.38	3.24	0.48	2.38	0.28	96
5/18/10	Site A Swale	1.49	0.14	1.63	0.14	1.35	0.09	14
5/24/10	Site A Swale	1.58	0.16	1.75	0.13	1.46	0.12	25

Table E.4. Nutrient and sediment concentrations for the PFC-overlayed highway at site B.

Date Sampled	Sample Location	TKN (mg/L)	NO_{2-3} (mg/L)	TN (mg/L)	NH_4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/6/08	Site B PFC	0.35	0.13	0.48	0.19	0.15	0.03	5
9/17/08	Site B PFC	1.56	0.71	2.27	0.74	0.82	0.09	6
9/29/08	Site B PFC	0.29	0.24	0.53	0.12	0.17	0.03	8
11/6/08	Site B PFC	0.64	0.41	1.05	0.33	0.31	0.05	8
11/17/08	Site B PFC	0.47	0.23	0.70	0.25	0.22	0.07	22
12/2/08	Site B PFC	0.29	0.34	0.63	0.18	0.11	0.02	5
12/12/08	Site B PFC	0.48	0.36	0.84	0.23	0.25	0.04	14
1/29/09	Site B PFC	3.67	0.28	3.95	0.79	2.88	0.45	178
2/19/09	Site B PFC	0.87	0.41	1.28	0.27	0.60	0.28	64
3/16/09	Site B PFC	0.61	0.63	1.24	0.23	0.38	0.09	17
6/10/09	Site B PFC	2.39	0.47	2.86	1.17	1.22	0.16	44
6/17/09	Site B PFC	1.06	0.44	1.50	0.50	0.56	0.09	20
7/14/09	Site B PFC	4.19	0.51	4.70	1.22	2.97	0.32	82
7/21/09	Site B PFC	0.94	0.51	1.45	0.66	0.29	0.03	4
7/24/09	Site B PFC	0.97	0.52	1.49	0.39	0.58	0.05	21
7/28/09	Site B PFC	1.33	0.32	1.65	0.78	0.55	0.09	14
8/31/09	Site B PFC	1.81	0.53	2.34	0.76	1.05	0.13	38
11/13/09	Site B PFC	0.46	0.27	0.73	0.17	0.30	0.05	7
11/20/09	Site B PFC	1.31	0.37	1.68	0.41	0.90	0.11	59
11/24/09	Site B PFC	0.63	0.40	1.02	0.16	0.47	0.05	14
4/9/10	Site B PFC	2.06	0.33	2.39	0.54	1.52	0.19	51
5/18/10	Site B PFC	1.10	0.37	1.47	0.34	0.76	0.07	14
5/24/10	Site B PFC	1.44	0.58	2.02	0.27	1.17	0.08	21

Table E.5. Nutrient and sediment concentrations for the wetland swale at site B.

Date Sampled	**Sample Location**	**TKN (mg/L)**	**$NO_{2\text{-}3}$ (mg/L)**	**TN (mg/L)**	**NH_4 (mg/L)**	**Org-N (mg/L)**	**TP (mg/L)**	**TSS (mg/L)**
		RL = 0.14 mg/L	**RL = 0.0056 mg/L**	**RL = 0.1456 mg/L**	**RL = 0.007 mg/L**	**RL = 0.14 mg/L**	**RL = 0.01 mg/L**	**RL = 1 mg/L**
9/6/08	Site B Swale	0.39	0.02	0.40	0.07	0.32	0.04	3
9/17/08	Site B Swale	0.70	0.09	0.79	0.10	0.60	0.07	22
9/29/08	Site B Swale	0.73	0.07	0.80	0.04	0.69	0.06	12
11/17/08	Site B Swale	1.02	0.03	1.04	0.07	0.95	0.14	27
12/12/08	Site B Swale	0.92	0.04	0.96	0.06	0.86	0.13	35
2/19/09	Site B Swale	0.69	0.24	0.93	0.05	0.64	0.14	24
3/16/09	Site B Swale	0.85	0.08	0.93	0.06	0.79	0.13	17
6/17/09	Site B Swale	1.63	0.16	1.80	0.06	1.57	0.18	61
7/21/09	Site B Swale	1.27	0.40	1.67	0.19	1.08	0.07	10
7/24/09	Site B Swale	1.11	0.04	1.16	0.07	1.05	0.10	13
7/28/09	Site B Swale	0.85	0.19	1.04	0.06	0.79	0.08	12
8/31/09	Site B Swale	1.28	0.02	1.30	0.04	1.24	0.08	20
11/13/09	Site B Swale	0.89	0.13	1.02	0.03	0.85	0.13	15
11/20/09	Site B Swale	0.90	0.05	0.95	0.05	0.86	0.14	27
11/24/09	Site B Swale	0.86	0.06	0.92	0.06	0.80	0.12	17
4/9/10	Site B Swale	2.38	0.07	2.45	0.05	2.33	0.21	47
5/18/10	Site B Swale	1.79	0.13	1.92	0.10	1.70	0.13	24
5/24/10	Site B Swale	1.83	0.12	1.94	0.10	1.73	0.18	39

Table E.6. Nutrient and sediment concentrations for the PFC-overlayed highway at site C.

Date Sampled	Sample Location	TKN (mg/L)	NO_{2-3} (mg/L)	TN (mg/L)	NH_4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/6/08	Site C PFC	0.26	0.18	0.45	0.11	0.16	0.04	5
9/17/08	Site C PFC	0.97	0.92	1.89	0.47	0.50	0.07	6
9/29/08	Site C PFC	0.43	0.27	0.70	0.19	0.24	0.07	8
11/6/08	Site C PFC	0.83	0.90	1.73	0.42	0.41	0.07	10
11/17/08	Site C PFC	1.47	0.25	1.72	0.17	1.30	0.08	15
12/2/08	Site C PFC	0.45	0.52	0.97	0.29	0.16	0.06	4
12/12/08	Site C PFC	0.46	0.75	1.21	0.22	0.24	0.05	8
1/29/09	Site C PFC	2.71	1.10	3.81	1.77	0.93	0.13	8
2/19/09	Site C PFC	1.29	0.77	2.06	0.87	0.42	0.20	15
6/10/09	Site C PFC	4.86	0.99	5.85	1.92	2.95	0.30	16
6/17/09	Site C PFC	2.99	0.82	3.81	0.77	2.21	0.18	21
7/14/09	Site C PFC	1.23	0.89	2.12	0.79	0.44	0.13	10
7/21/09	Site C PFC	1.48	0.61	2.08	0.89	0.59	0.06	5
7/24/09	Site C PFC	1.04	0.78	1.82	0.46	0.59	0.09	9
7/28/09	Site C PFC	0.89	0.40	1.29	0.48	0.41	0.06	9
8/31/09	Site C PFC	1.08	0.49	1.56	0.53	0.55	0.09	12
11/13/09	Site C PFC	0.67	0.64	1.31	0.34	0.34	0.11	7
11/20/09	Site C PFC	0.64	0.74	1.38	0.22	0.42	0.09	8
11/24/09	Site C PFC	0.49	0.81	1.30	0.14	0.35	0.07	6
5/24/10	Site C PFC	2.18	1.34	3.51	1.28	0.90	0.10	8

Table E.7. Nutrient and sediment concentrations for the wetland swale at site C.

Date Sampled	Sample Location	TKN (mg/L)	NO_{2-3} (mg/L)	TN (mg/L)	NH_4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/6/08	Site C Swale	0.58	0.03	0.61	0.03	0.56	0.08	7
9/17/08	Site C Swale	1.25	0.01	1.26	0.22	1.03	0.10	26
9/29/08	Site C Swale	0.71	0.08	0.79	0.03	0.67	0.07	16
11/6/08	Site C Swale	0.67	0.07	0.74	0.05	0.62	0.06	35
11/17/08	Site C Swale	0.90	0.15	1.05	0.07	0.83	0.13	67
12/2/08	Site C Swale	0.40	0.20	0.60	0.02	0.39	0.03	5
12/12/08	Site C Swale	0.58	0.23	0.81	0.03	0.56	0.05	6
1/29/09	Site C Swale	0.76	0.30	1.05	0.23	0.53	0.05	10
2/19/09	Site C Swale	0.71	0.77	1.48	0.17	0.55	0.06	5
6/10/09	Site C Swale	1.40	0.37	1.78	0.11	1.29	0.14	70
6/17/09	Site C Swale	0.94	0.05	0.99	0.03	0.90	0.08	17
7/14/09	Site C Swale	1.83	1.34	3.16	0.27	1.56	0.17	24
7/21/09	Site C Swale	1.36	0.30	1.65	0.07	1.29	0.10	27
7/24/09	Site C Swale	1.16	0.41	1.58	0.09	1.07	0.13	26
7/28/09	Site C Swale	0.91	0.05	0.96	0.03	0.89	0.07	8
8/31/09	Site C Swale	0.69	0.03	0.72	0.03	0.65	0.06	6
11/13/09	Site C Swale	0.61	0.14	0.75	0.19	0.42	0.05	13
11/20/09	Site C Swale	0.86	0.21	1.07	0.06	0.80	0.09	11
11/24/09	Site C Swale	0.67	0.17	0.84	0.03	0.64	0.05	10
5/24/10	Site C Swale	1.00	0.07	1.07	0.06	0.93	0.10	17

Table E.8. Nutrient and sediment concentrations for the PFC-overlayed highway at site D.

Date Sampled	Sample Location	TKN (mg/L)	NO_{2-3} (mg/L)	TN (mg/L)	NH_4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/29/08	Site D PFC	0.35	0.35	0.69	0.06	0.28	0.07	9
11/6/08	Site D PFC	1.08	1.46	2.53	0.59	0.49	0.17	20
11/17/08	Site D PFC	0.61	0.68	1.28	0.21	0.39	0.11	21
12/2/08	Site D PFC	0.61	0.95	1.56	0.34	0.27	0.10	8
12/12/08	Site D PFC	0.37	1.11	1.47	0.15	0.22	0.07	6
1/29/09	Site D PFC	3.20	1.51	4.71	1.98	1.22	0.15	9
2/19/09	Site D PFC	1.57	1.37	2.94	0.83	0.74	0.23	18
6/10/09	Site D PFC	1.10	2.45	3.55	0.35	0.75	0.11	6
6/17/09	Site D PFC	1.14	0.84	1.98	0.57	0.57	0.10	9
7/14/09	Site D PFC	1.30	2.54	3.84	0.09	1.21	0.14	5
7/21/09	Site D PFC	1.17	0.33	1.50	0.09	1.08	0.08	48
7/24/09	Site D PFC	0.75	1.92	2.67	0.09	0.66	0.06	5
7/28/09	Site D PFC	1.04	0.55	1.60	0.48	0.56	0.09	9
8/31/09	Site D PFC	1.18	1.02	2.20	0.63	0.55	0.10	7
11/13/09	Site D PFC	0.63	3.77	4.40	0.08	0.55	0.08	5
11/20/09	Site D PFC	0.74	1.36	2.10	0.29	0.44	0.10	5
11/24/09	Site D PFC	0.52	0.92	1.45	0.20	0.32	0.08	4
4/9/10	Site D PFC	2.73	0.74	3.47	0.75	1.98	0.33	36
5/18/10	Site D PFC	3.10	0.83	3.93	1.81	1.28	0.24	47
5/24/10	Site D PFC	2.28	1.77	4.05	1.49	0.79	0.22	4

Table E.9. Nutrient and sediment concentrations for the highway filter strips at site D.

ate Sampled	Sample Location	TKN (mg/L)	$NO_{2\text{-}3}$ (mg/L)	TN (mg/L)	NH_4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/29/08	Site D FS	1.03	0.09	1.13	0.07	0.97	0.24	27
11/6/08	Site D FS	2.11	1.06	3.17	0.63	1.47	0.37	10
11/17/08	Site D FS	0.99	0.28	1.27	0.13	0.86	0.25	19
12/12/08	Site D FS	1.11	0.18	1.29	0.07	1.04	0.28	35
1/29/09	Site D FS	1.64	0.44	2.08	0.54	1.10	0.25	NS
6/10/09	Site D FS	1.47	0.08	1.55	0.04	1.43	0.23	9
6/17/09	Site D FS	2.03	0.01	2.04	0.04	1.99	0.35	165
7/14/09	Site D FS	3.76	0.83	4.59	0.47	3.29	0.89	88
7/21/09	Site D FS	1.07	0.34	1.41	0.29	0.78	0.24	24
7/28/09	Site D FS	0.96	0.18	1.14	0.07	0.89	0.15	11
8/31/09	Site D FS	1.47	0.44	1.91	0.13	1.34	0.22	20
11/13/09	Site D FS	1.19	0.32	1.51	0.07	1.12	0.39	9
4/9/10	Site D FS	2.67	0.98	3.65	0.42	2.25	0.42	40
5/18/10	Site D FS	3.14	0.59	3.73	0.86	2.29	0.68	23
5/24/10	Site D FS	2.80	0.65	3.45	0.36	2.44	0.38	24

Table E.10. Nutrient and sediment concentrations for the dry swale at site D.

Date Sampled	Sample Location	TKN (mg/L)	NO_{2-3} (mg/L)	TN (mg/L)	NH_4 (mg/L)	Org-N (mg/L)	TP (mg/L)	TSS (mg/L)
		RL = 0.14 mg/L	RL = 0.0056 mg/L	RL = 0.1456 mg/L	RL = 0.007 mg/L	RL = 0.14 mg/L	RL = 0.01 mg/L	RL = 1 mg/L
9/29/08	Site D Swale	1.06	0.05	1.11	0.11	0.95	0.14	53
11/6/08	Site D Swale	1.58	0.09	1.67	0.16	1.42	0.29	250
11/17/08	Site D Swale	1.31	0.20	1.51	0.15	1.17	0.22	100
12/2/08	Site D Swale	1.01	0.14	1.15	0.05	0.96	0.22	178
12/12/08	Site D Swale	0.36	0.01	0.37	0.03	0.34	0.06	67
1/29/09	Site D Swale	1.21	0.37	1.58	0.36	0.85	0.15	118
2/19/09	Site D Swale	1.01	0.06	1.07	0.08	0.92	0.14	104
6/10/09	Site D Swale	1.37	0.51	1.88	0.14	1.23	0.20	45
6/17/09	Site D Swale	2.24	0.04	2.28	0.08	2.16	0.21	33
7/21/09	Site D Swale	0.79	0.40	1.20	0.19	0.60	0.15	20
7/24/09	Site D Swale	1.02	0.31	1.33	0.24	0.78	0.13	19
7/28/09	Site D Swale	0.83	0.18	1.00	0.06	0.77	0.12	19
8/31/09	Site D Swale	1.32	0.17	1.50	0.06	1.26	0.13	49
11/20/09	Site D Swale	1.40	0.15	1.54	0.06	1.34	0.19	34
11/24/09	Site D Swale	0.89	0.17	1.06	0.04	0.85	0.13	24
4/9/10	Site D Swale	2.35	0.40	2.75	0.11	2.23	0.28	79
5/18/10	Site D Swale	3.15	0.06	3.20	0.48	2.67	0.51	28
5/24/10	Site D Swale	2.34	0.54	2.88	0.17	2.17	0.21	43

Appendix F: Nutrient and Sediment Loads.

Table F.1. Nutrient and sediment loads for site A.

Date	TKN (lb/ac)			NO2-3-N (lb/ac)			TN (lb/ac)			NH4N (lb/ac)			Org N (lb/ac)			TP (lb/ac)			TSS (lb/ac)		
	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale
6-Sep-08	0.04	0.52	0.40	0.02	0.04	0.01	0.06	0.56	0.40	0.03	0.11	0.05	0.02	0.41	0.35	0.00	0.24	0.04	0.90	10.17	4.85
17-Sep-08	0.12	0.12	-	0.10	0.01	-	0.23	0.13	-	0.06	0.04	-	0.06	0.08	-	0.01	0.02	-	1.45	3.14	-
29-Sep-08	0.25	0.10	0.12	0.18	0.01	0.01	0.44	0.11	0.13	0.09	0.01	0.01	0.17	0.09	0.12	0.02	0.03	0.01	5.10	3.54	1.68
3-Nov-08	0.19	-	0.08	0.13	-	0.00	0.32	-	0.08	0.10	-	0.01	0.09	-	0.07	0.01	-	0.01	1.53	-	1.04
14-Nov-08	0.48	-	0.47	0.31	-	0.07	0.79	-	0.54	0.17	-	0.03	0.31	-	0.44	0.04	-	0.05	11.41	-	9.71
30-Nov-08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Dec-08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28-Jan-09	0.16	-	-	0.07	-	-	0.23	-	-	0.08	-	-	0.08	-	-	0.02	-	-	1.99	-	-
18-Feb-09	0.30	-	-	0.25	-	-	0.55	-	-	0.13	-	-	0.18	-	-	0.07	-	-	10.08	-	-
13-Mar-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26-May-09	0.11	-	-	0.02	-	-	0.13	-	-	0.08	-	-	0.02	-	-	0.00	-	-	0.61	-	-
4-Jun-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jun-09	0.12	0.05	0.01	0.10	0.03	0.00	0.21	0.08	0.01	0.06	0.01	0.00	0.06	0.04	0.01	0.01	0.01	0.00	1.12	-	0.08
13-Jul-09	0.16	-	-	0.10	-	-	0.26	-	-	0.06	-	-	0.10	-	-	0.01	-	-	0.76	-	-
21-Jul-09	-	0.08	0.05	-	0.03	0.02	-	0.11	0.06	-	0.04	0.01	-	0.05	0.03	-	0.02	0.00	-	1.19	0.23
24-Jul-09	0.24	0.12	0.12	0.17	0.03	0.02	0.41	0.15	0.14	0.17	0.02	0.01	0.07	0.10	0.11	0.01	0.02	0.01	2.88	2.29	1.26
28-Jul-09	0.31	0.21	0.18	0.12	0.06	0.04	0.43	0.27	0.22	0.23	0.03	0.02	0.08	0.18	0.16	0.01	0.03	0.01	2.29	2.51	2.05
30-Aug-09	0.04	-	-	0.02	-	-	0.06	-	-	0.01	-	-	0.04	-	-	0.01	-	-	0.56	-	-
10-Nov-09	0.67	0.32	0.43	0.52	0.23	0.11	1.19	0.55	0.54	0.29	0.04	0.02	0.38	0.27	0.41	0.07	0.06	0.05	9.76	6.08	4.94
19-Nov-09	0.13	-	-	0.04	-	-	0.17	-	-	0.05	-	-	0.08	-	-	0.01	-	-	2.18	-	-
24-Nov-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9-Apr-10	0.17	0.20	0.14	0.03	0.02	0.02	0.21	0.23	0.16	0.04	0.01	0.02	0.13	0.20	0.12	0.01	0.03	0.01	3.71	5.18	4.65
16-May-10	1.64	0.22	0.15	0.64	0.03	0.01	2.28	0.25	0.17	0.39	0.03	0.01	1.25	0.19	0.14	0.09	0.03	0.01	12.66	1.90	1.44
24-May-10	-	-	0.10	-	-	0.01	-	-	0.11	-	-	0.01	-	-	0.09	-	-	0.01	-	-	1.58

Table F.2. Nutrient and sediment loads for site B.

Date	TKN (lb/ac)		NO2-3-N (lb/ac)		TN (lb/ac)		NH4N (lb/ac)		Org N (lb/ac)		TP (lb/ac)		TSS (lb/ac)	
	Site B PFC	Site B Swale	Site B PFC	Site B Swale	Site B PFC	Site B Swale	Site B PFC	Site B Swale	Site B PFC	Site B Swale	Site B PFC	Site B Swale	Site B PFC	Site B Swale
6-Sep-08	0.720	0.012	0.275	0.001	0.995	0.013	0.401	0.002	0.319	0.010	0.065	0.001	9.600	0.094
17-Sep-08	0.068	-	0.031	-	0.098	-	0.032	-	0.036	-	0.004	-	0.273	-
25-Sep-08	0.175	-	0.141	-	0.316	-	0.071	-	0.104	-	0.020	-	4.764	-
3-Nov-08	0.145	-	0.094	-	0.240	-	0.074	-	0.071	-	0.011	-	1.823	-
14-Nov-08	0.395	0.562	0.189	0.577	0.584	0.577	0.212	0.037	0.183	0.525	0.055	0.079	18.459	14.930
30-Nov-08	0.079	-	0.093	-	0.172	-	0.050	-	0.029	-	0.005	-	1.363	-
11-Dec-08	0.219	-	0.165	-	0.384	-	0.103	-	0.116	-	0.017	-	6.393	-
29-Jan-09	0.164	-	0.012	-	0.177	-	0.035	-	0.129	-	0.020	-	7.951	-
19-Feb-09	0.251	-	0.118	-	0.370	-	0.077	-	0.174	-	0.081	-	18.490	-
14-Mar-09	0.131	-	0.136	-	0.267	-	0.050	-	0.082	-	0.020	-	3.660	-
9-Jun-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jun-09	0.103	-	0.043	-	0.146	-	0.049	-	0.055	-	0.009	-	1.947	-
13-Jul-09	0.232	-	0.028	-	0.260	-	0.067	-	0.164	-	0.018	-	4.532	-
20-Jul-09	0.256	0.137	0.138	0.043	0.394	0.181	0.178	0.021	0.078	0.117	0.009	0.008	1.087	1.082
23-Jul-09	0.560	0.094	0.303	0.004	0.864	0.098	0.227	0.006	0.333	0.088	0.030	0.008	12.154	1.097
27-Jul-09	0.754	0.000	0.183	0.000	0.937	0.000	0.441	0.000	0.314	0.000	0.049	0.000	7.959	0.000
31-Aug-09	0.078	0.002	0.023	0.000	0.101	0.002	0.033	0.000	0.045	0.002	0.006	0.000	1.636	0.036
11-Nov-09	1.690	-	0.969	-	2.659	-	0.612	-	1.078	-	0.164	-	25.494	-
20-Nov-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24-Nov-09	-	0.025	-	0.002	-	0.027	-	0.002	-	0.024	-	0.003	-	0.503
9-Apr-10	0.124	0.000	0.020	0.000	0.144	0.000	0.033	0.000	0.092	0.000	0.011	0.000	3.081	0.000
16-May-10	0.387	0.064	0.128	0.005	0.516	0.068	0.121	0.003	0.267	0.060	0.025	0.004	4.913	0.857
23-May-10	0.240	-	0.096	-	0.336	-	0.045	-	0.194	-	0.014	-	3.502	-

Table F.3. Nutrient and sediment loads for site C.

Date	TKN (lb/ac)		NO2-3-N (lb/ac)		TN (lb/ac)		NH4N (lb/ac)		Org N (lb/ac)		TP (lb/ac)		TSS (lb/ac)	
	Site C PFC	Site C Swale	Site C PFC	Site C Swale	Site C PFC	Site C Swale	Site C PFC	Site C Swale	Site C PFC	Site C Swale	Site C PFC	Site C Swale	Site C PFC	Site C Swale
6-Sep-08	0.502	-	0.350	-	0.852	-	0.203	-	0.300	-	0.071	-	8.789	-
16-Sep-08	0.071	-	0.067	-	0.139	-	0.034	-	0.037	-	0.005	-	0.403	-
25-Sep-08	0.787	-	0.493	-	1.280	-	0.350	-	0.436	-	0.122	-	14.238	-
4-Nov-08	0.058	-	0.062	-	0.120	-	0.029	-	0.029	-	0.005	-	0.694	-
14-Nov-08	1.293	-	0.224	-	1.517	-	0.146	-	1.147	-	0.069	-	13.206	-
2-Nov-08	ND	-	ND	-	ND	-	ND	-	ND	-	ND	-	ND	-
11-Dec-08	0.083	-	0.134	-	0.217	-	0.040	-	0.043	-	0.008	-	1.432	-
28-Jan-09	0.079	-	0.032	-	0.111	-	0.052	-	0.027	-	0.004	-	0.234	-
18-Feb-09	0.293	-	0.174	-	0.467	-	0.197	-	0.096	-	0.045	-	3.399	-
10-Jun-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-Jun-09	0.356	-	0.098	-	0.454	-	0.092	-	0.264	-	0.021	-	2.504	-
13-Jul-09	0.260	-	0.189	-	0.448	-	0.168	-	0.092	-	0.027	-	2.115	-
21-Jul-09	0.355	-	0.146	-	0.502	-	0.214	-	0.142	-	0.015	-	1.204	-
23-Jul-09	0.372	-	0.277	-	0.649	-	0.162	-	0.210	-	0.032	-	3.211	-
27-Jul-09	0.457	-	0.205	-	0.662	-	0.247	-	0.210	-	0.030	-	4.620	-
31-Aug-09	0.273	-	0.124	-	0.397	-	0.134	-	0.139	-	0.022	-	3.051	-
11-Nov-09	2.447	-	2.316	-	4.762	-	1.218	-	1.229	-	0.385	-	25.448	-
20-Nov-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24-Nov-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24-May-10	0.069	-	0.042	-	0.111	-	0.040	-	0.028	-	0.003	-	0.252	-

Table F.4. Nutrient and sediment loads for site D.

Date	TKN (lb/ac)			NO2-3-N (lb/ac)			TN (lb/ac)			NH4N (lb/ac)			Org N (lb/ac)			TP (lb/ac)			TSS (lb/ac)		
	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale	Site D PFC	Site D VFS	Site D Swale
25-Sep-08	0.17	-	-	0.17	-	-	0.33	-	-	0.03	-	-	0.13	-	-	0.03	-	-	4.21	-	-
3-Nov-08	0.08	0.16	-	0.11	0.08	-	0.18	0.24	-	0.04	0.05	-	0.04	0.11	-	0.01	0.03	-	1.44	0.75	14.58
14-Nov-08	0.31	-	-	0.34	-	-	0.65	-	-	0.11	-	-	0.20	-	-	0.06	-	-	10.66	-	-
2-Dec-08	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-Dec-08	-	0.25	-	-	0.02	-	-	0.29	-	-	0.02	-	-	0.23	-	-	0.06	-	-	7.83	-
28-Jan-09	0.12	0.05	-	0.06	0.02	-	0.17	0.06	-	0.07	0.02	-	0.04	0.03	-	0.01	0.01	-	0.33	-	-
28-Feb-09	0.86	-	-	0.75	-	-	1.61	-	-	0.45	-	-	0.41	-	-	0.13	-	-	9.87	-	-
16-Jun-09	0.11	-	0.29	0.08	-	0.01	0.19	-	0.29	0.05	-	0.01	0.05	-	0.28	0.01	-	0.03	0.85	-	4.25
14-Jul-09	-	0.09	-	-	0.02	-	-	0.11	-	-	0.01	-	-	0.08	-	-	0.02	-	-	2.15	-
17-Jul-09	-	1.12	0.20	-	0.35	0.10	-	1.47	0.30	-	0.30	0.05	-	0.81	0.15	-	0.25	0.04	-	24.92	5.07
23-Jul-09	-	-	0.22	-	-	0.07	-	-	0.28	-	-	0.05	-	-	0.17	-	-	0.03	-	-	4.08
27-Jul-09	0.19	0.49	0.13	0.10	0.09	0.03	0.29	0.58	0.16	0.09	0.03	0.01	0.10	0.45	0.12	0.02	0.08	0.02	1.63	5.59	2.99
31-Aug-09	0.21	0.18	-	0.18	0.05	-	0.39	0.24	-	0.11	0.02	-	0.10	0.17	-	0.02	0.03	-	1.24	2.47	-
11-Nov-09	0.59	0.96	-	3.53	0.26	-	4.13	1.22	-	0.07	0.06	-	0.52	0.90	-	0.07	0.32	-	4.68	7.29	-
20-Nov-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24-Nov-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9-Apr-10	0.20	1.44	0.14	0.05	0.53	0.02	0.25	1.97	0.16	0.05	0.23	0.01	0.14	1.22	0.13	0.02	0.23	0.02	2.59	21.60	4.61
18-May-10	1.88	5.86	0.49	0.50	1.10	0.01	2.38	6.96	0.50	1.10	1.60	0.08	0.78	4.26	0.42	0.14	1.26	0.08	28.52	42.91	4.40
24-May-10	-	-	0.54	-	-	0.12	-	-	0.66	-	-	0.04	-	-	0.50	-	-	0.05	-	-	9.93

Appendix G: Cumulative Probability Plots.

Cumulative probability plots are presented below in Figures G.1-G.12. They are created by ranking effluent concentrations from each SCM. Ranked concentrations are then regressed against the relative probability of that data point occurring. They are an excellent exploratory tool for water quality data, and provide an idea of the variation, range, and distribution of the data. For TN, TP, and TSS, there appeared to be little improvement in expected concentrations at low pollutant concentrations. As pollutant concentrations increased at the edge-of-pavement, there was a better chance of pollutant removal by either the swale or filter strip. In general, about than 80% of the edge-of-pavement TN samples exceed the water quality benchmark of 0.99 mg/L. This percentage was improved to 40% by the two wetland swales (sites B and C), with little improvement observed in the dry swales or filter strips. At sites A and C, 80% of the sampled storm events for TP met the good water quality metric at the edge-of-pavement. The swales produced consistently similar ranked concentrations when compared against the edge-of-pavement. TP effluent concentrations were generally higher for the filter strips when compared against the other SCMs. At the four sites, the edge-of-pavement concentrations met the 25 mg/L TSS benchmark between 70-100% of the sampled events. At three of the four sites, the upper quartile of concentrations produced by the swales was much higher than the upper quartile of concentrations produced by the PFC. This means that the PFC produced a more consistent sediment concentration. TSS concentrations for the filter strips were generally higher than the PFC, due to re-suspension of sediment in the filter strip, possibly due to poor vegetative cover.

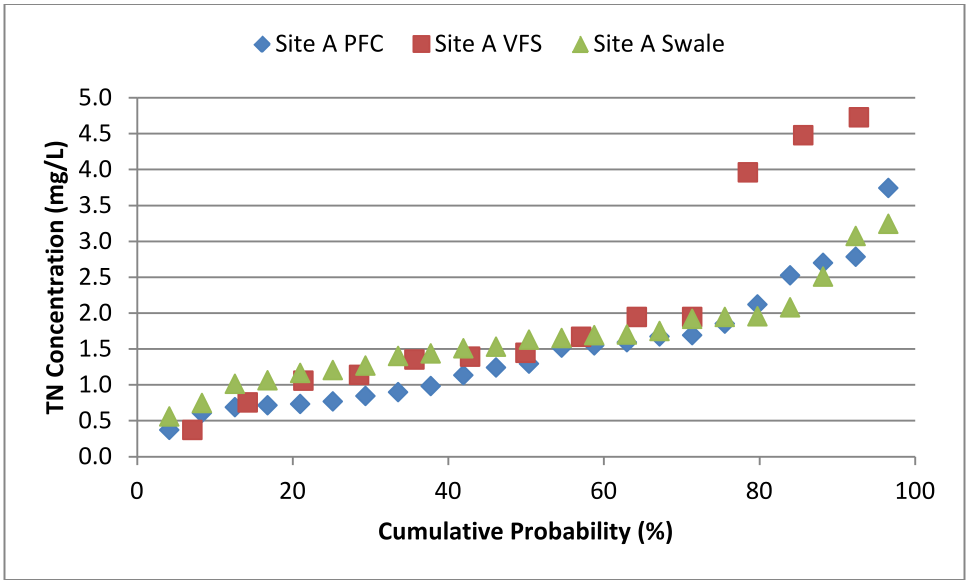

Figure G.1. Cumulative probability plot for TN at site A.

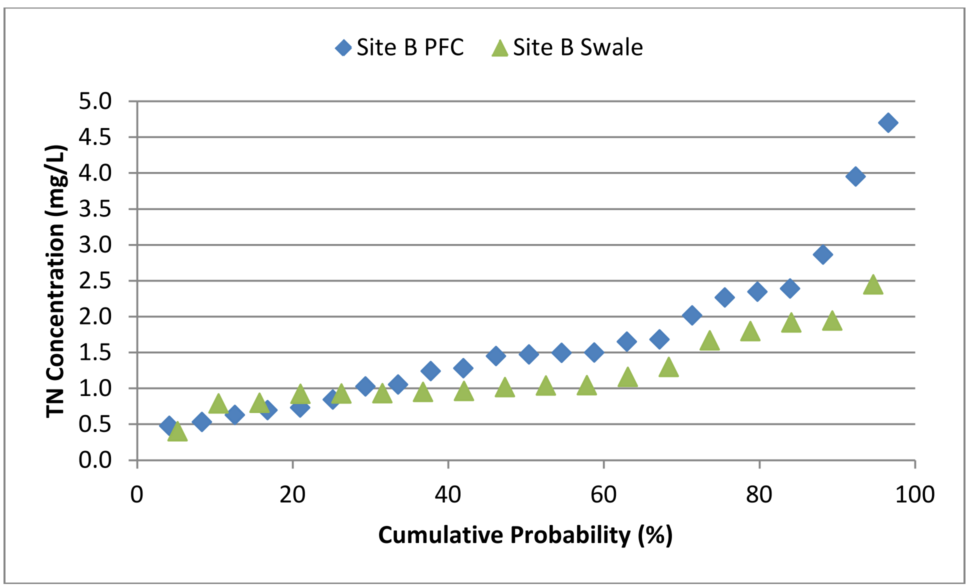

Figure G.2. Cumulative probability plot for TN at site B.

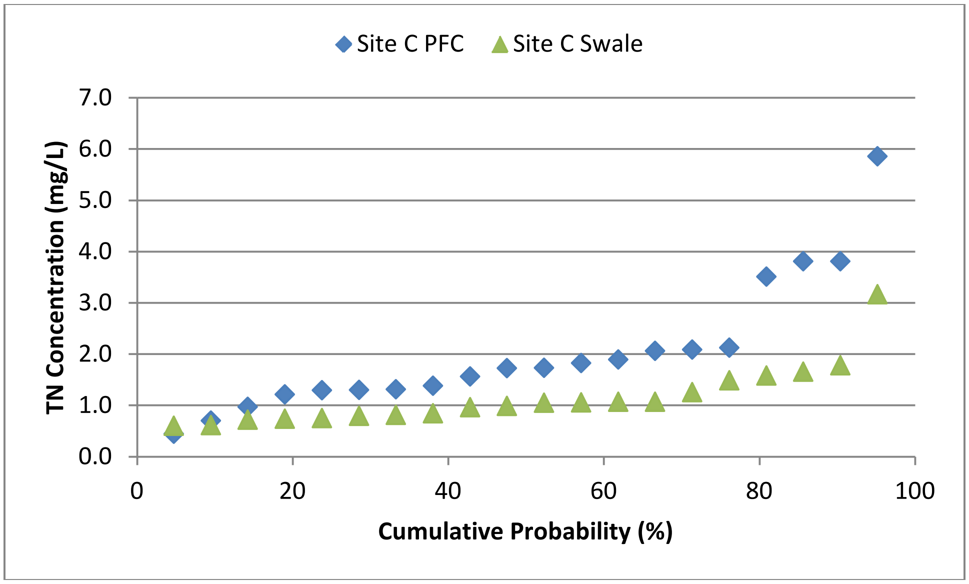

Figure G.3. Cumulative probability plot for TN at site C.

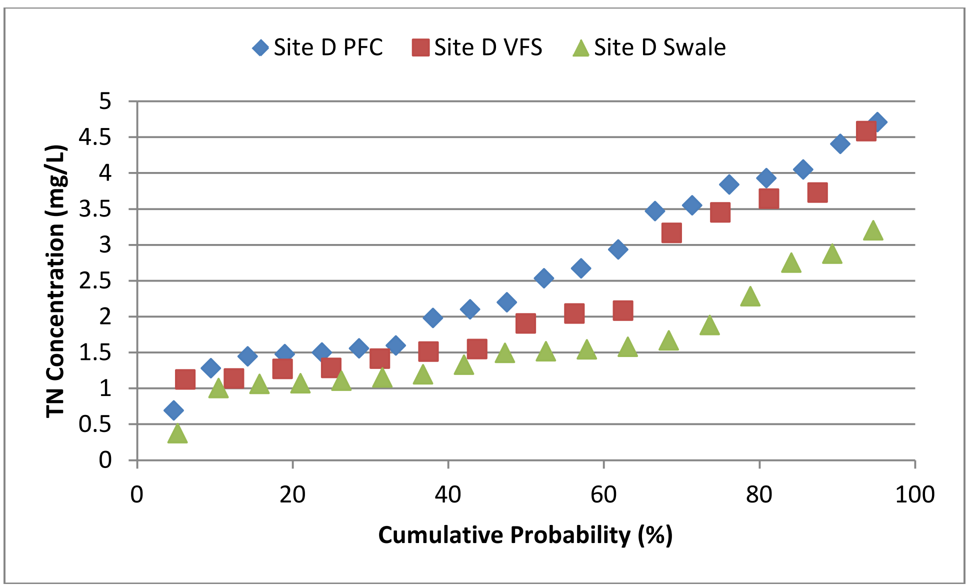

Figure G.4. Cumulative probability plot for TN at site D.

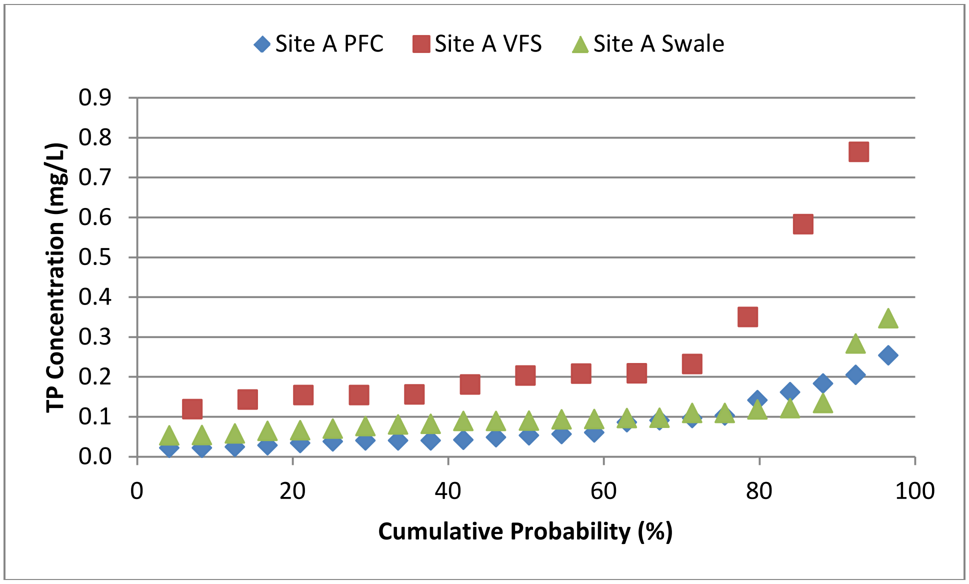

Figure G.5. Cumulative probability plot for TP at site A.

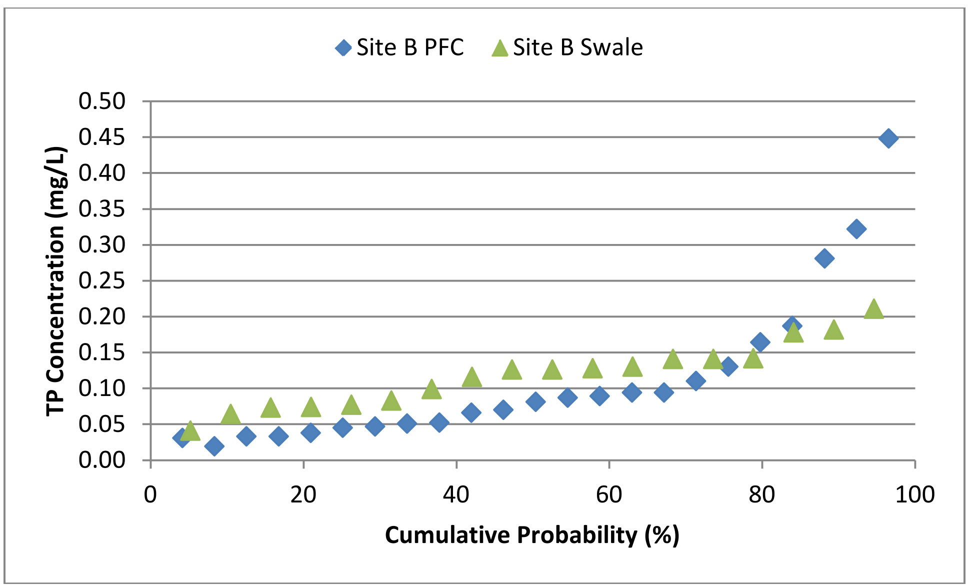

Figure G.6. Cumulative probability plot for TP at site B.

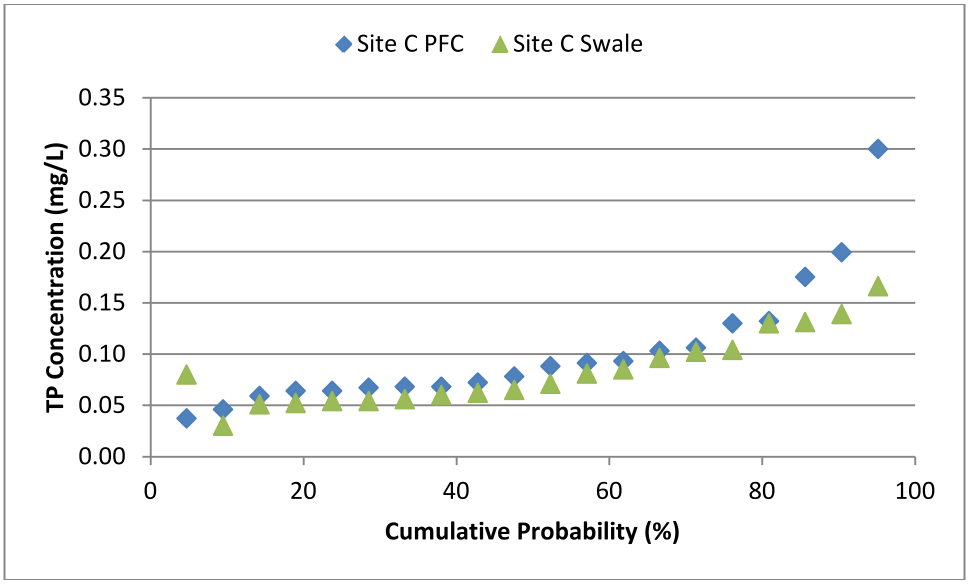

Figure G.7. Cumulative probability plot for TP at site C.

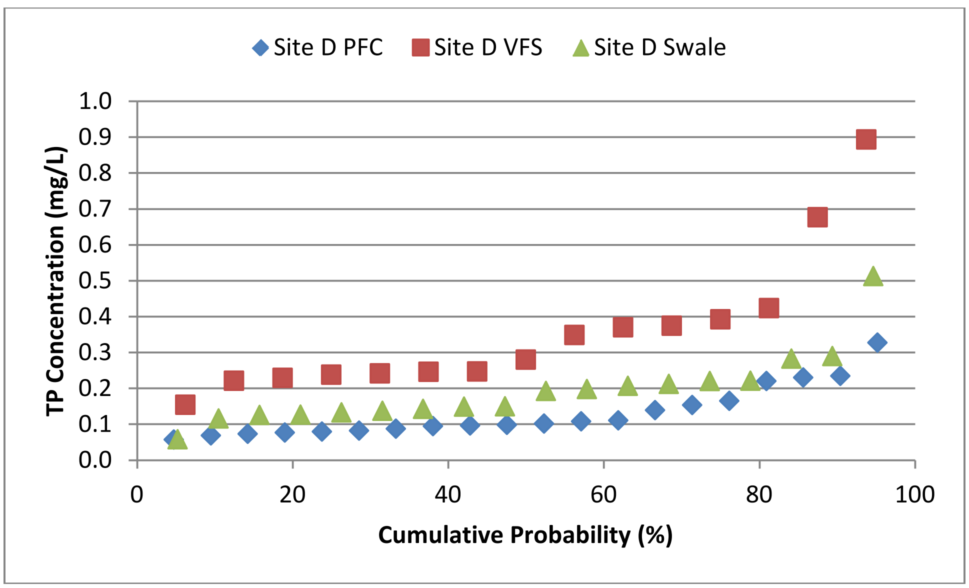

Figure G.8. Cumulative probability plot for TP at site D.

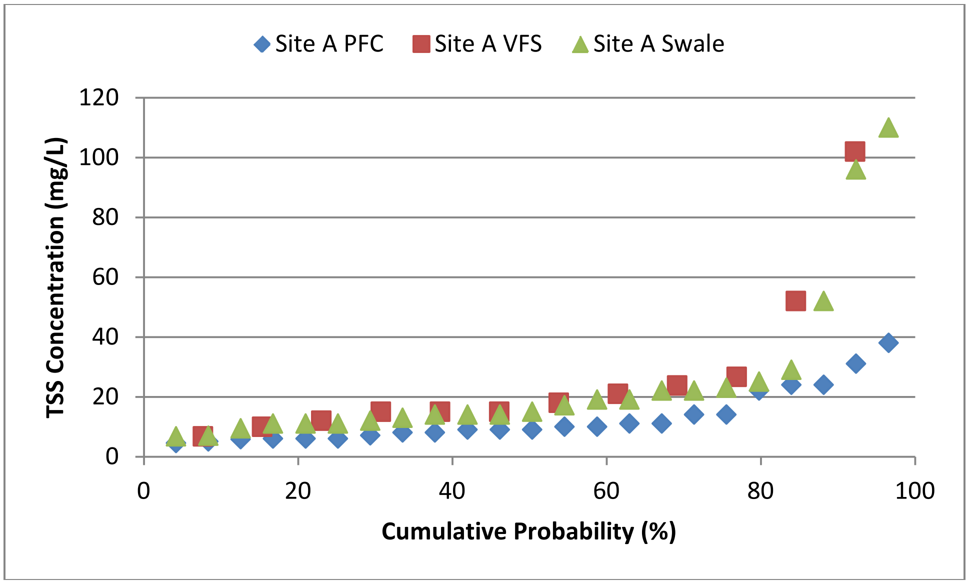

Figure G.9. Cumulative probability plot for TSS at site A.

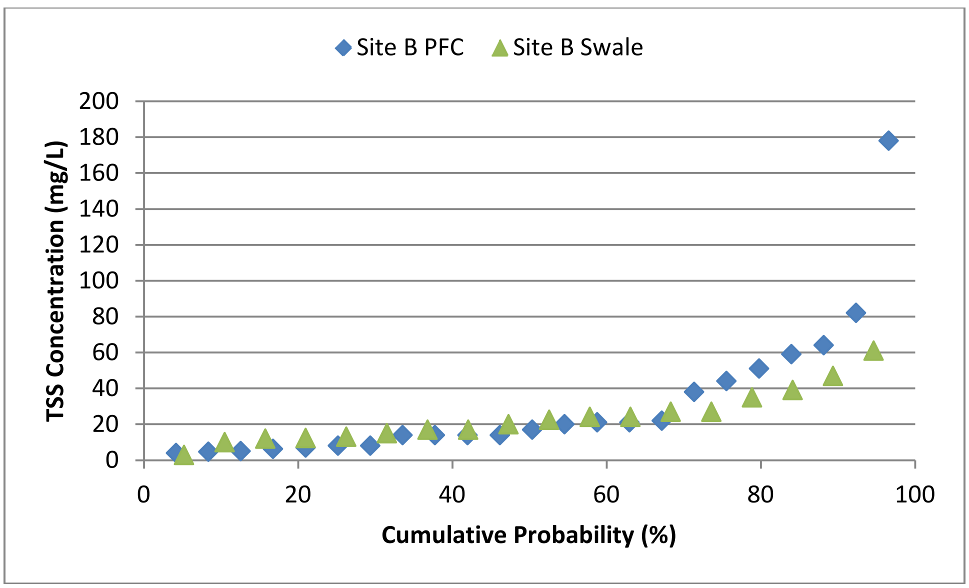

Figure G.10. Cumulative probability plot for TSS at site B.

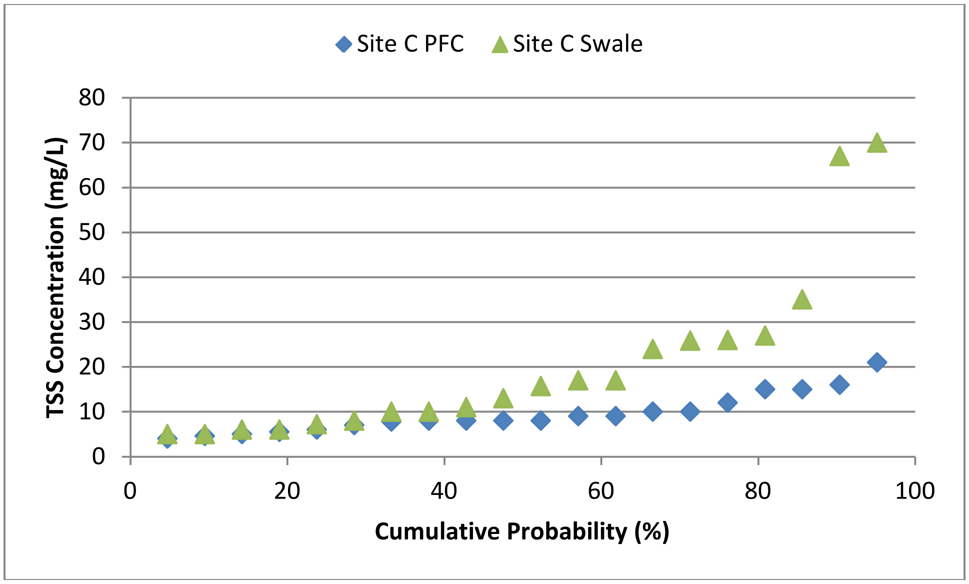

Figure G.11. Cumulative probability plot for TSS at site C.

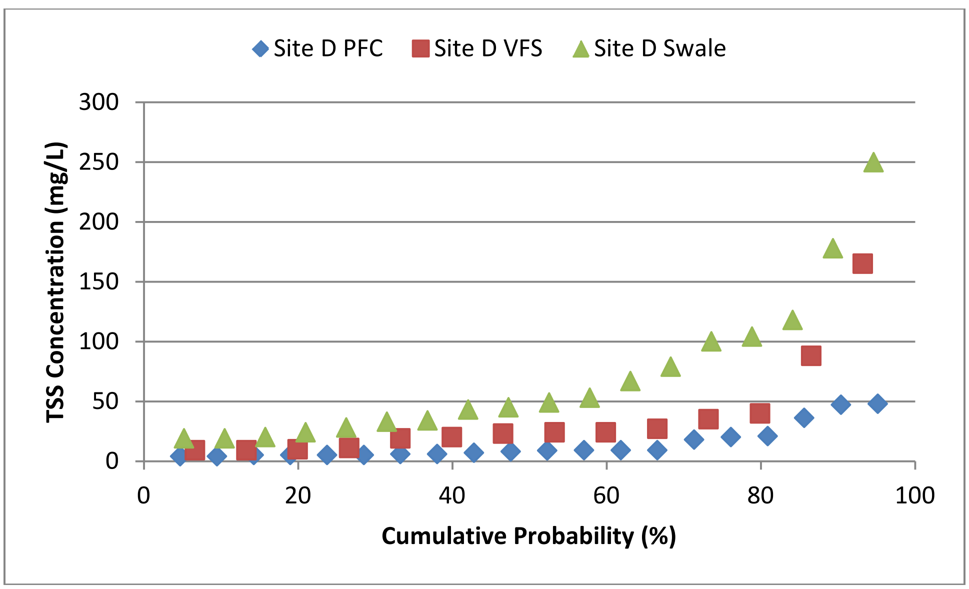

Figure G.12. Cumulative probability plot for TSS at site D.