Contract Research

GDOT PROJECT NO. 07-27
Final Report

STORMWATER CONTROLS FOR POLLUTANT REMOVAL ON GDOT RIGHT-OF-WAY

Susan E. Burns, Ph. D., P.E.
Professor
School of Civil and Environmental Engineering
Georgia Institute of Technology

Contract with
Department of Transportation
State of Georgia

Georgia Department of Transportation
Office of Materials and Research
15 Kennedy Drive
Forest Park, Georgia 30297-2599

April 11, 2012

Acknowledgements

The P.I. is pleased to acknowledge the contributions of Mr. Aditya Bhatt and Mr. Christopher Gray, who worked as graduate research assistants on this project. Thanks to Mr. Bradley R. Ehrman, P.E., and Mr. Jon D. Griffith, P.G., P.E., for their continued dedication and significant contributions in the formulation of this project and throughout the course of this work.

Abstract

The Georgia Department of Transportation (GDOT) operates a large number of roadside stormwater treatment facilities to contain and treat roadside stormwater runoff. The stormwater best management practices (BMPs) were designed with an emphasis on the removal of suspended solids to reduce the turbidity loading on streams receiving discharge. This investigation was funded to perform monitoring of the stormwater quality leaving currently operating roadside stormwater treatment facilities on GDOT right-of-way. The study objective was to quantify the level of contamination leaving GDOT right-of-way, as well as the change in pollutant levels between the inlet and the outlet of the treatment facilities.

Two permanent BMPs for collecting and treating runoff from the right-of-way of two state routes were monitored during the course of this study. One site is in the City of Canton and was monitored during construction of both an interchange improvement and an adjacent upstream shopping complex and after construction. The motivation for the construction of the Canton sand filter was to detain and treat roadway runoff being discharged to the habitat of the threatened Cherokee darter fish, which is a species endemic to the Etowah River system in North Georgia. The sand filter was constructed under an agreement between GDOT and the U.S. Fish and Wildlife Service. The other site is along McGuiness Ferry Road and was monitored during the construction phase only. Automatic samplers were used to collect first-flush samples, as well as composited flow-weighted samples for analysis. The in-situ parameters pH, temperature, and conductivity of the Canton sand filter were measured for 24 months at an interval of five minutes using in-situ measurement probes during construction.

Wavelet analysis of the data gathered from the Canton sand filter during the construction phase demonstrated that the effects of the concrete pours during culvert construction could be

detected in-stream with a transitory increase in the pH; however, turbidity did not show any significant change in value during the period of active construction, indicating that the solids generated during construction were well contained on the construction site. Background data from sampling performed at the Canton site after the conclusion of construction were consistent with the in-stream data gathered during the construction phase of the GDOT project.

Monitoring of the inflow and outflow concentrations at the Canton Creek BMP yielded the following results:

- The stormwater was being detained in the BMP longer than the 24-hour design residence time.
- Temperature of the stormwater decreased as water flowed through the sand filter; however, the temperature of the first-flush water directly leaving the road surface never exceeded the 90°F criteria in the state standards (note sampling was not performed during peak summer temperatures).
- pH values typically increased as the stormwater flowed from the inlet to the outlet of the sand filter, and were within the state standards of 6.0-8.5 in all but two measurements.
- Conductivity measured at the outlet was consistently higher than the conductivity at the inflow demonstrating a 5% to 25% between the inlet and the outlet, indicating that the stormwater was mobilizing ions as it flowed through the sand filter.
- Suspended solids (75%-95% reduction) and turbidity (20%-95% reduction) were consistently reduced between the inlet and the outlet of the BMP.
- Nutrient levels of nitrogen and phosphorus were consistently reduced between the inlet and the outlet of the BMP, indicating a reduction of at least 50% in half of the storm

events. However, the fact that some storm events showed increases in nutrient levels is important to note. This may indicate fertilization and maintenance on the filter surface.

- Lead and zinc concentrations were consistently reduced between the inlet and the outlet of the BMP.
- Copper concentrations increased within the BMP, suggesting a source of copper within the sand filter.
- The measured levels of dissolved copper, lead, and zinc measured at the inlet and outlet of the Canton sand filter were compared with the Georgia Environmental Protection Division (EPD) general in-stream criteria for all waters (EPD, 391-3-6-.03). The data demonstrated that the levels of lead coming from the roadway were low, as indicated by the "below detection limit" concentrations measured in all cases for the influent to the pond. For pond effluent, there were three instances of dissolved lead detectable at the outflow, with the lead concentration measured on the February 28, 2011, event exceeding the standard for both acute and chronic concentration. In 7 out of 9 storm events, the influent concentration of copper was below detection limits, but exceeded the acute and chronic concentrations in the last storm event in April 2011 and the chronic level in the event on 4/11/2011. However, the effluent copper concentration exceeded both the acute and chronic concentrations in five out of nine storm events. Dissolved concentrations of zinc did not exceed the standards (acute or chronic) in any of the nine storm events monitored.

Monitoring data gathered at the McGinnis Ferry Road BMP during the fall/winter of 2011 demonstrated an increase in the suspended solids, turbidity, total nitrogen, and NO_x concentrations measured between the BMP inlet and outlet, with conductivity and total phosphorus remaining largely unchanged in concentration between the inlet and outlet.

Construction activity was ongoing at the BMP location during monitoring, and it is believed that the transitory site conditions contributed to the observed anomalous results at the McGinnis Ferry site. This location should be monitored again in the future, once the conditions have stabilized.

In summary, the data gathered at the Canton sand filter indicate:

- Erosion control measures enacted during the interchange construction were effective, with only transitory increases in the pH of the river detected during concrete pours.
- Temperature and pH values measured for roadway runoff (filter influent) and at the filter effluent were consistent with state standards.
- The filter decreased suspended solids and turbidity discharging to the receiving stream, and in about half the cases, decreased the nutrient load; however, the conductivity increased between the filter influent and effluent.
- The levels of dissolved metals (copper, lead, zinc) coming from the roadway were low, with only copper exceeding state standards in two storm events. Effluent dissolved concentrations of lead and zinc were below state standards in all but one instance, while effluent dissolved copper exceeded state standards in five events. The cause of the suspected source of copper within the filter design should be identified and prevented in future sand filter construction projects.

Abbreviations

Annual average daily traffic (AADT)

Average daily traffic (ADT)

Best management practice (BMP)

Biochemical oxygen demand (BOD)

Chemical oxygen demand (COD)

Discrete wavelet transform (DWT)

Edge of pavement (EOP)

Event mean concentration (EMC)

Extended detention (ED)

Maximal overlap discrete wavelet transform (MODWT)

Natural attenuation (NA)

Total dissolved solids (TDS)

Total Kjeldahl nitrogen (TKN)

Total phosphorous (TP)

Total suspended solids (TSS)

Vehicles during storm (VDS)

Table of Contents

List of Tables

List of Figures

1. INTRODUCTION

Stormwater runoff from impervious or low permeability pavements can transport environmental pollutants to sensitive receiving waters. The runoff from highway systems can contain elevated levels of a variety of contaminants including suspended solids, phosphorous, nitrogen, fecal coliform, salts, heavy metals, organics, and oil and grease, all of which can be at least partially immobilized in stormwater controls. The Georgia Department of Transportation (GDOT) has constructed a variety of roadside stormwater treatment facilities to contain and treat roadside runoff, with an emphasis on the removal of suspended solids. This investigation was funded to perform monitoring of stormwater quality leaving currently existing roadside stormwater treatment facilities on GDOT right-of-way. The study objective was to quantify the level of contamination leaving GDOT right-of-way, as well as the change in pollutant levels between the inlet and the outlet of the treatment facilities.

Several questions in relation to the stormwater runoff at two locations adjacent to GDOT roadways were investigated in this work: What are the primary pollutants from Georgia roads that need remediation before discharge to receiving waters? What are the optimal removal mechanisms for each pollutant? Are passive remediation techniques and processes, including natural attenuation (NA), sufficient to reduce pollutant load to receiving waters? Are current commercially available stormwater controls effective in reducing pollutant loads effectively or should alternative stormwater controls be developed? What currently available controls conform to the significant space and usage restrictions in a GDOT right-of-way?

This report includes a review of the type of pollutants and their sources that are typically encountered on roadways, along with the factors that affect highway runoff quality and existing post construction structural stormwater controls used to attenuate or treat stormwater runoff. Stormwater monitoring, existing stormwater monitoring practices, in-situ monitoring equipment, flow measurement and rainfall measurement techniques are also reviewed. Finally, the results of the Canton Creek monitoring by GDOT during construction and post-construction monitoring by Georgia Tech are presented and discussed. Sand filter monitoring and detention pond monitoring, as well as in-situ and laboratory results of the samples collected during the rain events pertaining to these locations are presented. The quality of stormwater runoff from two state routes is discussed in the next section. Also, the performance of the two structural stormwater controls is analyzed for the removal of conventional parameters, heavy metals, and nutrients. Additionally, guidance by application to aid in the selection of the most appropriate post-construction structural stormwater control is included in this report; and recommendations for maintenance of structural stormwater controls used in GDOT applications are given.

2. HIGHWAY RUNOFF

2.1 Pollutants and Sources

Pollutants can be deposited on roadways under wet or dry conditions and typically result from sources such as pavement and vehicle wear, exhaust, litter, deicing compounds, and atmospheric deposition. Contaminants that are captured in stormwater best management practices (BMPs) can remain permanently bound to the matrix material, or can be removed through processes such as wind erosion, maintenance, or future stormwater events. A brief summary of processed that influence the mass flow of pollutants in urban catchments is given in Figure 1.

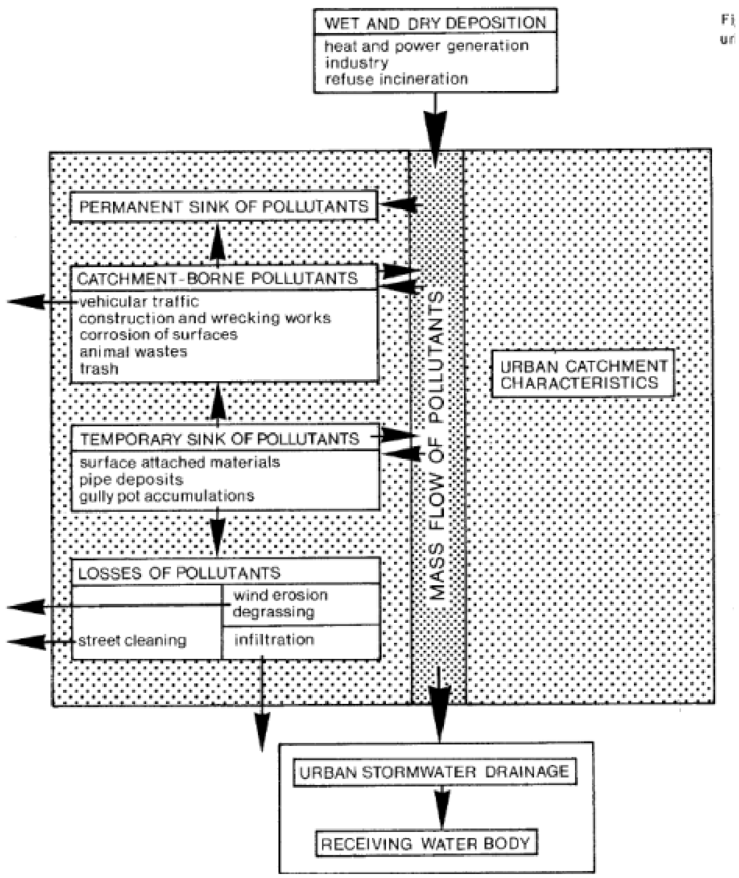

Figure 1. Mass flow of pollutants in urban catchments (Source: Brinkmann, 1985).

In general, the contaminants that are of most concern in roadside stormwater runoff are categorized into physical contaminants (e.g., suspended or dissolved solids), inorganic contaminants (e.g., heavy metals and nutrients), organic contaminants (e.g., pesticides, oil, and grease), microbial (e.g., fecal coliform and E. Coli), and other chemical parameters (e.g., chemical or biochemical oxygen demand). Table 1 is a summary of the stormwater pollutants most commonly encountered in highway runoff, along with their source. For comparative purposes, the mean loadings of pollutants reported in the literature are reported, along with the Environmental Protection Agency's (EPA) prescribed drinking water limits. Finally, treatment methods commonly used to treat each pollutant/pollutant category are included in the table.

Table 1. Typical Stormwater Pollutants and Sources

Pollutant	Source	Mean loading (mg/l)	Range (mg/l)	EPA Drinking Water limit (mg/l)	Treatment methods
Physical Contaminants					
a) Total solids	All particulates and dissolved contaminants	481-1440	76 - 36,200	-	Bioretention systems , stormwater wetlands
b) Total suspended solids	Pavement wear, atmospheric deposition, maintenance, vehicles	4-1223, 100[14]	1.0 - 36,200	-	permeable friction course stormwater ponds sand filters
c) Total dissolved solids	Pavement wear, atmospheric deposition	178	75.9 - 2,792	500	Vegetated roadsides appear to effectively remove TSS
Inorganic Chemical Contaminants					
a) Arsenic	Some pesticides, weed killers	0.024-0.21	0.001 - 0.21	0.01	Processes involved are precipitation, dissolution,
b) Asbestos	Wear of clutch and brake linings in vehicles, water mains	-	-	7 x 10^6 fibres/l	adsorption, deposition, dissociation, transformation, complexation and biochemical
c) Cadmium	Wear of tires and break pads, combustion of lubricating oils, insecticide application, corrosion	0.0003 to 0.011	0.00005 - 13.73	0.005	reactions. Biofiltration, infiltration trenches
d) Calcium	Road deicing	4.8 to 26.5	0.04 - 2113.8	-	constructed wetlands are the efficient BMP's to remove
e) Chloride	Deicing salts, road ballast, pesticides	33	0.3 - 25000	250	heavy metals
f) Chromium	Metal plating, moving parts, brake lining	0.01 - 0.23, 0.022[3]	0.001 - 2.3	0.1	Constructed wetlands,

Pollutant	Source	Mean loading (mg/l)	Range (mg/l)	EPA Drinking Water limit (mg/l)	Treatment methods
	wear				biological uptake in wet ponds are efficient in removal
g) Copper	Metal plating, bearing and brushing wear, moving engine parts, brake lining wear, fungicides and insecticides	0.0065 - 0.15, 0.034[14]	0.00006 - 1.41	1.3	of nitrogen and phosphorous from the stormwater
h) Iron	Auto rust, steel highway structures (guard rails), moving engine parts	0.988 - 12.0, 7.63[3]	0.08 - 440.0	0.3	Oil and Grease can be removed by using manufactured separators or oil and grease traps
i) Lead	Auto exhaust, tire wear, lubricating oil and grease, bearing wear	0.0209 - 1.558, 0.144[14]	0.00057 - 26.00	0.015	
j) Manganese	Wear of tires and brake pads	0.11 to 0.67	0.007 to 3.80	0.05	
k) Mercury	Batteries, paints	15.42 μg/l	0.00005 - 0.067	0.002	
l) Nickel	Diesel fuel and petrol exhaust, lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving	0.006 - 0.015	0.001 - 49.0	0.05 - 1.0	
m) Nitrogen					
i) Total nitrogen		-	0.32 - 16.0	-	
ii) Inorganic nitrogen		-	0.09 - 5.44	-	
iii) Organic nitrogen	Fertilizers, animal excrement, vegetation	-	0.32 - 16.0	-	

Pollutant	Source	Mean loading (mg/l)	Range (mg/l)	EPA Drinking Water limit (mg/l)	Treatment methods
iv) Nitrate	matter, litter	} 0.84[3], 0.68[14]	0.01 - 12.0	10	
v) Nitrite			0.02 - 1.49	1	
vi) Ammonia		-	0.01 - 4.3	-	
vii) Total Kjeldahl nitrogen*(includes organic N, ammonia and ammonium)		1.7, 2.3 [12]	0.32 - 16.0	-	
n) Sodium	Deicing salts	-	0.18 - 660	200	
o) Sulphate	Atmospheric deposition by precipitation (acid rain), fertilizers	-	0.06 - 1252	250	
p) Total Phosphorous	Tree leaves, fertilizers, lubricants	0.015 to 0.82, 0.435[3]	0.01 to 7.30	-	
q) Zinc	Tire wear, motor oil, grease	0.0166 - 0.58, 0.160[14]	0.0007 - 22.0	5	
Other Chemical Parameters					
a) Biochemical oxygen demand	Biological organisms	23	1.0 - 7700.0	-	BOD can be removed using treatment wetlands [11].
b) Chemical oxygen demand	Organics	103, 65[14]	7.0 - 2200.0	-	Alum treatment systems result in efficient removal.
c) pH	-	6.5[3]	4.5 - 8.7	6.5 - 8.5	
Organic Contaminants					
a) Total Polycyclic aromatic	incomplete combustion of organic material,	-	0.00024 - 0.013	-	Most of the organic matter

Pollutant	Source	Mean loading (mg/l)	Range (mg/l)	EPA Drinking Water limit (mg/l)	Treatment methods
hydrocarbons	gasoline				can be removed using dry detention basins and wet retention ponds.
b) Benzo (a) pyrene	leaching	1.1µg/l [15]	2.5E-6 - 1E-2	0.0002	
c) Polychlorinated bi phenyl	leaching of lubricants, hydraulic fluids, landfills	-	2.7E-5 - 1.1E-3	0.0005	Organics are removed in wet retention ponds by biological breakdown using bacteria [10].
d) Benzene	spills and combustion of fuels	-	0.0035 -0.013	0.005	Infiltration techniques are also helpful in removing dissolved organic substances . [10]
e) Pentachlorophenol	decomposition of wood preservative products	-	0.001 to 0.115	0.001	
f) Ethylene glycol	deicing agent		3.4 mg/m^3 (in air)	-	
g) Oil and Grease	Leaks, spills, asphalt surface leachate, anti- freeze and hydraulic fluids, blow- by of motor lubricants	15	0.001 - 110	-	
Microbial Contaminants					
a) Fecal coliforms	fecal material deposited from dogs, cats rodents, and birds onto soil, pavement and cross sections	$1.6\times10^2 – 2.5\times10^5$ CFU/100ml	0.2 - 1.9E6 CFU/100ml	-	Stormwater ponds [9], stormwater wetlands [8],[9], infiltration trenches [9] dry detention basins [10]
b) E Coli	fecal matter	-	1.2×10^1 - 4.7×10^3 CFU/100ml	-	

2.2 Factors Affecting Highway Runoff

Runoff from highways contains pollutants that span a range of concentrations, depending on the contaminant and deposition environment. These variations can be attributed to the following factors: traffic volume, precipitation, type of road surface, and site specific factors.

2.2.1 Traffic Volume:

The traffic volume on a road plays an important role in determining the concentration of pollutants in highway runoff. Vehicles play a dual role with respect to pollutant concentration on road surfaces: (1) they serve as a source for the accumulation of pollutants on road surfaces; and (2) they create pollutant-disseminating air turbulence due to their motion and cause the removal of solids from the road surfaces for deposition elsewhere (Barrett et al., 1995). Therefore, a clear relationship between pollutant concentrations and the Average Daily Traffic (ADT) has not been established. As a result, some investigators use vehicles during a storm (VDS) as an indicator of traffic volume (Huber et al., 2006). The variation of mean total suspended solids (TSS) with annual average daily traffic yields a weak correlation that breaks down at an AADT of about 100 K/day (Figure 2). The data in the vicinity of 100 K/day suggest a physical equilibrium is reached.

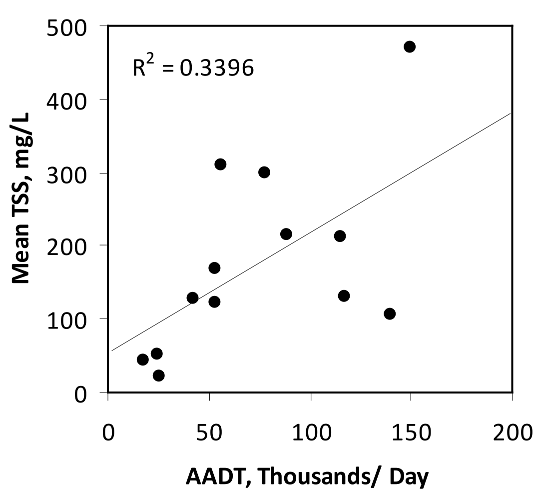

Figure 2. Total suspended solids as a function of AADT (Huber et al., 2006).

Pollutant concentrations for sites with varying traffic levels are shown in Table 2 . In general, event mean concentrations (EMCs) from urban highways are greater than rural highways, although it is important to note that some studies have noted increased levels of TSS, chemical oxygen demand (COD), total dissolved solids (TDS), turbidity, ammonia and diazinon EMCs in rural highways compared to urban highways (Kayhanian et al., 2003).

Table 2. Site Median Concentrations in mg/l (adopted from Driscoll et al., 1990)

Pollutant	Urban Highways ADT > 30,000	Rural Highways ADT < 30,000
Total Suspended Solids	142	41
Volatile Suspended Solids	39	12
Total Organic Carbon	25	8
Chemical Oxygen Demand	114	49
Nitrate+ Nitrite	0.76	0.46
Total Kjeldahl Nitrogen	1.83	0.87
PO_4^{3-}	0.4	0.16
Copper	0.054	0.022
Lead	0.4	0.08
Zinc	0.329	0.08

2.2.2 Precipitation:

The main storm event related factors that influence the concentration of pollutants in the stormwater are (1) the length of the antecedent dry weather period preceding a storm event, (2) the intensity of the storm, and (3) the duration of the storm. The effect of an antecedent dry period on the concentration of pollutants in the runoff has been reported in various studies. Hewitt and Rashed (1992) showed a relationship between the antecedent dry period and the concentrations of dissolved lead and dissolved copper. However, Horner (1979) found that the length of the antecedent dry period was not sufficient to predict TSS loadings, and ”removal processes such as air turbulence and volatilization, photo-oxidation processes, limit the accumulation of solids and other pollutants on road surfaces, thereby decreasing the importance of dry periods between storms" (Barrett et al.,1995). Again this suggests a physical equilibrium closely akin to chemical equilibrium. In general, contaminant concentrations in stormwater runoff are weakly correlated with the number of antecedent dry days (Figure 3).

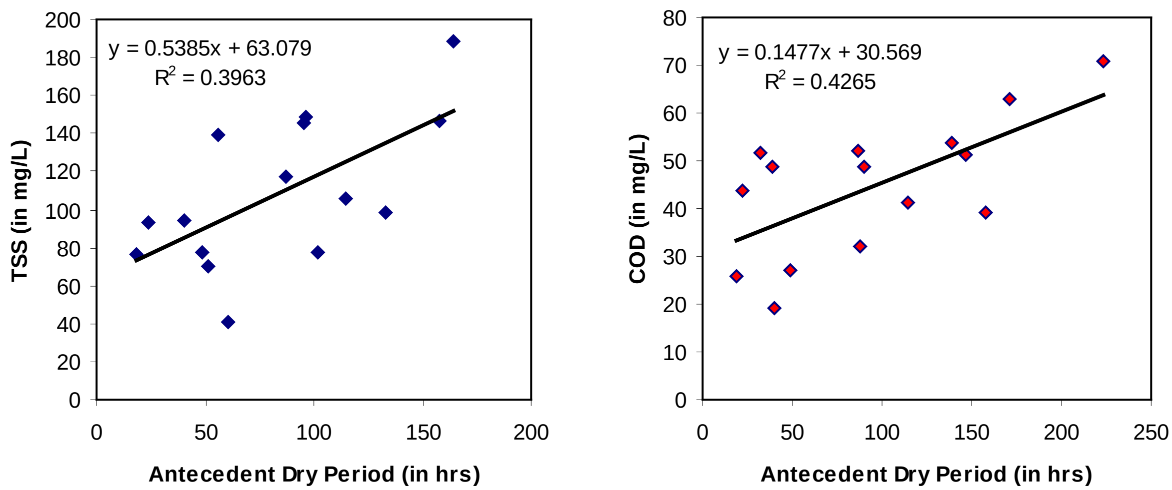

Figure 3. Effect of Antecedent Dry Period on the concentration of pollutants (Chui, 1997).

The intensity of a storm can be an important factor in determining the concentration of pollutants because many pollutants are associated with solids that are mobilized in high intensity storms (Barrett et al., 1995). Chui (1997) showed that both TSS and COD concentrations generally increase with increasing rainfall intensity, as storms with a higher rainfall intensity have a greater capacity to scour materials from exposed surfaces (Figure 4).

Concentrations of pollutants are generally greater during shorter low volume storms compared to larger storms, which dilute the highway runoff and lower the concentrations of pollutants. Even though the concentrations of pollutants in longer storms is lower, it is important to note that the pollutant loading is greater for storms with longer duration.

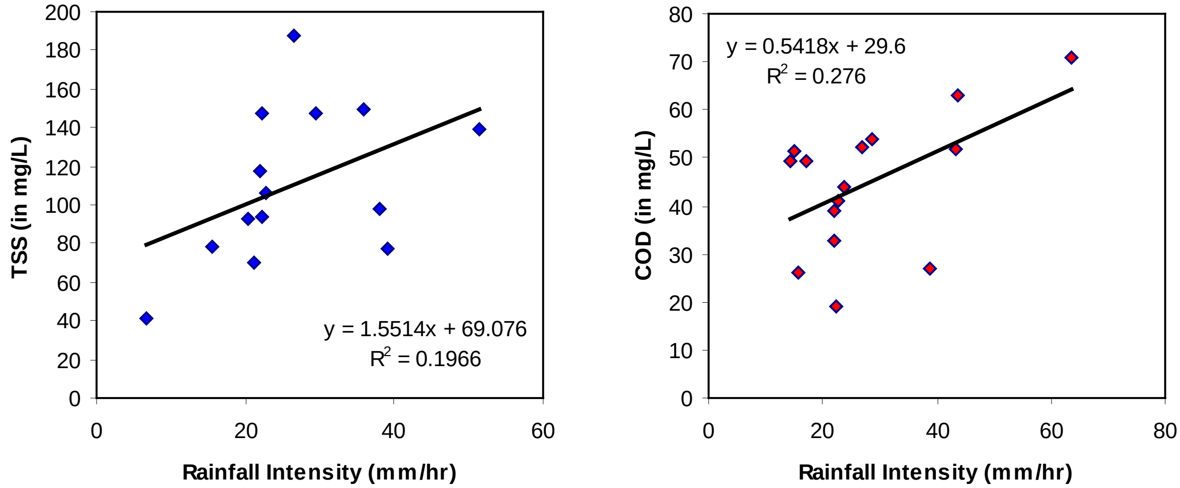

Figure 4. Effect of rainfall intensity on pollutant concentrations (Chui, 1997).

Higher concentrations of pollutants are generally observed during the initial timeframe of the highway runoff. This is known as the first-flush effect. Horner (1979) found that the concentrations of pollutants were both higher and highly fluctuating during the first hour of a storm event (Figure 5). Hewitt and Rashed (1992) concluded that the first-flush effect had a significant influence on the removal of metals in the road runoff waters. This effect is clearly seen for the dissolved metals, while the behavior of the particulate metals closely follows that of the total suspended solids. Sansalone and Buchberger (1997) concluded that a first flush occurred for all events for all solid fractions. For the metal elements, the solids first-flush behavior varied depending on whether the solids fraction was dissolved or suspended.

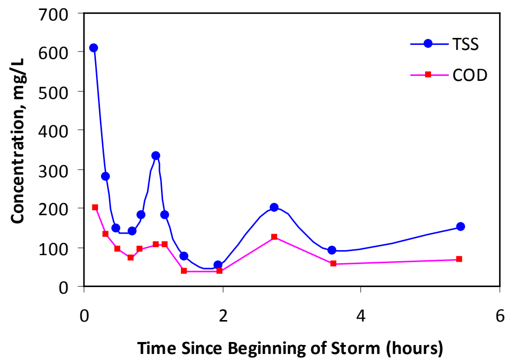

Figure 5. High pollutant concentrations during the initial part of the storm (Horner, 1979).

2.2.3 Highway Surface Type

Highway surface type is another factor that can influence the amount of pollutants present in the runoff. Gupta et al. (1981) concluded that oil and grease concentrations were higher in runoff from asphalt surfaces compared to other road surface types, though the study suggested that adjacent land use was the most important factor affecting the runoff quality. The annual pollutant loads from different highway surfaces are give in Table 3.

Table 3. Annual Pollution Export from Different Highway Surface Types (Gilbert and Clausen, 2006)

Pollutant	Asphalt (kg/ha/yr)	Paver (kg/ha/yr)	Crushed Stone (kg/ha/yr)
TSS	230.1	23.1	9.6
Nitrate	1.78	1.25	0.15
Ammonia	0.65	0.12	0.03
Total Phosphorous	0.81	0.25	0.04
Total Kjeldahl Nitrogen[1]	13.06	1.08	0.47

[1]Total Kjeldahl nitrogen is the sum of organic nitrogen, ammonia, and ammonium.

2.2.4. Site-Specific Factors

Maintenance practices and the efficiency with which they are applied also have some influence on pollutant loads. For example, maintaining the height of grassed areas at levels that result in the most efficient operation for overland flow and grassed swales enhances the retention of pollutants contained in highway runoff (Driscoll, 1990).

Deicing practices are another important factor that affects the concentration of pollutants. Studies have shown high chloride concentrations adjacent to roads where deicing is done during winters.

Institutional characteristics (e.g., litter ordinances, speed limit enforcement. car emission regulations) may be presumed to have some degree of influence on pollutant discharge levels, but they are very likely minor and are difficult to quantify.

The topographic cross-section of a highway segment is considered to have an influence on pollutants leaving the roadway on the basis of whether it tends to enhance or to restrict the wind-induced dispersion of pollutant accumulation on the road surface. For example, a greater net accumulation of deposits on the roadway for cut sections and less net accumulation for fill sections is expected (Driscoll, 1990). Net accumulation amounts vary among different sites.

Highway drainage conditions also affect the pollutant quantities that reach receiving waters. Runoff discharged directly into a receiving water body usually transfers higher concentrations of pollutants as opposed to roads where runoff is immediately collected by a stormwater drainage system. In such a system, particularly a lengthy system, attenuation of the pollutant concentrations would be effected to some extent by adsorption onto the system's substrate and onto any debris being carried through the system. Passing runoff through vegetated drainage channels also reduces contaminate concentrations (Driscoll, 1990).

2.3 Post-Construction Stormwater Controls

Post-construction stormwater controls can be divided into categories on the basis of the primary method of treatment including detention, filtration, or infiltration. These controls are summarized on Table 4--Table 6.

Table 4. Structural Stormwater Controls with Primary Treatment: Detention

S. No.	Technology	Description	Pollutant Removal	Construction Considerations	Remarks	Reference
1.	Stormwater Wetlands	1. Stormwater wetlands or constructed wetlands are vegetated detention areas that are designed and built specifically to remove pollutants from stormwater runoff. 2. Depending on their design, constructed wetlands can also serve to attenuate larger storm events and reduce peak flows 3. There are some variations in constructed wetlands- a) Shallow wetlands- most of the water quality treatment volume is in the relatively shallow high marsh or low marsh depths. b) Extended Detention Shallow Wetland- similar to shallow wetlands except part of the water quality treatment volume is provided as extended detention above the surface of the marsh and released over a period of 24 hours.	Total suspended solids 65–95% Total nitrogen 40–80% Total phosphorus 60–85% Coarse sediment > 95% Heavy metals 55–95%	Design Criteria for the four types of wetlands has been shown in the table(Iowa Storm Water Manual). Minimum of 35% of total surface area should have a depth of 6 inches or less; 10 to 20% of surface area should be deep pool (1.5- to 6-foot depth) If open water is to be included in the wetland, it should be less than 50% of the total wetland area	Requires large land area Sediment regulation is critical to sustain wetlands Replace wetland vegetation to maintain at least 50% surface area coverage	Section 2H1,General Information for Stormwater Wetlands, Iowa Stormwater Management Manual Section 5.2, Chapter 9, Structural Controls, Stormwater Manual for Western Australia, Deptt. Of Water Section 3.2.2, Stormwater Wetlands Georgia Stormwater Management Manual Volume II Chapter 3, Structural BMP Design Practices Swarna Muthukrishnan, Richard Field and Daniel Sullivan, The use of best management practices in Urban Watershed, USEPA

		c) Pond Wetland Systems- Two separate cells: A wet pond and a shallow marsh. The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland, where stormwater flows receive additional treatment. d) Pocket Wetland- intended for smaller drainage areas of 2-10 acres and typically requires excavation down to the water table for a reliable water source.			Treatment of Stormwater Runoff, Soil and Water onservation Society of Metro Halifax.

2.	Dry and Wet Detention	Dry Detention A dry detention or extended dry detention basin is a surface storage basin or facility designed to provide water quantity control through detention and/or extended detention of stormwater runoff.	Suspended solids, Phosphorous, Metals- 65% Nitrogen, Bacteriological, Hydrocarbons – 30%	Applicable for drainage areas up to 75 acres. The maximum depth of the basin should not exceed 10 feet. Vegetated embankments should be less than 20 feet in height and have side slopes no steeper than 3:1 (horizontal to vertical), although 4:1 is preferred. Riprap-protected embankments should be no steeper than 3:1.	Less costly than stormwater (wet) ponds for equivalent flood storage Controls for stormwater quantity only – not intended to provide water quality treatment. Used in conjunction with water quality structural control.	Section 2G2,2G3 Detention Systems, Iowa Stormwater Management Manual Chapter 9, Structural Controls, Stormwater Manual for Western Australia, Deptt. Of Water
		Wet Detention A wet detention basin is a constructed stormwater detention basin that has a permanent pool of water. Runoff from each rain event is detained and treated in the pool primarily through settling and biological uptake	Total suspended solids – 85% Total phosphorus – 50%	A minimum of 25 acres is needed for wet pond and wet ED pond to maintain a permanent pool; 10 acres minimum for micro-pool ED pond.	Wet basins can provide substantial aesthetic/recreational value and wildlife and wetlands habitat.	

	mechanisms. Wet pond. A wet pond is a stormwater basin constructed with a permanent (dead storage) pool of water equal to the water quality volume. Stormwater runoff displaces the water already present in the pool. Temporary storage (live storage) can be provided above the permanent pool elevation for larger flows. Wet extended detention (ED) pond. A wet extended detention pond is a wet pond where the water quality volume is split evenly between the permanent pool and extended detention (ED) storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 24 hours. Micro-pool extended detention (ED) pond The micro-pool extended detention pond is a variation of the wet ED pond where only a small “micro-pool” is	Total nitrogen – 30% Fecal coliform – 70% (if no resident waterfowl population present) Heavy metals – 50%	Space required. Approximately 2-3% of the tributary drainage area. There should be more than 15% slope across the pond site.	Mosquito and midge breeding is likely to occur in ponds. Cannot be placed on steep unstable slopes.

		maintained at the outlet to the pond. The outlet structure is sized to detain the water quality volume for 24 hours. The micropool prevents re-suspension of previously-settled sediments, and also prevents clogging of the low flow orifice. Multiple pond systems Multiple pond systems consist of constructed facilities that provide water quality and quantity volume storage in two or more cells. The additional cells can create longer pollutant removal pathways and improved downstream protection.				

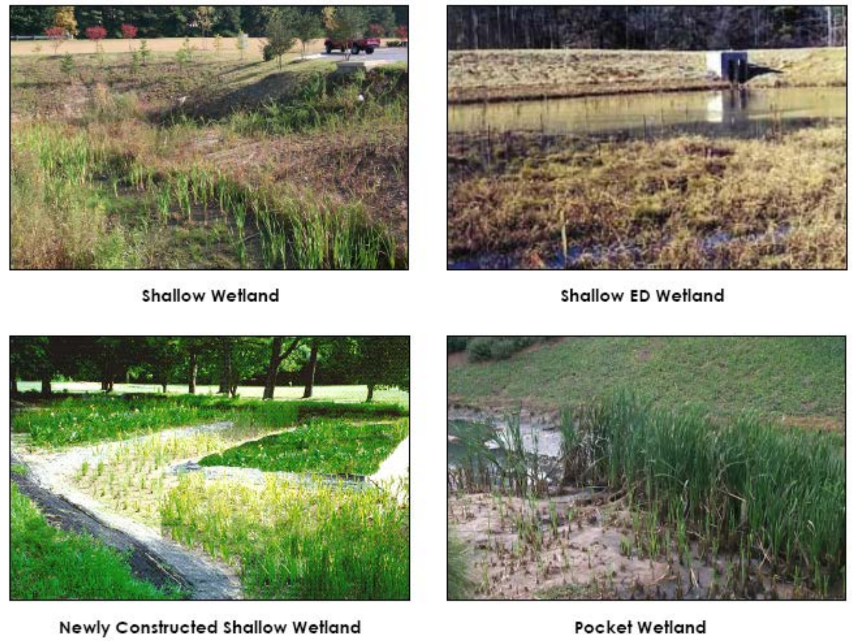

Figure 6. Stormwater wetlands (figure from Georgia Stormwater Manual).

Table 5. Structural Stormwater Controls with Primary Treatment: Filtration

S. No.	Technology	Description	Pollutant Removal	Construction Considerations	Remarks	Reference
3.	Sand Filters	A sand filter is a multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay and a sand bed as its primary filter	Total Suspended Solids – 80% Total Phosphorus – 50%	Drainage area- 10 acres maximum for surface sand filter; 2 acres maximum for perimeter sand filter.	Stormwater filters have their greatest applicability for small development sites – drainage areas of up to 5	Section 2F1,Sand Filter, Iowa Stormwater Management Manual Section 3.12, Sand Filters,

	media. Typically, an underdrain is used to return the filtered runoff to the conveyance system. Surface sand filter- The surface sand filter is a ground-level open-air surface structure that consists of a pre-treatment sediment forebay and a filter bed chamber This system is typically used to treat drainage areas 2-10 acres in size and is typically located off-line. Perimeter sand filter- The perimeter sand filter is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area. This system is usually used to treat drainage areas up to 2 acres in size, and consists of a sedimentation chamber and a sand bed filter. **3.** Underground sand filter- **The underground sand filter is intended primarily for extremely space-limited and high-density areas. In this design, the sand filter is placed in a three-chamber underground**	Total Nitrogen – 25% Fecal Coliform – 40% Heavy Metals – 50%	Space required- Function of available head at site. Site slope- No more than 6% slope across filter location. Minimum head-Elevation difference needed at a site from the inflow to the outflow: 5 feet for surface sand filters; 2-3 feet for perimeter sand filters.	surface acres. Good for highly impervious areas. Good retrofit capability. Good for areas with extremely limited space. Not recommended for areas with high sediment content in stormwater or areas receiving significant clay/silt runoff.	Virginia Stormwater Management Handbook, Volumes 1 Section 3.2.4, Sand Filters Georgia Stormwater Management Manual Volume II

		vault (either on-line or off-line) accessible by manholes or grate openings. The initial chamber, a sedimentation (pre-treatment) chamber, temporarily stores runoff and utilizes a wet pool to capture sediment.				
4.	Upflow Filtration by Porous Propelene Media	The treatment consists of sedimentation and upflow filtration with porous polypropelene processes and the treated runoff is discharged into existing storm drainage pipe.	Total Suspended Solids – 60% COD- 40% Total Phosphorus – 40% Pb, Cd – 80% Zn, Cu, Mn and Cr- 70% PAH- > 60%	Two collector sections (inflow and outflow) and a treatment section. After the road runoff is continuously collected and treated by the treatment device, the flow is discharged into the drainage pipe. The structure of the treatment section is large enough to receive equal to or less than designed maximum flow rate.	Porous Polypropelene is excellent for removing smaller size particulates of suspended solids which originate basically from diesel exhaust, as well as larger size particulates from automobile tires, asphalt roads, and other accumulated sources of sand and clay.	B.C Lee, S. Matsui, Y. Shimizu, T. Matsuda, Y. Tanaka, A new installation for treatment of road runoff: up-flow filtration by porous propelene media, Water Science and Technology, Vol 52, No. 12, Page 225-232.

5.	Use of natural mineral sorbent	It consists of a sorbtive of layer 0.2 m sand and 10% of natural zeolite layer used in a ditch instead of using a sand layer alone.	Heavy metal sorption Pb- 100% Cu-52% Zn- 47% Mn- 25% Ni- 15% Removal of petroleum products by two fractions of natural zeolite from water was 89.8% and 76.4%.	Parameters of ditch- Width-1m Depth- 0.8 m Soil enriched with organic matter- 0.1 m	The efficiency of this treatment system is 10% higher than that of the ordinary runoff treatment system with sand layer alone	Evelina Branvall, Improvement of storm water runoff treatment system with natural mineral sorbent, Geologija, 2007, No 59, Page 72-76

6.	Organic Filter	Design variant of the surface sand filter using organic materials in the filter media.(organic materials such as leaf compost or a peat/sand mixture)	Total Suspended Solids – 80% Total Phosphorus – 60% Total Nitrogen- 40% Faecal coliform- 50% Heavy metals- 75%	Organic filters are typically used on relatively small sites (up to 10 acres), to minimize potential clogging. Two typical media bed configurations are the peat/sand filter and compost filter The peat filter includes an 18-inch 50/50 peat/sand mix over a 6-inch sand layer and can be optionally covered by 3 inches of topsoil and vegetation. The compost filter has an 18-inch compost layer. Both variants utilize a gravel underdrain system. Minimum head requirement of 5 to 8 feet	Intended for hotspot or space-limited applications, or for areas requiring enhanced pollutant removal capability Severe clogging potential if exposed soil surfaces exist Upstream Removal of dissolved pollutants is greater than sand filters due to cation exchange capacity	Section 3.3.3, Organic Filter Georgia Stormwater Management Manual Volume II

7.	Bioretention and Rain Garden Systems	a) Bioretention and rain garden systems incorporate shouldow landscaped stormwater basins (depressions) with an engineered soil subgrade. Stormwater runoff collected in the upper layer of the system is filtered through the surface vegetation, mulch layer, pervious soil layer, and then stored temporarily in a stone aggregate base layer. b) They are designed with a combination of plants that may include grasses, flowering perennials, shrubs, or trees. c) The filtered runoff can be allowed to either infiltrate into the underlying soils or be temporarily stored in the aggregate subdrain system and discharged at a controlled rate to the storm sewer system or a downstream open channel.	Total suspended solids 80% Total phosphorous 65-85% Total nitrogen 50% Pathogens 70-100% Heavy metals 45-95% Moderate Zinc Removal, Nitrogen Removal and Hydrocarbons removal.	• Space required: Approximately 5-8% of the tributary impervious area is required; minimum 200 ft2 area for small sites (10 feet x 20 feet) • Site slope: No more than 6% slope • Minimum head: Elevation difference needed at a site from the inflow to the outflow: 5 feet • Minimum depth to water table: A separation distance of 2 feet is recommended between the bottom of the bioretention facility and the elevation of the seasonally high water table. • Soils: No restrictions; engineered media required. For rain garden applications where no subdrain is provided,	Reduce runoff rate and volume from impervious areas; provide opportunity for filtration and infiltration processes. Flexible design options for varying site conditions; sub drain system allows use on sites with higher seasonal water table levels. Good retrofit opportunities. Not appropriate for steep slopes (> 15%). High sediment loads can cause premature failure; upstream practice is needed.	Section 2E4,Bioretention Systems, Iowa Stormwater Management Manual Chapter 9, Structural Controls, Stormwater Manual for Western Australia, Deptt. Of Water Section 3.2.3, Bioretention Areas Georgia Stormwater Management Manual Volume II Michael E. Dietz, John C. Clausen *Saturation to Improve Pollutant Retention in a Rain Garden* Environ. Science. Technology. 2006, Volume 40, Page 1335-1340

				HSG D soils should be avoided, or the system may experience longer periods of standing water.		

8.	Vegetated Biostrips	a) Pollutant removal achieved through filtering, infiltration, adsorption and settling. b) Vegetation includes grasses, forbs, and legumes. c) Effectiveness of these strips is a function of the length and slope of the filter strip, soil permeability, the size of the drainage area, and the type and density of the vegetative cover	a) Total Suspended solids (TSS) b) Cu, Pb and Zn c) Total Phosphorous d) Total Nitrogen	a) 30-m collection systems and automated samplers designed to capture highway runoff. b) Test strip lengths between edge of pavement (EOP) and collection channels were 1.1 to 13.0 m. c) Slopes were 5 to 52 percent. d) b) Design parameters: flow velocity, residence time as a function of length and slope, infiltration, and vegetation density	a) TSS concentration (conc.) reduction occurred on slopes 5 to 50 percent from an EOP concentration of 55 mg/L to a conc. of 15 to 20 mg/L. b) 60% conc. reduction at 1 m from edge of pavement. c) For slopes > 35% Final conc. 20 mg/L within 8 m of EOP d) Significant reduction in total and dissolved conc. of Cu, Pb and Zn. e) Good performance for pollutant removal can be expected from widths of 50 to 75 feet and an additional 4 feet of width for every one percent of slope.	a) Scharff, Misty, Lantin, Anna, Othmer, Ed, *Effectiveness of Vegetated Biostrips in the Treatment of Highway Storm Water Runoff*, American Water Resources Association Conference, San Diego, CA, November 2-5, 2003. b) James M. Hafner, Jr., Michael Panzer, P.E., and Kane Rade, *Best Management Practices as They Relate to the Treatment of Stormwater Runoff in the Minnehaha Creek Watershed District* c) *Stormwater Treatment for Roads,* Practice Note: LB 301 - June 2006 ARC Technical Publication

S. No.	Technology	Description	Pollutant Removal	Construction Considerations	Remarks	Reference
9.	Grass Channels	a) Grass channels also known as "biofilters," are typically designed to provide nominal treatment of runoff as well as meet runoff velocity targets for the water quality design storm. b) Can partially infiltrate runoff from small storm events in areas with pervious soils. c) Two primary considerations are channel capacity and minimization of erosion. e) Grass channels must have broader bottoms, lower slopes and denser vegetation than most drainage channels.	1. Total Suspended Solids – 50% 2. Total Phosphorus – 25% 3. Total Nitrogen – 20% 4. Heavy Metals – 30%	a) Total length of a grass channel should provide at least 5 minutes of residence time b) Used to treat small drainage areas < 5 acres c) Trapezoidal or parabolic cross section with relatively flat side slopes (generally 3:1 or flatter) is desirable. d) The bottom of the channel should be between 2 - 6 feet wide. e) Depth from the bottom of the channel to the groundwater should be at least 2 feet to prevent a moist swale bottom,	a) Should not be used on slopes greater than 4%; slopes between 1% and 2% recommended b) Ineffective unless carefully designed to achieve low flow rates in the channel (<1.0 ft/s) c) Runoff velocity < 2 foot/sec at peak discharge	Section 3.3.2, Georgia Stormwater Management Manual, Volume 2

Figure 7. Perimeter sand filter (Georgia Stormwater Manual).

Figure 8. Surface sand filter (Georgia Stormwater Manual).

Figure 9. Newly constructed bioretention area (Georgia Stormwater Manual).

Table 6. Structural Stormwater Controls with Primary Treatment: Infiltration

S. No.	Technology	Description	Pollutant Removal	Construction Considerations	Remarks	Reference
10.	Swales	a) Dry Swale – The dry swale is a vegetated conveyance channel designed to include a filter bed of prepared soil that overlays an underdrain system. b) Wet Swale (Wetland Channel) – The wet swale is a vegetated channel designed to retain water or marshy conditions that support wetland vegetation. A high water table or poorly drained soils are necessary to retain water. c) Grass swales- designed to convey stormwater runoff at a non-erosive velocity, as well as enhance its water quality through infiltration, sedimentation, and filtration. Check dams can be used within the swale to slow the flow rate, promote infiltration, and create small, temporary ponding areas.	1. Total Suspended Solids – 80% 2. Total Phosphorus – Dry Swale 50% / Wet Swale 25% 3. Total Nitrogen – Dry Swale 50% / Wet Swale 40% 4. Fecal Coliform – 5. Heavy Metals – Dry Swale 40% / Wet Swale 20%	1. Longitudinal slopes must be less than 4% 2. Bottom width of 2 to 8 feet 3. Side slopes 2:1 or flatter; 4:1 recommended 4. Minimum Head – Elevation difference needed at a site from the inflow to the outflow: 3 to 5 feet for dry swale; 1 foot for wet swale 5. Minimum Depth to Water Table – 2 feet required between the bottom of a dry swale and the elevation of the seasonally high water table, if an aquifer or treating a hotspot; wet swale is below water table or placed in poorly	1. Max velocity 1.5 ft/sec 2. During high pollutant loading rates, grassed swales retain significant amount of pollutants, mainly due to sedimentation of particulate matter. 3. When they receive urban runoff with low pollutant concentrations, they may release rather than pollutants.	1. Backstrom, M ,*Grass Swales for stormwater pollution control during rain and snowmel*t, Water science and Technology, Vol 48, No 9, pp 123-134 2. Section 3.2.6, Georgia Stormwater Management Manual, Volume 2 3. Virginia Stormwater Management Handbook, Volumes 1 and 2, First Edition, 1999 , Section 3.13

				drained soils 6. Average grass height – 4 to 6 inches 7.Design criteria-hydraulic mean retention time, surface loading rate or specific swale area.		

11.	Porous Pavements	Porous Asphalt Infiltration practices that are alternatives to traditional Asphalt surfaces. Stormwater runoff is infiltrated into the ground through a permeable layer of pavement and is naturally filtered.	1. Total Suspended Solids – not applicable 2. Total Phosphorus – 80% 3. Total Nitrogen – 80%	1. Design considerations are similar to any paved area (soil properties, load-bearing design, hydrologic design of pavement and subgrade). 2. Soil infiltration rate of	1. Not appropriate for heavy or high traffic areas. 2. Reduces runoff volume, attenuates peak runoff rate and outflow. 3. Can be used as	1. Section 4.3.12, Porous Pavement, Knox County Tennessee Stormwater Management Manual 2. Michael E. Barrett, Pam Kearfott, Joseph F. Malina, Jr.*Stormwater Quality Benefits of a Porous Friction Course and Its Effect on Pollutant Removal by Roadside*

		4. Heavy Metals – 90%	0.5 in/hr or greater is required if no underdrain is present. 3. The infiltration rate of native soil determines appropriateness and need for an underdrain. 4. The void space in an asphalt overlay layer generally is 18 to 22%	pretreatment for other technologies for pollutants other than TSS.	*Shoulders* 3. Section 3.3.7, Porous Concrete, Georgia Stormwater Management Manual, Vol. 2 4. C.J Pratt, Use of Permeable Pavement Reservoir Construction for Stormwater Treatment and Storage for Reuse, Water Science Technology, Vol 39, No. 5, Page 145-151.
	Porous Concrete Porous concrete is the term for a mixture of coarse aggregate, portland cement and water that allows for rapid infiltration of water and overlays a stone aggregate reservoir. This reservoir provides temporary storage as runoff infiltrates into underlying permeable soils and/or out through an underdrain system.	1. Total Suspended Solids – not applicable 2. Total Phosphorus – 50% 3. Total Nitrogen – 65% 4. Heavy Metals – 60%	1. The void space in porous concrete is in the 15% to 22% range compared to three to five percent for conventional pavements. 2. Designed primarily for stormwater quality	1. Traditionally high failure rate and short life span 2. Should not be used in areas of soils with low permeability, wellhead protection zones, or recharge areas of water supply aquifer recharge areas. 3. Should not be used on slopes greater than 5% with slopes of no greater than 2% recommended.	

		Modular Porous Paver Systems A pavement surface composed of structural units with void areas that are filled with pervious materials such as sand or grass turf. Porous pavers are installed over a gravel base course that provides storage as runoff infiltrates through the porous paver system into underlying permeable soils.	1. Total Suspended Solids – not applicable 2. Total Phosphorus – 80% 3. Total Nitrogen – 80% 4. Heavy Metals – 90%	1. Soil infiltration rate of 0.5 in/hr or greater required 2. A minimum of 40% of the surface area should consist of open void space.	1. Porous paver systems are not recommended on sites with a slope greater than 2%. 2. Potential for groundwater contamination

Figure 10. Dry swale (Georgia Stormwater Manual).

Figure 11. Grass swale. (Georgia Stormwater Manual).

Figure 12. Porous concrete installation (Georgia Stormwater Manual).

3. STORMWATER MONITORING

3.1. Objective and Scope

Studies directed at addressing the efficiency of BMPs in attaining water quality goals are generally carried out to answer some or all of the following questions (ASCE-EPA, 2002):

a. What degree of pollution control or effluent quality does the BMP provide under normal conditions?
b. How does this performance vary from pollutant to pollutant?
c. How does this normal performance vary with large or small storm events?
d. How does this normal performance vary with rainfall intensity?
e. How do design variables affect performance?
f. How does performance vary with different operational and/or maintenance approaches?
g. Does performance improve, decay, or remain stable over time?
h. How does this BMP's performance compare with the performance of other BMPs?
i. Does this BMP help achieve compliance with water quality standards?

3.2. INFORMATION NEEDS

Prior information if available about a site is always helpful in designing a practical monitoring program (ASCE-EPA, 2002). These data include but are limited to:

a. Results from prior surface water and groundwater quality studies, sediment quality studies, aquatic ecology surveys, dry weather reconnaissance, etc.
b. Drainage system maps
c. Land use maps (or general plan or zoning maps)
d. Aerial photographs
e. Precipitation and stream flow records
f. Reported spills and leaks
g. Interviews with public works staff

h. Literature on design of structural BMPs to understand functionality and pollutant removal processes

To optimize the collection and treatment of data within the limits of the proposed study and to ensure that useful results are obtained, determining the type of data to be collected, the variables affecting the data, and the expected variability of data as compared to previous studies, and the subsequent analytical methods.

3.3 Selecting Parameters

Stormwater runoff may contain a variety of parameters that can affect the quality of receiving water bodies along with some parameters that might be site specific (ASCE-EPA, 2002); consequently, it is essential to select the parameters accordingly to rule out the collection of irrelevant data. The base list of constituents recommended by ASCE-EPA (2002) for stormwater monitoring is given in Table 7 (Table 7). The choice of which constituents to include as standard parameter is subjective and can vary according to the needs of a project.

Table 7. Recommended Detection Limits (ASCE-EPA, 2002)

Parameter	Units	Target Detection Limit
Conventional		
pH	pH	N/A
Turbidity	mg/L or NTU	4
Total Suspended Solids (TSS)	mg/L	4
Total Hardness	mg/L	5
Chloride (Cl)	mg/L	1
Bacteria		
Fecal Coliform	MPN/ 100 ml	2
Total Coliform	MPN/ 100 ml	2
Enterococci	MPN/ 100 ml	2
Nutrients		
Orthophosphate	mg/L	0.05
Phosphorous- Total (TP)	mg/L	0.05
Total Kjeldahl Nitrogen (TKN)	mg/L	0.3
Nitrogen-N	mg/L	0.1
Metals- Total Recoverable		
Total Recoverable Digestion	µg/L	0.2
Cadmium (Cd)	µg/L	1
Copper (Cu)	µg/L	1
Lead (Pb)	µg/L	5

Parameter	Units	Target Detection Limit
Zinc (Zn)	µg/L	
Metals- Dissolved		
Filtration/ Digestion	µg/L	0.2
Cadmium (Cd)	µg/L	1
Copper (Cu)	µg/L	1
Lead (Pb)	µg/L	5
Zinc (Zn)	µg/L	
Organics		
Organophosphate Pesticides	µg/L	0.05 -2

The factors considered in developing the above list of monitoring parameters include the following (ASCE-EPA, 2002):

1. The pollutant has been identified as prevalent in typical urban stormwater at concentrations that could cause water quality impairment (NURP, 1983)
2. The analytical result can be related back to potential water quality impairment.
3. Sampling methods for the pollutant are straightforward and reliable for a moderately careful investigator.
4. Analysis of the pollutant is economical on a widespread basis.
5. Controlling the pollutant through practical BMPs, rather than trying to eliminate the source of the pollutant (e.g., treating to remove pesticide downstream instead of eliminating pesticide use).

3.4. Monitoring Equipment and Methods

A wide range of sampling/monitoring equipment exists to quantify the performance of BMPs in the field. A summary of the equipment and sampling techniques used in this study is given in the following section. A description of the specific equipment used in this investigation is given in the summary section.

3.4.1 Data Loggers

Data loggers are used to monitor signals from various pieces of equipment and store the impulses that they generate. Most data loggers have several input ports and can accommodate a variety of sensory devices, such as a probe or transducer (flow meters, rain gauges etc.). They are designed to operate at extreme temperatures, from as low as -55^o C to as high as 85^{o}C. Typical data loggers for field use consist of the following components: a weatherproof external housing (case), a central processing unit (CPU) or microprocessor, a quantity of random-access memory (RAM) for recording data, one or several data input ports, a data output port, at least one power source, and an internal telephone modem. In addition, most data loggers have an input panel or keyboard and a display screen for field programming. The CPU processes the input data for storage in RAM (secondary memory that is used for storage), which usually has a backup power source (such as a lithium battery) to ensure that data are not lost in the event of a failure of the primary power. Data stored in RAM may be retrieved by downloading to a personal computer (PC), or to a host PC via modem. Some manufacturers of data loggers suitable for stormwater monitoring include: Campbell Scientific (Logan, UT), Global Water Instrumentation (Fair Oaks, CA), Handar, Inc. (Sunnyvale, CA), In-Situ, Inc. (Laramie, WY), ISCO, Inc. (Lincoln, NE), Logic Beach, Inc. (La Mesa, CA), and Sutron Corporation (Sterling, VA). A schematic of a typical data logger with components is given in Figure 13.

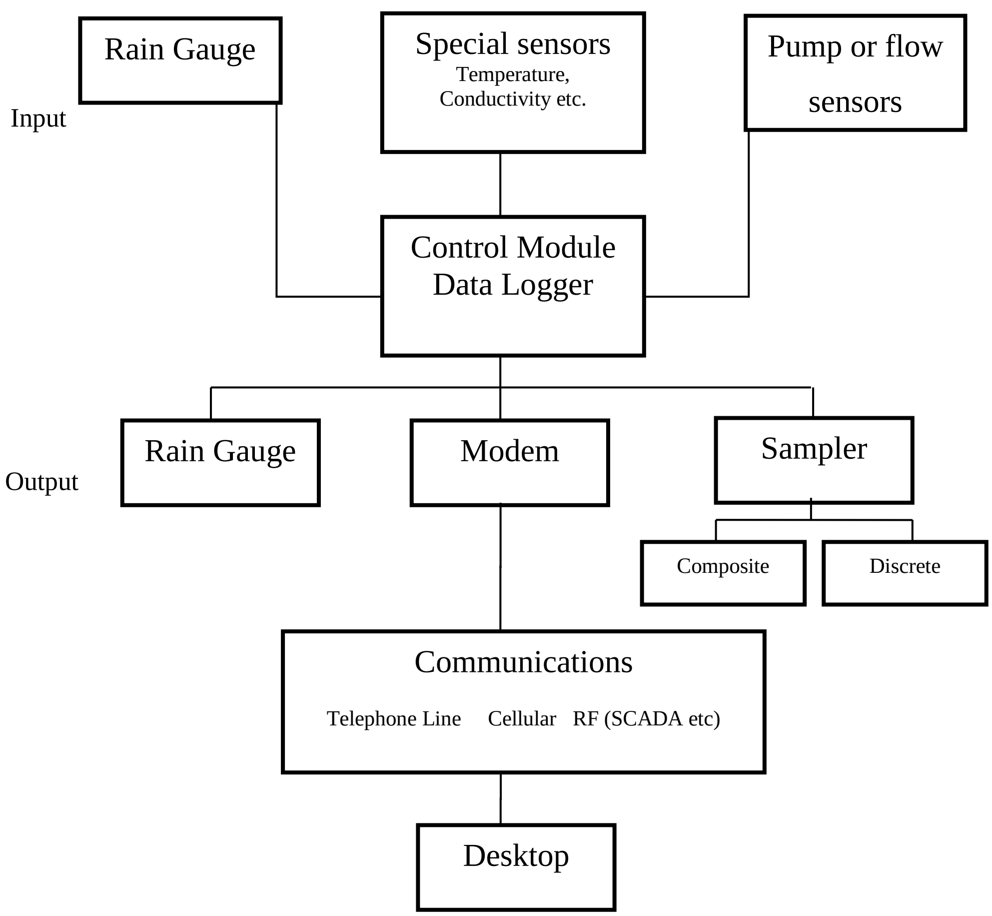

Figure 13. Schematic of typical components for data logger system, including input and output devices (ASCE-EPA, 2002).

3.4.2 Flow, Depth, and Velocity Measurement

A variety of testing methods exist for measuring the flow, depth, and velocity of stormwater into a BMP. A summary of the most significant characteristics of these methods is given in the following.

3.4.2.1 Volume-Based Method

Volume-based methods involve collection of flow for a short period of time, followed by measurement of the volume divided by the length of the collection time period. A bucket, drum or a holding tank can be used to collect water and a stopwatch can be used to measure the time period.

$$Q = V/T$$

where,
Q: flow, m^3/s (ft^3/s)
V: volume, m^3 (ft^3)
T: time, s

3.4.2.2 Stage- Based Method

Flow rate can be estimated from the depth of flow using empirically derived mathematical relationships. Manning's equation is appropriate for open channels in which flow is in a steady state and uniform. It is also used in automated samplers to estimate the flow rate.

$$Q = (1/n)\, AR^{2/3}\, S^{1/2}$$

where,

Q: flow, m^3/s (ft^3/s)

n: Manning roughness coefficient (dimensionless)

A: flow cross-sectional area, m^2 (ft^2)

R: hydraulic radius, m (ft) = A/ (wetted perimeter)

S: slope of the channel, m/m (ft/ft)

3.4.2.3 Stage-Based Method using Weirs and Flumes

The accuracy with which flow is estimated can be improved by using a weir or flume to create an area of the channel where the hydraulics is controlled (control section). Each type of weir or flume is calibrated (i.e., in the laboratory or by the manufacturer) such that the stage at a predetermined point in the control section is related to the flow rate using a known empirical equation (ASCE-EPA,2002).

3.4.2.4 Stage-Based Variable Gate Meters

A relatively new development in flow metering technology is ISCO Inc.'s (Lincoln, NE) Variable Gate Metering Insert. Discharge flows through the insert and under a pivoting gate, creating an elevated upstream level that is measured with a bubbler system. The meter uses an empirical relationship to calculate the discharge rate based on the angle of the gate and the depth of flow upstream of the gate. This approach can be used only under conditions of open channel flow in circular pipes. It was designed to measure the flow rate under fluctuating flows and is effective at both very high and very low flow rates. Its main limitation is the size of the conveyance for which it is designed. The insert may be useful for sampling very small catchment areas.

3.4.2.5 Velocity-Based Method

The continuity method is a velocity-based technique for estimating flow rate. Each determination requires the simultaneous measurement of velocity and depth of flow. Flow rate is calculated as the sum of the products of the velocity and the cross-sectional area of the flow at various points across the width of the channel:

$Q = A_i\ V_i$

Although this method is useful for calibrating equipment, it is more sophisticated and expensive than the stage-flow relationships previously discussed. In addition, this method is suitable only for conditions of steady flow.

3.4.2.6 Tracer Dilution Method

The tracer dilution method is used where the flow stream turbulence and the mixing length are sufficient to ensure that an injected tracer is completely mixed throughout the flow stream (USGS 1980; Gupta 1989). Tracers are chosen so that they can be distinguished from other substances in the flow. For example, chloride ion can be injected into fresh water, and dyes or fluorescent material can be used if turbidity is not too high. Dilution studies are well suited for short-term measurements of turbulent flow in natural channels and in many manmade structures such as pipes and canals. However, these methods are better suited to equipment calibration than to continuous monitoring during a storm event.

3.4.2.7 Pump Discharge Method

The overall discharge rate for a catchment may be measured as the volume of water that is pumped out of a basin per unit time while holding the water level in the basin constant. This method can be applied at sites where flow runs into a natural or manmade basin from several directions or as overland flow. If the pump is precalibrated, the number of revolutions per minute, or the electrical energy needed to pump a given volume, may be used as a surrogate for measuring the pumped volume during a stormwater runoff event. A summary of all methods available for flow measurement is given in Table 8.

Table 8. Flow Measurement Methods (ASCE-EPA, 2002)

Method	Major Requirements for use	Typical BMP use	Required Equipment
Volume Based	Low flow rates	Calibrating Equipment Manual Sampling	Container and Stopwatch
Stage- Based Empirical Equations	Open Flow, Known channel/ pipe slope, Channel slope, geometry, roughness consistent upstream	Manual or automatic sampling	Depth Measurer
Stage- Based Weir/ Flume	Open flow, Constraint will not cause flooding	Manual or automatic sampling	Weir/ Flume and depth measurer
Stage- Based Variable Gate Meter	4- , 6- or 8- inch pipes only	Not typically used for BMP's	ISCO Variable Gate Meter
Velocity- Based	None	Automatic sampling	Depth measurer and velocity

Tracer Dilution	Adequate turbulence and mixing length	Typically used for calibrating equipment	Tracer and concentration meter
Pump-Discharge	All runoff into one pond	Not typically used for BMPs	Pump

Depth and Velocity Measurement Methods

The variety of techniques that are available to measure depth have been summarized in Table 9.

Table 9. Depth Measurement Methods (ASCE-EPA, 2002)

Method	Major Requirement For Use	Use in a BMP Monitoring Program
Visual Observations	Small number of sites and events to be sampled. No significant health and safety concerns	Manual sampling
Float Gauge	Stilling well required	Manual or automatic sampling
Bubbler Tube	Open channel flow No velocities greater than 5ft/sec	Automatic sampling
Ultrasonic Depth Sensor	Open channel flow, No significant wind, loud noises, turbulence, foam, steam, or floating oil and grease	Automatic sampling
Ultrasonic Up looking	No sediment or obstructions likely to cause errors in measurement	Automatic sampling
Radar/Microwave	Similar to Ultrasonic Depth Sensor but can see through mist and foam	Automatic sampling
3-D Point Measurement	Highly controlled systems Typically not useful in field	Automatic sampling
Pressure Probe	Open channel flow, No organic solvents or inorganic acids and bases	Automatic sampling

Tracer methods have been developed to measure flow velocity under uniform flow (USGS, 1980) as the recommended method (ASCE-EPA, 2002). A discrete slug of tracer is injected into the flow, and concentration-time curves are constructed at two downstream locations. The time for the peak concentration of the dye plume to pass the known distance between the two locations is used as an estimate of the mean velocity of the flow. This method is not practical for continuous flow measurement, but is useful for site calibration.

3.4.3 Sample Collection Techniques

3.4.3.1 Grab Samples

The term "grab sample" refers to an individual sample collected within a short period of time at a particular location. Grab samples are suitable for virtually all of the typical stormwater quality parameters. In fact, grab samples are the only option for monitoring parameters that transform rapidly (requiring special preservation) or adhere to containers, such as oil and grease, TPH, and bacteria. The results from a single grab sample generally are not sufficient to develop reliable estimates of the event mean pollutant concentration or pollutant load because stormwater quality tends to vary dramatically during a storm event. A single grab sample collected during the first part of a storm can be used to characterize pollutants associated with the "first flush." To estimate event mean concentrations or pollutant loads, a series of grab samples at short time intervals throughout the course of a storm event are collected.

3.4.3.2 Composite Samples

Another sampling method is to combine appropriate portions of each grab to form a single composite sample for analysis, but this is generally impractical if there are more than a few stations to monitor. If detecting peak concentrations or loading rates is not essential, composite sampling can be a more cost effective approach for estimating event mean concentrations and pollutant loads. Composite samples are suitable for most typical stormwater quality parameters, but are unsuitable for parameters that transform rapidly (e.g., fecal coliform, residual chlorine, pH, volatile organic compounds) or adhere to container surfaces (e.g., oil and grease). The two basic approaches for obtaining composite samples are referred to as time-proportional and flow-proportional.

- **Time-proportional**: prepared by collecting individual sample "aliquots" of equal volume at equal increments of time (e.g., every 20 minutes) during a storm event, and mixing the aliquots to form a single sample for laboratory analysis. Time proportional composite samples generally do not provide reliable estimates of event mean concentrations or pollutant loads, unless the interval between sample aliquots is very brief and flow rates are relatively constant.

- **Flow-weighted**: more suitable for estimating event mean concentrations and pollutant loads. A flow-weighted composite sample can be collected in several ways :

  Constant Time - Volume Proportional to Flow Rate - Sample aliquots are collected at equal increments of time during a storm event and varying amounts of each aliquot are combined to form a single composite sample. The amount of water removed from each aliquot is proportional to the flow rate at the time the aliquot was collected.

  Constant Time - Volume Proportional to Flow Volume Increment - Sample aliquots are collected at equal increments of time during a storm event and varying amounts from each aliquot are combined to form a single composite sample. The amount of water removed from each aliquot is proportional to the volume of flow since the preceding aliquot was collected.

  Constant Volume - Time Proportional to Flow Volume Increment - Sample aliquots of equal volume are taken at equal increments of flow volume (regardless of time) and combined to form a single composite sample. This type of compositing is generally used in conjunction with an automated monitoring system that includes a continuous flow measurement device.

3.4.3.3 Automatic Sampling

Automatic sampling involves sample collection using electronic or mechanical devices that do not require an operator to be on-site during actual stormwater sample collection. It is the preferred method for collecting flow-weighted composite samples. Automated methods are better than manual methods if it is not possible to accurately predict storm event starting times. If the automated equipment is set to collect flow-weighted composite samples using the constant volume-time proportional to flow method, it reduces the need to measure samples for compositing.

An automated sampler is a programmable mechanical and electrical instrument capable of drawing a single grab sample, a series of grab samples, or a composited sample, in-situ. The basic components of an automated sampler are a programming unit capable of controlling sampling functions, a sample intake port and intake line, a peristaltic or vacuum/compression pump, a rotating controllable arm capable of delivering samples into sample containers and a housing capable of withstanding moisture and some degree of shock. Commonly used brands include ISCO, Lincoln, Nebraska, American Sigma, Medina, New York, Manning, Round Rock, Texas, and Epic/Stevens, Beaverton, Oregon.

An automated sampler can be programmed to collect a sample at a specific time, at a specific time interval, or on receipt of a signal from a flow meter or other signal (e.g., depth of flow, moisture, temperature). The sampler distributes individual samples into either a single bottle or into separate bottles which can be analyzed individually or composited. Some automated samplers offer multiple bottle configurations that can be tailored to program objectives.

Some important features of automated samplers include:

- Portability. (See Fig. 16)
- Refrigeration
- Volatile Organic Compound sample collection (if required). (See Fig 17.)
- Alternate power supplies.

In-Situ Water Quality Devices:

In-situ monitoring devices offer a possible solution to obtaining a continuous record of water quality; however, at this time, they are only practical for a limited set of parameters. In general, water quality monitors are electronic devices that measure the magnitude or concentration of certain specific target constituents through various types of sensors. Discrete measurements can be made at one minute or less intervals. Probes to detect and measure the following physical and chemical parameters are currently available for practical use in the field:

Physical parameters

- Temperature
- Turbidity

Chemical parameters

- pH
- Oxidation-reduction potential (redox)
- Conductivity
- Dissolved oxygen
- Salinity
- Nitrate
- Ammonia
- Resistivity
- Specific conductance
- Ammonium

Manufacturers of this type of instrument include YSI, Inc., Yellow Springs, Ohio, ELE International, England, Hydrolab, Austin, Texas, Solomat,Norwalk, Connecticut , and Stevens, Beaverton, Oregon.

Despite the advantage of these instruments for measuring near-continuous data, they require frequent inspection and maintenance in the field to prevent loss of accuracy due to fouling by oil and grease, adhesive organics, and bacterial and algal films.

3.5. Conclusions

The stormwater sampling that took place in this investigation utilized automatic samplers (Sigma 900 MAX PS 1 Portable Automatic Sampler with a standard bas, #900MAXPS1) that were equipped with four one-gallon polyethylene bottles per sampler for sample collection. (#2217). Flow was measured with a HACH Sigma Area Velocity Sensor (#77065-030). In-situ parameters pH, temperature, and conductivity were measured with an integral pH- temperature / ORP meter with pre-amp interface (# 8793), HACH pH probe (#3328), integral DO and Conductivity meter with a pre-amp interface (# 3227), and a HACH Conductivity probe kit (#3225). Rainfall levels were measured with a Sigma Tipping Bucket Rain Logger (#2459). In-Situ parameters (Temperature, Conductivity, Dissolved Oxygen, pH, Flow Depth and Rainfall) were recorded at an interval of 5 minutes. The recorded data were transferred to a personal computer using HACH Insight software.

Sample collection was performed for each sampler using three bottles to capture the first flush for the first 30-45 minutes of the storm. In the fourth bottle, 200 ml grab samples were collected at an interval of 15 minutes for the whole event. Sample collection was automated, and the automated samplers collected flow-weighted composite samples using the Constant Time - Volume Proportional to Flow Volume Increment method.

4. CANTON CREEK MONITORING

4.1 In-Situ Monitoring

4.1.1. Study Site

The project site was located in the City of Canton, Cherokee County, Georgia on the Interstate 575 (I-575) at State Road 20 (SR 20) (Figure 14). The project was 2.4 kilometers in length and the total area under the project was 0.63 square kilometers. The annual average daily traffic on I-575 as of 2007 was 56100. Canton Creek flows across the I-575. It has a drainage area of 36.21 square kilometers. The site is located in the Etowah watershed basin.

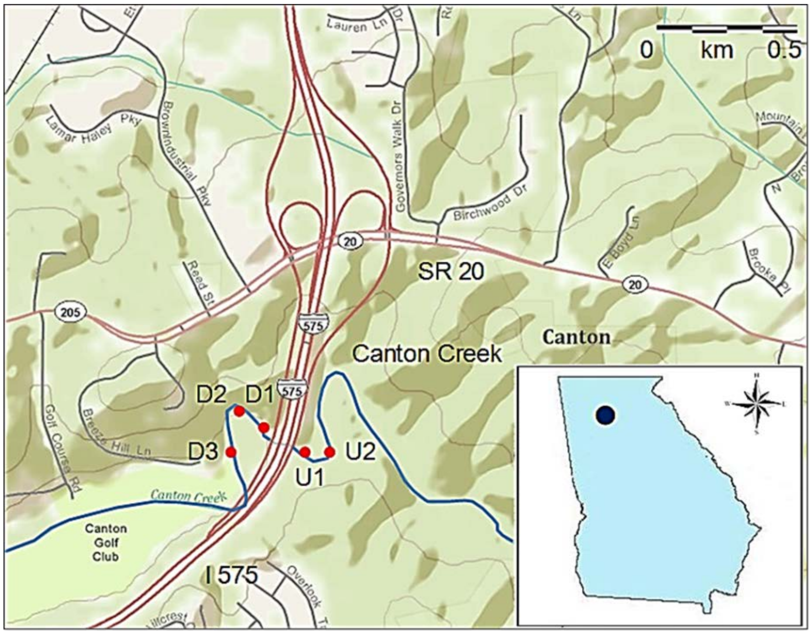

Figure 14. Layout of the major interchange reconstruction project site. Five sampling locations are marked on the Canton Creek which flows across the I-575 from east to west. Two sampling locations are situated upstream (U1 and U2) of the culvert. Meanwhile three sampling locations are situated downstream (D1, D2 and D3) of the culvert [Source ESRI ArcGIS].

4.1.2 Construction Details

The aim of the project was the reconstruction of an interchange between I- 575 and SR 20. This included addition of a diamond exit ramp from I-575 northbound to SR 20 as well as a southbound diamond entrance ramp from SR 20 to I-575 southbound. Existing ramps were also reconstructed and a collector distributor between the diamond ramps and loop ramps were added. During the initial stage of the construction a culvert was constructed between 12 Jul 2007 and 26 Aug 2007 located on the Canton Creek. For the construction of the culvert initially flow from the Canton Creek was diverted into two barrels of the existing culvert while the two barrels not receiving the flow were extended. After the extensions were completed the flow from Canton Creek was now diverted to the extended barrels while the culvert extensions were constructed for the remaining two barrels not receiving the flow. GDOT incorporated several best management practices during the construction phase. Silt fences were installed along the outside of the project. Also, silt fences were installed along stream buffer. Two rows of Type C silt fence and one row of Type A silt fence were installed no more than 10 feet in width. Silt fence consist of a woven synthetic fabric placed in front of a wire fence. It is used to capture sediment from fills over 3.04 meters high and under all bridges. GDOT also agreed to contain and treat the first 3.7 inches of pavement runoff of each rainfall event by running it through specially designed sand-filter detention ponds. The ponds were constructed under the project budget and were designed to permanently treat runoff for total suspended solids, heavy metals, petroleum products, and thermal pollution. During the construction phase these detention ponds were used as temporary sedimentation basin to collect receiving water during a rain event and hence preventing direct discharge of stormwater runoff to the Canton Creek. Erosion control mats were installed on the sedimentation basin slopes. Riprap protection was provided at the temporary sedimentation basin inlets to prevent erosion. Also, the slopes adjacent to the culvert were protected using rip rap.

4.1.3 Stream Monitoring

GDOT monitored the water quality of Canton Creek from February 13, 2007, to October 31, 2008. GDOT conducted the water quality monitoring in response to a request by the U.S. Fish and Wildlife Service because Canton Creek, which lies within the Etowah River Basin, is an imperiled aquatic ecosystem. Among the many native species it supports is the threatened Cherokee darter fish. To monitor the Canton Creek five locations were selected. Two upstream locations U1 and U2 and three downstream locations D1, D2 and D3. The upstream monitoring points were located at a distance of 61 meters and 152 meters from the culvert. Whereas, downstream locations were situated at a distance of 61 meters, 152 meters and 305 meters. The upstream and downstream placement of samplers ensured that effect of the construction of culvert on the water quality of the Canton Creek could be ascertained. ISCO 3700/6700 samplers were used to measure real time in-stream water quality. For parameters were measured - dissolved oxygen, temperature, turbidity, and pH using sensor probes. The monitoring probes were placed at the center of the stream. The parameters were measured at an interval of 15-minute intervals. Monitoring yielded a wealth of information in terms of the construction project's actual impact on the quality of the receiving water.

4.1.4. Methodology

The high resolution water quality data selected for analysis is from 18th April 2007 through 18th November 2007. The culvert on Canton Creek was constructed from 13th July 2007 through 26th August 2007 (Figure 15). The total data set included N = 20480 values for each parameter. The time series was divided into three sets according to the stages of construction – before construction (18th April 2007 – 13th July 2007), during construction (13th July 2007 – 26th August 2007) and after construction (26th August 2007 – 18th November 2007). Before and after construction data sets had N = 8192 values for each parameter while during construction data set contained N = 4096 values for each parameter. Collection of high resolution water quality monitoring data results in some gaps in the time series due to regular maintenance or calibration of the probes and replacement of batteries. Thus, there were some gaps in the water quality data collected from the site. Usually the length of the gaps was small and only 1 or 2 values were missing from the data. Maximal overlap discrete wavelet transform (MODWT) requires that no gaps should be present in the data to be analyzed. Linear interpolation was considered sufficient to fill the gaps without any significant effect on the water quality time series (Gnauck 2004). Data before 18th April and after 26th August was excluded from the data set. Firstly, because there were significant number of missing values in the collected water quality time series. Hence, linear interpolation would have introduced significant errors in the water quality time series data. Secondly, for convenience and homogeneity sample size selected to be analyzed for each phase of was chosen to be a multiple of 2 ($N = 2^j$) values were selected for each of the three stages of construction although this is not a requirement for a MODWT analysis

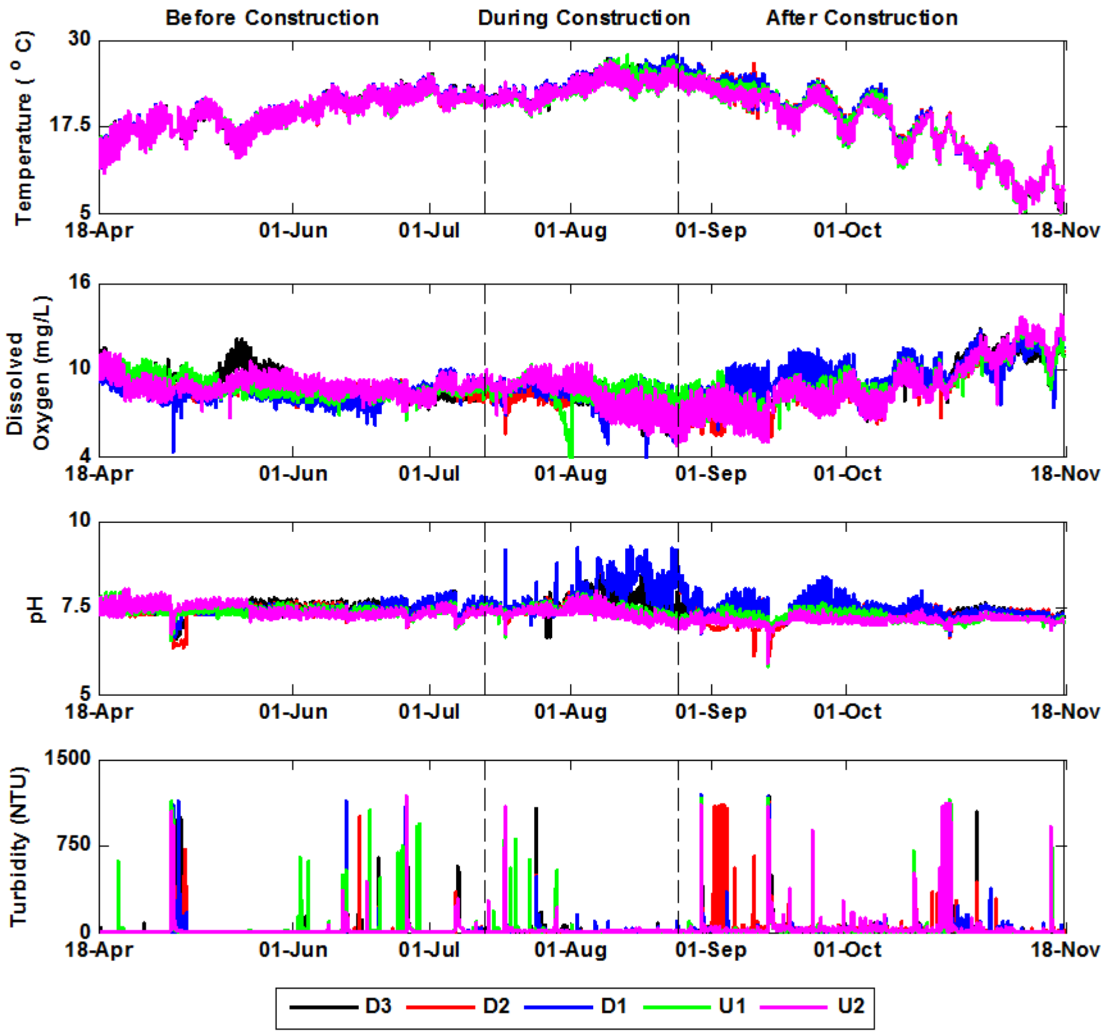

Figure 15. Water quality time series data collected during the three stages of construction of the culvert which is used for analysis. Four parameters- Temperature, Dissolved Oxygen, pH and Turbidity are presented in the four subplots from top to bottom respectively. Each subplot contains the water quality data for all the five locations monitored.

MODWT analysis

MODWT is a modified form of discrete wavelet transform (DWT). Unlike DWT which is an orthogonal and a non-redundant transform, MODWT is a highly redundant and a non-orthogonal transform (Percival and Walden 2006). The filtered coefficients that we get after each decomposition are discarded in DWT, but all the down sampled coefficients are retained in a MODWT analysis. MODWT has several advantages that make it a better option for statistical time series analysis as compared to a DWT. Firstly, MODWT can be used for sample sizes with all values of N. Meanwhile, DWT can only be used for sample sizes which are multiple of 2^j. Also, due to the redundant nature of the MODWT, as the number of sample values at each resolution scale remain the same without being discarded the data points at each level are aligned and useful for a more meaningful analysis. In this study the methodology suggested by (Whitcher, Guttorp et al. 2000; Cornish, Bretherton et al. 2006; Percival and Walden 2006) is followed so readers are directed to those references where the literature pertaining to the methodology is covered in detail.

For a time series *X* with a number of values *N*, the *j*th level MODWT wavelet ($\tilde{W}_j$) and scaling ($\tilde{V}_j$) coefficients are given by (Percival and Walden 2006),

$$\tilde{W}_{j,t} \equiv \sum_{l=0}^{L_j-1} \tilde{h}_{j,l} X_{t-l \bmod N}$$

$$\tilde{V}_{j,t} \equiv \sum_{l=0}^{L_j-1} \tilde{g}_{j,l} X_{t-l \bmod N}$$

Here,

$$\tilde{h}_{j,l} \equiv h_{j,l} / 2^{j/2}$$

and

$$\tilde{g}_{j,l} \equiv g_{j,l} / 2^{j/2}$$

are the MODWT wavelet and scaling filters respectively. If there is a signal X containing N values, the Multiresolution analysis (MRA) of the time series is given by (Percival and Walden 2006)

$$X = \sum_{j=1}^{J_0} \tilde{D}_j + \tilde{S}_{J_0}$$

Where,

$$\tilde{D}_{j,t} = \sum_{l=0}^{N-1} \tilde{h}^{\circ}_{j,l} \tilde{W}_{j,t+l \bmod N}$$

$$\tilde{S}_{j,t} = \sum_{l=0}^{N-1} \tilde{g}^{\circ}_{j,l} \tilde{V}_{j,t+l \bmod N}$$

Where $\tilde{D}_{j,t}$ and $\tilde{S}_{j,t}$ are *t*th elements of scale *j*, a set of coefficients are obtained each with the same number of samples (*N*) as in the original signal (*X*). These are called wavelet details as they capture local fluctuations over the whole period of a time series at each scale. The set of values S_{J0} provide a "smooth" or overall "trend" of the original signal. Adding D_j to S_{J0}, for $j = 1, 2, \ldots, J_0$, gives an increasingly more accurate approximation of the original signal.

Wavelet Variance

In calculating the wavelet variance the methodology suggested by (Percival and Walden 2006) was incorporated. Energy is conserved when we perform MODWT (Cornish, Bretherton et al. 2006):

$$\|X\|^2 = \sum_{j=1}^{J_o} \|\tilde{W}_j\|^2 + \|\tilde{V}_{J_o}\|^2$$

According to the required scale of an analysis of variance (ANOVA) can be derived from(Percival and Walden 2006):

$$\hat{\sigma}_X^2 = \|X\|^2 - \overline{X}^2 = \sum_{j=1}^{J_o} \|\tilde{W}_j\|^2 + \|\tilde{V}_{J_o}\|^2 - \overline{X}^2$$

A biased estimator of variance ν_X^2 was used (Cornish, Bretherton et al. 2006). In the analysis reflection boundary coefficients are used. It includes all 2N wavelet coefficients which are obtained from down sampling after MODWT is used. This is applied to the reflected series $\{X_t^{'}\}$. The biased estimator is given by:

$$\hat{\nu}_{X,b}^2(\tau_j) = \frac{1}{2N} \sum_{t=0}^{2N-1} \tilde{W}_{j,t}^2$$

The wavelet variance gives an idea of the contribution of each scale to the total variance of the original signal.

Wavelet Covariance

In calculating the wavelet covariance, the methodology suggested by (Cornish, Bretherton et al. 2006) was implemented. Using a biased covariance estimator wavelet covariance covariance can be calculated using (Cornish, Bretherton et al. 2006):

$$\hat{v}_{X,Y}\left(\tau_j\right)=\frac{1}{2N}\sum_{t=0}^{2N-1}\widetilde{W}_{X,j,t}\widetilde{W}_{Y,j,t}$$

When we calculate the wavelet covariance the covariance between two signals is decomposed according to the down sampled scales. For a bivariate signal the wavelet covariance is the covariance between the wavelet coefficients of a particular scale (Whitcher, Guttorp et al. 2000).

4.1.5 Results

The data demonstration a seasonal variation of temperature, with dissolved oxygen varying inversely with temperature values (Figure 15). Descriptive statistics in each subplot contain the mean value with error bars (1 standard deviation) of the single water quality parameter for all the five monitoring locations (Figure 16). Plots from left to right show different stages of construction. Meanwhile, plots from top to bottom show the values for the different water quality parameters. The mean values of temperature appear to be elevated for the active construction phase, although it is not possible to distinguish this from seasonal variations based on the data in Figure 15. There is no significant change in the mean values for temperature and dissolved oxygen, although variation is somewhat higher for the post construction period (Figure 16). Mean pH values appeared higher for downstream locations D1 and D2 during the active construction phase. Mean turbidity values for all the locations during the three phases of construction were approximately similar, although variances were slightly higher before and after construction phase.

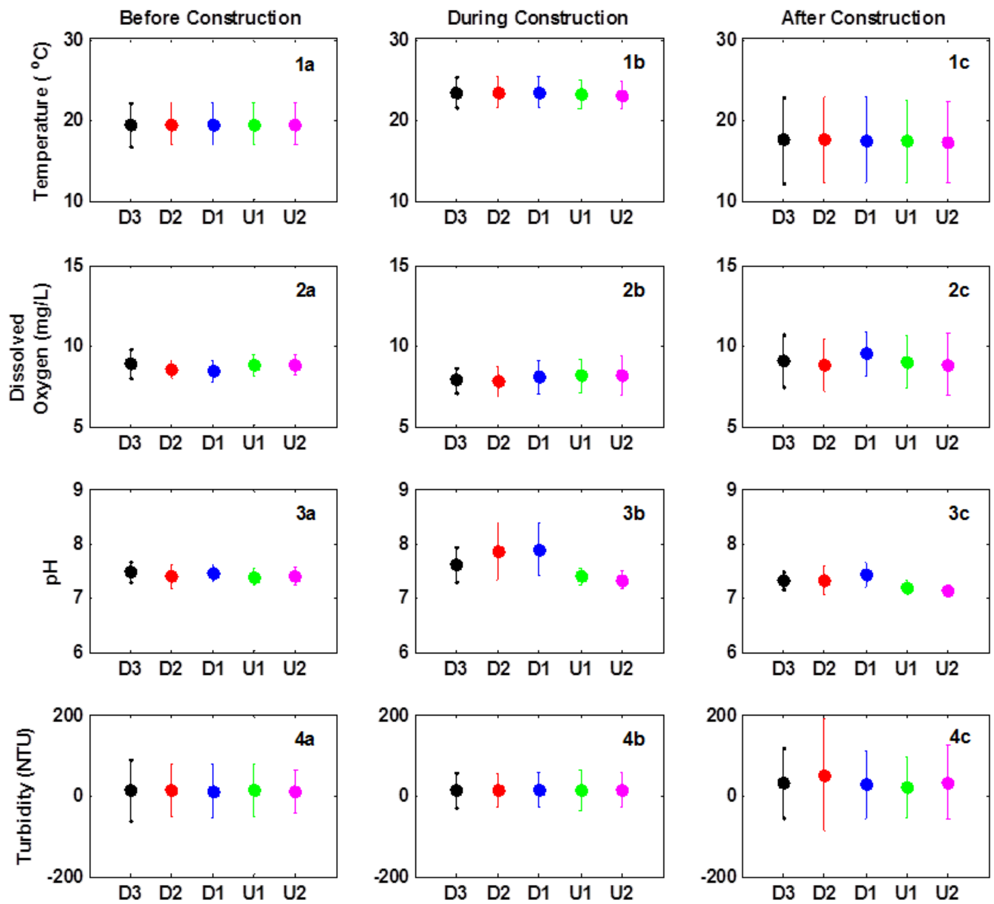

Figure 16. Mean values for the water quality parameters.

Figure 17 shows the Multiresolution analysis plots for temperature at location 1 during the pre-construction phase. The original signal is plotted at the top. Following the original signal, the frequency components are plotted highest to lowest from top to bottom, where X represents the original signal. S9 is the approximation of the original signal at decomposition level 9 while D1 through D9 are details of the signal at levels of decomposition from 1 through 9.

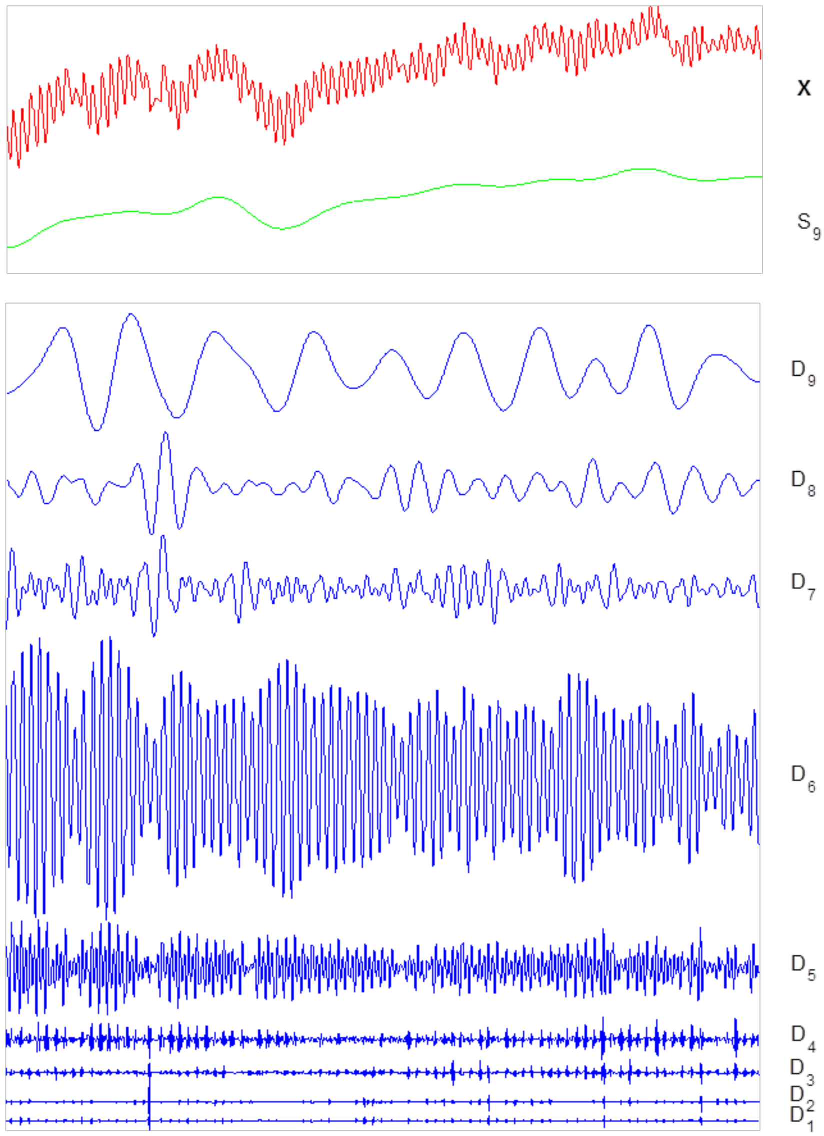

Figure 17. Wavelet Multiresoulution Analysis for temperature before construction.

Wavelet variance is presented in Figure 18 and Figure 19. Figure 18 shows the wavelet variance for the water quality parameters as plotted against different levels of signal decomposition. The subplots from left to right show three different phases of construction of the culvert. Meanwhile, the different water quality parameters are plotted from top to bottom. Each subplot represents wavelet variances for all the five locations monitored. Figure 19 shows the wavelet variance for the water quality parameters as plotted against different stages of construction. The subplots from left to right show the five different locations that were monitored. Meanwhile, the different water quality parameters are plotted from top to bottom. Each subplot represents wavelet variances for all the nine levels of decomposition.

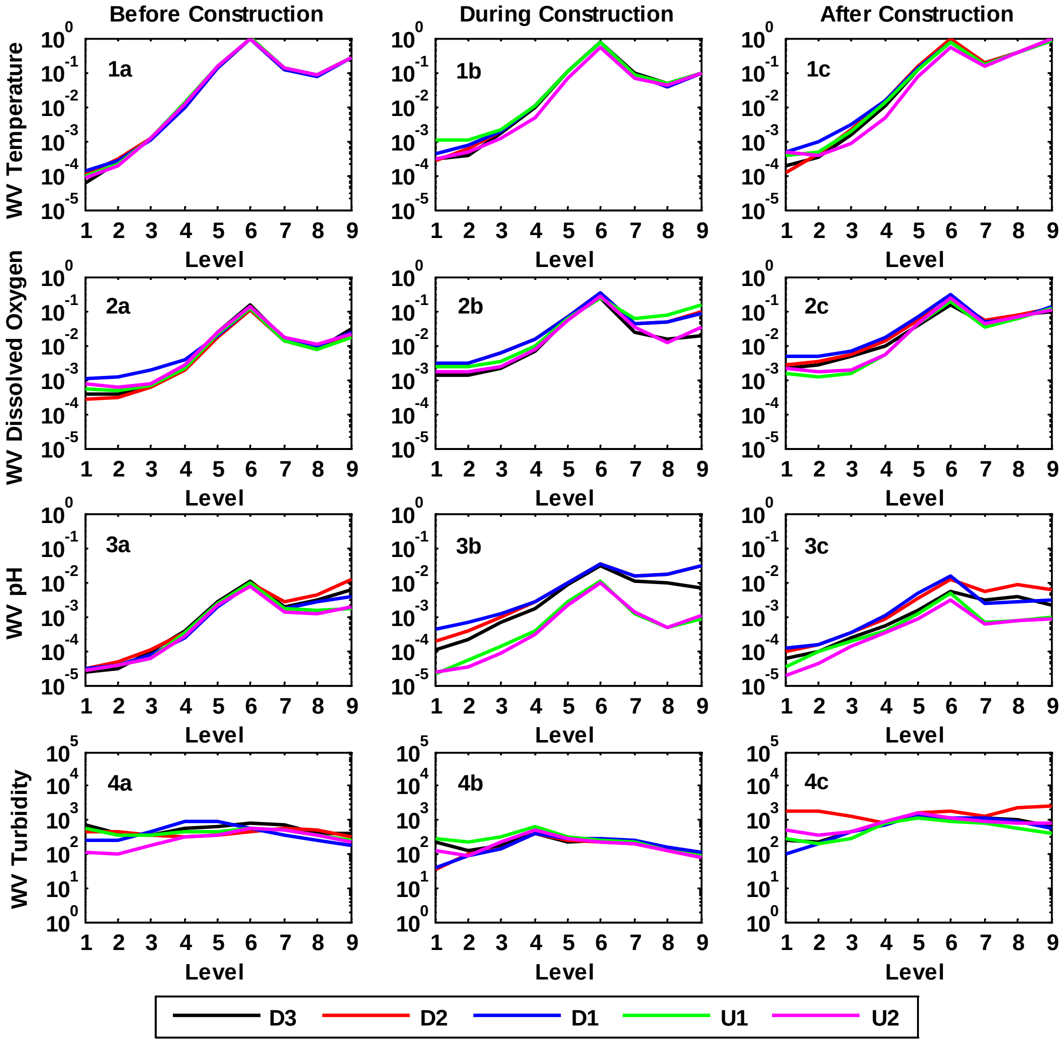

Figure 18. Wavelet Variance for different time scales.

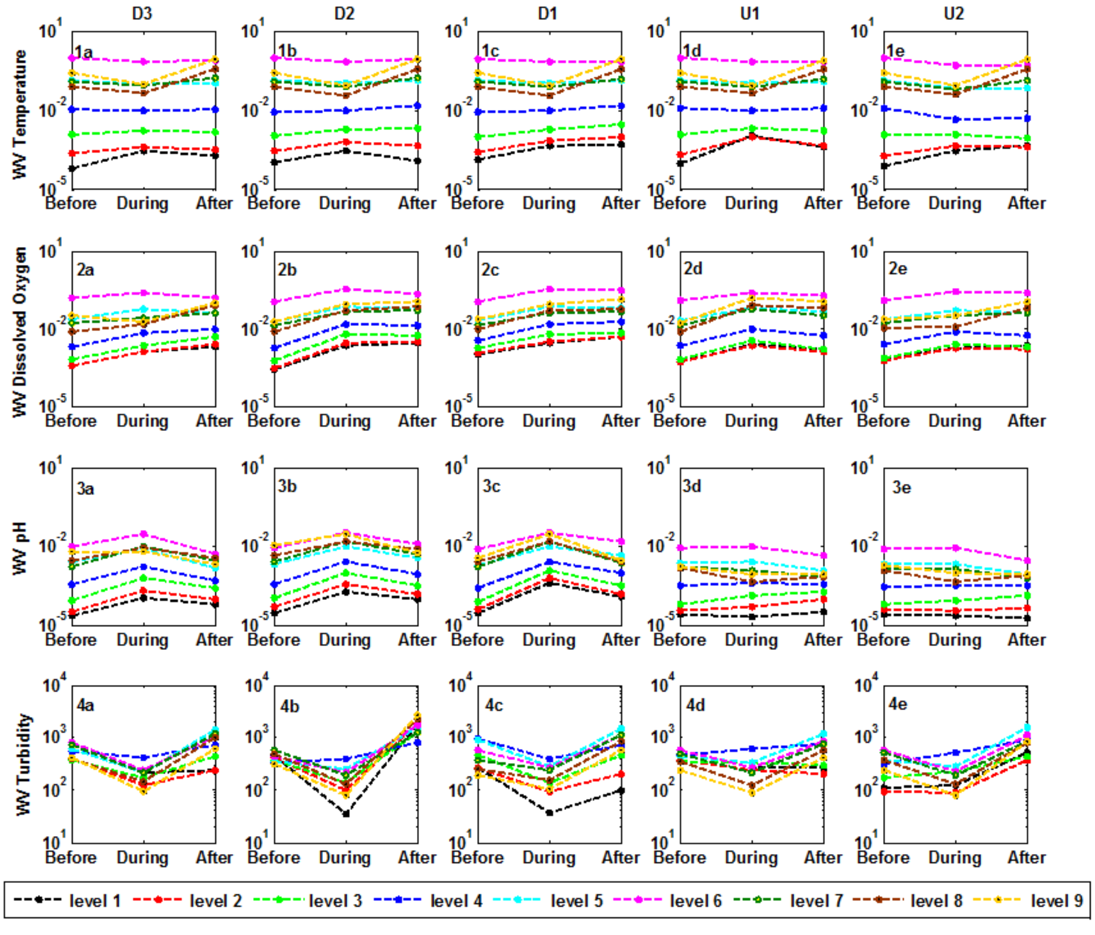

Figure 19. Wavelet variance for different stages of construction.

The wavelet covariance for the water quality parameters is plotted against different levels of decomposition (Figure 20 and Figure 21). The subplots from left to right show the three different stages of construction. Meanwhile, the covariance between different water quality parameters is plotted from top to bottom.

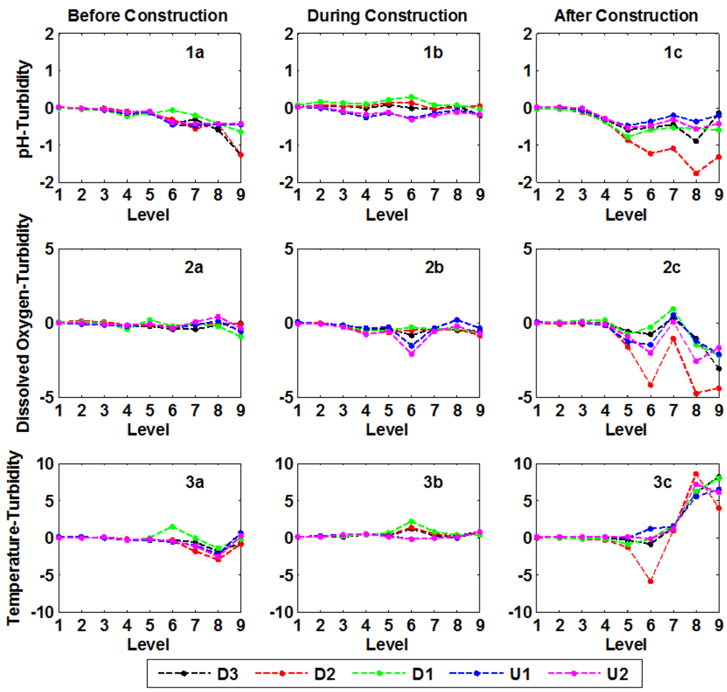

Figure 20. Wavelet covariance

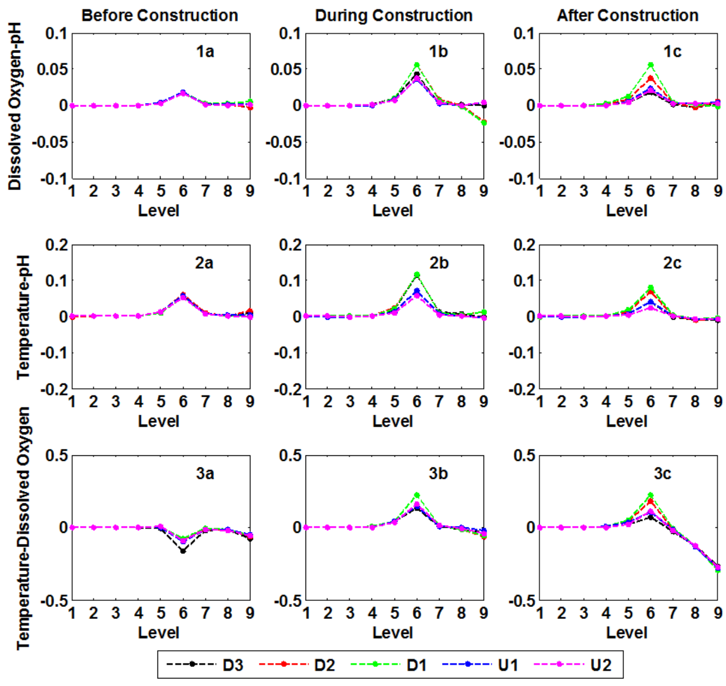

Figure 21. Wavelet covariance as a function of level of decomposition.

4.1.6 Discussion

Diurnal variations are not evident in (Figure 15) for the Temperature time series, but when the signal is decomposed using multiresolution analysis diurnal variations in the temperature signal are observed. This can be observed in Figure 17 for level D5 (16 hr – 32 hr) where the diurnal behavior of the temperature data is evident. The details reveal that the sub daily variations (D1,D2,D3) are less prominent than the daily (D6) variations. The variations again become smaller at scales higher than the daily scale.

The wavelet variance reveals the intensity of variation from one scale to the other of the water quality time series. The wavelet variance presented plots presented in Figure 18 show the variance contribution of an individual scale to the total variance. Temperature, dissolved oxygen and pH wavelet variance plots indicate that variation in the time series increases progressively till the sixth level (16 – 32 hr) where a maximum is achieved. This shows that diurnal variation in the three parameters contributes maximum to the total variance. Also, variance at all the locations during the three stages of construction is comparable. Figure 19 demonstrates that the variance in temperature increases during the construction for the five locations at sub-daily scales. At the sixth level (16-32 hr) variance remains consistent. This shows that there is an increased variance in temperature at smaller scales during the construction as compared to higher scales. Reduction in variance was observed for higher levels during the construction for temperature. Similar trends can be observed for dissolved oxygen and pH. Variance in turbidity did not show any particular trend. The variance contribution by various scales remained consistent. Although, from Figure 19 it can be observed that reduced variance in turbidity was observed for the period during construction.

The wavelet covariance plots for dissolved oxygen-turbidity remain fairly constant with at different scales for the five locations before construction. During construction, a decrease is observed at level 6 (16-32 hrs), while covariance values after construction are erratic for higher scales. For pH-turbidity and temperature-turbidity negative covariance above level 5 (8 -16 hrs before construction is observed. During the construction both pH-turbidity and temperature-turbidity show marginal consistent covariance. All the dissolved oxygen-pH, temperature-pH and temperature- dissolved oxygen covariance plots showed a peak at level 6 (16-32 hrs) except in the temperature-dissolved oxygen plot for before construction stage where the covariance decreased at level 6 (16 – 32 hrs). These results show a diurnal interdependence between the parameters.

4.2 Post-Construction Monitoring

Post construction background samples were collected at Canton Creek on 23rd April 2010 at five locations to establish ambient levels of contaminants within the creek (Figure 22 and Figure 23).

Figure 22. Sample collection at Canton Creek.

Figure 23. Test site configuration at Canton Creek test location.

The data demonstrated that the pH values were similar in all the locations sampled, and varied between pH = 6-7 (Table 10). The only exception was the U/S Tributary Location 1-2, where pH was higher at 10.5. Temperature for all locations varied between 56 and 58 °F. Suspended solids and turbidity were higher for U/S Tributary 1-1 than other locations, which might be due to the fact that its runoff has contribution from the shopping center.

Table 10. Summary of Tested Background Samples

	Canton Creek Background	**Canton Creek @ Tributary 1**	**U/S Tributary 1-1**	**D/S Tributary**	**U/S Tributary 1-2**
Sample #	4	2	1	3	No Sample
Location	N 34°13'49.08" W 84°27'37.902"	N 34°13'54.66" W 84°27'48.9"	N 34°13'49.08"' W 84°27'48.54"	N 34°14'3.3"' W 84°27'55.2"	N 34°13'58.98" W 84°27'43.2"
Time of Sampling (EDT)	11:56 hrs	10:58 hrs	10:43 hrs	11:20 hrs	12:30 hrs
pH	6-6.5	6.5-7	6.5	6-6.5	10.5
Temperature (°F)	58	56	56	58	56
Turbidity (NTU)	1.99	2.29	3.58	0.75	-
Conductivity (µS/cm)	65	69	74	57	-
TSS (mg/L)	2.14	2.75	4.71	0.14	-
Fe (mg/L)	0.246	0.33	1.36	0.26	-
Cu (mg/L)	0.02	0.033	0.024	0.033	-
Zn (mg/L)	0.24	3.08	2.45	0.023	-
Mg (mg/L)	2.32	2.43	3.711	2.62	-
Al (mg/L)	0.14	0.48	0.383	0.15	-
Pb (mg/L)	0.025	0.08	0.048	0.021	-

An additional set of background samples at Canton Creek were collected on 26th August 2010 at seven locations (Figure 24). The results demonstrated that there was only a small variation in the temperature values at the sampling locations in the Canton Creek (Table 11). Tributary temperatures were slightly lower than the creek temperatures due to the canopy which blocks the sunlight because tributaries were not exposed to direct sunlight. pH values both for the creek and the tributaries varied between 6.7 and 7.1. Turbidity values for the creek remained between 3.73 and 5.01 NTU's. It was observed that the turbidity of the second tributary was significantly higher than the other two tributaries. Higher value of turbidity for the first and second tributary can be attributed to the discharge the two tributaries receive from the shopping center. On the other hand, the turbidity value in the third tributary was much lower. This indicates that the runoff from the ramps which contributes to the third tributary has lower suspended solids. Conductivity values for the creek varied between 84.29 and 90.01 µS. The conductivity value for the first tributary was significantly higher than the other two tributaries. Similarly, metal contaminants showed similar behavior .

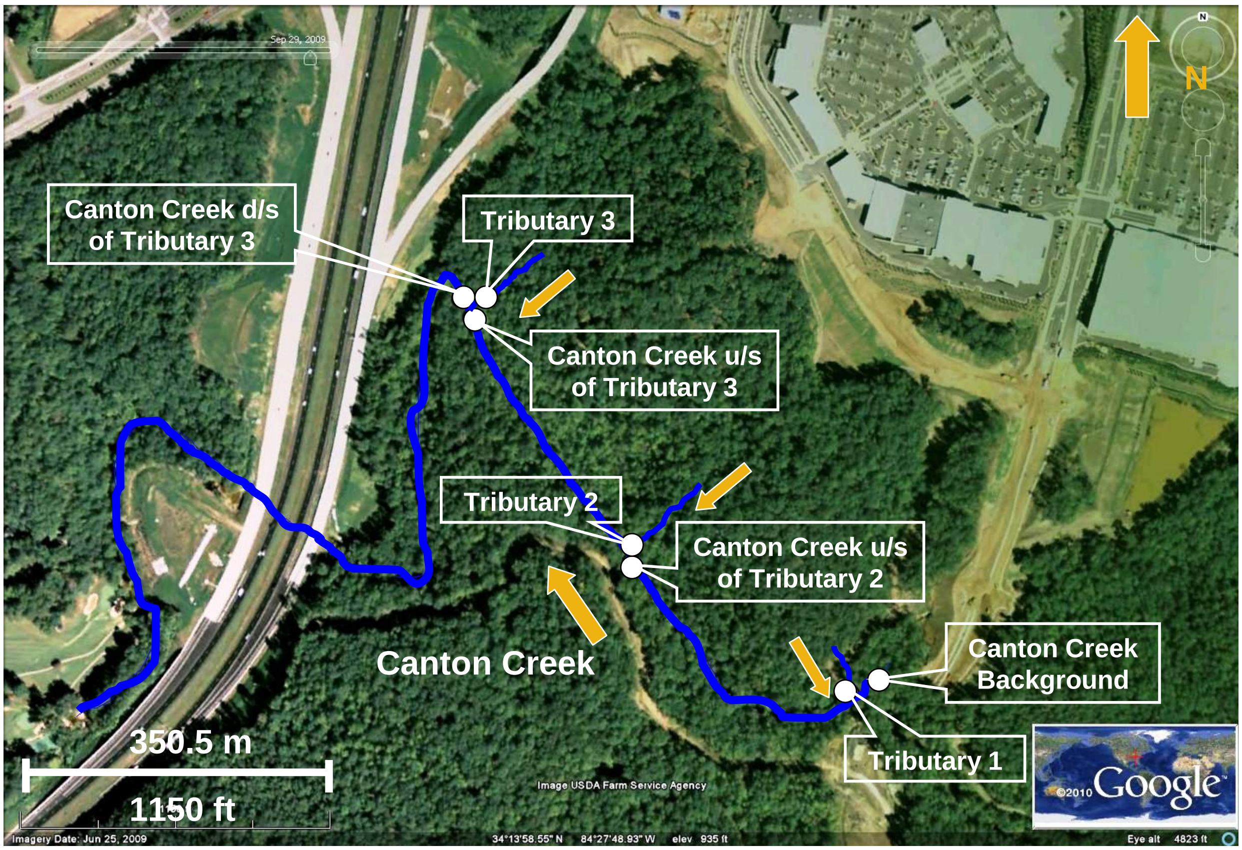

Figure 24. Canton creek background sample locations.

Table 11. Background Sampling Results (August, 2010)

	Canton Creek Background	Tributary 1	Canton Creek @ Tributary 2	Tributary 2	Canton Creek U/S of Tributary3	Tributary 3	Canton Creek D/S of Tributary3
Sample #	6	7	1	2	3	5	4
Location	34°13.824' N , 84° 27.630'W	34° 13.812 N , 84° 27.645' W	34°13.893' N ,84° 27.813' W	34°13.897 N , 84° 27.816'W	34°14.048 N, 84° 27.921'W	34°14.054 , 84°27.913'W	34°14.046' N , 84°27.932'
Time of Sampling (EDT)	12:54 PM	12:59 PM	11:59 AM	12:08 PM	12:19 PM	12:31 PM	12:25 PM
pH	7.1	6.7	6.8	6.9	6.8	6.8	6.9
Conductivity (µS/cm)	86.66	116.4	90.01	83.17	87.21	77.95	84.29
Turbidity (NTU)	4.65	1.98	5.01	6.45	4.06	1.32	3.73
Temperature (C)	23	21.5	23	20	22	22	23
Cu (mg/L)	0.02244	0.01218	0.01947	0.03804	0.02324	0.02033	0.01254
Pb (mg/L)	0.00316	0.00154	0.00747	0.00646	0.0043	0.00546	0.00206
Zn (mg/L)	0.00142	0.00786	0.00395	0.00285	0.00253	0.00322	0.00299
Ni (mg/L)	0.01291	0.01217	0.01314	0.01206	0.01327	0.01272	0.01295
Cd (mg/L)	0.14574	0.14583	0.14567	0.14565	0.14568	0.14562	0.1457
Cr (mg/L)	0.0433	0.04258	0.04366	0.04107	0.04313	0.04345	0.04362
Fe (mg/L)	0.32008	0.1315	0.18372	0.17863	0.24022	0.03012	0.25897
Al (mg/L)	0.01126	0.00331	0.00517	0.00492	0.011	0.01025	0.00517
Mn(mg/L)	0.04363	0.65996	0.05905	1.5588	0.05591	0.00681	0.05422

The results of the grab samples collected for measurement of background concentrations were compared with the in-stream monitoring data that were collected at 15 minute intervals during the construction phase. Temperature values were comparable to the values obtained during in-situ sampling except for Tributary 2. It is believed that the effect of shade was responsible for the lower temperature observed.

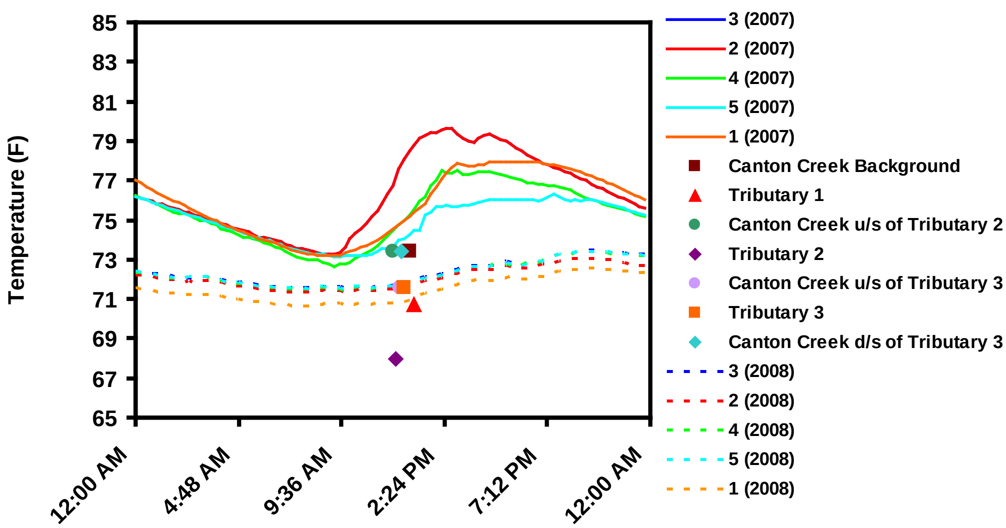

Figure 25. Post construction sampling data comparison with in-stream sampling data gathered during construction.

4.3 Conclusions

In summary, wavelet analysis of the data gathered during the construction phase facilitated an analysis of the impact of the construction activities on the water quality parameters measured in-stream. The apparent increase in the in-stream temperature recorded during construction was coincidental with the increased seasonal variation in temperature observed during late July and early August. As was anticipated, dissolved oxygen correlated inversely with the observed temperature data. Most notably, the influence of the concrete pours could be detected in-stream, with a transitory increase in the in-stream pH level, while turbidity did not show any significant change in value during the period of active construction. Background sampling performed after the conclusion of construction of the sand filters and the shopping center complex were consistent with data gathered in-stream during the active construction phase of the GDOT project.

5. Canton BMP Monitoring

5.1 BMP Description

The Canton stormwater BMP that was monitored in this study is located near the intersection of I-575 and SR-20. The BMP treats roadway surface stormwater runoff collected directly from I-575, and before it discharges into Canton Creek. The motivation for the construction of the Canton sand filter was to limit roadway runoff to the habitat of the Cherokee darter fish, which is a threatened species endemic to the Etowah river system in North Georgia. The sand filter was constructed under an agreement between GDOT and the U.S. Fish and Wildlife Service. The key site descriptors are summarized below in Table 12.

Table 12. Canton, Georgia BMP Description

Data Element	Description
General Test Site Information	
BMP Test Site Name	Canton Sand Filter (Pond 1)
Location	I-575, Canton, GA @ SR20
Elevation at top of sand filter	895 ft
Structural BMP Information	
Structural BMP Name	Detention Pond/Sand Filter
BMP Type	Type I. Well defined inlets and outlets
BMP Description	Substantial residence time and storage volume
Treatment Category	Sedimentation, Filtration
Number of Inlets	3
Inlet Descriptions	48” and 24” concrete pipe, one concrete open channel
Number of Outlets	1

Data Element	Description
Outlet Descriptions	Filter underdrain connected to 48” concrete outlet pipe
Catchment Area	20.1 Acres, plus direct precipitation on BMP
Watershed Stations	
Regional Watershed Name	Etowah
Station	Monitoring stations immediately u/s and d/s of pond
Upstream BMP	None, inflow received directly from I-575
Downstream BMP	None, effluent discharged to Canton Creek

The plan view of the BMP is shown below in Figure 26, along with a typical cross-section (Figure 27). A 48”, a 24” concrete pipe, and a single concrete flume discharge runoff from I-575 into the detention pond. The outlet of the detention pond consists of a 36” concrete pipe that allows water to bypass the riprap rock filter. The second stage of the BMP consists of a 21” thick sand filter overlying a gravel and 6” PVC underdrain collection system that discharges to Canton Creek via a 48” concrete pipe.

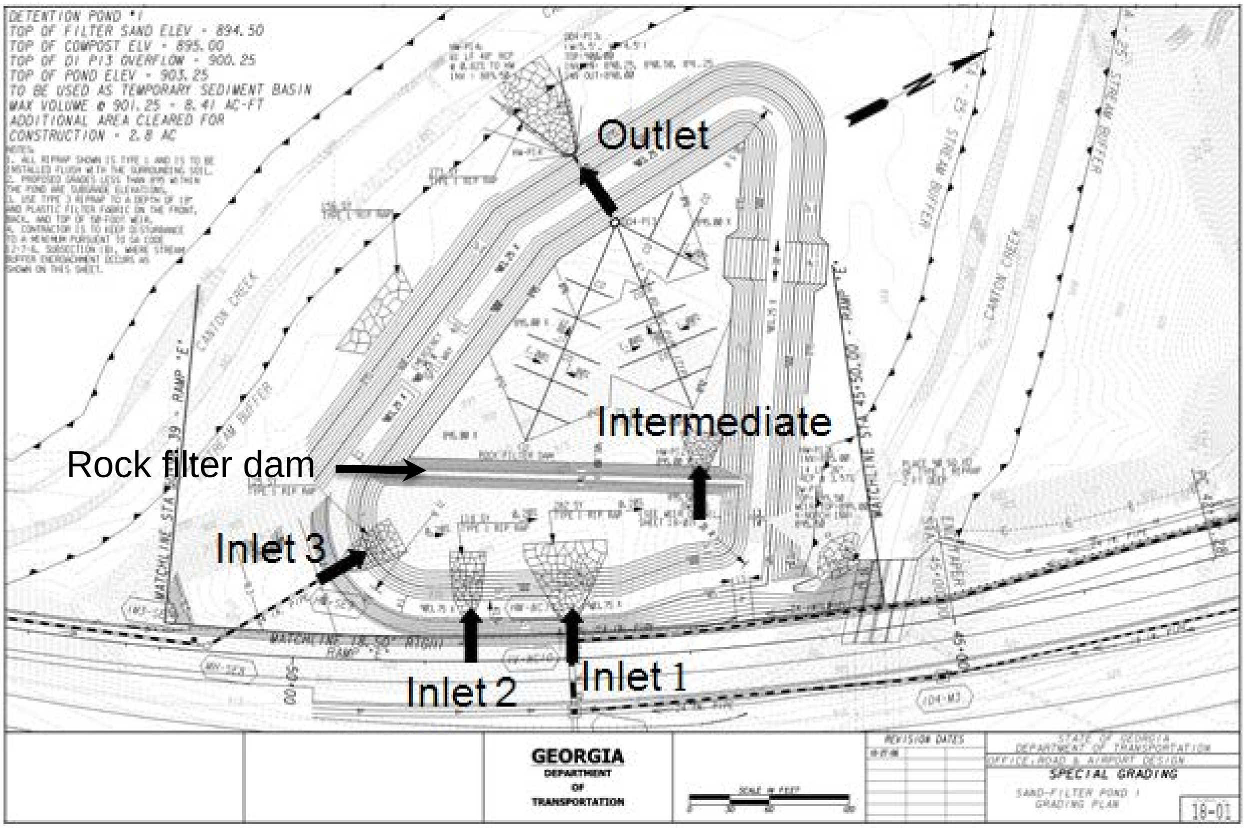

Figure 26. Sampling locations at the Canton Creek sand filter.

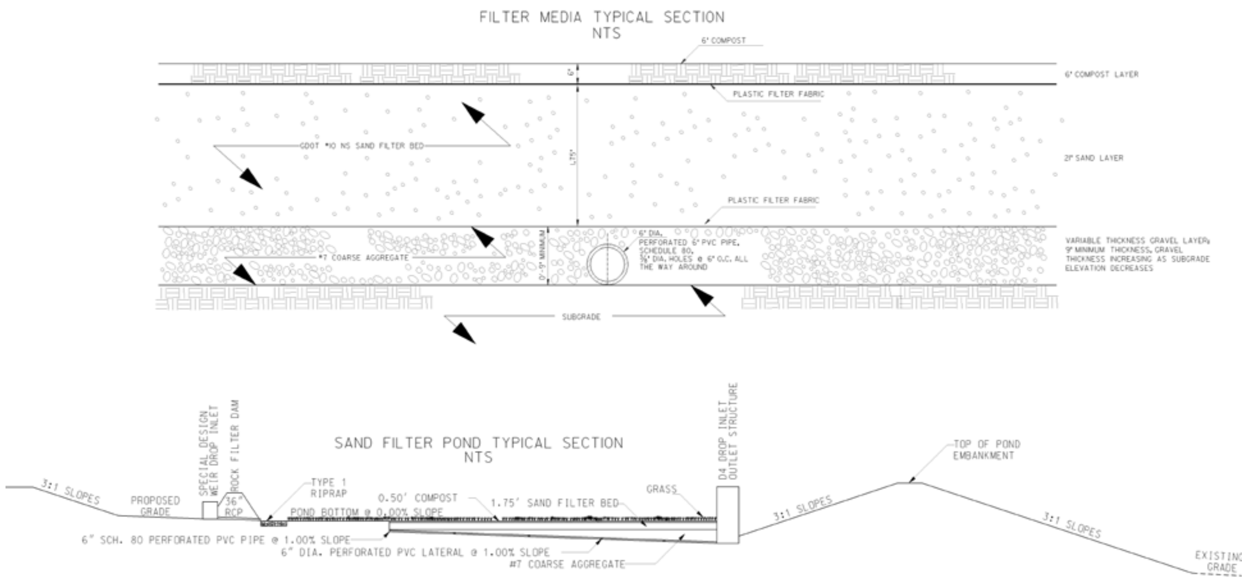

Figure 27. Cross-section of typical sand filter construction (GDOT).

A total of eleven events were monitored over the course of the study (Table 13). Due to the complex nature of the site, it was impractical to measure all inlet locations simultaneously. Grab samples taken July 2010 and data from in-situ samplers taken May 2011 were used to assess the three inlets. Inlet 1 was selected as representative of the three inlets because it received runoff from the largest catchment area and thus discharged the greatest volume of storwmater of the three inlets, and because it represented the highest TSS contaminant concentrations in the three inlets. To evaluate the overall site performance, monitoring was carried out at inlet 1, the intermediate location between the detention pond and sand filter, and the outlet of the sand filter.

Table 13. Summary of Events Monitored at I-575 Canton BMP

#	Event	In-Situ Monitoring			Stormwater Samples		
		Inlet	Intermediate	Outlet	Inlet	Intermediate	Outlet
1.	07/13/2010	○	○	○	●	○	○
2.	02/25/2011	○	●	●	○	●	●
3.	02/28/2011	○	●	●	○	●	●
4.	03/05/2011	○	●	●	○	●	●

5.	03/09/2011	○	●	●	○	●	●
6.	03/15/2011	○	●	●	○	●	●
7.	03/26/2011	○	●	●	●	●	●
8.	04/04/2011	●	●	●	●	●	●
9.	04/11/2011	●	●	●	●	●	●
10.	04/15/2011	●	●	●	●	●	●
11.	05/03/2011	●	○	○	●	○	○

● - Yes ○ - No

5.2. First Flush and Inlet Characterization

The three inlets were characterized by event 1 (E1) and event 11 (E11) in an effort to assess contaminants are entering the BMP. Event 1 was characterized by grab samples taken at 15 minute intervals from the three inlets for the first 45 minutes of the storm. The results of E1 are shown below in Figure 28 through Figure 32. Figure 28 and Figure 29 demonstrate that total suspended solids and turbidity decreased significantly within the first 15 minutes of the event. Additionally, inlet 1 had the highest observed concentration for these parameters in the first 15 minutes.

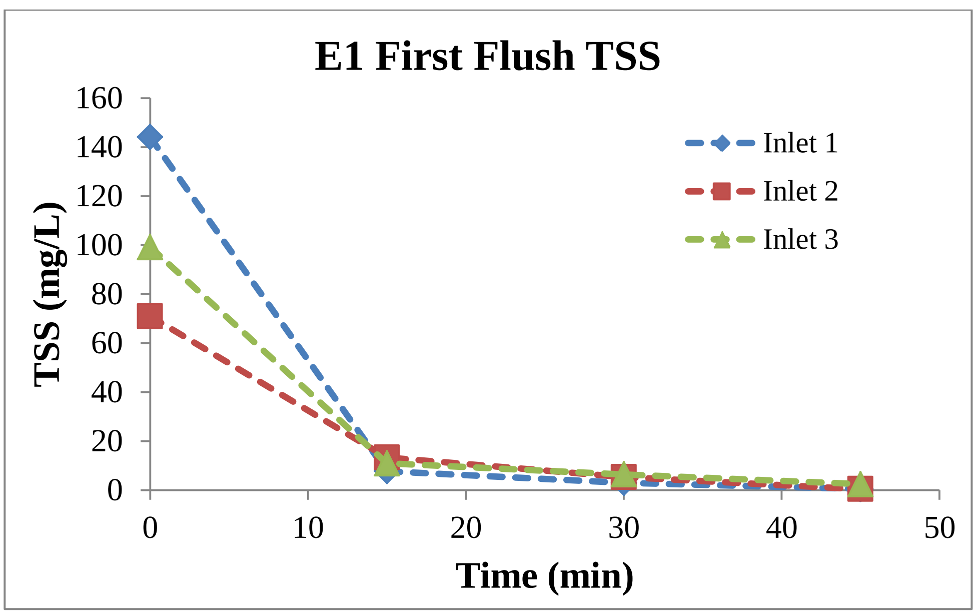

Figure 28. E1 First flush TSS at Canton sand filter.

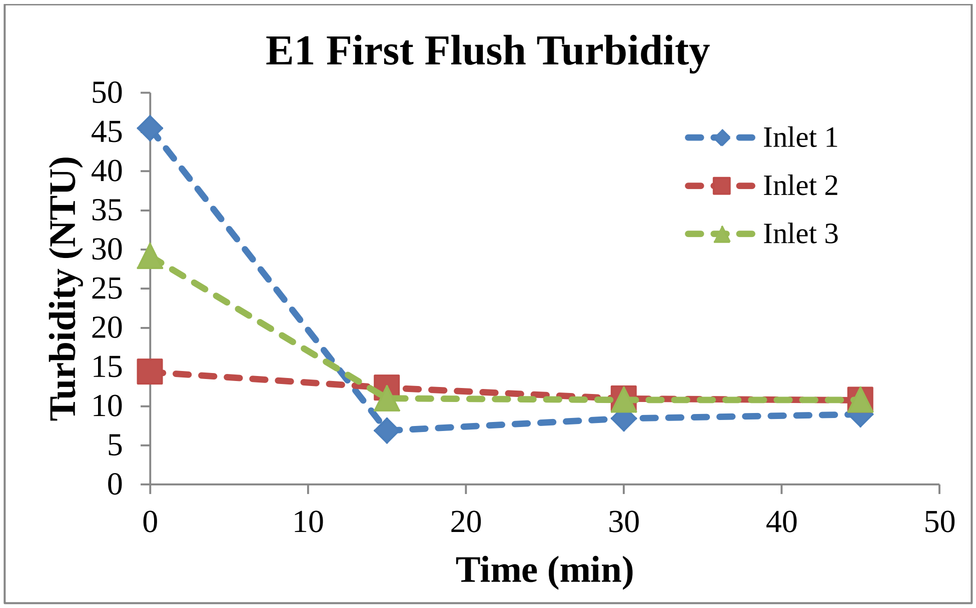

Figure 29. E1 First flush turbidity at Canton sand filter.

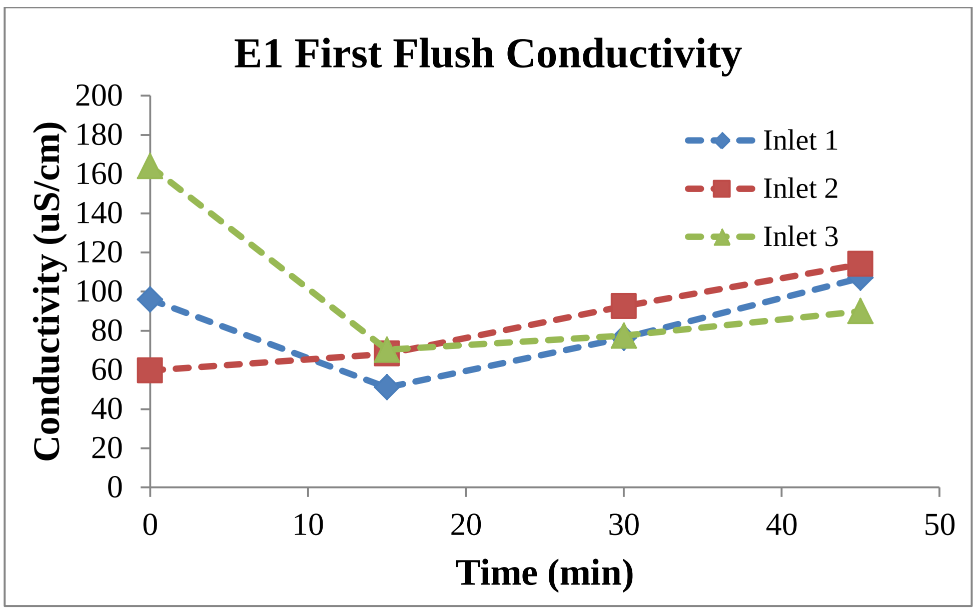

Figure 30. E1 First flush conductivity at Canton sand filter.

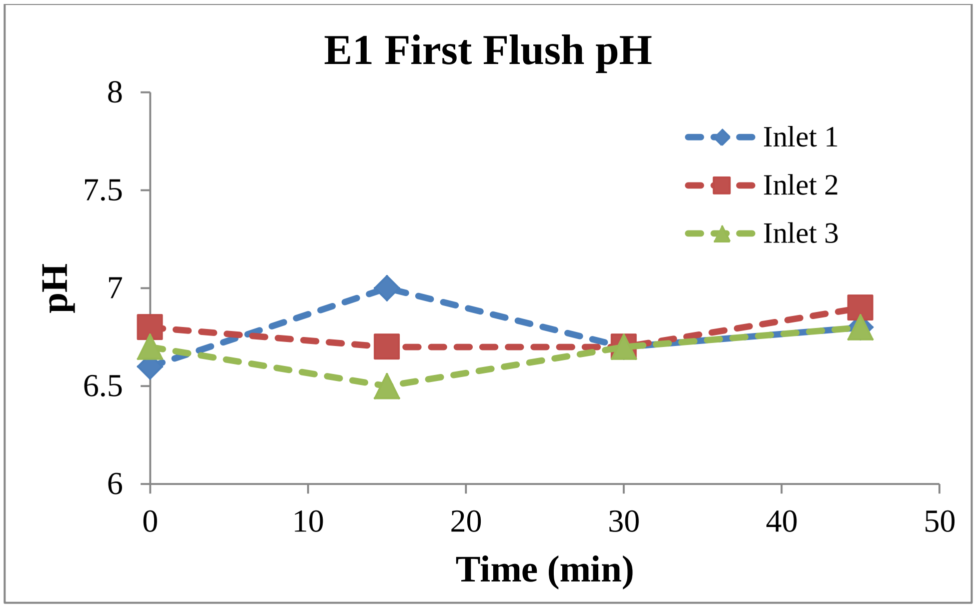

Figure 31. E1 First flush pH at Canton sand filter.

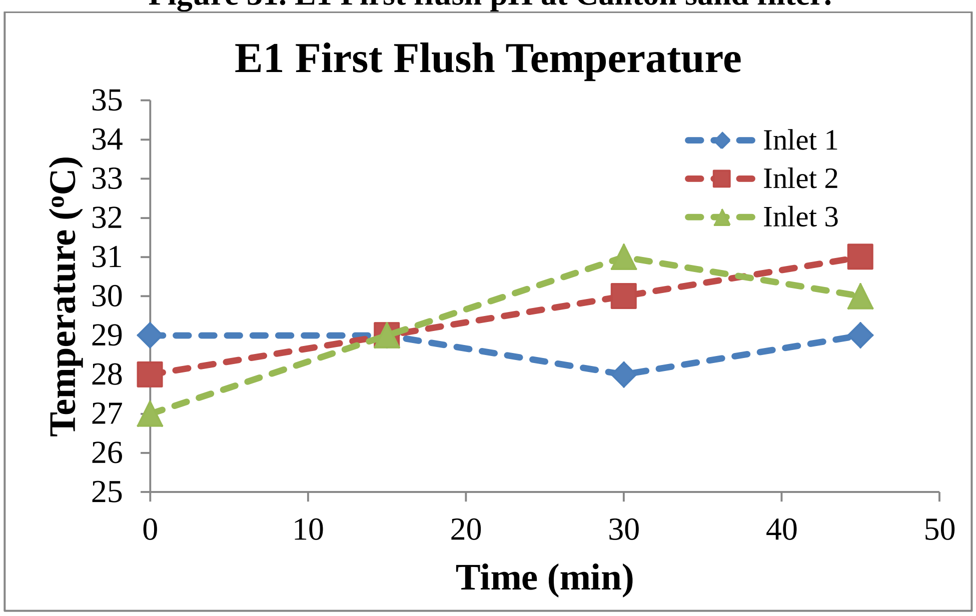

Figure 32. E1 First flush temperature at Canton sand filter.

The three inlets were also assessed using automated samplers during event 11. TSS, turbidity, and conductivity were measured at 5, 15 and 30 minutes after initiation of flow while a composite event mean concentration (EMC) was measured as well. Unfortunately, the depth of flow was inadequate in open channel inlet 2 for the automated samplers to function. As with E1, there was an obvious drop in concentration of contaminants with time, and higher levels of TSS and turbidity were measured at inlet 1.

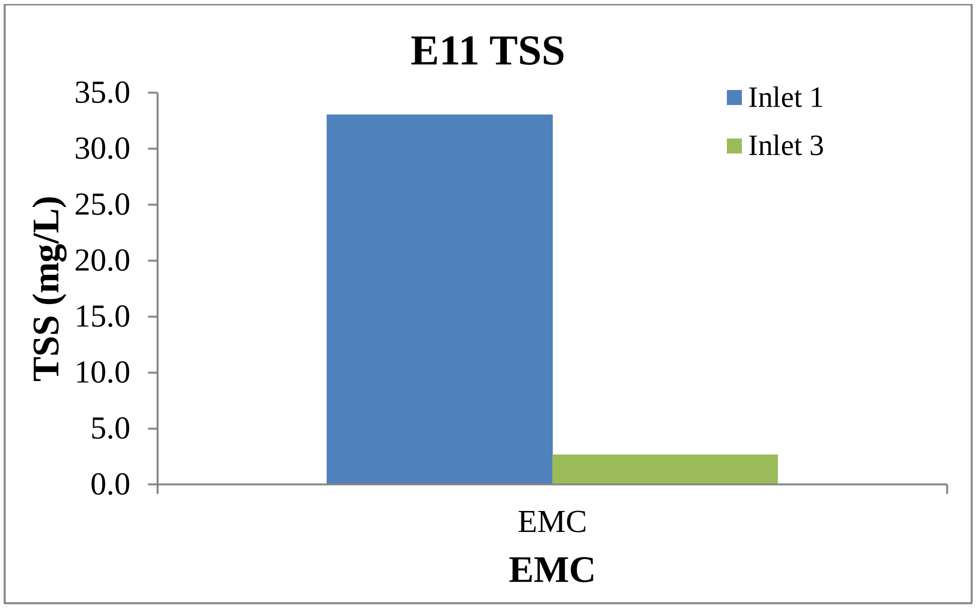

Figure 33. E11 First flush and EMC TSS at Canton sand filter.

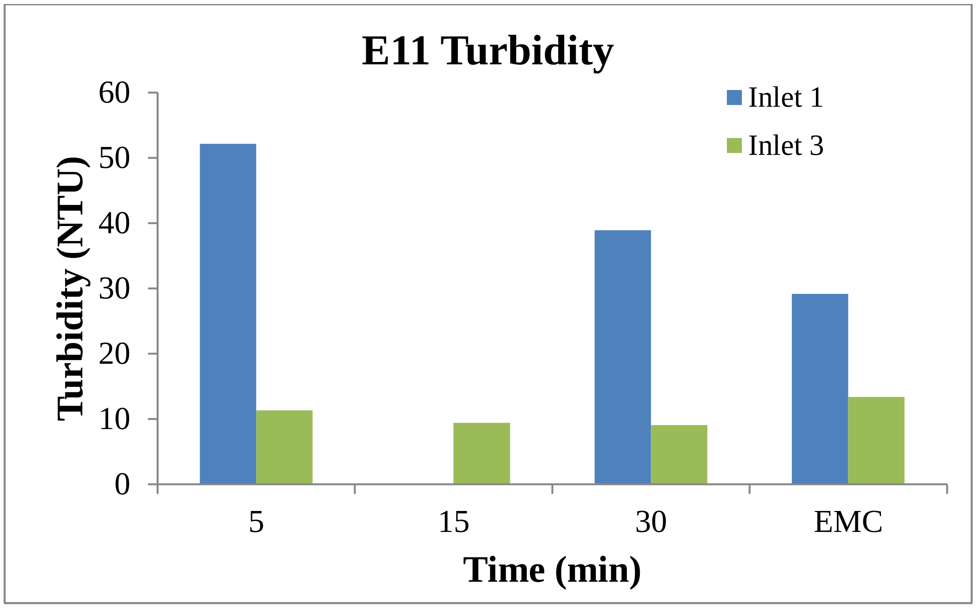

Figure 34. E11 First flush and EMC turbidity at Canton sand filter.

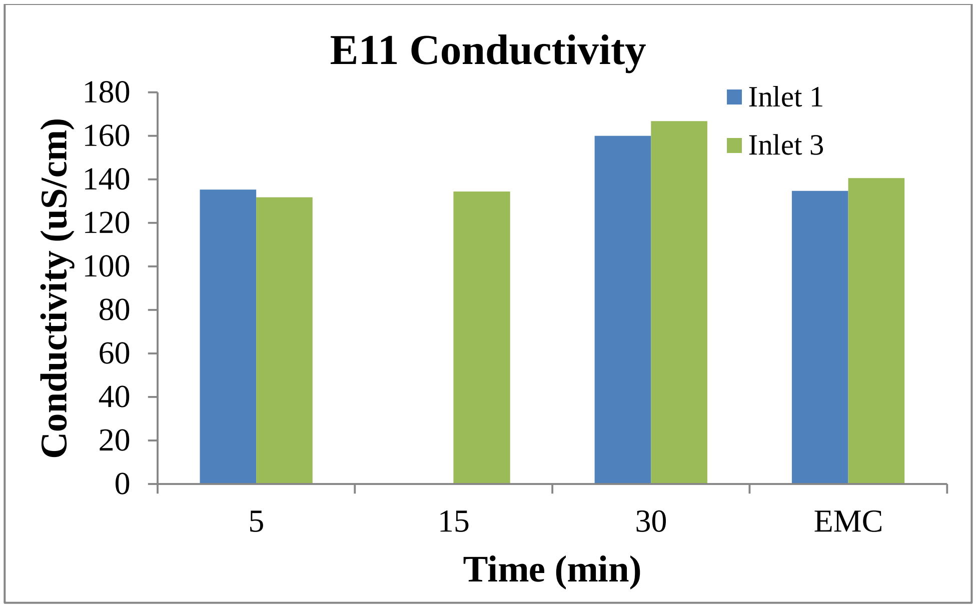

Figure 35. E11 First flush and EMC conductivity at Canton sand filter.

In addition to the conventional water quality parameters, total nitrogen, nitrites, and nitrates were measured during E11 (Figure 36 and Figure 37). The results mirror the above behavior, with a decrease in concentration with time. As with conventional parameters, a higher concentration of nutrients was measured at inlet 1.

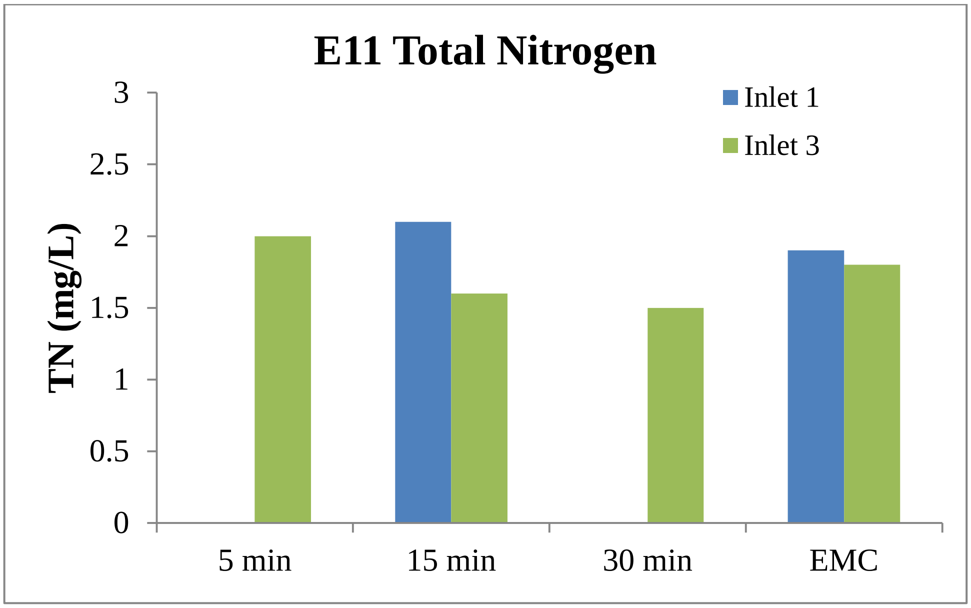

Figure 36. E11 First flush and EMC total nitrogen at Canton sand filter.

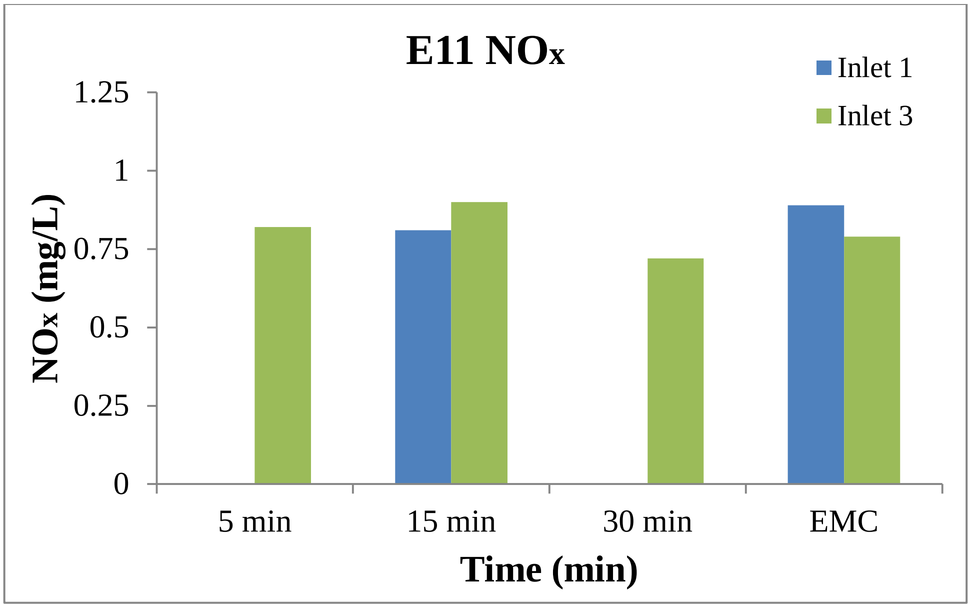

Figure 37. E11 First flush and EMC NO_x at Canton sand filter.

The total and dissolved lead, copper, and zinc measured during E11 show that in general that heavy metal concentrations drop during the first flush of the storm event (Figure 38 through Figure 42). While total heavy metals were consistently higher at inlet 1, slightly higher dissolved heavy metals were at inlet 2. This may be related to the decreased concentration of suspended solids measured at inlet 2, resulting in less suspended matter for heavy metals to sorb to. Note that dissolved lead was below detection limits at both inlets.

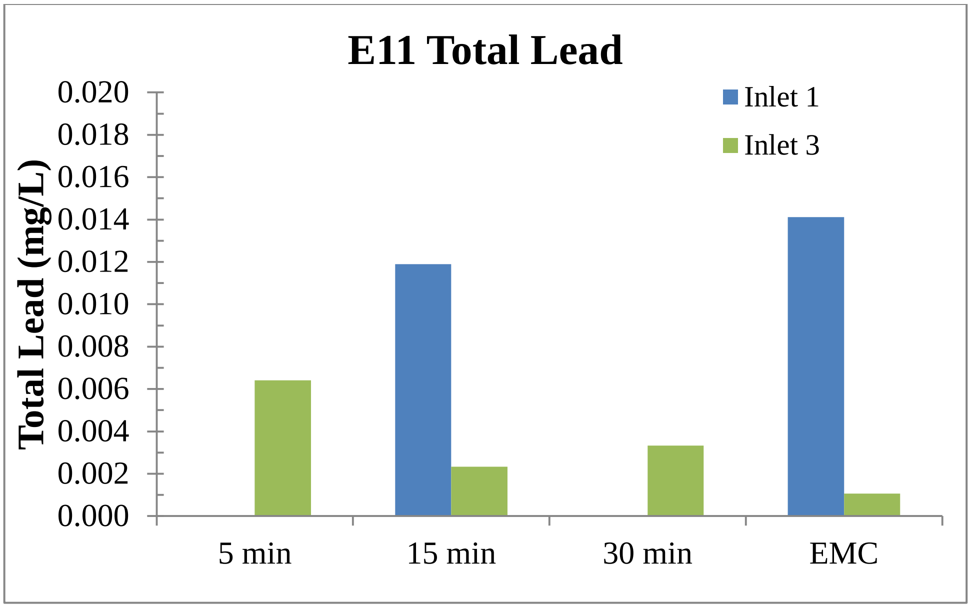

Figure 38. E11 First flush and EMC total lead at Canton sand filter.

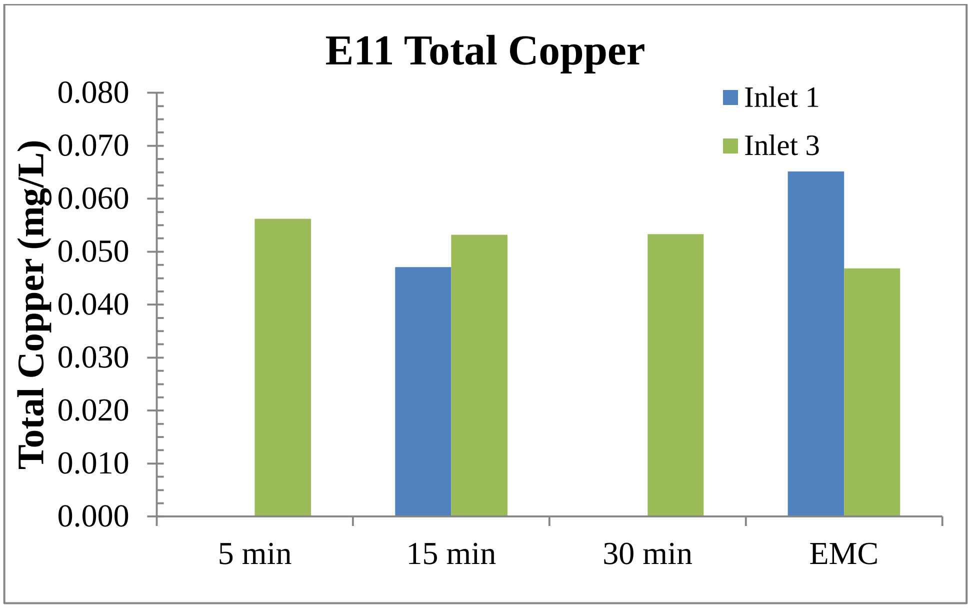

Figure 39. E11 First flush and EMC total copper at Canton sand filter.

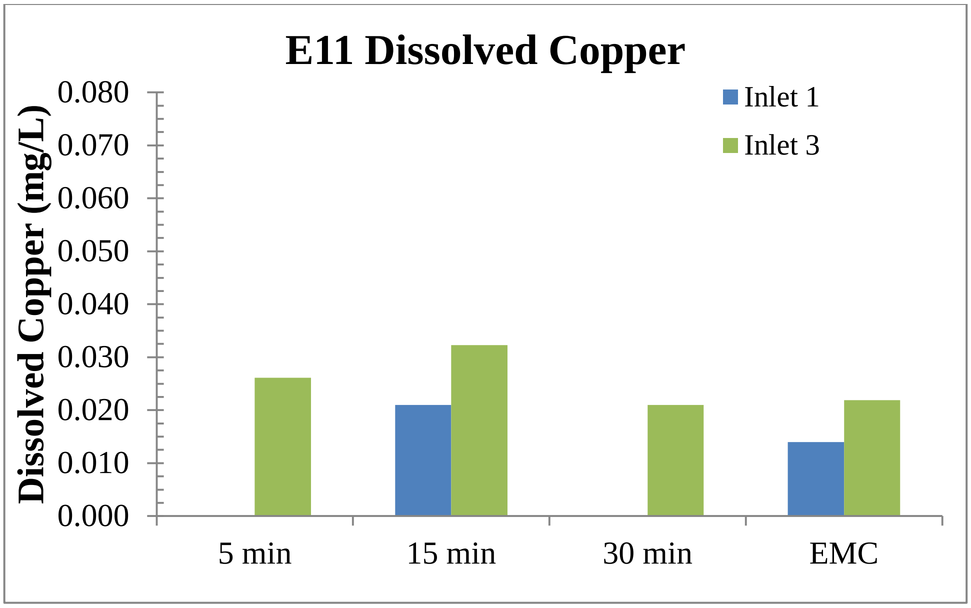

Figure 40. E11 First flush and EMC dissolved copper at Canton sand filter.

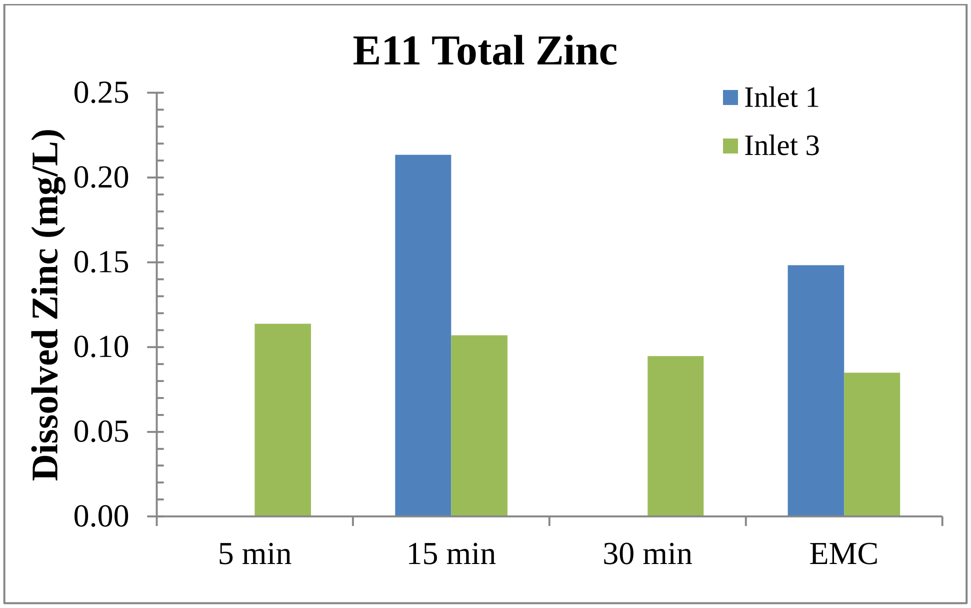

Figure 41. E11 First flush and EMC total zinc at Canton sand filter.

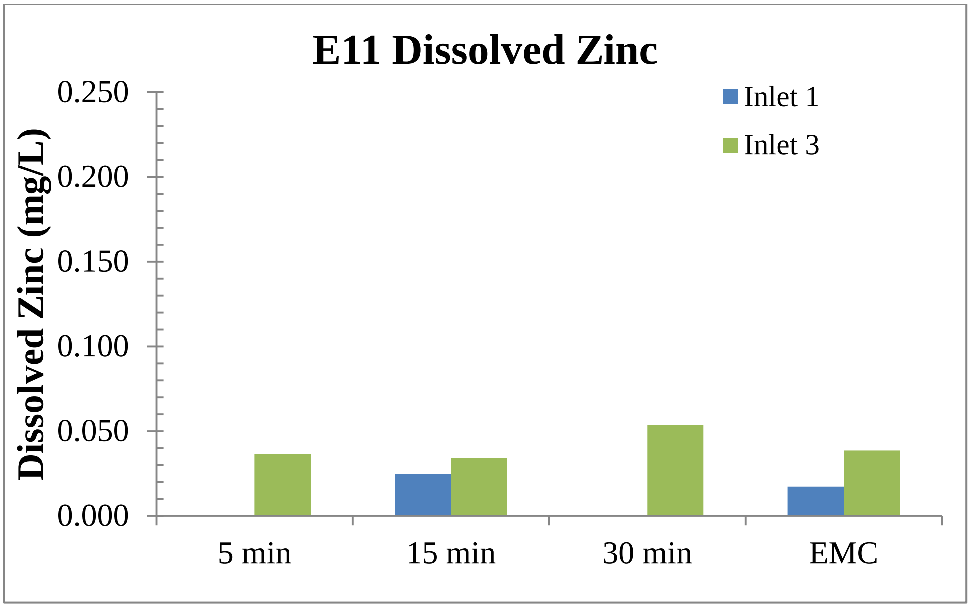

Figure 42. E11 First flush and EMC dissolved zinc at Canton sand filter.

5.3. Hydrological Characterization

The flow depth and rainfall data for event 2 (E2) through event 10 (E10) are shown in the following figures, with event 8 (E8) through E10 including samples collected at three locations in the BMP: inlet 1, the intermediate, and the outlet location (Figure 43 through Figure 51). E8-E10 show that the time between peak flow at the inlet and the outlet was 2.9 hours and that detention in the sedimentation pond detained peak flow for 0.8 hours. This suggests that the sedimentation pond may not be detaining stormwater for a significant period of time, and is likely being short-circuited due to the high hydraulic conductivity check dam. While the peak-to-peak retention time across the site is lower than expected, the very consistent trailing arm of the outlet hydrograph shows that stormwater is being detained within the BMP well over the 24-hour design residence time. It can also be observed that the volume of rainfall significantly impacts retention time between the inlet and outlet location. The hydrograph of E9 shows that for a lower rain intensity event the retention time is significantly higher than for the higher rain intensity observed during E8 and E10 (Figure 49 through Figure 51).

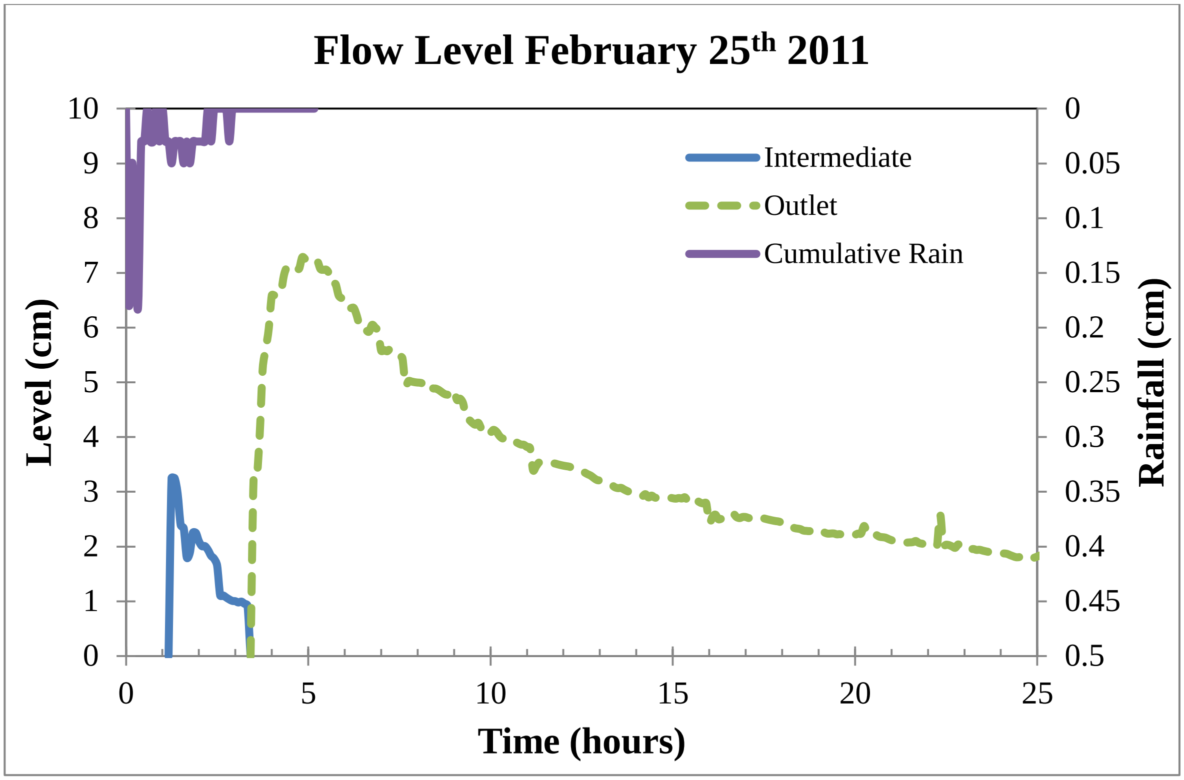

Figure 43. E2 Rainfall and hydrograph at Canton sand filter 02/25/2011. (Intermediate sampling was performed at the outflow of the rock filter dam.)

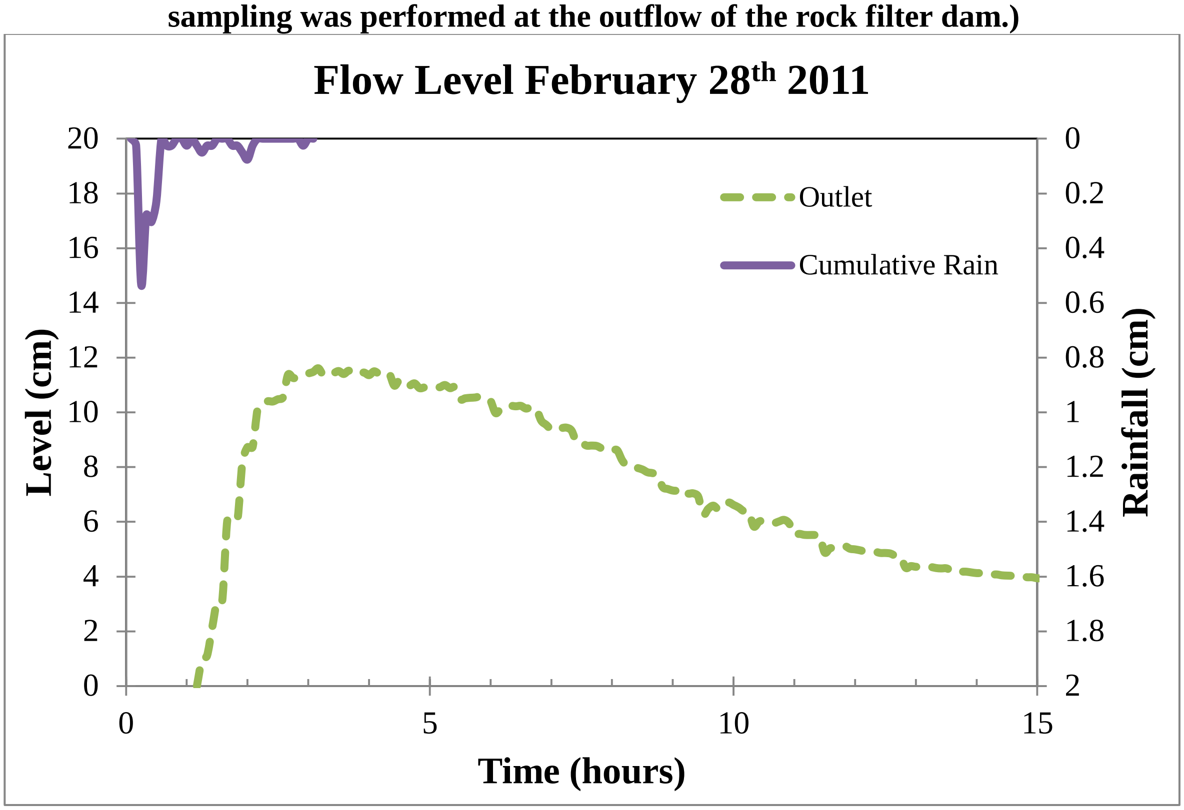

Figure 44. E3 Rainfall and hydrograph at Canton sand filter 02/28/2011.

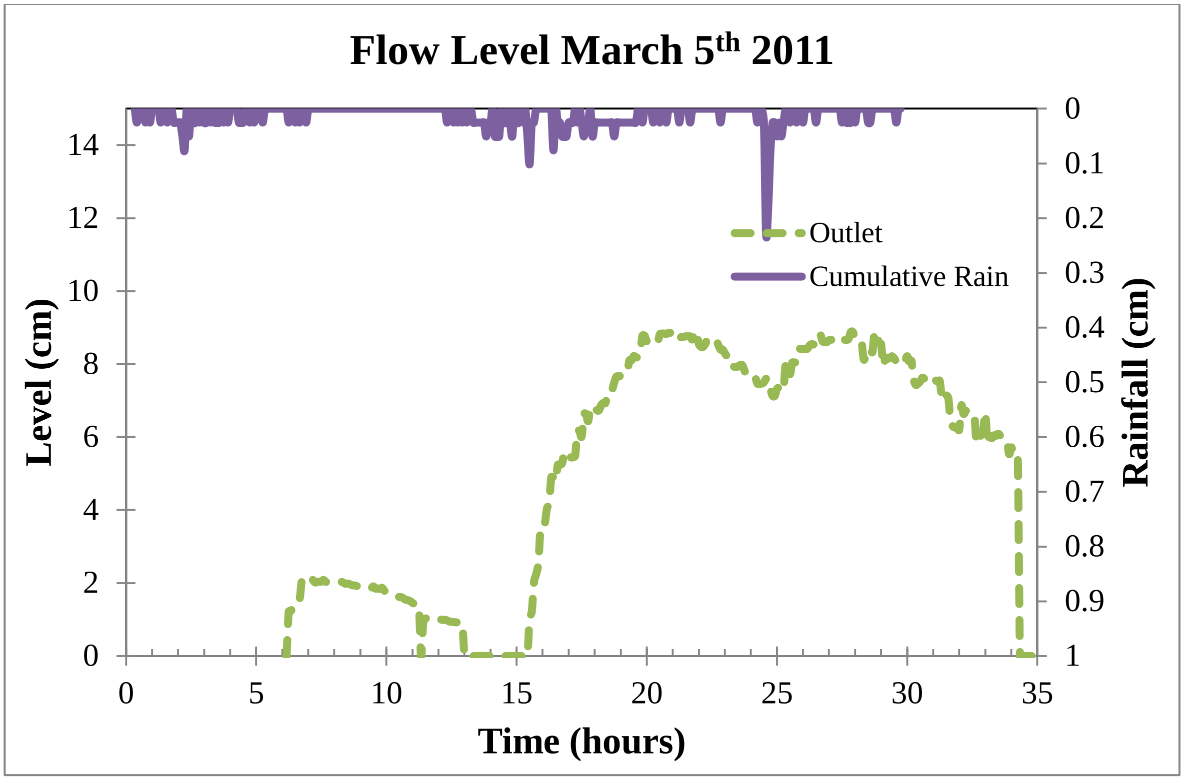

Figure 45. E4 Rainfall and hydrograph at Canton sand filter 03/05/2011.

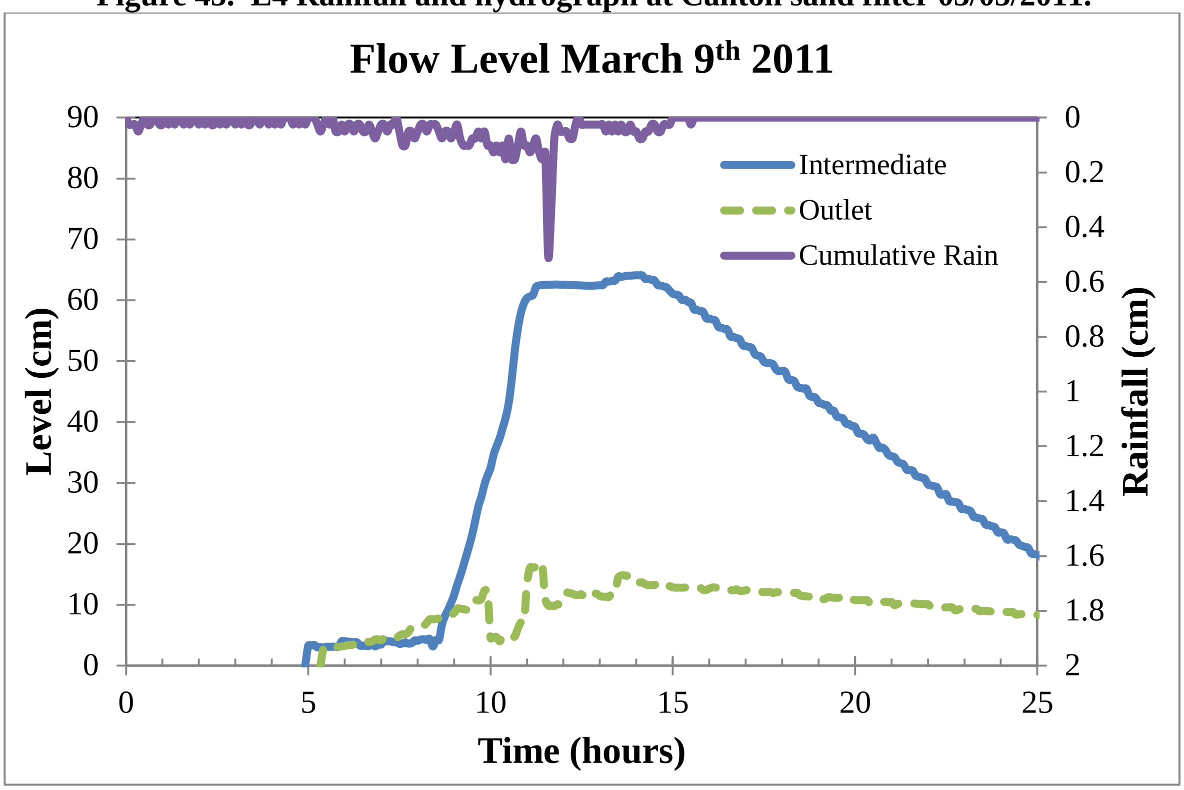

Figure 46. E5 Rainfall and hydrograph at Canton sand filter 03/09/2011. (Intermediate sampling was performed at the outflow of the rock filter dam.)

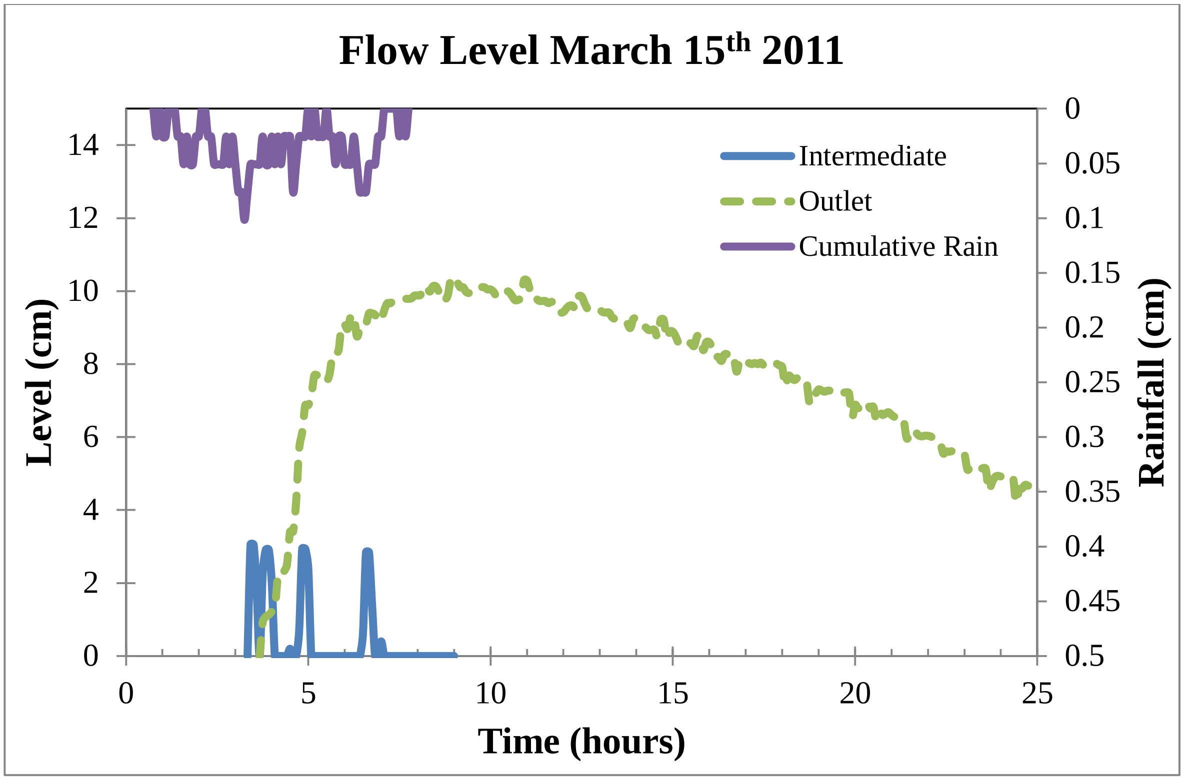

Figure 47. E6 Rainfall and hydrograph at Canton sand filter 03/15/2011. (Intermediate sampling was performed at the outflow of the rock filter dam.)

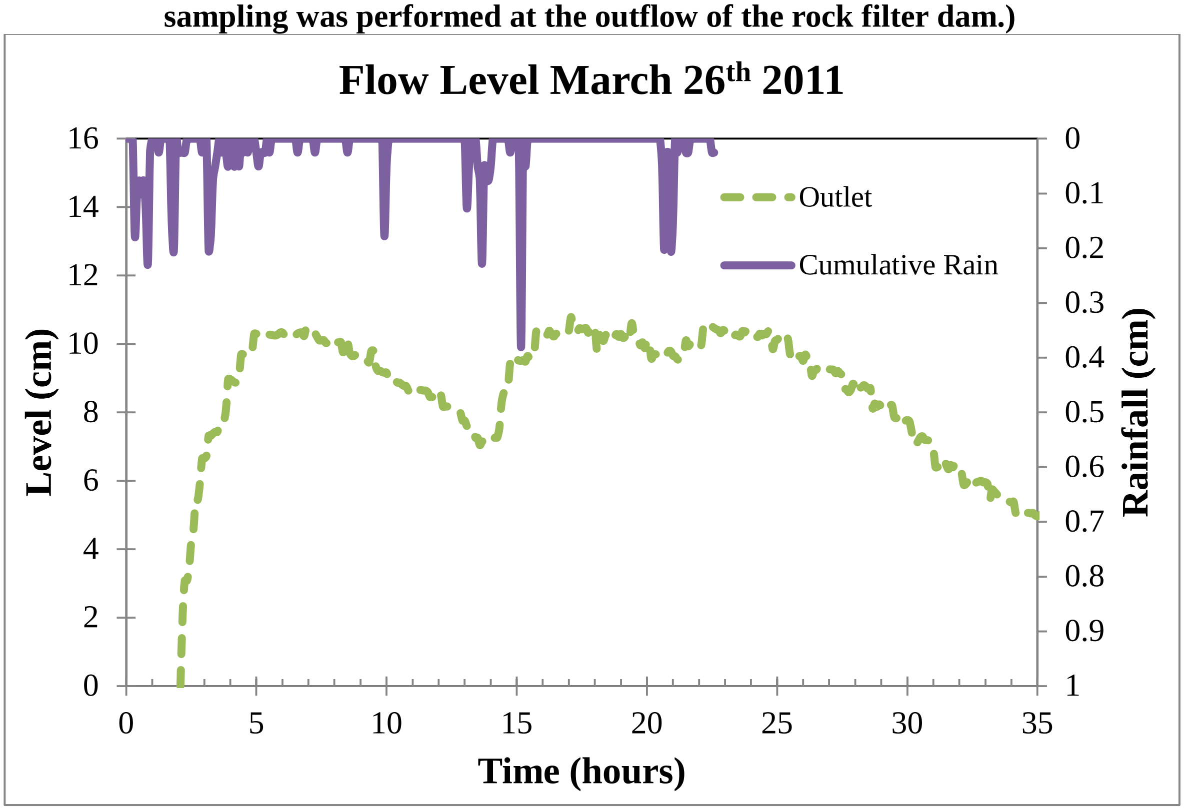

Figure 48. E7 Rainfall and hydrograph at Canton sand filter 03/26/2011.

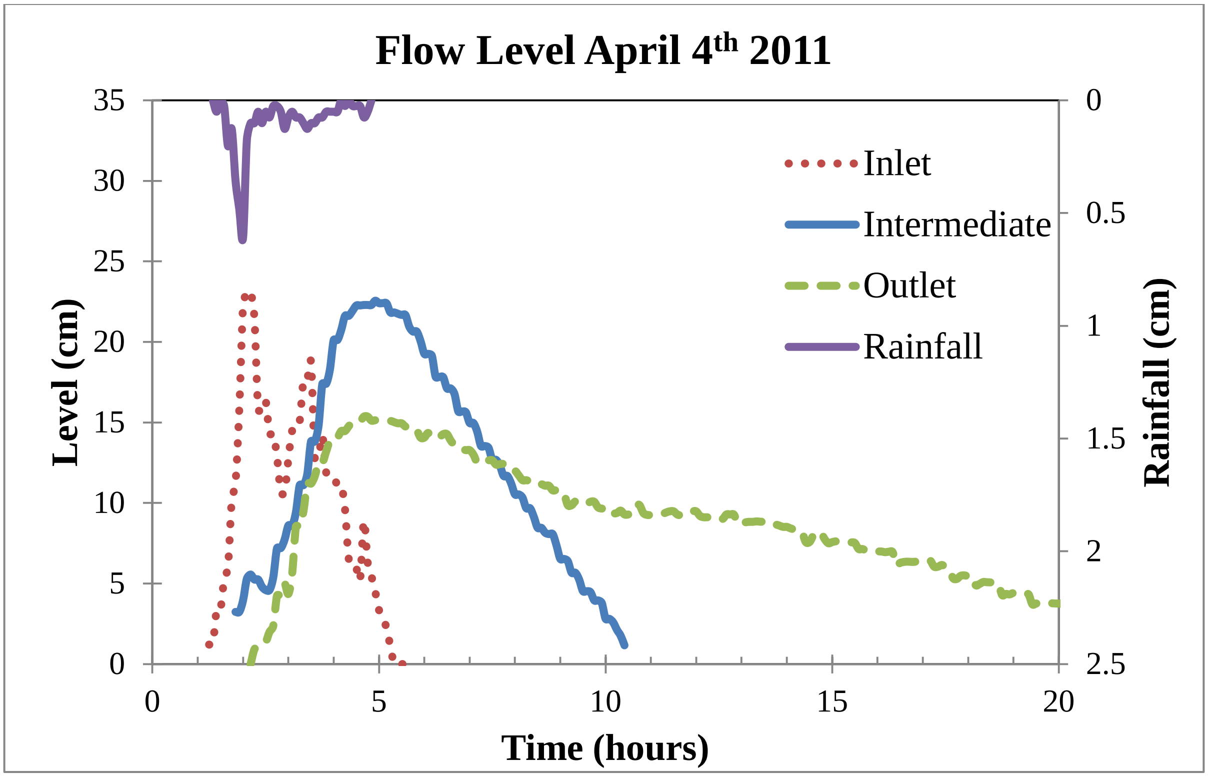

Figure 49. E8 Rainfall and hydrograph at Canton sand filter 04/04/2011. (Intermediate sampling was performed at the outflow of the rock filter dam.)

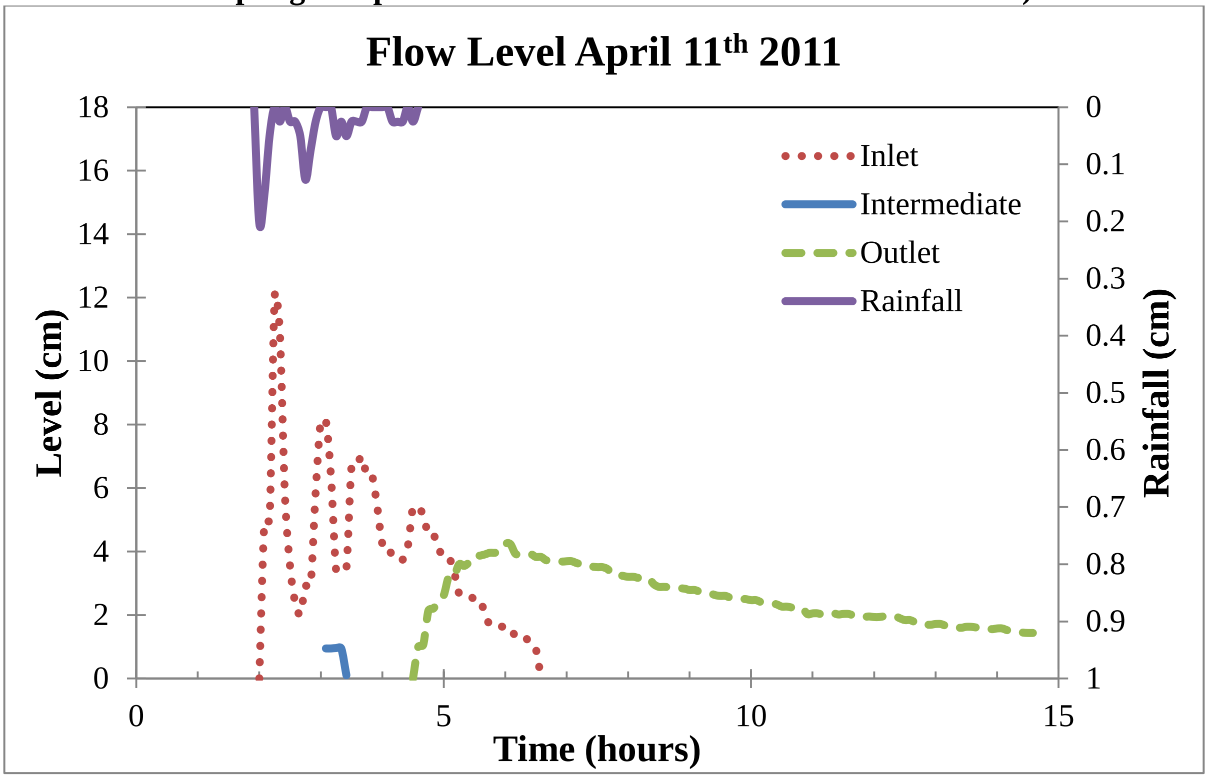

Figure 50. E9 Rainfall and hydrograph at Canton sand filter 04/11/2011. (Intermediate sampling was performed at the outflow of the rock filter dam.)

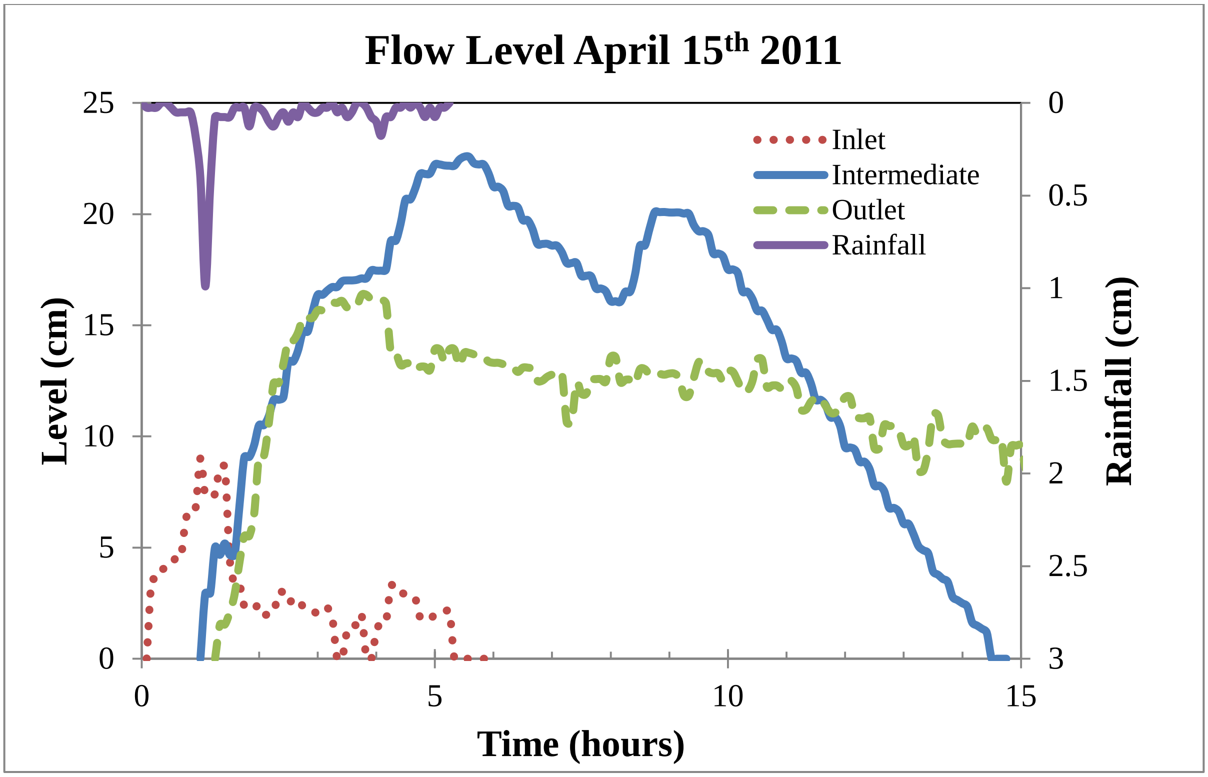

Figure 51. E10 Rainfall and hydrograph at Canton sand filter 04/15/2011. (Intermediate sampling was performed at the outflow of the rock filter dam.)

5.4. In-Situ Measurements

In-situ EMC conductivity, pH, and temperature were measured for storm events from February through April, 2011 (Figure 52 through Figure 54). Conductivity was consistently highest at the outlet, while pH across the site tended to be in the slightly basic range, likely due to measurements taking place in concrete pipes. Average temperatures measured at the three locations showed a reasonably consistent drop between the inlet and outlet. The majority of the drop in temperature took place at the sand filter, suggesting that during the summer, the sand filter will likely act as a heat sink, preventing high temperature runoff from reaching Canton creek.

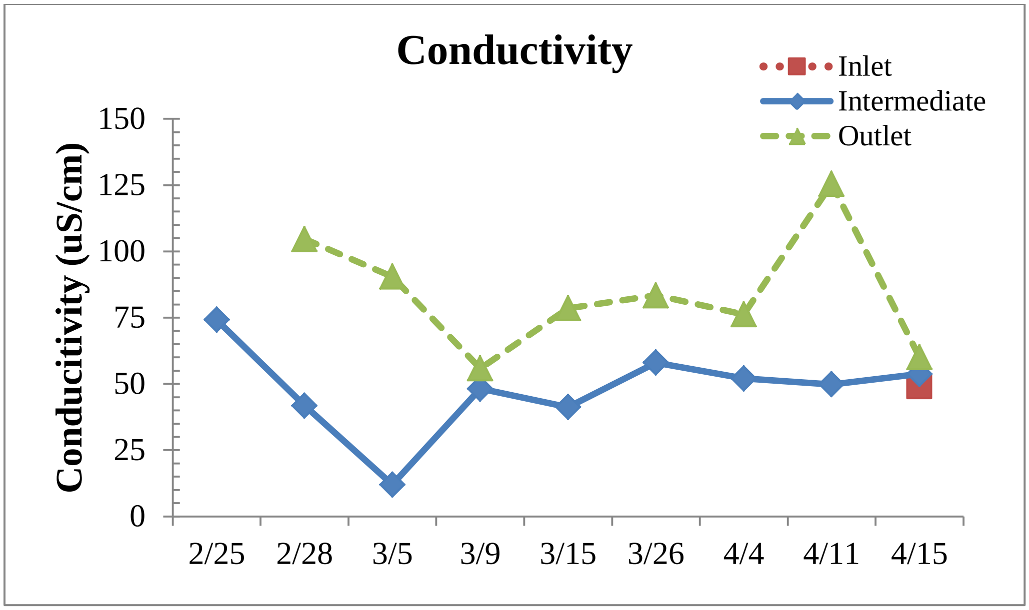

Figure 52. In-situ conductivity at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

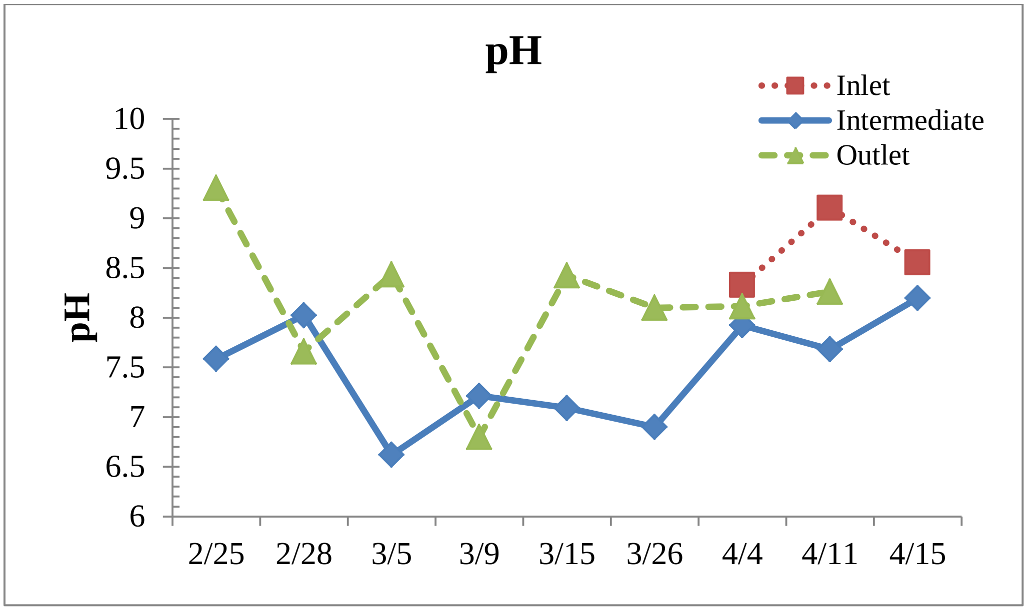

Figure 53. In-situ pH at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

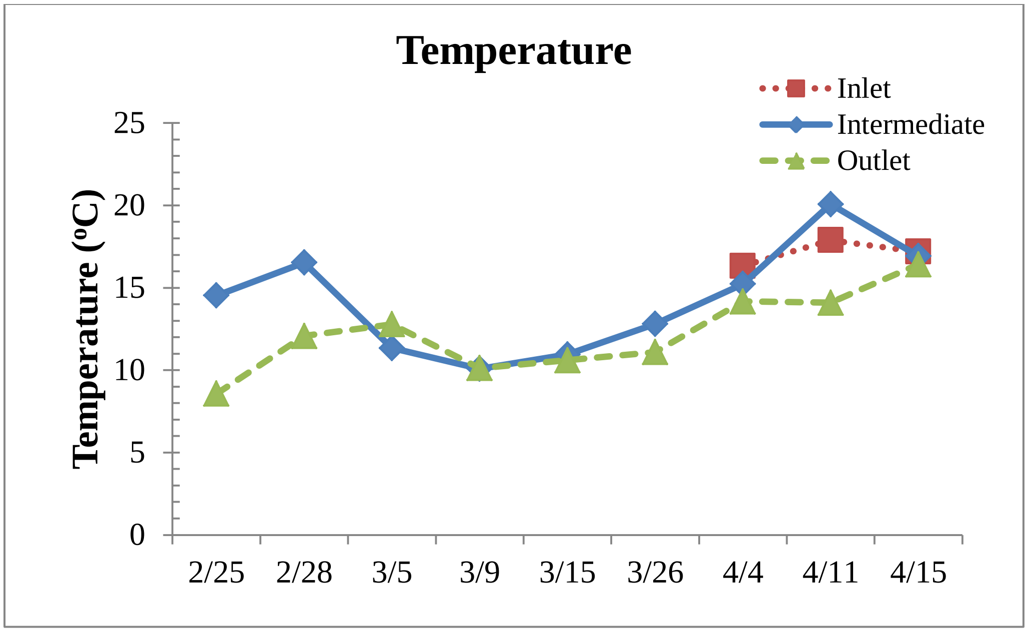

Figure 54. In-situ temperature at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

5.5. Conventional Parameter Measurements

A consistent reduction in suspended solids and turbidity was observed between the inlet and outlet locations (Figure 55 through Figure 57). Despite the short retention time observed from the hydrographs, the large reduction in TSS and turbidity between the inlet and the intermediate location suggests that there is sufficient time for a large amount of settlement and particle removal to take place. As observed in-situ, although conductivity decreased from the inlet to the intermediate location, the conductivity observed at the outlet was consistently the highest measured value.

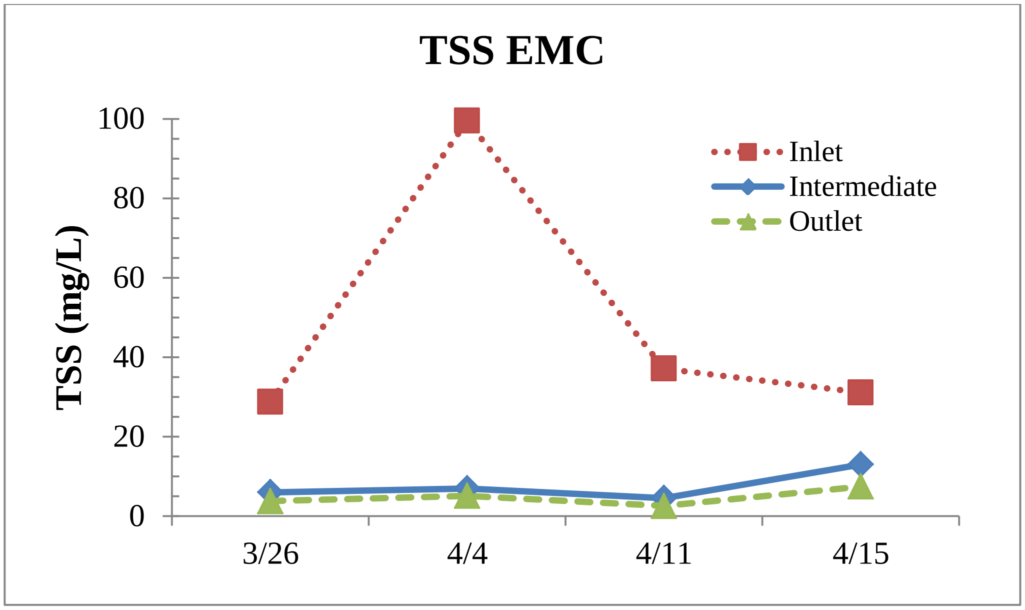

Figure 55. EMC Total suspended solids at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

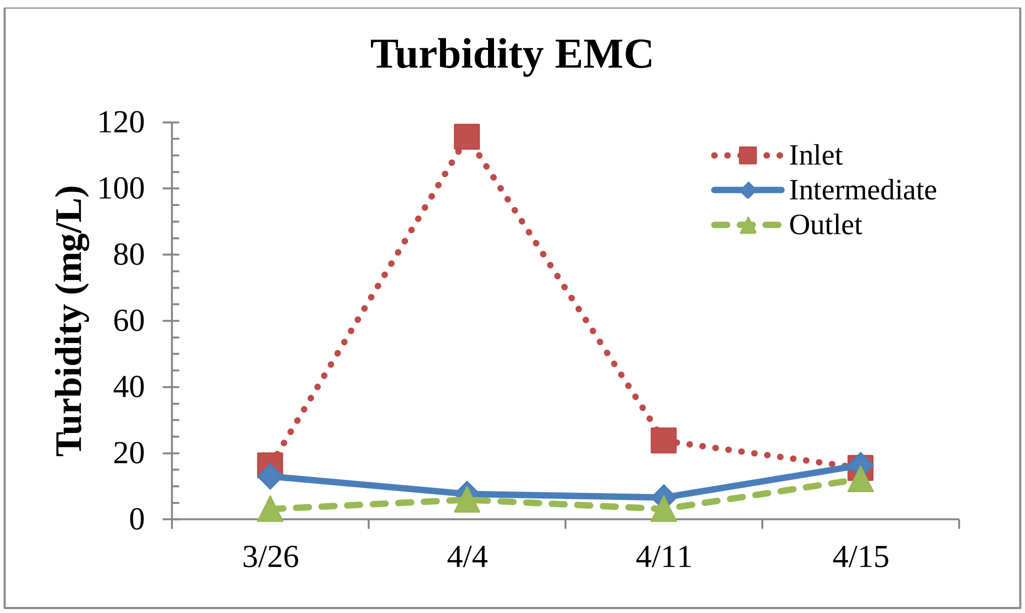

Figure 56 . EMC turbidity at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

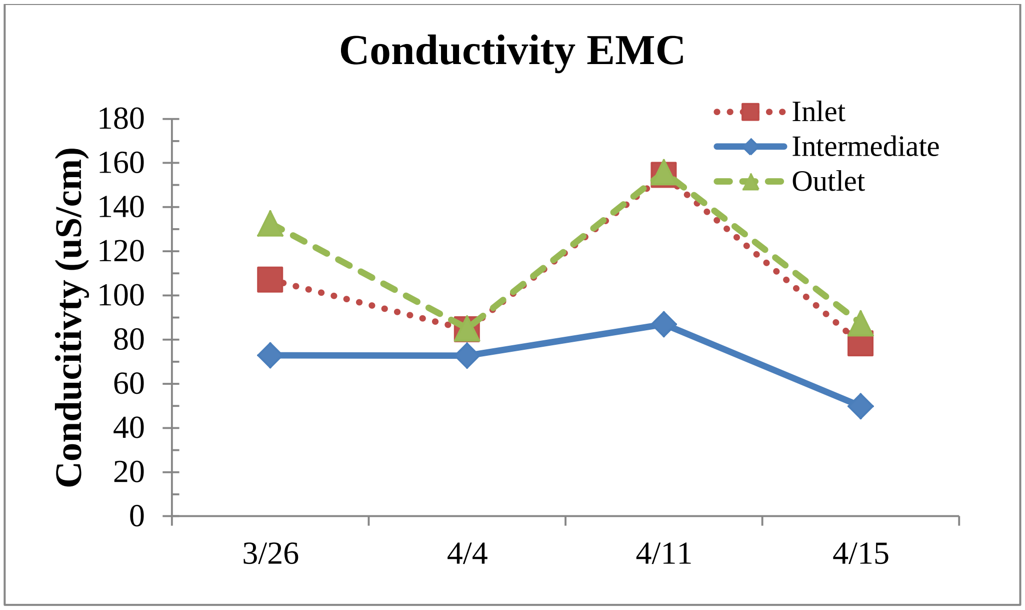

Figure 57. EMC conductivity at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

5.6. Total & Dissolved Heavy Metal Measurements

Results from measurements of total and dissolved lead, copper, and zinc measured in Canton were mixed in terms of treatment efficiency (Figure 58 through Figure 63). While the total zinc underwent a consistent decrease from the inlet to the outlet, elevated levels of copper were consistently measured at the outlet compared to the inlet. Lead performance was mixed, with only one half of the events measured from late March through April experiencing a decrease in the total lead from inlet to outlet. Measured dissolved heavy metals were significantly lower than the total heavy metals, and in many cases were below detection limits, which suggests that the bulk of heavy metals measured at Canton were associated with suspended solids.

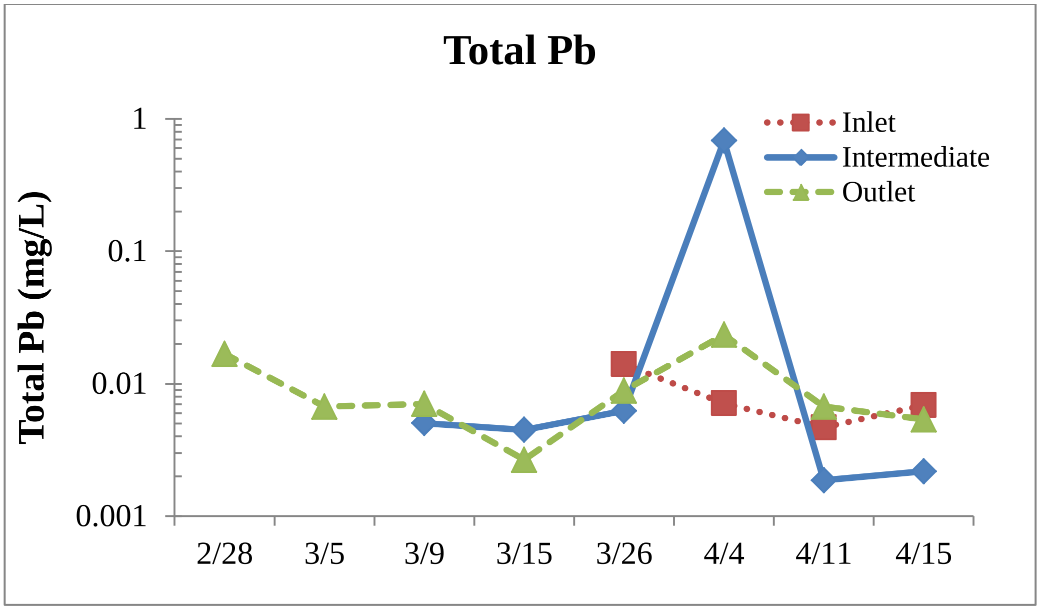

Figure 58. EMC Total lead at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

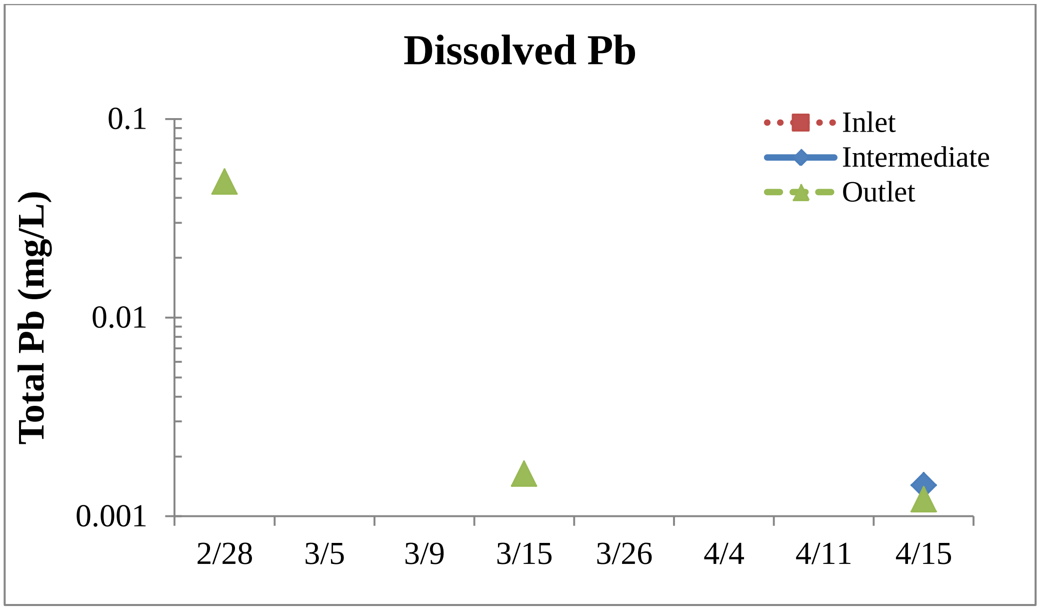

Figure 59. EMC Dissolved lead at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

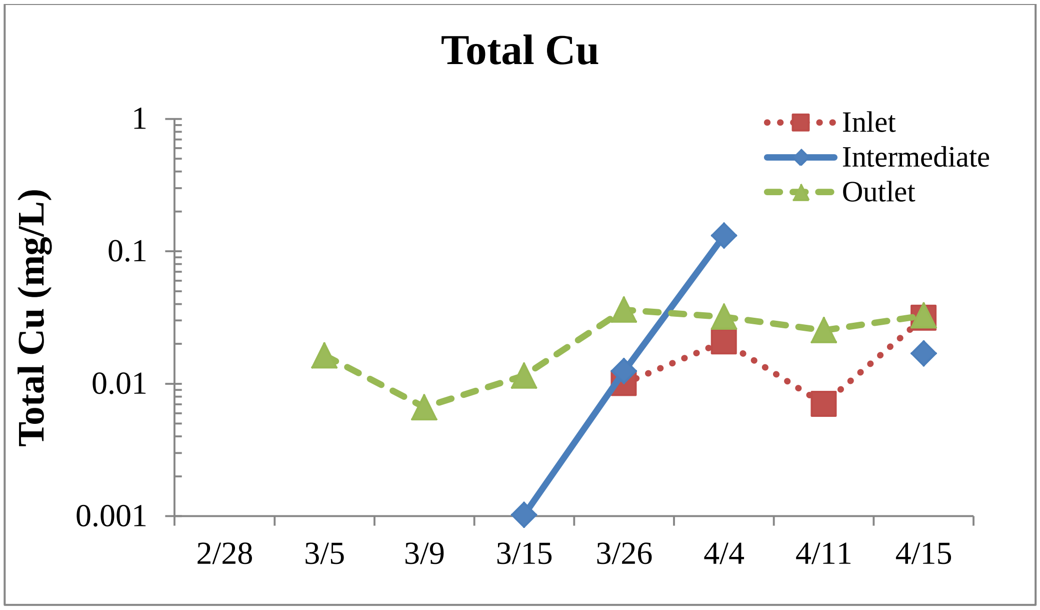

Figure 60. EMC Total copper at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

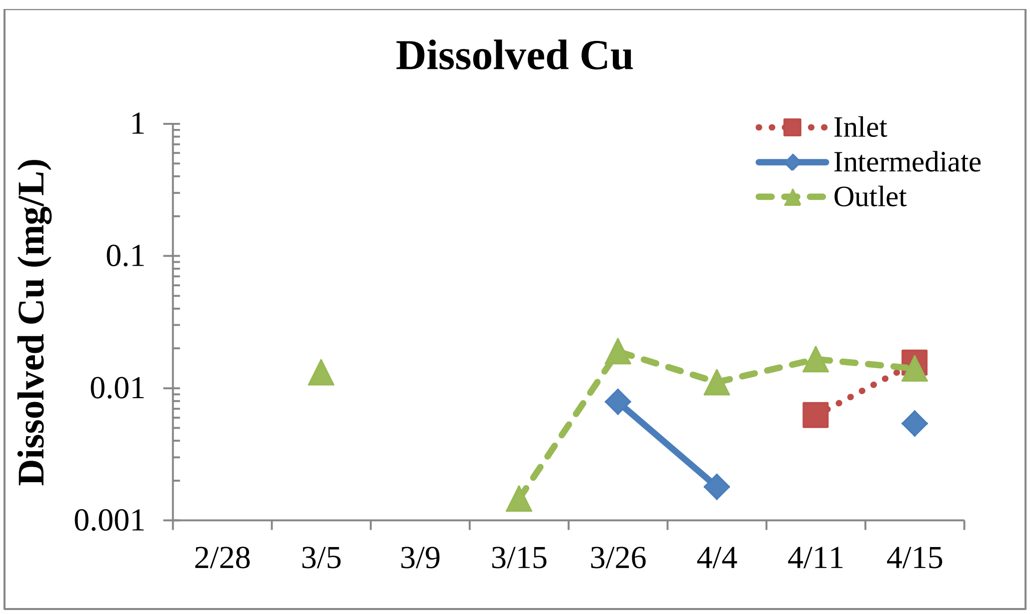

Figure 61. EMC Dissolved copper at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

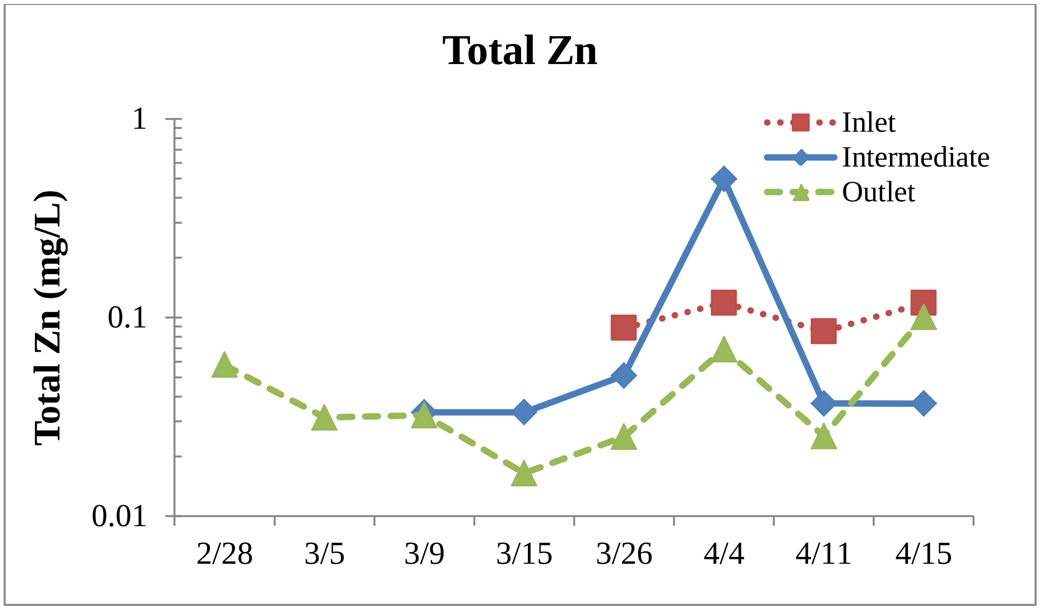

Figure 62. EMC Total zinc at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

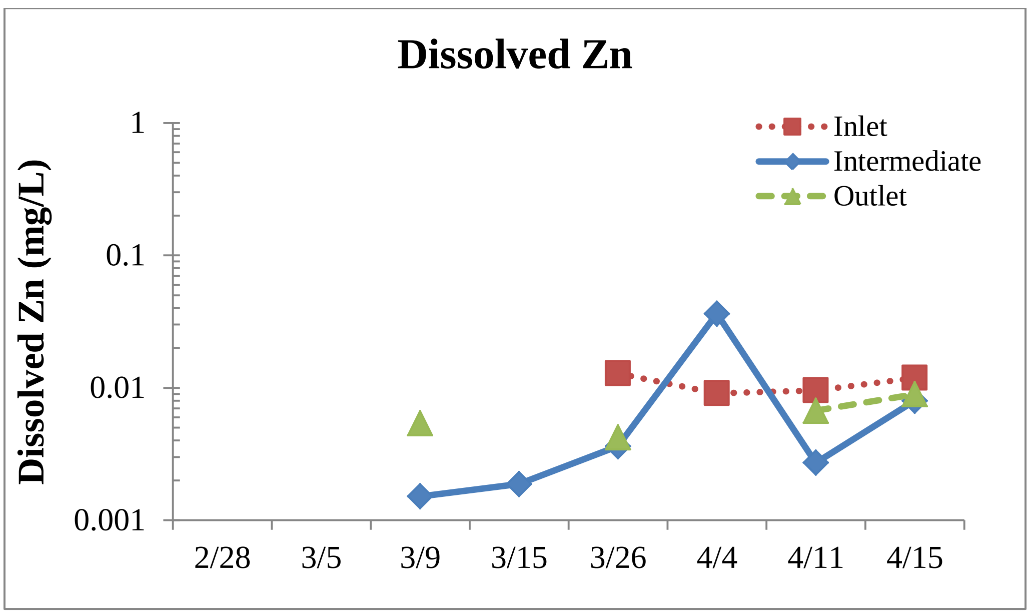

Figure 63. EMC Dissolved zinc at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

5.7. Nutrient Measurements

Total nitrogen, nitrites+nitrates (NO_x), and total phosphorus were measured throughout March and April (Figure 64 through Figure 66). Total nitrogen and NO_x were removed between the outlet for three out of four measured events. In the case of total nitrogen, a significant portion of the removal appears to be occurring in the detention pond. Measured concentrations of total phosphorus were lower than total nitrogen and NO_x, and decreased across the site from inlet to outlet during all but one observed event.

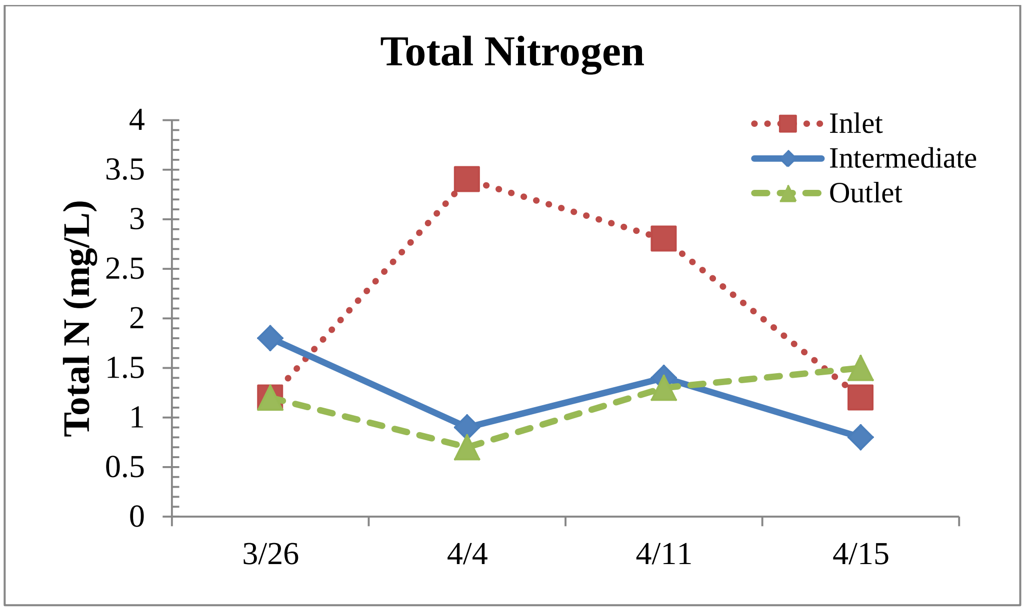

Figure 64. EMC Total nitrogen at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

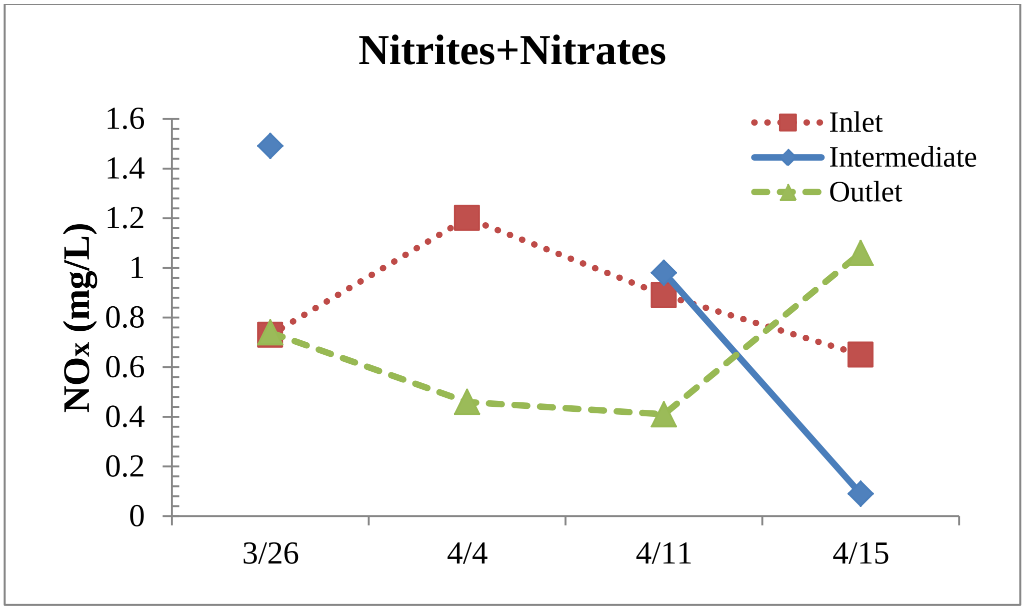

Figure 65. EMC NO_x at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

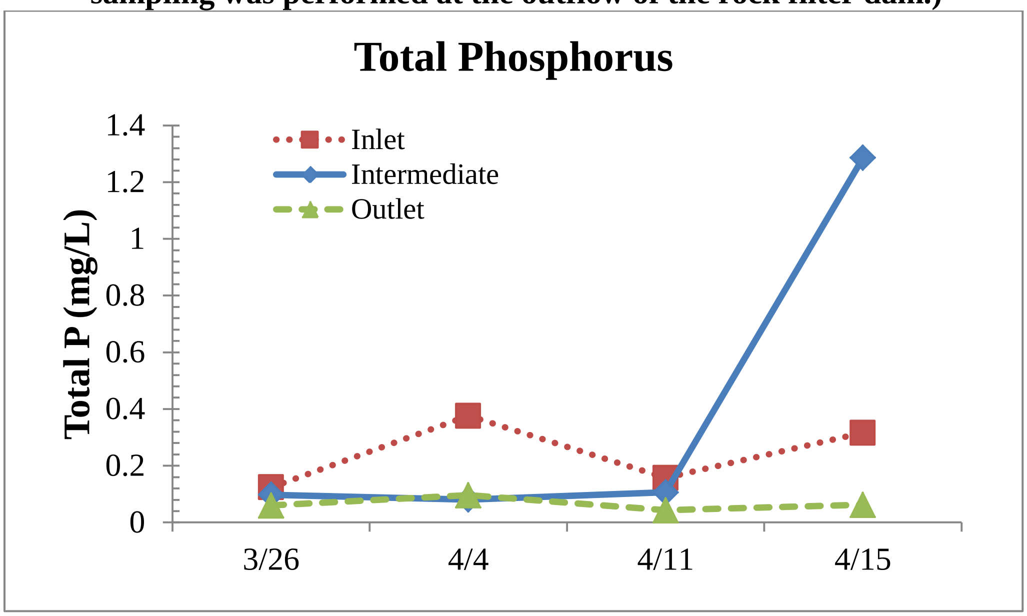

Figure 66. EMC Total phosphorus at Canton sand filter over sampled storm events. (Intermediate sampling was performed at the outflow of the rock filter dam.)

5.8. Dependence on Antecedent Dry Conditions

Because it is possible for pollutants to accumulate on roadway surfaces during periods between rain events, contaminant concentrations were measured at the inlet as a function of the antecedent dry period (ADP) (Figure 67). The data demonstrate that a weak correlation between

ADP and measured concentration exists for all parameters except total lead. Despite this positive trend between ADP and concentration, the correlation is poor likely due to competing factors, such as wind and traffic removing contaminants from roadways during dry periods.

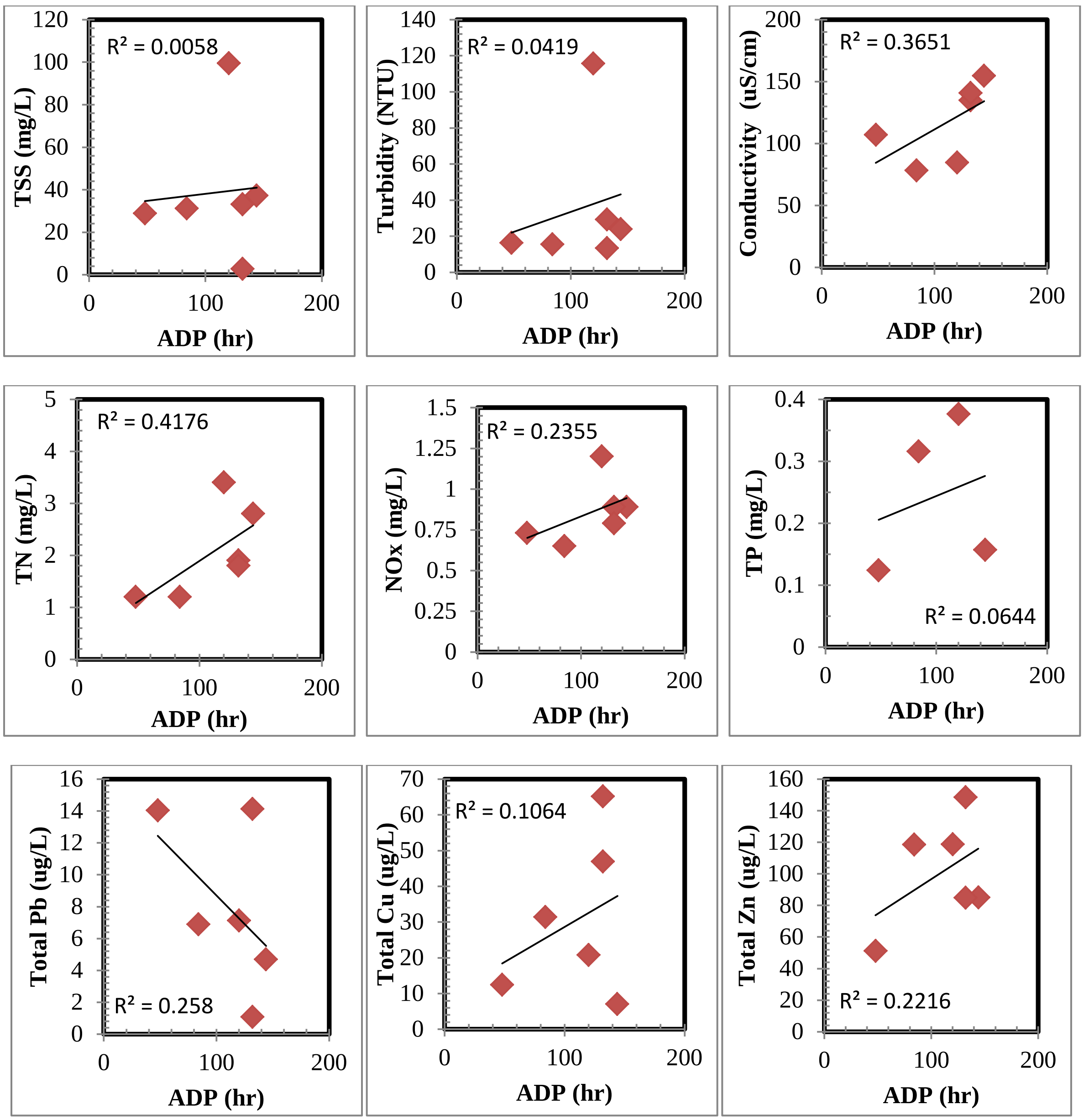

Figure 67. Inlet concentration - antecedent dry period correlation at Canton sand filter.

5.9. Parameter Correlation

Correlation plots can provide valuable information on relationships between important parameters. TSS is of particular interest due to the tendency for contaminants to sorb to the surface of suspended solids. Correlation plots show that nearly all measured parameters were positively correlated with TSS, with nutrients showing a stronger correlation. Copper and lead demonstrated no correlation with suspended solids, while zinc had a slight positive correlation with suspended solids.

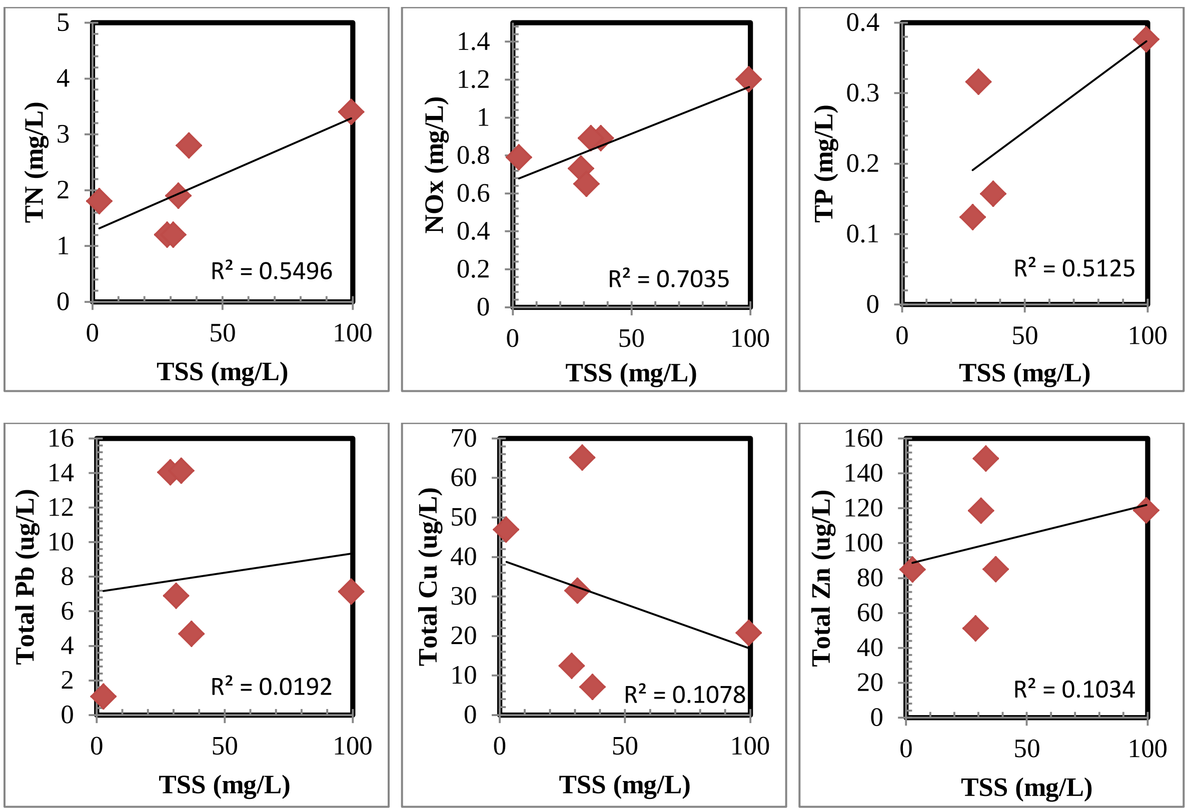

Figure 68. Inlet concentration and correlation with total suspended solids at the Canton sand filter.

5.10. Performance Summary & Recommendations

The measured influent and effluent concentrations during the storm events that were monitored at the Canton Sand Filter are detailed in Table 14 through Table 16. The overall performance of the Canton BMP was evaluated by plotting the inlet influent event mean concentration versus the outlet effluent concentration (Figure 69). The top row of the figure includes the conventional water quality parameters, total suspended solids, turbidity, and conductivity. TSS and turbidity removal was very consistent, with a net decrease occurring for all events monitored. Conductivity was consistently raised between the inlet and outlet location due to the sand filter. The BMP was less consistent in treating nitrogen, with half of the events monitored showing a net decrease in total nitrogen and NO_x. Total phosphorus was decreased in all monitored events. Total heavy metals treatment was mixed, with only half of the monitored events showing a decrease in total lead and an *increase* in total copper occurring. The total zinc was reduced in three of four monitored events.

Table 14. TSS, Turbidity, Conductivity, and pH Values Measured at Canton Sand Filter Influent and Effluent

	TSS (mg/l)		**Turbidity (NTU)**		**Conductivity (µS/cm)**		**pH**	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/25/ 2011								
2/28/ 2011								9.3
3/5/ 2011								7.7
3/9/ 2011								8.4
3/15/ 2011								6.8
3/26/ 2011	28.8	3.8	16.27	3.18	107	133		8.4
4/ 4/ 2011	99.5	5.2	115.6	5.99	85	85	8.3	8.1
4/11/ 2011	37.1	2.6	23.77	3.17	155	156	9.1	8.1
4/15/ 2011	31.1	7.5	15.4775	12.215	78	87	8.6	8.3

*Blanks indicate data not measured.

Table 15. Nutrient and Temperature Values Measured at Canton Sand Filter Influent and Effluent

	Total Nitrogen (mg/l)		Nitrite + Nitrate (mg/l)		Total Phosphorus (mg/l)		Temperature (^oC)	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/25/ 2011								9
2/28/ 2011								12
3/5/ 2011								13
3/9/ 2011								10
3/15/ 2011								11
3/26/ 2011	1.2	1.2	0.73	0.74	0.098	0.06		11
4/ 4/ 2011	3.4	0.7	1.2	0.46	0.081	0.096	16	14
4/11/ 2011	2.8	1.3	0.89	0.41	0.106	0.043	18	14
4/15/ 2011	1.2	1.5	0.65	1.06	1.286	0.062	17	16

*Blanks indicate data not measured.

Table 16. Metal Concentrations Measured at Canton Sand Filter Influent and Effluent

	Total Lead (mg/l)		**Dissolved Lead (mg/l)**		**Total Copper (mg/l)**		**Dissolved Copper (mg/l)**		**Total Zinc (mg/l)**		**Dissolved Zinc (mg/l)**	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/25/2011	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2/28/2011	BDL	0.017	BDL	0.048	BDL	BDL	BDL	BDL	BDL	0.058	BDL	BDL
3/5/2011	BDL	0.007	BDL	BDL	BDL	0.016	BDL	0.013	BDL	0.031	BDL	BDL
3/9/2011	BDL	0.007	BDL	BDL	BDL	0.007	BDL	BDL	BDL	0.032	BDL	0.005
3/15/2011	BDL	0.003	BDL	0.002	BDL	0.012	BDL	0.001	BDL	0.016	BDL	BDL
3/26/2011	0.014	0.009	BDL	BDL	0.010	0.036	BDL	0.019	0.088	0.025	0.013	0.004
4/ 4/2011	0.007	0.023	BDL	BDL	0.021	0.032	BDL	0.011	0.119	0.069	0.009	BDL
4/11/2011	0.005	0.007	BDL	BDL	0.007	0.025	0.006	0.017	0.085	0.025	0.010	0.007
4/15/2011	0.007	0.005	BDL	0.001	0.031	0.033	0.016	0.014	0.118	0.101	0.012	0.009

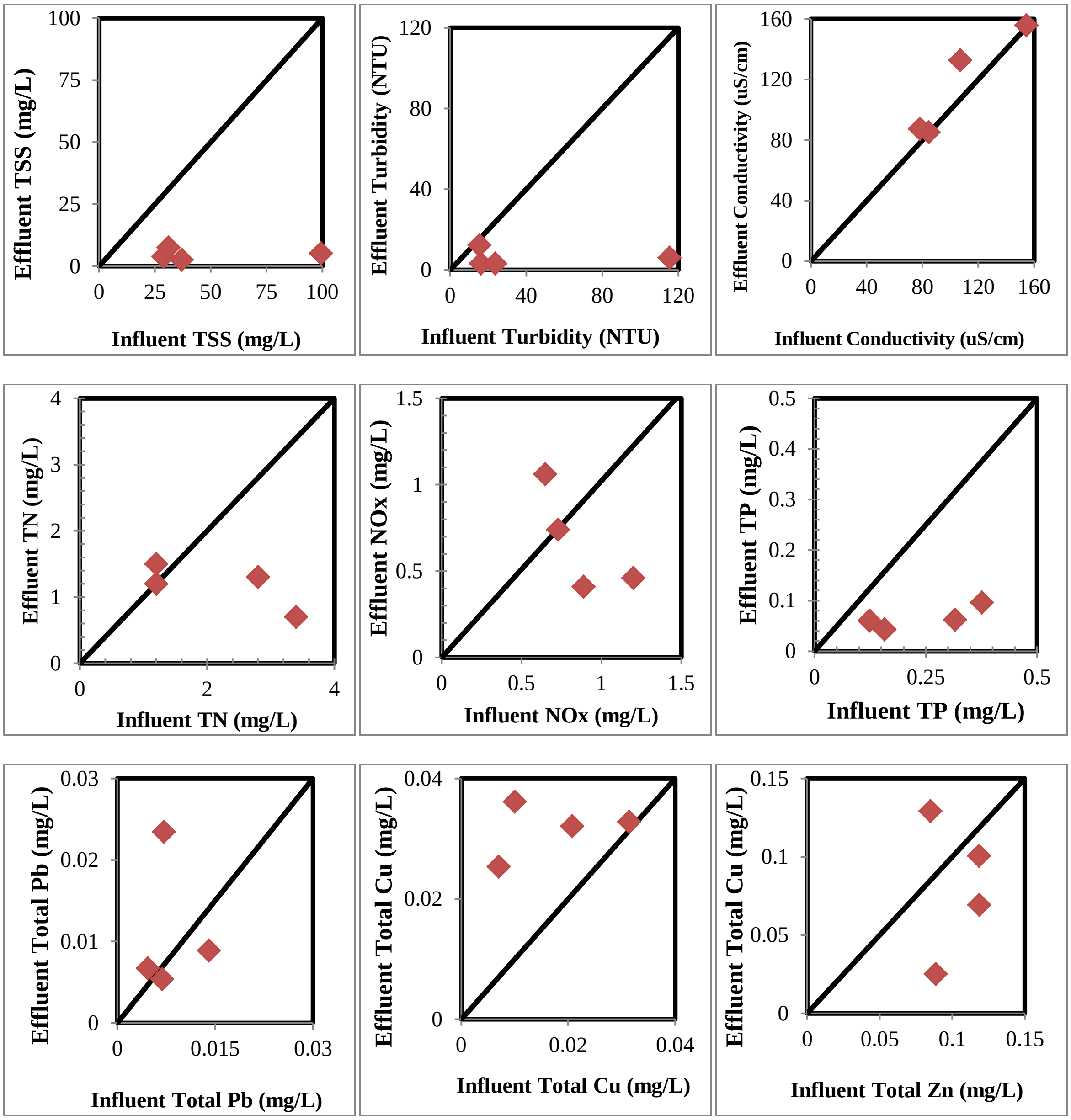

Figure 69. Influent vs. effluent concentration at Canton sand filter.

Overall, the Canton BMP performed well at improving the quality of runoff entering Canton Creek. However, performance of the BMP may be further enhanced by increasing the detention time associated with the intermediate check dam. By including a low conductivity core to the dam, runoff would be detained longer, allowing for increased time for settling of contaminants to occur. The mixed performance in total metals removal may be improved by maintenance of the sand filter. A layer of organics rich topsoil overlaying the sand filter was included in the original plan to remove additional contaminants through sorption. Due in part to the sedimentation pond's short detention time, there is evidence that in many places near the inlet to the filter that the top soil has largely been eroded away, exposing the underlying geotextile and allowing stormwater to bypass the top soil layer.

5.11. Conclusions

In summary, monitoring of the inflow and outflow concentrations at the Canton Creek BMP yielded the following results:

- The stormwater is being detained in the BMP longer than the 24 hour design residence time.
- Temperature of the stormwater is decreasing as water flows through the sand filter.
- Conductivity measured at the outlet is consistently higher than the conductivity at the inflow, indicating that the stormwater is mobilizing ions as it transports through the filter.
- Suspended solids and turbidity are consistently reduced between the inlet and the outlet of the BMP.
- Nutrient levels of nitrogen and phosphorus are consistently reduced between the inlet and the outlet of the BMP.
- Lead and zinc concentrations are consistently reduced between the inlet and the outlet of the BMP.
- Copper concentrations increase within the BMP, suggesting that there is a source of copper within the sand filter.

6. McGinnis Ferry Road BMP Monitoring

6.1. BMP Description

The McGinnis Ferry Road stormwater BMP is located on McGinnis Ferry Road on the western bank of the Chattahoochee River near Suwanee, GA. The BMP treats runoff from McGinnis Ferry Road as well as the adjacent construction site associated with construction of a replacement bridge. The keysite descriptors are summarized below (**Table 17**).

Table 17. McGinnis Ferry BMP Description, Suwanne, GA

Data Element	Description
General Test Site Information	
BMP Test Site Name	McGinnis Ferry Detention Pond
Location	McGinnis Ferry Rd, Suwanee, GA 30024
Elevation	~930 ft
Structural BMP Information	
Structural BMP Name	Sedimentation/Water Quality Pond
BMP Type	Type I. Well defined inlets and outlets
BMP Description	Substantial residence time and storage volume
Treatment Category	Sedimentation, Biological Processes
Number of Inlets	3 (only 1 active)
Inlet Descriptions	48” concrete pipe
Number of Outlets	1
Outlet Descriptions	Concrete sedimentation chamber with gravel packed trash rack inlet
Catchment Area	21.991 Ac.
BMP Plan	See Figure 70

Data Element	Description
Watershed Stations	
Regional Watershed Name	Upper Chattahoochee River
Station	Monitoring stations immediately u/s and d/s of pond
Upstream BMP	None, Inflow received directly from McGinnis Ferry Rd
Downstream BMP	None, Effluent discharged to Chattahoochee River

The site plan for the BMP Pond currently consists of only one inlet (shown), which is tied into the BMP and receives runoff directly from McGinnis Ferry Road (**Figure 70**). An additional inlet receiving runoff from the eastbound section of McGinnis Ferry Road will be added as the bridge extension continues, and an additional inlet receiving runoff from an adjacent parking lot will be added at a later date. The BMP is a detention pond with significant vegetation on the slopes as well as the floor of the pond, allowing for the possibility of biological treatment to take place. The inlet is a 48” concrete pipe which discharges directly into the pond, with an overflow outlet that consists of a concrete sedimentation chamber, which is surrounded by gravel packed trash rack.

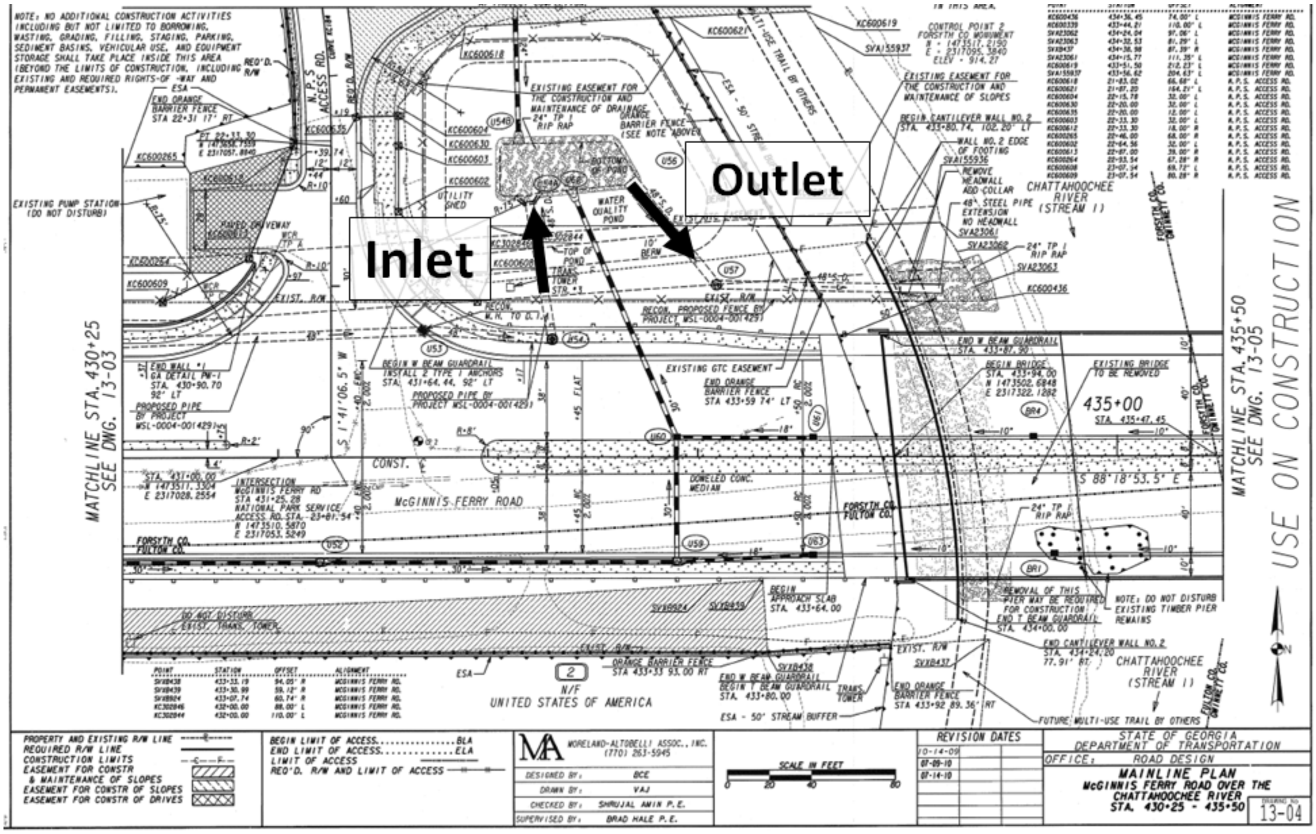

Figure 70. Site plans and sampling locations, McGinnis Ferry BMP, Suwanee, GA.

As with Canton, in-situ temperature, conductivity, and hydraulic data were collected at the inlet and outlet. First flush of the first thirty minutes of flow and EMC grab samples were collected for three events for laboratory analysis. A summary of the events monitored is given below (**Table 18**).

Table 18. Summary of Events Monitored at McGinnis Ferry Sedimentation Pond

#	Event	Data			
		First Flush	Inlet	Outlet	Cumulative Rain (cm)
1.	11/15/2011	○	●	●	4.22
2.	12/06/2011	●	●	●	12.98
3.	12/20/2011	●	●	●	7.87

● - Yes ○ - No

6.2. Hydrological Characterization

The flow depth and precipitation data for the three monitored events demonstrate that the BMP consistently detains stormwater from 1.5 to 2 hours from the initiation of precipitation to detection at the outflow (Figure 71 through Figure 73). The time taken between stormwater entering to exiting the pond is on the order of 0.5 to 1 hours, allowing a relatively short amount of time for larger particles to settle out of suspension.

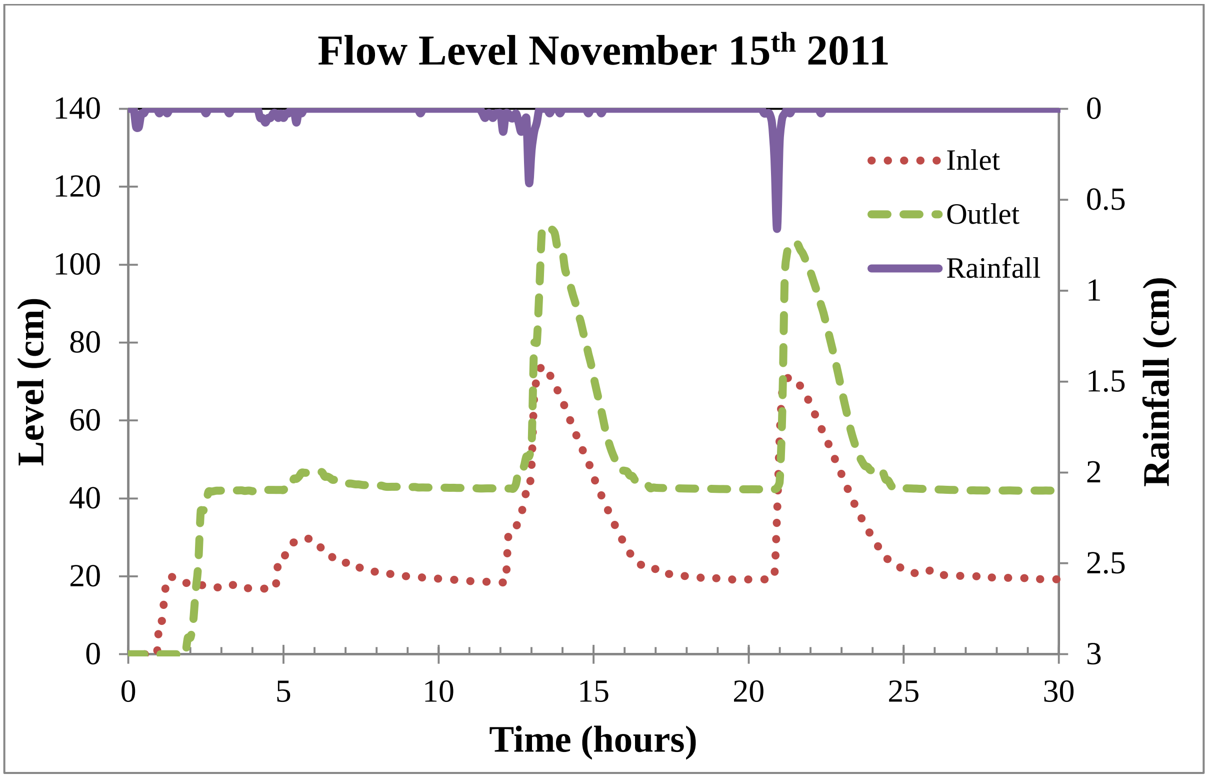

Figure 71. E1 Rainfall and hydrograph at McGinnis Ferry BMP 11/15/2011.

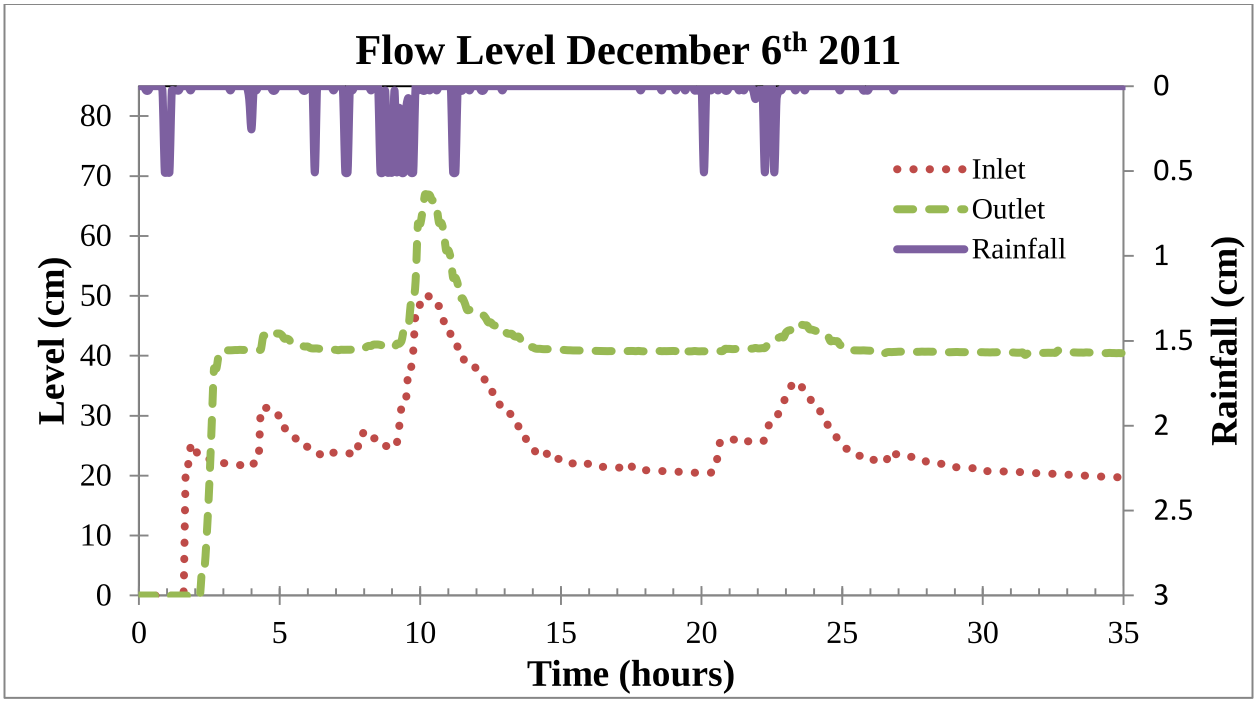

Figure 72. E2 Rainfall and hydrograph at McGinnis Ferry BMP 12/06/2011.

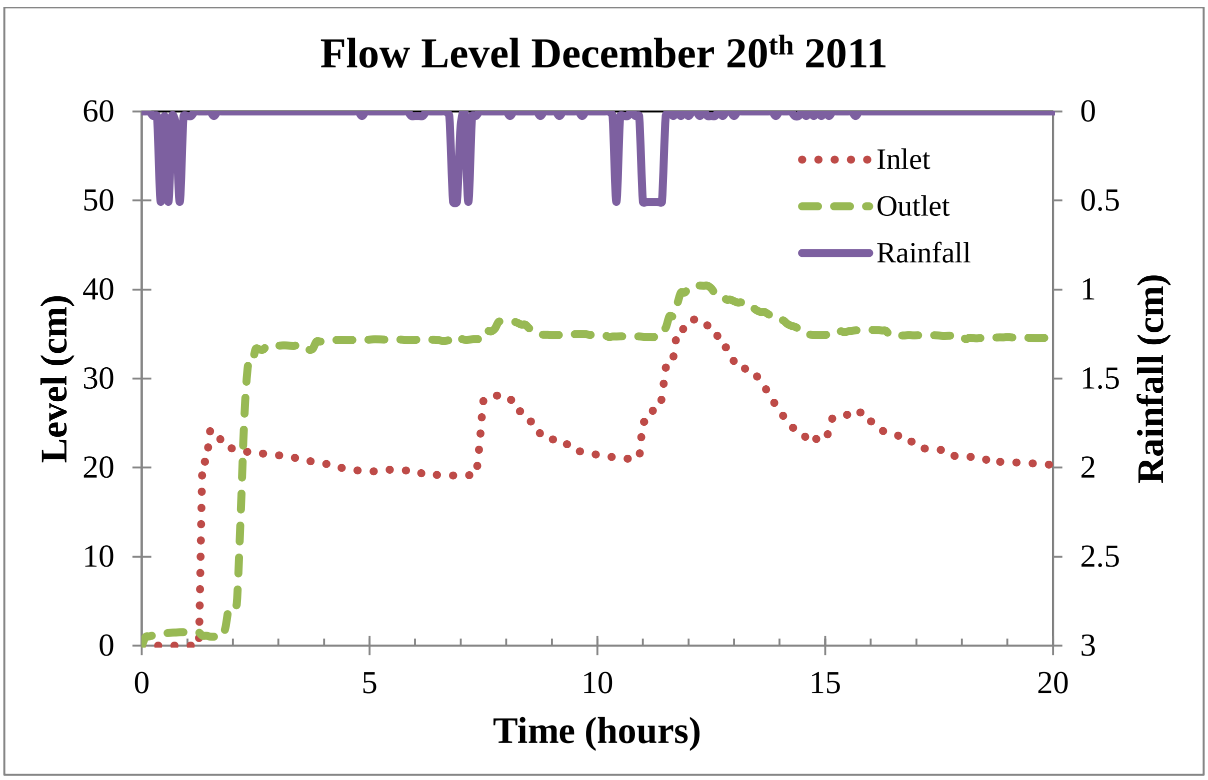

Figure 73. E3 Rainfall and hydrograph at McGinnis Ferry BMP 12/20/2011.

6.3. In-Situ Measurements

Measured in-situ EMC conductivity, pH, and temperature showed a slight but consistent decrease in conductivity that occured from the inlet to the outlet (Figure 74). The pH varied little from inlet to outlet and was slightly basic (Figure 75). Temperature remained nearly constant from inlet to outlet (Figure 76).

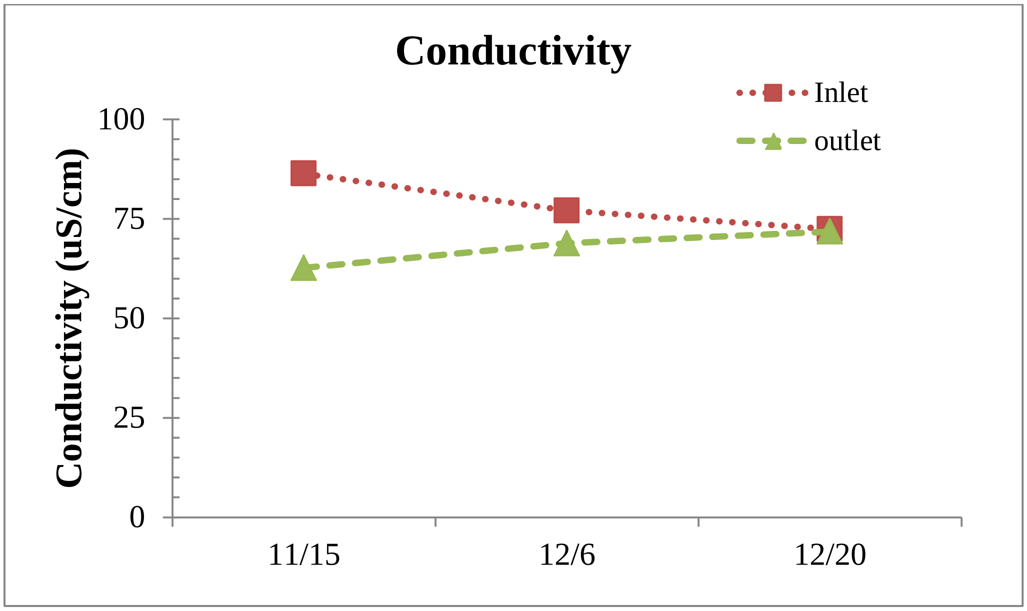

Figure 74. In-situ conductivity at McGinnis Ferry BMP over sampled storm events.

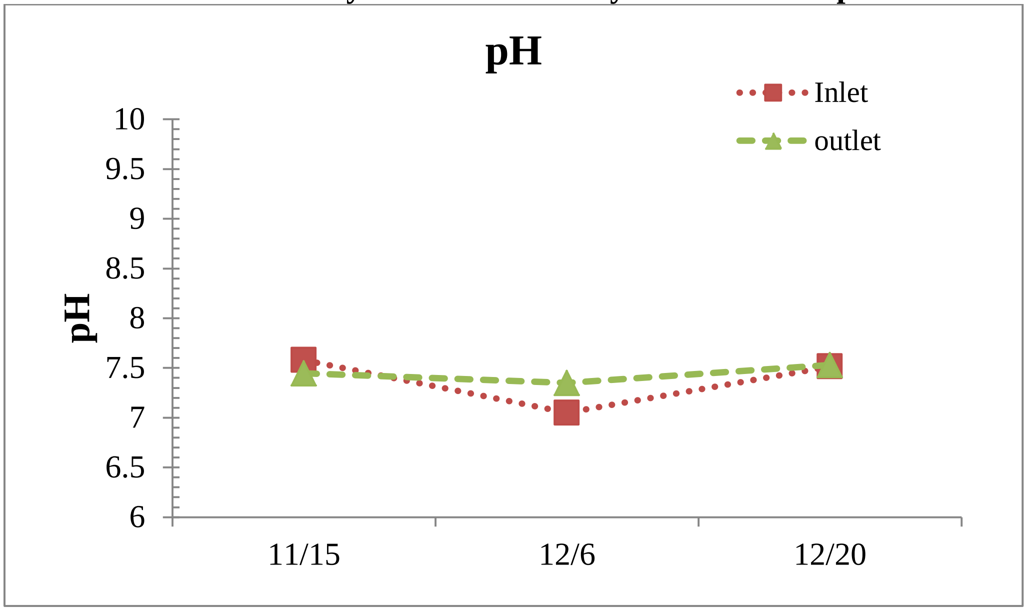

Figure 75. In-situ pH at McGinnis Ferry BMP over sampled storm events.

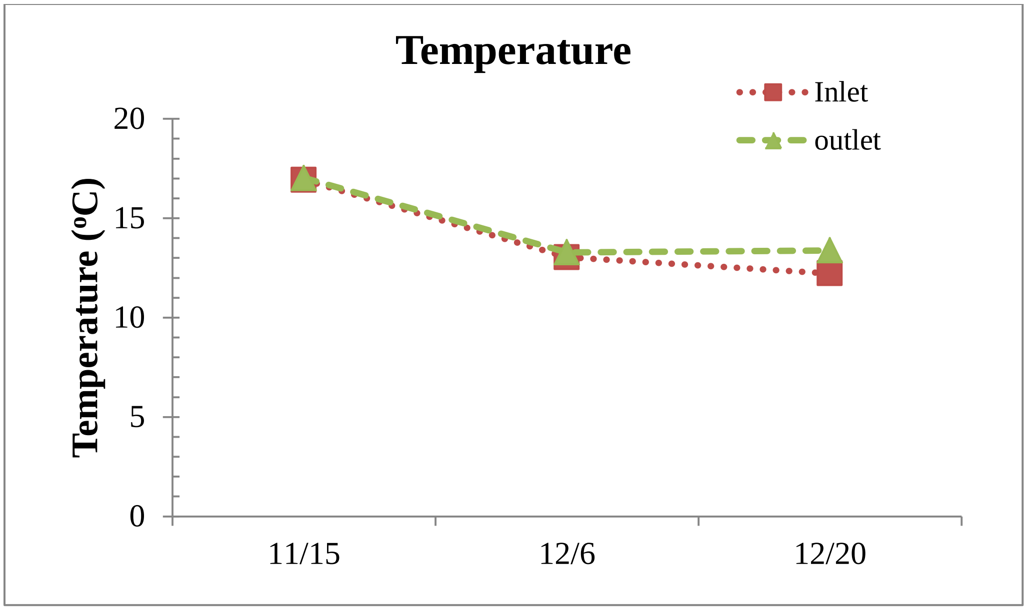

Figure 76. In-situ temperature at McGinnis Ferry BMP over sampled storm events.

6.4. Conventional Parameter Measurements

Water quality parameters for the three events are shown below for the inlet, the outlet, and the first flush, which is taken was a composite sample of the first 30 minutes of flow, and demonstrate that the turbidity and the measured total suspended solids (TSS) followed a similar trend in all of the monitored events (Figure 77). In the two measured first flushes, TSS and turbidity were higher than in either the inlet or outlet EMC (Figure 77 and Figure 79). In all three events, the turbidity and the TSS increased from the inlet to the outlet location. Additionally, the pH was nearly essentially neutral at all locations, and did not vary significantly. The conductivity data demonstrate that the first flush had the highest conductivity, while in two of three events there was a slight drop in conductivity from the inlet to the outlet location (Figure 79).

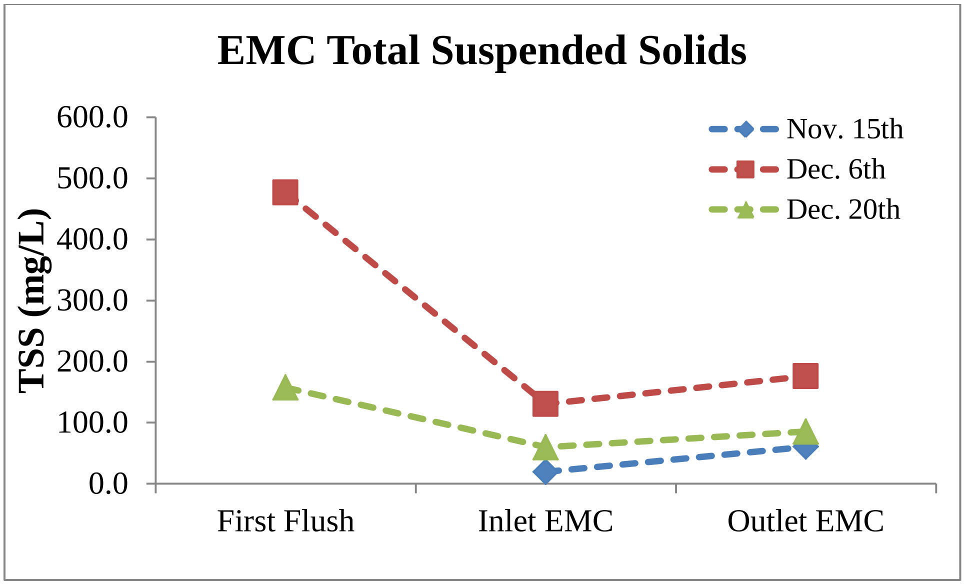

Figure 77. EMC total suspended solids at McGinnis Ferry BMP.

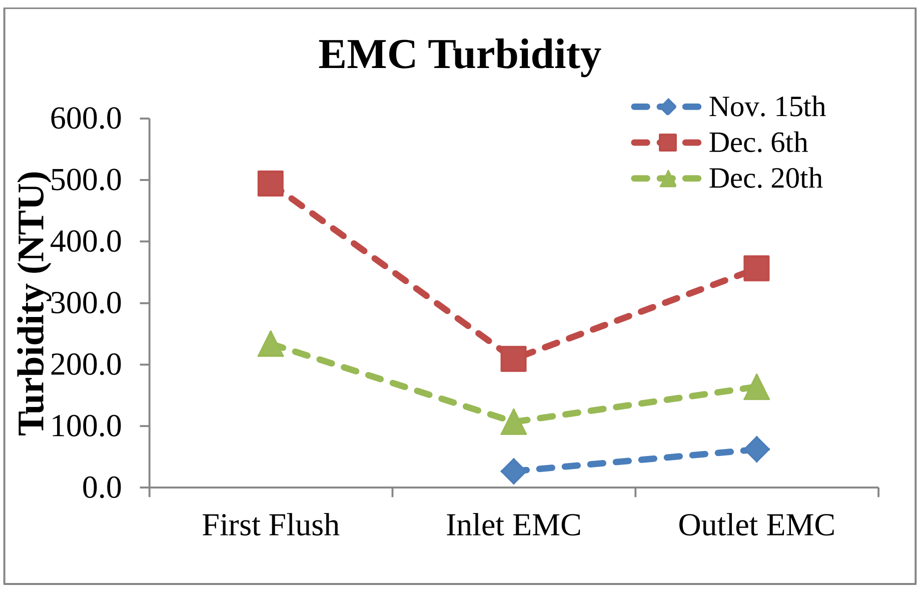

Figure 78. EMC turbidity at McGinnis Ferry BMP.

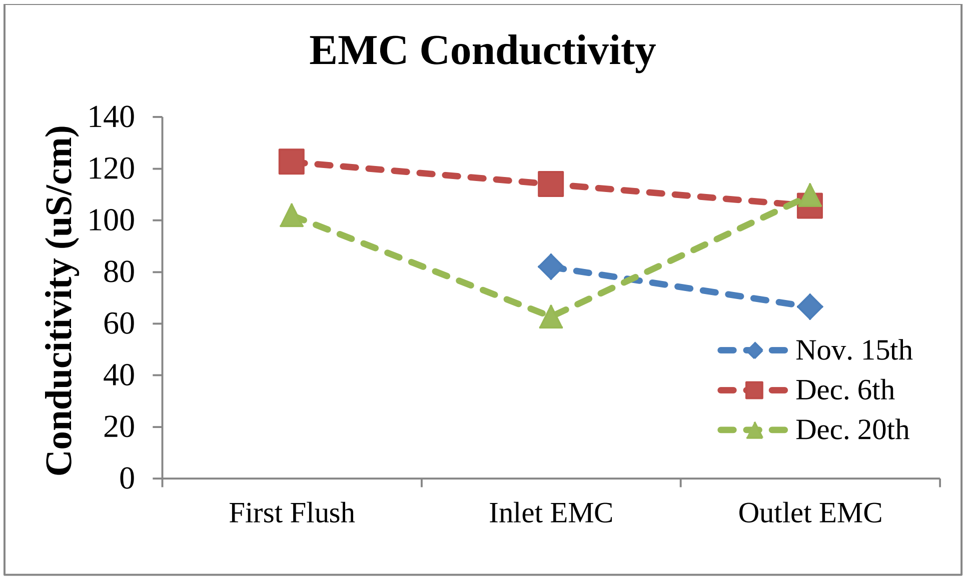

Figure 79. EMC conductivity at McGinnis Ferry BMP.

6.5. Nutrient Measurements

Nutrients measured at the McGinnis Ferry project demonstrated a consistently higher proportion of contaminants associated with the first flush of stormwater, as was anticipated (Figure 80 through Figure 82). Total phosphorus concentrations consistently decreased from the inlet to the outlet location for two of three events. However, there was a consistent increase in the EMC total nitrogen and EMC NO_x from the inlet to the outlet. Although this behavior was observed with other water quality parameters, such as turbidity and TSS, it was more pronounced with these two parameters.

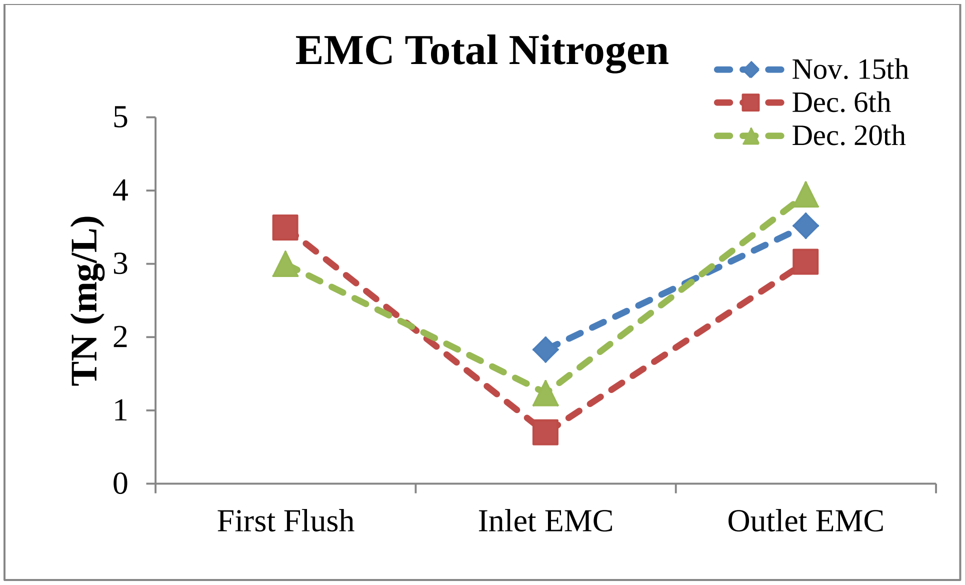

Figure 80. EMC total nitrogen at McGinnis Ferry BMP.

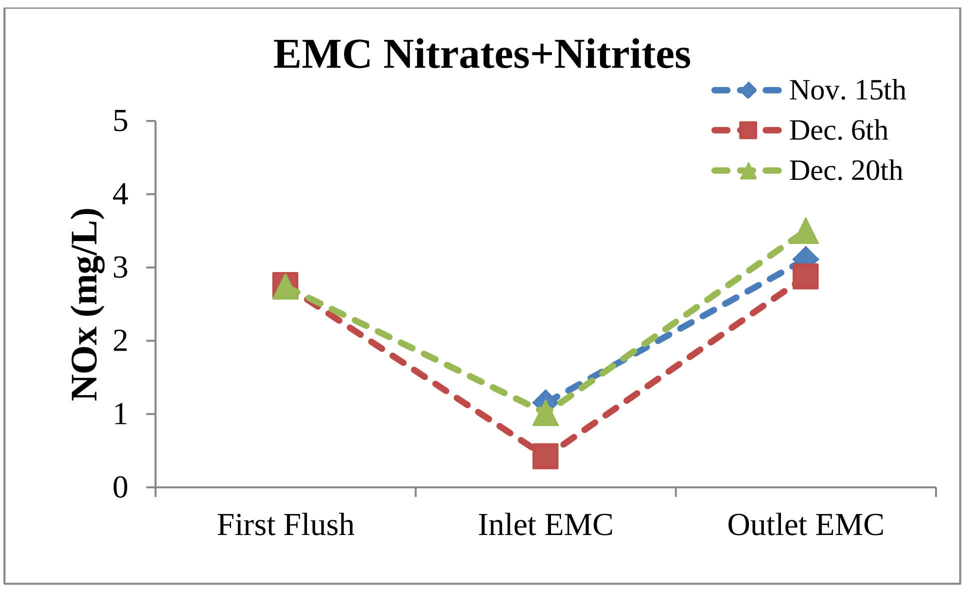

Figure 81. EMC NOx at McGinnis Ferry BMP.

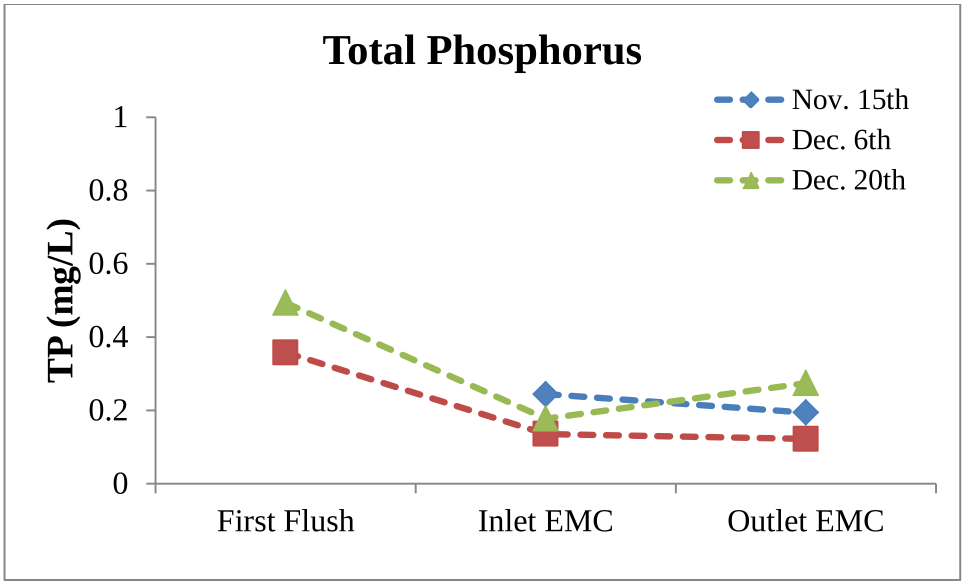

Figure 82. EMC Total phosphorus at McGinnis Ferry BMP.

6.6. Dependence on Antecedent Dry Conditions

The relationship between the antecedent dry period (ADP) and various parameter concentrations at the McGinnis Ferry Road site was developed, although the dataset was limited (Figure 83). There was no significant correlation between the antecedent dry period and the various parameters measured at this site. It is important to note that construction activity was ongoing during the monitoring phase of this project, and normal roadway conditions were disturbed as construction vehicles and materials were transported across the bridge to the construction zone adjacent to the test site.

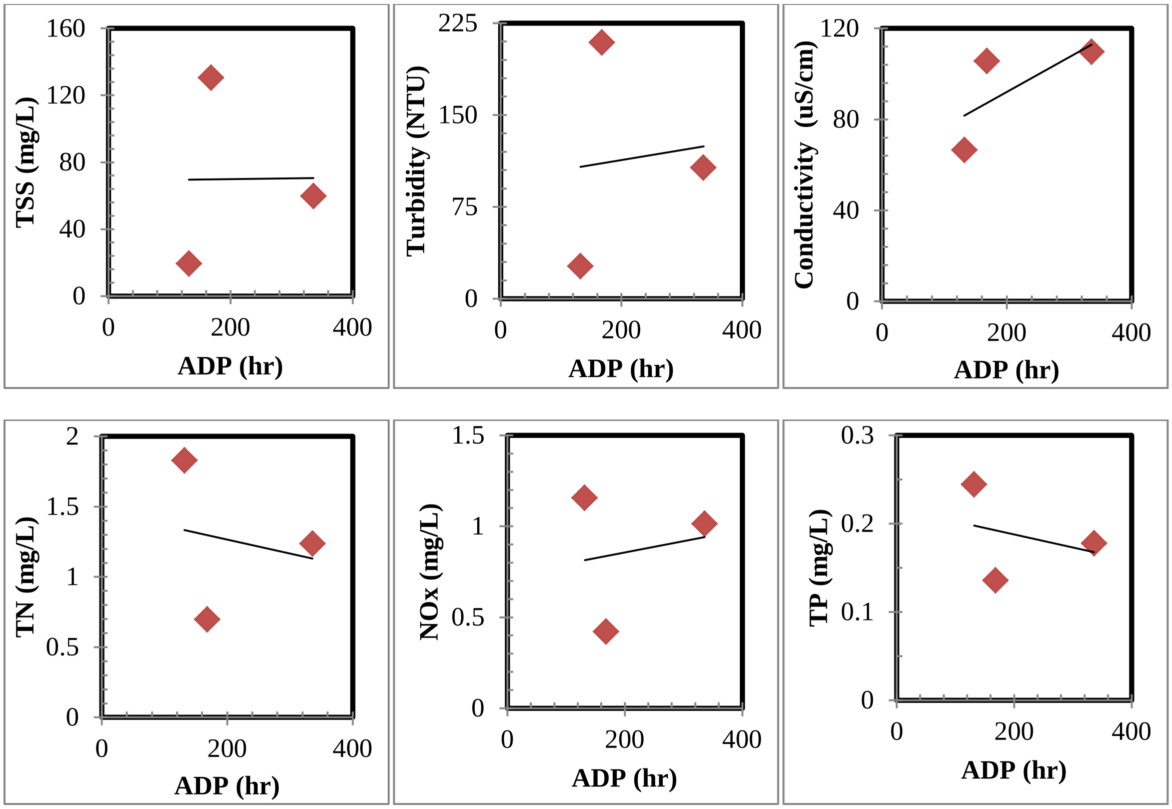

Figure 83. Inlet concentration antecedent dry period correlation at McGinnis Ferry BMP.

6.7. Parameter Correlation

Correlation plots between different parameters and the total suspended solids demonstrated that the inlet nutrient concentrations measured were negatively correlated with the total suspended solids (Figure 84). This suggests that that the nutrients were present in the dissolved phase, which resulted in a highly mobile nutrient phase.

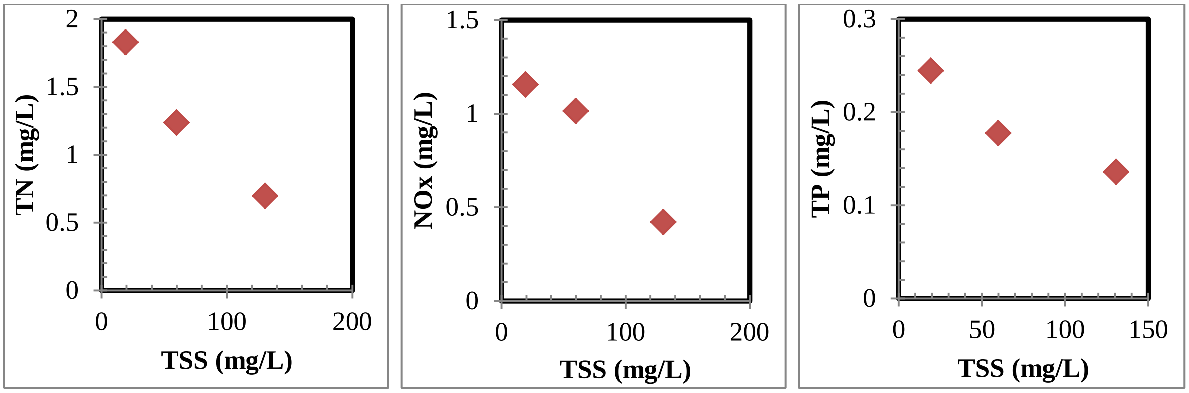

Figure 84. Inlet concentration correlation with total suspended solids at McGinnis Ferry BMP.

6.8. Performance Summary & Recommendations

In summary, the influent and effluent concentrations measured for the McGinnis Ferry BMP are given in Table 19 and Table 20. The water quality data showed a consistent increase in TSS, turbidity, conductivity, and nutrients between the inlet and outlet (Figure 85). At the outlet, a consistently higher EMC was observed when compared to the inlet, which strongly suggests that other sources of contaminants are present at the site other than from roadway runoff from McGinnis Ferry Road. The most likely contributor is the ongoing construction activity that was taking place in and around the detention pond over the course of the study period. Coinciding with first observation in November, the northern slope of the detention pond was cut to install pipe to handle runoff from the planned parking lot (Figure 86). After the pipe was installed, the entire slope was plowed and re-seeded with no additional erosion control. This activity is likely responsible for the increase in total suspended solids and turbidity measured at the outlet, and additional seeding of the road embankment of the bridge section directly above the southern pond slope took place over the course of the study and likely contributed additional nutrients to the outlet concentration. Another possible explanation for the increase in measured nutrients across the site may be a function of both the vegetation present in the detention pond, as well as the season. Leaves and other decaying plant matter were observed both before and after events and may be leaching nutrients that are detected at the outlet (Figure 86). Future stormwater BMP performance assessments should be conducted at the site once it has been stabilized to more accurately assess its performance. Additionally, consideration should be given to the vegetation in and around detention ponds to ensure that is maintained and that clippings do not accumulate within the BMP.

Table 19. TSS, Turbidity, Conductivity, and pH Measured at McGinnis Ferry Sand Filter Influent and Effluent

	TSS (mg/l)		Turbidity (NTU)		Conductivity (μS/cm)		pH	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
11/15/ 2011	19.4	60.7	26.7	62.2	82.0	66.5	7.6	7.4
12/6/ 2011	130.6	176.1	209.0	356.0	114.0	105.6	7.1	7.4
12/20/ 2011	59.8	85.4	107.0	163.9	62.7	109.7	7.4	7.5

Table 20. Nutrients and Temperature Measured at McGinnis Ferry Sand Filter Influent and Effluent

	Total Nitrogen (mg/l)		Nitrite + Nitrate (mg/l)		Total Phosphorus (mg/l)		Temperature (°C)	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
11/15/ 2011	1.8	3.5	1.2	3.1	0.24	0.19	17	17
12/6/ 2011	0.7	3.0	0.4	2.9	0.14	0.12	13	13
12/20/ 2011	1.2	3.9	1.0	3.5	0.18	0.27	12	13

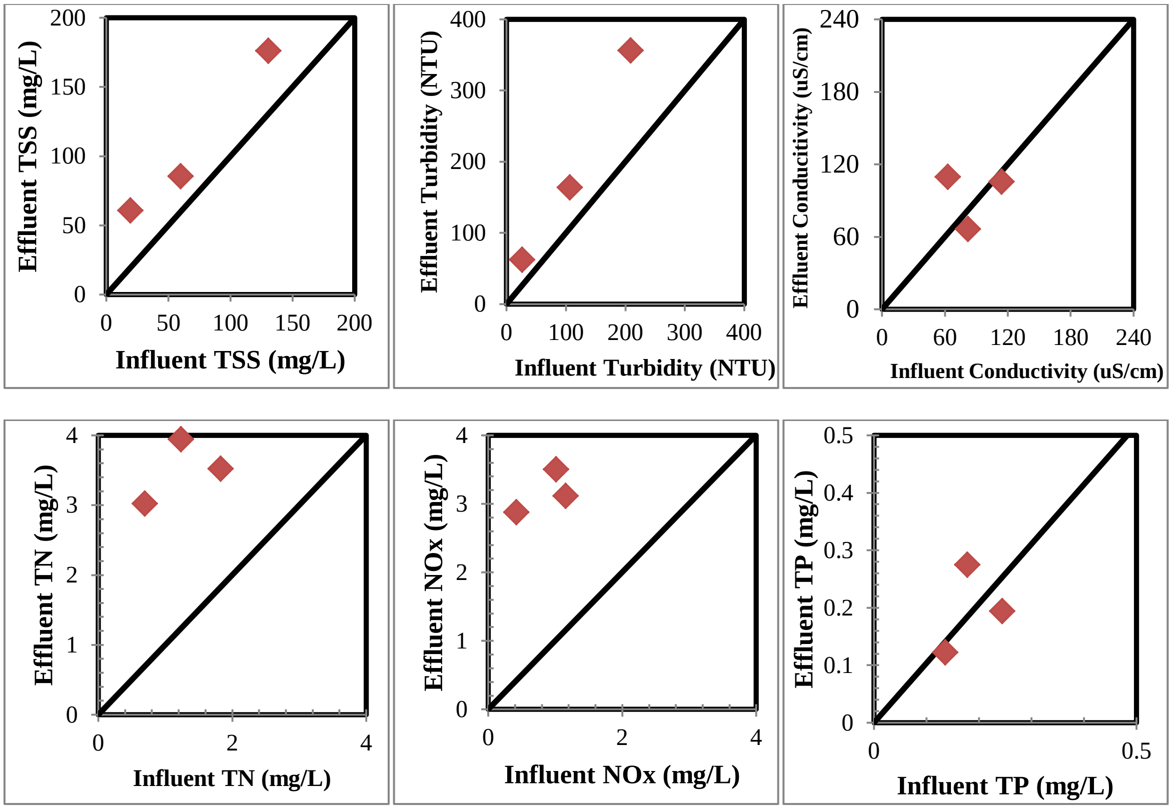

Figure 85. Influent versus effluent EMC at McGinnis Ferry BMP.

Figure 86. Construction activity and decaying vegitation at McGinnis Ferry BMP.

6.9. Conclusions

Three storm events were sampled at the McGinnis Ferry Road BMP during the fall/winter of 2011. Monitoring during the ongoing construction activity indicated an increase in the suspended solids, turbidity, total nitrogen, and NO_x concentrations between the BMP inlet and outlet, with conductivity and total phosphorus remaining largely unchanged in concentration between the inlet and outlet. Construction activity was ongoing at the BMP location, and it is believed that the transitory site conditions contributed to the observed anomalous results at the McGinnis Ferry site. It is recommended that this location be monitored again in the future, once the conditions have stabilized.

7. SELECTION OF STORMWATER BEST MANAGEMENT PRACTICES

7.1 Introduction

Stormwater BMPs are being used by throughout United States for attenuation and treatment of highway runoff. Since each BMP has its own specific characteristics and usage, it may not be applicable to all locations and conditions, which complicates the selection of the best BMP for a given site. The current practice is to use selection matrices suggested in various state department of transportation manuals to facilitate the selection of an adequate BMP for a particular application. Using these selection matrices can become a cumbersome process to come up with a BMP for a specific site because the user has to compare several BMP alternatives on the basis of several site specific criteria. Hence, using multi-criteria decision analysis (MCDA) provides a method to eliminate this difficulty and it has attracted the attention of decision makers for a long time. This is suitable for addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information (Wang et al, 2009).

Generally, the MCDA problem expressed as follows:

$$
\begin{array}{llcccc}
 & \text{criteria} & C_1 & C_2 & \cdots & C_n \\
 & \text{(weights} & w_1 & w_2 & \cdots & w_n) \\
\text{alternatives} & & & & & \\
\end{array}
$$

$$
X = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{pmatrix}_{m \times n}
$$

Where,

x_{ij} is the performance of j-th criteria of i-th alternative, w_j is the weight of criteria j, n is the number of criteria and m is the number of alternatives available. There are several MCDA methods available today. One such method is the Analytical Hierarchy Process (AHP), which was developed by Saaty (1980). It is a hierarchical technique for organizing and analyzing complex decisions.

7.2 Methodology

The AHP is a four-step process, which can be described as follows -

Step 1. Construction of BMP and Criteria Comparison Matrices.

The first step in performing the AHP is to identify all possible BMP alternatives from which a single alternative is to be selected. A list of general application stormwater controls is presented in Table 11.

Table 21. List of General Application BMPs

S.No.	BMPs
1	Wet Pond
2	Wet ED Pond
3	Micro pool ED Pond
4	Multiple Ponds
5	Shallow Wetland
6	Shallow ED Wetland
7	Pond/Wetland
8	Pocket Wetland
9	Bioretention Areas
10	Surface Sand Filter
11	Perimeter Sand Filter
12	Infiltration Trench
13	Dry Swale
14	Wet Swale

The next step is to identify a list of criteria influencing the selection of a single alternative from the list of feasible alternatives. Relevant criteria pertaining to the selection include:

Stormwater treatment suitability – water quality, channel protection, overbank flood protection, extreme flood protection, rate control and volume reduction.

Water quality – percent removal of total suspended solids, heavy metals, nutrients and fecal coliform.

Site Applicability – drainage area, space required for the BMP, site slope, minimum head required, depth to water table and type of soils available at the site.

Implementation Considerations – pretreatment, community acceptance and wildlife habitat.

Some selection criteria are either not quantifiable or the units of measurement are different; consequently, a relative scale of importance is implemented as an alternative (Saaty, 1980) (Table 22).

Table 22. Scale of Relative Importance (Saaty, 1980)

Intensity of importance	Definition
1	The alternatives being compared contribute equally to the defined objective
3	One alternative is favored slightly over the other in terms of achieving the defined objective
5	One alternative is favored strongly over the other in terms of achieving the defined objective
7	One alternative is favored very strongly over the other in terms of achieving the defined objective
9	The evidence favoring one alternative over the other is absolute in terms of achieving the defined objective
2,4,6,8	Intermediate values available to express user-defined comparisons

This table can be used to make pairwise comparisons among different alternatives for a particular selection criteria and a weight can be assigned to that alternative. This comparison between the selected alternatives is done for each criterion. Finally, criteria are also compared and ranked against each other. Hence for a total number of M alternatives, for each criterion we get a M x M matrix. This is called as BMP comparison matrix. For N criterions, after pairwise comparing each criterion we get an N x N matrix. This is known as the criteria judgment matrix.

Step 2. Extraction of Priority Vectors.

After creating the various BMP comparison matrices as well as the criteria judgment matrix, the relative importance of each matrix is calculated by finding the right principal eigenvector of each judgment matrix.

Step 3. Ranking of Competing Alternatives.

The final step is the construction of the BMP decision matrix. Column entries in the BMP decision matrix are made by entering the priority vectors obtained from each individual BMP comparison matrix. The decision matrix is of dimensions M x N. M representing the number of BMP alternatives being considered and N indicating the total number of influential criteria for which BMP comparison matrices were constructed (Figure 87).

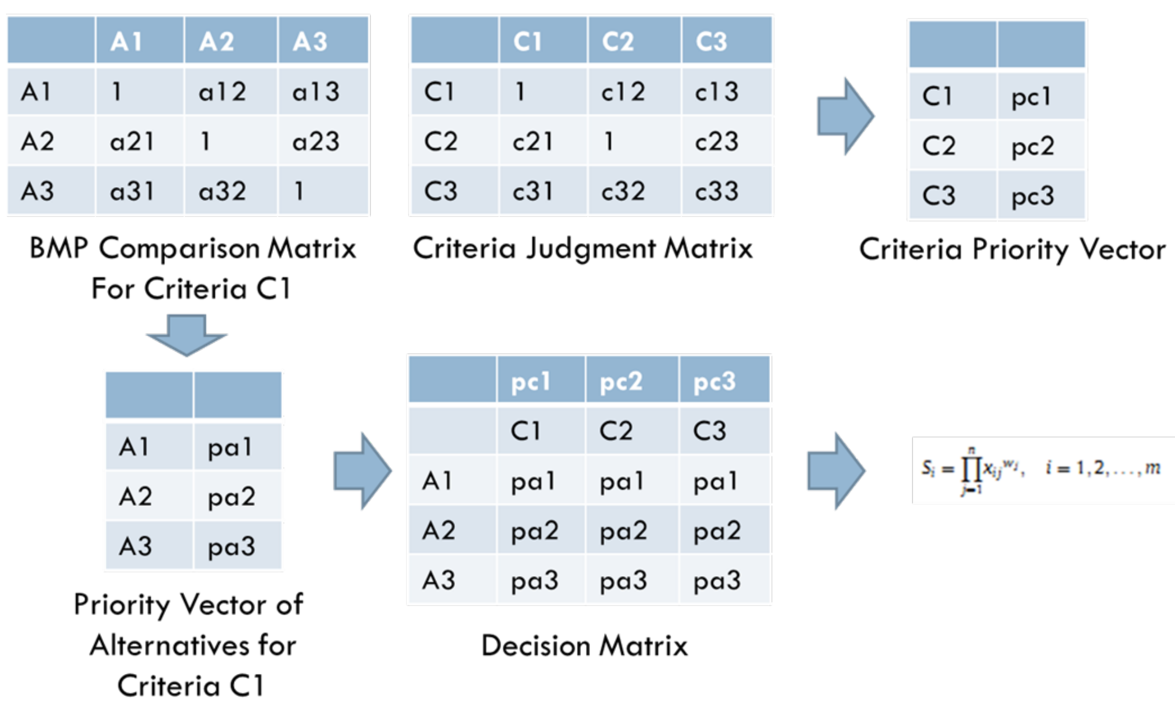

Figure 87. Flowchart for multiplicative AHP.

After the decision matrix and criteria priority vector is obtained by finding the right principal eigenvector of the BMP comparison matrix and the criteria judgment matrix, a matrix of the form as shown in the general expression results. Using the decision matrix we can calculate the ranks by pairwise calculating weighted products. Weighted product can be calculated by using the following relation –

$$P\left({}^{A_k}/_{A_l}\right) = \prod_{j=1}^{n} \left(a_{Kj}/a_{Lj}\right)^{w_j}$$

For K,L = 1,2,3, …m

If

$$P\left({}^{A_k}/_{A_l}\right) \geq 1$$

Then alternative A_k is better than A_l . The best alternative is the one which is better than or at least equal to all other alternatives. Hence, using this method, we can come up with a stormwater BMP which is best suited for a particular site (Table 23).

Table 23. Example of a Decision Matrix

	Weights →	0.288	0.288	0.288	0.093	0.043
#	BMP	TSS	TP	TN	Aesthetic	Site Area
1	Dry Pond	0.014	0.011	0.088	0.012	0.022
2	ED Pond	0.014	0.096	0.088	0.012	0.013
3	Wet Pond	0.014	0.096	0.088	0.039	0.01
4	Infiltration Trench	0.129	0.096	0.088	0.039	0.066
5	Infiltration Basin	0.129	0.096	0.088	0.012	0.022
6	Porous Pavement	0.129	0.096	0.088	0.093	0.113
7	Constructed Wetland	0.014	0.096	0.088	0.046	0.013
8	Bioretention	0.129	0.096	0.088	0.169	0.113
9	Filter Strip	0.014	0.011	0.01	0.169	0.113
10	Vegetated Swale	0.014	0.011	0.01	0.039	0.066
11	Filters	0.129	0.096	0.088	0.093	0.113
12	Propreitary	0.014	0.011	0.01	0.093	0.113

8. CONCLUSIONS AND RECOMMENDATIONS

This investigation monitored two BMPs collecting and treating runoff on the right-of-way of two state routes. Automatic samplers were used to collect first flush samples, as well as composited flow-weighted samples for analysis. In-situ parameters pH, temperature, and conductivity were measured at an interval of five minutes using in-situ measurement probes.

Wavelet analysis of the data gathered during the construction phase of the Canton sand filter demonstrated most notably that the influence of the concrete pours during culvert construction could be detected in-stream with a transitory in-stream pH increase. However, turbidity did not show any significant change in value during the period of active construction. Background sampling performed after the conclusion of construction of the sand filters and the shopping center complex were consistent with in-stream data gathered during the active construction phase of the GDOT project.

Under an agreement between GDOT and the U.S. Fish and Wildlife Service, the Canton sand filter was constructed to limit the impact of roadway runoff to the habitat of the Cherokee darter fish, which is a threatened species endemic to the Etowah river system in North Georgia. Monitoring of the inflow and outflow concentrations at the Canton Creek BMP yielded the following results:

- The stormwater was being detained in the BMP longer than the 24-hour design residence time.
- Temperature of the stormwater decreased as water flowed through the sand filter; however, the temperature of the first flush water directly leaving the road surface never exceeded the 90°F criteria in the state standards (note sampling was not performed at during peak summer temperatures).

- pH values typically increased as the stormwater transported from the inlet to the outlet of the sand filter, and were within the state standards of 6.0-8.5 in all but two measurements.
- Conductivity measured at the outlet was consistently higher than the conductivity at the inflow demonstrating a 5% to 25% between the inlet and the outlet, indicating that the stormwater was mobilizing ions as it flowed through the sand filter.
- Suspended solids (75%-95% reduction) and turbidity (20%-95% reduction) were consistently reduced between the inlet and the outlet of the BMP.
- Nutrient levels of nitrogen and phosphorus were consistently reduced between the inlet and the outlet of the BMP, indicating a reduction of at least 50% in half of the storm events. However, it is important to note that some storm events showed increases in nutrient levels, which may indicate fertilization and maintenance on the filter surface.
- Lead and zinc concentrations were consistently reduced between the inlet and the outlet of the BMP. Copper concentrations increased within the BMP, suggesting that there is a source of copper within the sand filter. The measured levels of dissolved copper, lead, and zinc measured at the influent and effluent of the Canton sand filter were compared with the Georgia Environmental Protection Division (EPD) General criteria for all waters (EPD, 391-3-6-.03), and are shown in Table 24. The data demonstrated that the levels of lead coming from the roadway were low, as indicated by the "below detection limit" concentrations measured in all cases for the influent to the pond. For pond effluent, there were three instances of dissolved lead detectable at the outflow, with the lead concentration measured on the February 28, 2011 event exceeding the standard for both acute and chronic concentration. In 7 out of 9 storm events, the influent concentration of

copper was below detection limits, but exceeded the acute and chronic concentrations in the last storm event in April, 2011, and the chronic level in the event on 4/11/2012. However, the effluent copper concentration exceeded both the acute and chronic concentrations in five out of nine storm events, indicating a source of copper within the sand filter, most likely within the piping. Dissolved concentrations of zinc did not exceed the standards (acute or chronic) in any of the nine storm events monitored.

Table 24. Comparison of Dissolved Metal Concentrations Measured at the Canton Sand Filter with Georgia EPD Standards[1]

	Dissolved Lead (mg/l)[2]		Dissolved Copper (mg/l)[3]		Dissolved Zinc (mg/l)[4]	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/25/2011	BDL	BDL	BDL	BDL	BDL	BDL
2/28/2011	BDL	0.048	BDL	BDL	BDL	BDL
3/5/2011	BDL	BDL	BDL	0.013	BDL	BDL
3/9/2011	BDL	BDL	BDL	BDL	BDL	0.005
3/15/2011	BDL	0.002	BDL	0.001	BDL	BDL
3/26/2011	BDL	BDL	BDL	0.019	0.013	0.004
4/ 4/2011	BDL	BDL	BDL	0.011	0.009	BDL
4/11/2011	BDL	BDL	0.006	0.017	0.010	0.007
4/15/2011	BDL	0.001	0.016	0.014	0.012	0.009

[1]From: General criteria for all waters, EPD, 391-3-6-.03 Water Use Classifications and Water Quality Standards

[2]Lead, acute = 0.03 mg/L, Lead, chronic = 0.0012 mg/L

[3]Copper, acute = 0.007 mg/L, Copper, chronic = 0.005 mg/L

[4]Zinc, acute = 0.065 mg/L, Zinc, chronic = 0.065 mg/L

Monitoring data gathered at the McGinnis Ferry Road BMP during the fall/winter of 2011 demonstrated an increase in the suspended solids, turbidity, total nitrogen, and NO_x concentrations measured between the BMP inlet and outlet, with conductivity and total phosphorus remaining largely unchanged in concentration between the inlet and outlet. Construction activity was ongoing at the BMP location during monitoring, and it is believed that the transitory site conditions contributed to the observed anomalous results at the McGinnis Ferry site. It is recommended that this location be monitored again in the future, once the conditions have stabilized.

The Canton sand filter, as constructed, included a surface layer of organic mulch which would contribute to the retention of contaminants coming from the roadway. Mulch is sorptive for organic phases and dissolved metals; however, at the time of the monitoring, the majority of the mulch had decomposed or washed away. In terms of maintenance, it is recommended that the mulch layer at the top of the sand filter be replaced and disposed offsite on an annual basis, with replenishment occurring on a semi-annual basis. Vegetative growth, which had occurred on the surface of the detention pond and sand filter, will also contribute to retardation of contaminants, so frequent mowing is not necessary. However, mowing on an annual or semi-annual basis, accompanied by offsite disposal of the mowed vegetation would enhance the removal capacity of the filter.

In summary, the data gathered at the Canton sand filter indicate:

- Erosion control measures enacted during the interchange construction were effective, with only transitory increases in the pH of the river detected during concrete pours.
- Temperature and pH values measured for roadway runoff (filter influent) and at the filter effluent were consistent with state standards.
- The filter decreased suspended solids and turbidity discharging to the receiving stream, and in about half the cases, decreased the nutrient load; however, the conductivity increased between the filter influent and effluent.
- The levels of dissolved metals coming from the roadway were low, with only copper exceeding state standards in two storm events. Effluent dissolved concentrations of lead and zinc were below state standards in all but one instance,

while effluent dissolved copper exceeded state standards in five events. It is recommended that the source of copper within the filter design be identified removed in future sand filter construction projects.

Because the McGinnis Ferry BMP was not stabilized at the time of sampling, it is not possible to draw conclusions on its performance; however, the Canton sand filter is functioning well, making it a viable alternative for use at other interchange sites with reasonable areas for construction.

9. REFERENCES

American Society of Civil Engineers; United States Environmental Protection Agency. (2002). *Urban Stormwater BMP Performance Monitoring*. EPA-821-B-02-001; ASCE and U.S. EPA Office of Water: Washington, DC.

Arnold, J.A., ed., D.E. Line, S. W. Coffey, and J. Spooner. (1993). Stormwater Management Guidance Manual, North Carolina Cooperative Extension Service and North Carolina Division of Environmental Management. Raleigh, N.C.

Backstrom, M. (2003). Grass swales for stormwater pollution control during rain and snowmelt, Water Science and Technology, Volume 48, No. 9, Page 123-134.

Ball J.E., R. Jenks, D. Aubourg, (1998). An assessment of the availability of pollutant constituents on road surfaces, The Science of the Total Environment, 209, 243-254.

Barrett, M. E., L. B. Irish, J.F. Malina, R.J. Charbeneau. (1998). Characterization of Highway Runoff in Austin, Texas, Area, Journal of Environmental Engineering, 124(2): 131-137.

Barrett, M.E. (2008). Effects of a permeable friction course on highway runoff, Journal of Irrigation and Drainage Engineering, Vol. 134, No. 5, Pg. 646- 651.

Barrett, M.E., P. Kearfott, J.F. Malina. (2006). Stormwater quality benefits of a porous friction course and its effect on pollutant removal by roadside shoulders, Water Environment Research, Vol. 78, page 2177-2185.

Bomboi, M. T. and A. Herande. (1991) Hydrocarbons in urban runoff: Their contribution to the waste waters, Water Research, Vol. 25, No. 5, pp. 557-565.

Branvall, E. (2007). Improvement of storm water runoff treatment system with natural mineral sorbent, Geologija, No. 59, Page 72-76.

Brinkmann, W.L.F (1985). Urban stormwater pollutants: Sources and loadings, GeoJournal 11.3, 277-283.

Caltrans. (1997). Guidance Manual: Stormwater Monitoring Protocols. prepared by Larry Walker and Associates and Woodward-Clyde Consultants. August 15.

Cooperative Extension Service and North Carolina Division of Environmental Management. Raleigh, N.C.

Dietz, M.E. and J.C. Clausen. (2006). Saturation to improve pollutant retention in a rain garden, Environmental Science and Technology, Vol. 40, Page 1335-1340.

Drinking water contaminants.
Weblink http://www.epa.gov/safewater/contaminants/index.html#inorganic

Driscoll, E.D., P.E. Shelley, and E.W. Strecker. (1990). Pollutant loadings and impacts from highway stormwater runoff. Vol. I: Design Procedure, Tech. Rep. No. FHWA-RD-88-007, Prepared for the FHWA. Washington, D.C.

Georgia Stormwater Management Manual. (2001). Volume 2, Technical Handbook, 1st Edition, August.

Iowa Stormwater Management Manual. (2007). Version 1, February.

Gupta, R.S. (1989). *Hydrology and Hydraulic Systems.* Prentice Hall. NJ.

Hafner, J.M., M. Panzer, and K. Rade, (1998). Best Management Practices as They Relate to the Treatment of Stormwater Runoff in the Minnehaha Creek Watershed District B.C.

Huber W.C., E.W. Strecker, J.P. Heaney, N. Weinstein. (2006). Evaluation of Best Management Practices and Low Impact Development for Highway Runoff Control; User's Guide for BMP/LID Selection Guidelines Manual. National Cooperative Research Program.

Knight, R. L., R. H. Kadlec, H.M. Ohlendorf. (1999). The use of treatment wetlands for petroleum industry effluents, Environmental Science & Technology, 33(7), pages 973-980.

Knox County Tennessee Stormwater Management Manual, Porous Pavement, Section 4.3.12.

Lee, S. Matsui, Y. Shimizu, T. Matsuda, Y. Tanaka. (2005) A new installation for treatment of road runoff: up-flow filtration by porous propylene media, Water Science and Technology, Vol. 52, No. 12, Page 225-232.

Legret, M. and C. Pagotto (1999). Evaluation of pollutant loadings in the runoff waters from a major rural highway, The Science of The Total Environment 235(1-3): 143-150.

Li, M.-H., M. E. Barrett, P. Rammohan, F. Olivera, and H.C. Landphair. (2008). Documenting stormwater quality on Texas highways and adjacent vegetated roadsides. Journal of Environmental Engineering, 134(1): 48-59.

Makepeace, D.K., D.W. Smith, and S.J. Stanley. (1995). Urban stormwater quality: Summary of contaminant data, Critical Reviews in Environmental Science and Technology, 25(2), 93-139.

National Urban Runoff Program. (1983). Final Report. U.S. Environmental Protection Agency Water Planning Division, Washington, D.C.

C.J Pratt (1999). Use of permeable pavement reservoir construction for stormwater treatment and storage for reuse, Water Science Technology, Vol. 39, No. 5, Page 145-151.

D.M. Revitt, L. Scholes, and J.B. Ellis. (2008). A pollutant removal prediction tool for stormwater derived diffuse pollution, Water Science and Technology, Vol. 57, No. 8, Pg. 1257 – 1264.

Saaty, T. L. 1(980). The analytic hierarchy process, McGraw-Hill, New York.

M. Scharff, A. Lantin, E. Othmer. (2003). Effectiveness of vegetated biostrips in the treatment of highway storm water runoff, American Water Resources Association Conference, San Diego, CA, November 2-5.

Stormwater Treatment for Roads, Practice Note: LB 301 - June 2006, ARC Technical Publication.

Structural BMP Design Practices, Swarna Muthukrishnan, Richard Field and Daniel Sullivan, The use of best management practices in Urban Watershed, USEPA.

Structural Controls, Stormwater Manual for Western Australia, Department of Water.

Treatment of Stormwater Runoff, Soil and Water Conservation Society of Metro Halifax, 2006.

U.S. Environmental Protection Agency. (1983). Results of the nationwide urban runoff program. Water Planning Division, Washington, D.C.

USGS. (1980). National Handbook of Recommended Methods for Water-Data Acquisition. U.S. Geological Survey. Reston, VA.

Virginia Stormwater Management Handbook. (1999). Volumes 1 and 2, First Edition.

Wang, J.J., Y.-Y. Jing, C.-F. Zhang, J.-H. Zhao. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making, Renewable and Sustainable Energy Reviews, Vol. 13, Issue 9, Pages 2263-227.