ABSTRACT

Title of Document: EVALUATION OF TRANSITIONAL PERFORMANCE OF A STORMWATER INFILTRATION BASIN MANAGING HIGHWAY RUNOFF

Poornima Natarajan, Doctor of Philosophy, 2012

Directed By: Professor Allen P. Davis
Department of Civil and Environmental Engineering

Infiltration basins are widely employed stormwater control measures (SCMs) to manage and treat urban stormwater runoff. However, these SCMs experience progressive failure and the environmental functionality of such 'failed' infiltration basins in managing stormwater runoff is unknown.

The purpose of this research study was to systematically quantify through field-scale research, the hydrologic and water quality performances of a failed infiltration basin facility managing highway runoff in Maryland, U.S.A. Stormwater runoff flows were continuously monitored and representative runoff samples were collected during storm events and for time periods between events over a three-year research period. Runoff samples were analyzed for a suite of pollutants including total suspended solids, nitrogen species, phosphorus, heavy metals, and chloride, that are of greatest concern in roadway runoff. The hydrologic and water quality

performances were quantified using appropriate performance metrics and compared to established goals.

The research study showed that the failed infiltration basin was naturally transforming into a wetland and/or wetpond-like practice and possessed both hydrologic management and water quality functions. The transforming infiltration basin effectively reduced the highway runoff flows by providing dynamic flow attenuation, and total volume and peak flow reductions. Water quality improvements were achieved through reductions in the mean pollutant concentrations and pollutant mass for all water quality parameters during both storm events and dry-weather periods. The discharge concentrations met the established water quality goals for all pollutants except total phosphorus.

Comprehensive analysis of various pollutant species, coupled with hydrologic analysis and characterization of environmental conditions in the infiltration basin during different seasons and storm characteristics, showed that sedimentation, adsorption, and denitrification were the main mechanisms controlling water quality at the facility. The infiltration basin also provided ancillary benefits such as wildlife habitat, which added an overall ecological value to the facility.

The transforming infiltration basins providing both hydrologic and water quality functions must be considered as functioning, innovative SCMs. Results and research information obtained from this study are applicable for assessing similar SCM facilities and improve understanding of SCM performances and designs. Ultimately, the knowledge obtained will lead to widespread and reliable implementation of SCMs for improved environmental quality.

EVALUATION OF TRANSITIONAL PERFORMANCE OF A STORMWATER INFILTRATION BASIN MANAGING HIGHWAY RUNOFF

By

Poornima Natarajan

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Advisory Committee:
Professor Allen P. Davis, Chair
Dr. Alba Torrents
Dr. Andrew H. Baldwin
Dr. Kaye L. Brubaker
Dr. Sujay Kaushal

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Chapter 1: Introduction

Land use changes induced by urbanization and highway construction have resulted in large scale replacement of pervious land cover by impervious areas. Consequently, increased stormwater runoff volumes, higher peak flows, frequent flooding, faster routing of the runoff, reduced infiltration and evapotranspiration, and lower dry weather flows in streams have been observed (Dunne and Leopold 1978; Walsh *et al.* 2005). Such hydrologic modifications in the rate, timing, and delivery of flow can deleteriously affect the physical, chemical, and biological conditions of the receiving waters (Paul and Meyer 2001; Wang *et al.* 2003; Konrad and Booth 2005).

Urban stormwater runoff is also a leading source of water quality impairment in surface waters (U.S. EPA 2005). The impervious surfaces (roads, driveways, parking lots, sidewalks, and rooftops) accumulate pollutants, including suspended solids, metals, nutrients, pesticides, pathogenic microorganisms, oil and grease, and deicing salts, which are washed off during storm events and eventually delivered to the streams (Barrett *et al.* 1998; Davis *et al.* 2001b; Paul and Meyer 2001; Davis and McCuen 2005; Kaushal *et al.* 2005). The term "urban stream syndrome" has been used to describe the consistently observed urban stormwater-induced ecological degradation of streams characterized by flashy hydrographs, decreased baseflow, channel instability, elevated levels of contaminants, stream warming, riparian deforestation, and decline in biodiversity (Walsh *et al.* 2005).

Stormwater control measures (SCMs) have been widely implemented to control the non-point pollution due to urban stormwater runoff. Infiltration basins and trenches, wetponds, rain gardens, vegetated filter strips, permeable pavements, and constructed wetlands are some examples of structural SCMs employed to reduce the post-development runoff flows and pollutant loadings in urban areas (U.S. EPA 2005). These SCMs provide on-site control and treatment of runoff before the runoff reaches the nearby water bodies.

Over the past few decades, a multitude of infiltration basin SCMs have been constructed for stormwater management. Infiltration basins are designed to capture, temporarily store, and infiltrate stormwater runoff into the underlying soil over a period of days (Ferguson 1990; PA DEP 2006). In addition to reducing the runoff volume leaving the site, these SCMs can remove pollutants through detention and filtration of runoff as the water percolates through the underlying soil (Ferguson 1990; U.S. EPA 1999; Birch *et al.* 2005; Dechesne *et al.* 2005; Barraud *et al.* 2005). Efficiency of infiltration basins in reducing stormwater runoff flows and treatment of pollutants such as total suspended solids, nutrients, metals, and fecal coliforms has been satisfactory (Birch *et al.* 2005; Barraud *et al.* 2005; Dechesne *et al.* 2005; Emerson *et al.* 2008; Emerson *et al.* 2010).

However, recent field inspections have shown that the infiltration basins may no longer be functioning as originally intended and designed. The original design of the infiltration basin is to facilitate complete infiltration of the incoming runoff and drying out of the facility over a period of time. An infiltration basin showing permanent ponding of the water suggests no active infiltration and thus the facility is considered to have 'failed' from an engineering perspective.

A two-part field survey conducted by Lindsey *et al.* (1992) in Maryland showed that stormwater infiltration basins (2-4 years old) exhibited inappropriate ponding of water, reduced infiltration rates, excessive sedimentation, clogging, and failure with time. About 51% of the infiltration basins were inappropriately ponded due to clogging by sediment input and needed rehabilitation. Although qualitative in nature, these site inspections showed that the longevity of infiltration basins could be compromised over time.

Decrease in infiltration ability of an infiltration trench due to deposition of sediments from urban stormwater runoff over a period of three years was reported by Emerson *et al.* (2010). In that study, the infiltration trench had an intentionally oversized impervious drainage area (160:1 drainage area to SCM footprint ratio vis-à-vis the recommended ratio of 5:1) in order to study the evolution and longevity of such infiltration SCMs. The excess areal suspended solids loading led to an exponential clogging process in the first two years that resulted in a corresponding exponential decay in infiltration performance. The study noted that the performance declined significantly over the first two years and only marginally in the third year. This was because as the infiltration trench aged, the solids captured clogged the bottom of the trench to a point where additional suspended solids input had minimal further impact on the infiltration performance of the facility.

Two research studies that focused on the long-term hydrology performances of infiltration basins, however, did not detect any systematic reduction in their performances (Dechesne *et al.* 2005; Emerson *et al.* 2008). In the study conducted by Emerson *et al.* (2008), the hydrology performance of two stormwater infiltration basins located in the Villanova University campus exhibited seasonal trends in performance driven by temperature, but no discernible systematic loss of performance with age over a period of 4.5 years. It must be noted that monitoring of these infiltration basins began 1.5 years after their inception and no performance data are available for the first 1.5 years. As noted earlier, the study conducted by Emerson *et al.* (2010) showed that an 'early start-up period characterized by a decrease in infiltration' can occur in infiltration-based SCMs. Hence, onset of monitoring relative to the duration of operation of the infiltration basin is an important consideration in interpreting the long-term performance of these SCMs.

Dechesne *et al.* (2005) studied the clogging and soil pollution in four infiltration basin facilities aged between 10 and 25 years, located in mixed urban land use area in Lyon, France. The study showed that, surprisingly, the facilities had similar hydraulic capacities and were still operating with good infiltration rates. The nutrient and metals pollution was contained in the top 30 *cm* depth of the infiltration basin. This study noted that infiltration basins of similar age but draining industrial regions exhibited permanent pooling. The operational condition or the lack thereof was justified by the nature of runoff pollutant loading from the watershed land use (heavily-used impervious area and industrial vis-à-vis less-developed) (Dechesne *et al.* 2005).

Thus, existing research on infiltration basin SCMs show that precluding pretreatment, improper and irregular maintenance of the infiltrating soil (removing debris and litter, and scraping off the sediment to restore the original infiltration rate), and disproportionate influent solids loading can negatively impact the sustainability of these SCMs and can lead to failure (Lindsey *et al.* 1992; Dechesne *et al.* 2005; SMRC 2008; Emerson *et al.* 2010).

Nevertheless, the environmental functionality of failed infiltration basins is not known. While the previous studies have focused on performances of infiltration basins under operation (Birch *et al.* 2005; Dechesne *et al.* 2005; Emerson *et al.* 2008), performances of failed infiltration facilities in mitigating stormwater runoff flows and treating the runoff have not been evaluated.

This research proposes that a separate ecological function may develop in the failed infiltration basin with time. The failed infiltration basin can gradually transform into or may possess qualities of a wetpond or wetland-like practice. Functions of stormwater wetponds and wetlands in providing hydrologic benefits and in reducing pollutant loads in runoff from impervious surfaces are well documented (Wu *et al.* 1996; U.S. EPA 1999; Carleton *et al.* 2000; Walker and Hurl 2002; German *et al.* 2003; Mallin *et al.* 2002; Birch *et al.* 2004; Brydon *et al.* 2006; Yeh 2008; Wadzuk *et al.* 2010). Hence, it was hypothesized that a 'transitioning' infiltration basin can possess both hydrology management and water quality functions.

In addition to providing flood control and water quality improvements, wetland ecosystems are among the most productive habitats in the world (U.S. EPA 2001). Wetlands support abundant vegetation, provide vital habitats for fish, and wildlife, and serve as a breeding ground and nursery for numerous species (Tiner, 2009). Suitability of an infiltration basin, naturally evolving into a wetland-like practice, as a habitat for wildlife is also of interest.

The purpose of this research study was to investigate the overall performance of a 'transitioning' stormwater infiltration basin from a hydrology and water quality perspective. A stormwater infiltration basin, built along a highway in a suburban area in Maryland, was the focus of the study. This infiltration basin manages stormwater runoff from a section of this highway. The main objectives of this research were:

1. To determine the effectiveness of the transitioning infiltration basin in managing runoff flows
2. To determine the effectiveness of the transitioning infiltration basin in reducing pollutant loads and improving the water quality of runoff

3. To identify the controlling mechanisms for the water quality and hydrologic performances
4. To assess the ecological value of the infiltration basin site

The runoff flow and water quality characteristics at the infiltration basin were monitored during several storm events and for time periods directly subsequent to storm events, over a period of three years. The water quality parameters examined include total suspended solids (TSS), phosphorus, nitrogen species, heavy metals, and chloride. These pollutants are of the greatest concern in roadway runoff because their concentrations often exceed the limits set by anticipated total maximum daily loads (TMDL) requirements.

The hydrologic and water quality performances of the infiltration basin were systematically quantified based on appropriate performance metrics and goals. Ancillary benefits such as habitat for wildlife and supporting vegetation were evaluated. The ecological value of the facility in terms of providing hydrology, water quality, and habitat functions was assessed collectively. A set of 'indicators of functionality' that are applicable towards assessment of other failed infiltration basins was also developed.

Thus, this research was aimed to determine the functionality of a transitioning stormwater infiltration basin and utilize the information obtained to develop tools that are applicable to evaluate similar infiltration basins. The 'transitioning' infiltration basins that demonstrate adequate water quality improvement and control the hydrology, as they exist, need not be treated as 'failed'. Rather than failure, these transitioning SCMs should be reclassified as a functioning stormwater management practice and permitted to remain as they are. This can save the funds involved in rehabilitating these facilities to restore original conditions and/or reconstruction to a new detention basin. If these new wetland-like SCMs provide additional functions such as habitat for wildlife, these facilities can be considered valuable in terms of better site-control of stormwater runoff as well as beneficial to the fauna supported by these facilities in developed areas.

Chapter 2: Materials and Methods

2.1 Site Description

An infiltration basin, located along MD 175 East in Columbia, Howard County, Maryland (Figure 1 and Figure 2), was selected as the site for this research study. This infiltration basin has been classified as a 'failed' facility by the Maryland State Highway Administration (SHA). Table 1 summarizes the design characteristics of the infiltration basin, as extracted from the construction plans. Total drainage area to the basin is 2.9 *ha*, of which 33% is impervious. The infiltration basin has one inflow and one outflow point. The source of inflow is sheet flow from MD-175 and ramp to Snowden River Parkway south, along with culvert and swale flow; all of these flows concentrate within a vegetated swale as the input to the infiltration basin (Figure 2).

Figure 1. Photograph showing the infiltration basin located along MD 175 East. Photo, looking west, shows single concentrated inflow point to the infiltration basin.

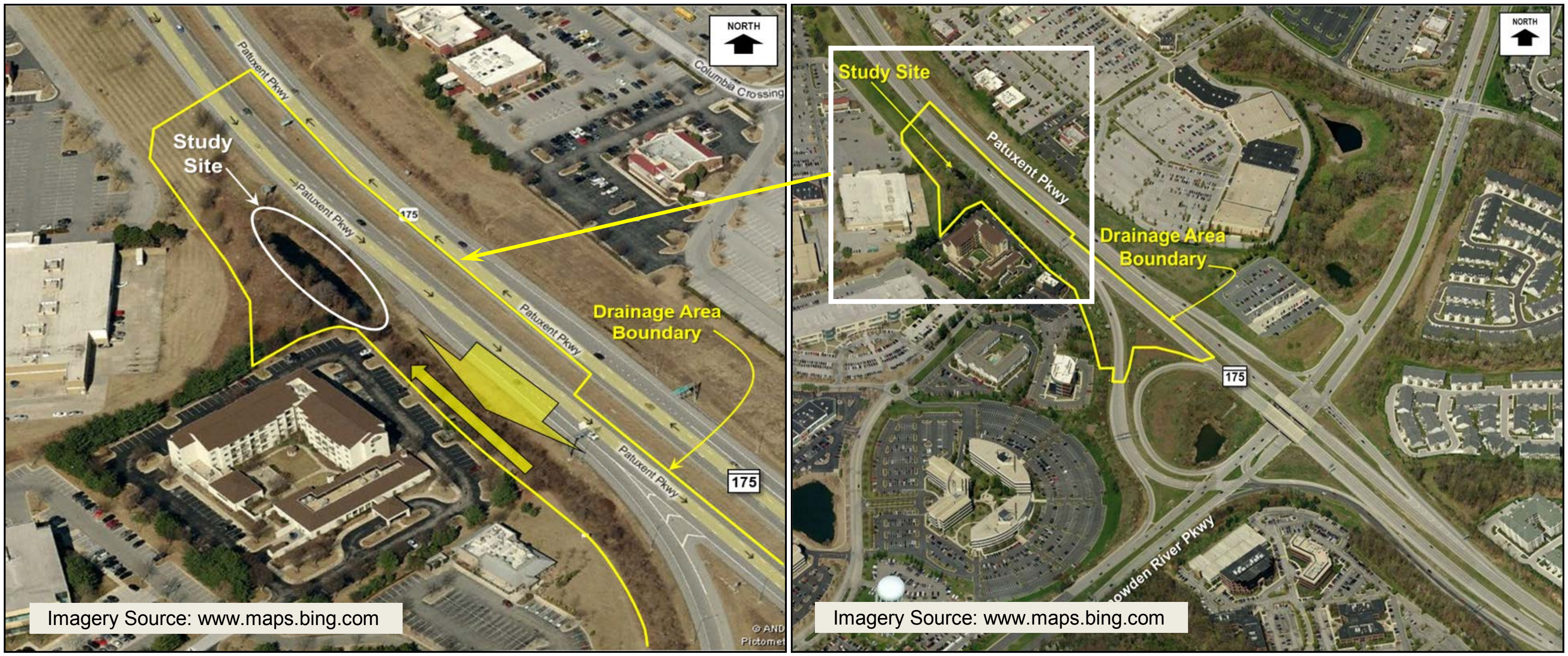


Figure 2. Aerial map showing the location of the infiltration basin site along MD 175 East. Photograph on left shows a closer view of the infiltration basin site. (Source: <www.maps.bing.com>)

Table 1. Characteristics of the MD 175 infiltration basin site.

Characteristics	Details
Infiltration Basin Characteristics	
Year of construction	2002
Size	Length 71 *m*, bottom width varying from 3.7 to 7.6 *m*, depth 0.91 *m* (from permanent bottom to outlet channel invert), side slope 4:1
Storage capacity	650 m^3
Bed material	0.31 *m* of sand beneath the permanent bottom of the infiltration
Soil type around the facility	USDA Loam (mica note)
Native soil infiltration rate	1.32 $cm\ hr^{-1}$
Vegetation planted upland	Black chokeberry, silky dogwood, and redosier dogwood
Drainage Area Characteristics	
Total drainage area	2.9 *ha* (impervious area = 0.96 *ha*)
Weighted curve number	75
Time of concentration	0.29 *hr*

2.2 Site Monitoring

2.2.1 Hydrology Monitoring

An input/output approach was employed to monitor the runoff hydrology and water quality at the infiltration basin. Runoff flows to and from the infiltration basin were directed through wooden V-notch weirs. Automated portable samplers (ISCO 6712, Teledyne ISCO, Lincoln, NE) with integrated flow meters (ISCO 730 bubbler flow module) recorded the runoff flows at the inlet and outlet of the infiltration basin (Figure 3). Rainfall depth measurements were taken using a tipping bucket rain gauge (ISCO 674) with 0.254 *mm* sensitivity, installed on top of the inlet sampler vault. Both flows and rainfall depths were continuously recorded on a 2-minute increment basis. A water level probe (Global Water Instrumentation, Gold River, CA) installed within the infiltration basin continuously recorded the water level at 10-minute intervals from March 2010 to August 2012. The accuracy of the water level measurements is ± 0.182 *cm* (per manufacturer specifications).

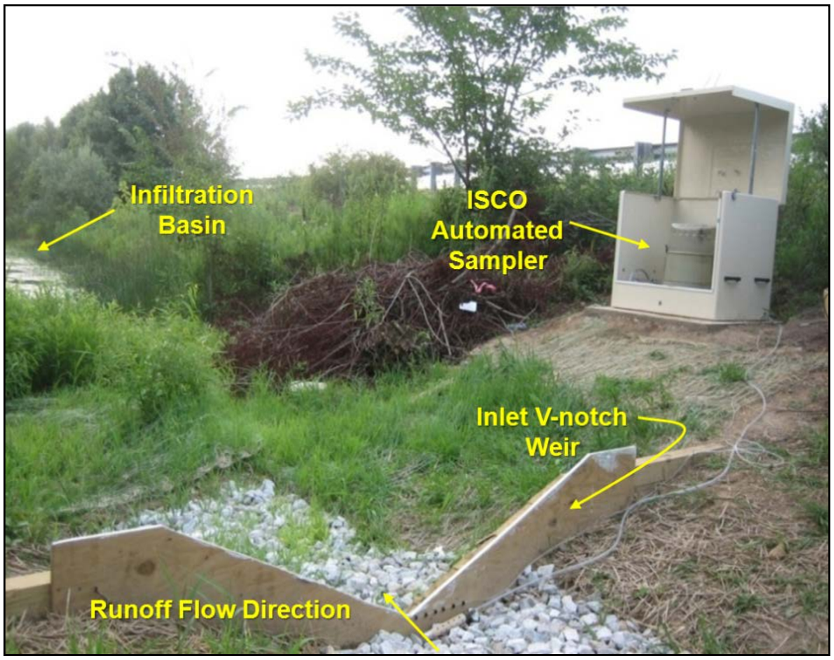


Figure 3. Photograph showing the sampler and weir installed at the inlet side of the infiltration basin.

2.2.2 Water Quality Monitoring

The ISCO portable samplers were used for water sample collection at the inlet and the outlet of the infiltration basin during storm events. Each sampler was programmed to collect 12 samples per event spread over the entire hydrograph (Figure 4). Based on the expected rainfall amount and duration from weather forecasts, a sampling program ranging from 6 up to 22-hour duration was employed in order to collect runoff samples representative of the rainfall event. Emphasis was placed on obtaining more samples in the early part of the rainfall event. The sampling program at the outlet was spread over a longer duration due to the expected flow attenuation through the infiltration basin facility. The multiple-sample collection method was adopted for 27 rainfall events. Flow-weighted composite samples were collected in a 10 L glass container during 11 rainfall events (Figure 5).

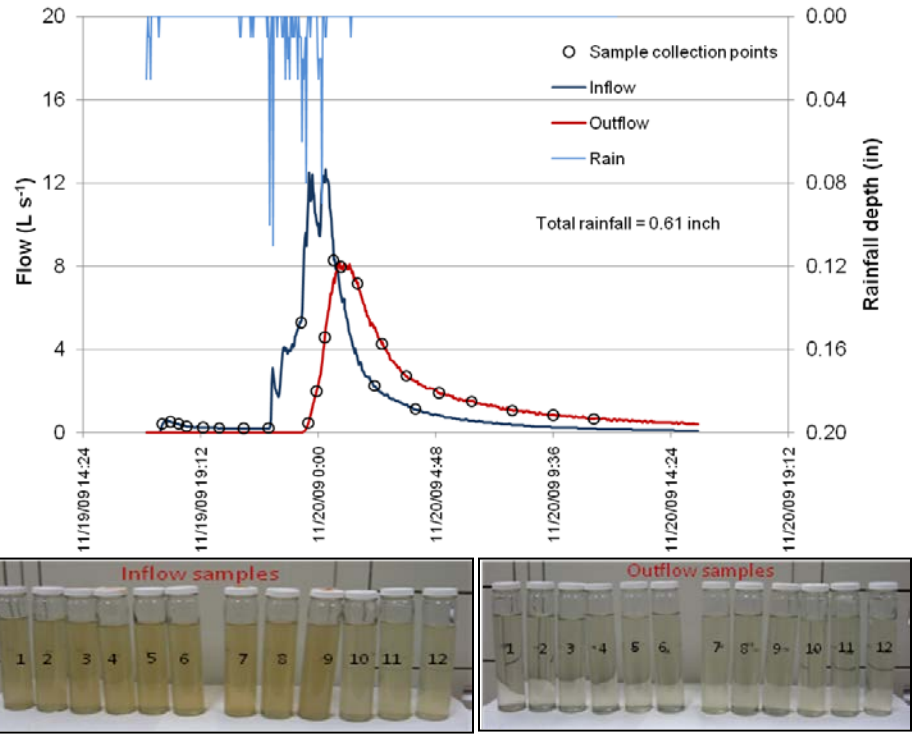


Figure 4. Inflow and outflow hydrographs recorded at the infiltration basin site during the Nov 19, 2009, rainfall event. Inlet sampling duration= 10 *hr* and outlet sampling duration= 12 *hr*. Photographs show the inflow and outflow samples collected for this rainfall event.

Figure 5. Photograph showing the inflow and outflow composite samples collected during the Feb 29, 2012, rainfall event.

The sample containers were cleaned with phosphorus-free soap, acid-washed, thoroughly rinsed with de-ionized water, and completely dried before placement in the samplers. Water samples collected were placed in an iced cooler, and transported to the Environmental Engineering Laboratory, University of Maryland College Park, MD within 12 hours after a rainfall event. Nitrile gloves were worn during handling of sample containers at all times. Attempts were made to monitor a distribution of rainfall events for water quality, consistent with those expected in Maryland.

In addition to sampling runoff during rainfall events, water samples were collected directly from the infiltration basin during selected dry-weather periods. These grab samples were collected from multiple locations in the infiltration basin using a swing sampler, prior to and following target events. As an example, Figure 6 shows the sampling locations and the grab samples collected on June 24, 2009.

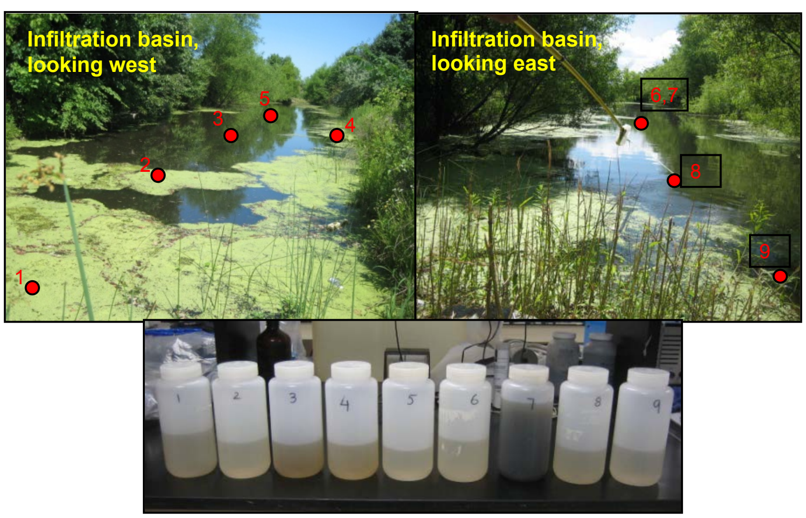


Figure 6. Sampling locations and samples collected during the 24 June, 2009, grab sampling. (Samples marked 1-6, 8, and 9 were water samples and sample 7 was a sediment sample)

At each location, samples were collected from the water column with efforts to not disturb the sediment bottom. Although care was taken to avoid plant material while taking a sample, some samples were found to have some plant material (fresh or decaying leaves). These were manually removed from the sample at the time of sample collection itself. The grab samples were analyzed for the target pollutants. The grab sample water quality data were utilized to support information obtained from stormwater runoff sampling and identify the mechanisms controlling pollutant transformations occurring in the infiltration basin.

In order to provide scientific justification to the environmental conditions facilitating pollutant transformations in the infiltration basin, additional water quality parameters were measured at the study site. Oxidation reduction potential (ORP), pH, temperature, and conductivity of the water column were continuously logged by sensors (Global Water Instrumentation, Gold River, CA) installed within the infiltration basin. Two ORP probes were installed, one close to the inlet side and one near the outlet side of the basin. The pH probe was installed near the ORP probe on the inlet side. The conductivity probe was installed near the ORP probe on the outlet side. The ORP, pH, and conductivity measurements were continuously taken in 20-minute increments for the period August 2011 to August 2012. Water temperature was continuously measured at 10-minute intervals from March 2010 through August 2012.

2.3 Analytical Methodology

The water samples were analyzed for total suspended solids (TSS), nitrate, nitrite, total Kjeldahl nitrogen (TKN), total phosphorus, total copper, total lead, total zinc, and chloride. In some cases, measurements for ammonium and dissolved phosphorus were additionally performed. All pollutant concentration determinations were based on *Standard Methods*

(APHA *et al.* 1995). The laboratory analytical method for each pollutant and detection limit of each method are summarized in Table 2.

Table 2. Laboratory analytical methods for determination of pollutant concentrations.

Pollutant	Standard Method (APHA *et al.* 1995)	Detection limit (mg L^{-1})
Total suspended solids	2540 D	1.0
Total phosphorus and dissolved phosphorus	4500-P	0.010
Total Kjeldahl nitrogen and ammonium	4500-N_{org} and 4500-NH_3	0.14 as N
Nitrite	4500-NO_2^- B	0.010 as N
Nitrate	Dionex DX-100 and ICS-1100 ion chromatograph	0.10 as N
Chloride	Dionex DX-100 and ICS-1100 ion chromatograph	2.0
Total Copper	3030, 3110	0.002
Total Lead	3030, 3110	0.005
Total Zinc	3030, 3111	0.025

Total suspended solids were determined by gravimetric method, following Standard Method 2540. Total phosphorus (TP) measurements were performed by persulfate digestion followed by colorimetric determination by the ascorbic acid method (Standard Method 4500-P) at 880 *nm* in a spectrophotometer (Shimadzu UV-160, Kyoto, Japan). Dissolved phosphorus measurements were performed on samples filtered through 0.2 μm membrane filters using the TP method. During TP analysis, runoff samples containing high TSS were observed to contain some suspended material after persulfate digestion. These digested samples were centrifuged or filtered to remove all suspended material before proceeding to the ascorbic method in order to avoid interferences during the spectrophotometric measurements.

TKN and ammonium analyses were performed by the macro-Kjeldahl method (Standard Methods 4500-N_{org} and 4500-NH_3). For nitrite analysis, samples were filtered through 0.2 *μm* filters and subjected to the colorimetric method (Standard Method 4500-NO_2^- B) and measurements were made at 543 *nm* in the spectrophotometer. Nitrate and chloride measurements on samples filtered through 0.2 *μm* membrane filters were performed by ion chromatography in Dionex DX-100 (2009 - 2010 period) and ICS-1100 (2011 - 2012 period) systems. Analyses of total Pb and Cu were performed on the furnace module of a Perkin Elmer (Waltham, MA) 5100ZL Atomic Absorption Spectrophotometer (AAS) (Standard Method 3110), and total Zn on the flame module of the AAS (Standard Method 3111).

In cases where the concentration of a pollutant was below the laboratory analytical detection limit (Table 2), a value equal to one-half of the detection limit was assigned for calculation and statistical purposes.

Appropriate quality assurance/check procedures were adopted during all laboratory analyses. Laboratory blanks were subjected to the same analytical procedure as the field samples during each pollutant analysis. Standard calibration curves were validated by checking at least one standard during each pollutant analysis. For ion chromatography determinations of nitrate and chloride, at least two standards were checked in a sample set run. During metal analyses, at least one standard concentration was checked after every ten samples. In all cases, if the error in standard concentration check exceeded ±5%, a new standard calibration was performed.

2.4 Data Analyses and Performance Metrics

2.4.1 Hydrology Data Evaluation and Performance Metrics

2.4.1.1 Peak Flow and Volume Reduction

The hydrology data were evaluated based on selected hydrology performance metrics to determine the effectiveness of the infiltration basin in mitigating the runoff flows. For each rainfall event, the maximum inflow and outflow were compared using the peak flow ratio, R_{peak}, computed as:

$$R_{peak} = \frac{Q_{peak-out}}{Q_{peak-in}} \quad (1)$$

where, $Q_{peak-in}$ and $Q_{peak-out}$ are the measured peak stormwater flow rates at the inlet and outlet, respectively, during the rainfall event (Davis 2008).

The total flow volume was calculated by a simple numerical integration of the flow measurements over time:

$$V = \int_0^{T_d} Q\, dt \quad (2)$$

In Equation 2, Q is the measured stormwater flow rate, and T_d is the rainfall event duration. The interval between measurements is dt. The total inflow and outflow volumes during a rainfall event were obtained by substituting the measured inflow and outflow rates, respectively. The inflow and outflow volumes were compared to determine the volume reduction achieved through the infiltration basin during the event. A new rainfall event was defined as an event occurring six hours after the end of the preceding event. Occasionally, outflow from the infiltration basin continued for extended periods, overlapping the next rainfall event. In such cases, the flow volumes of the two events were combined during volume analyses.

2.4.1.2 Statistical Evaluation

Probability plots (Davis 2008; Li and Davis 2009) for peak flows and flow volumes were also developed. Statistical tests were performed to determine if the observed runoff and discharge volumes were significantly different. A non-parametric statistical method, the Wilcoxon matched-pairs signed-ranks test (McCuen 2005), was employed to determine if the outflow volumes were significantly lower than the inflow volumes. Runoff volumes measured during all 138 recorded storm events were compared, which included rainfall events with and without outflow. A value of zero was assigned for outflow volume for storm events that did not produce outflow. This test determined if the overall hydrologic performance of the infiltration basin was statistically significant. In a second test, data for only the 52 storm events with both inflow and outflow were tested. Two levels of significance (α), 5% and 1%, were used in these tests.

2.4.1.3 Flow Duration Curve

While efforts have been directed towards matching estimated pre- and post-development peak flows, the cumulative duration of discharge flows have increased due to the overall increase in urban runoff volume, which has implications on the stream hydraulics and delivery of pollutants to the streams (Booth and Jackson 1997). The cumulative duration of runoff flows at the infiltration basin site were illustrated using a flow duration curve. The flow rate time series recorded at 2-minute intervals were ranked from the highest to the lowest flow rate values for the duration of interest. The ranked series was plotted against time to develop the flow duration curve.

A study goal was to compare the flow durations at the infiltration basin site with that of a forested site to evaluate the effectiveness of the infiltration basin site in mitigating the highway runoff flows. Unlike traditional stormwater management designs of reducing peak flows, 'low-impact development' (LID) approaches are aimed to match post-development runoff flows to pre-development flow characteristics (Booth and Jackson 1997; Holman-Dobbs *et al.* 2003; Dietz and Clausen 2008). The LID technologies promote infiltration and evapotranspiration to compensate for the rainfall abstraction possible in grassed areas, and reduce the rapid concentration of excess runoff and slow the runoff (Holman-Dodds *et al.* 2003; Dietz and Clausen 2008). Therefore, the flow durations at the infiltration basin SCM and forested (pre-development) site were compared to examine the extent to which the infiltration basin mimicked the pre-development hydrologic regime.

Pond Branch, located in the Gunpowder Falls watershed in Baltimore County in Maryland, was selected as the reference site. The catchment area of Pond Branch is 38 *ha* and is 100% forested. Streamflow data for Pond Branch (in 15-minute intervals) were accessed at the U.S. Geological Survey (USGS) website <http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01583570>.

Rainfall data for the reference site were obtained from a rain gauge station located at Oregon Ridge Park. This rain gauge station is located about 1.2 *km* north of the Pond Branch flow gage and about 52 *km* from the study site. The precipitation records for this station are managed by the Center for Urban Environmental Research and Education, University of Maryland Baltimore County, and are available at <http://hydro2.umbc.edu/Precip/>.

The rainfall distribution at the MD 175 infiltration basin site and Oregon Ridge Park were compared to determine if the rainfall depths and durations observed at the two sites were comparable. Figure 7 shows the rainfall depth-duration frequencies at the two sites for the monitoring duration. The two distributions were statistically compared using the hypothesis test on single proportions (McCuen 2005), where the equality of storm proportions in each depth-duration category was assessed at a 5% level of significance (α = 0.05).

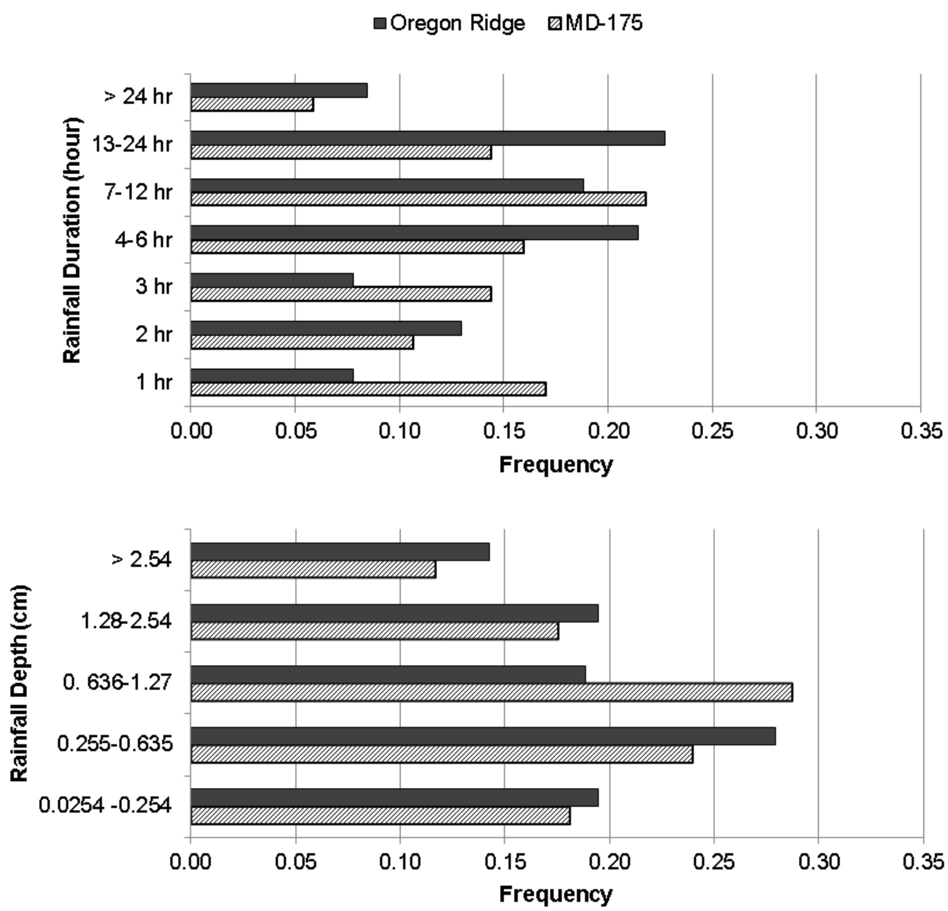


Figure 7. Rainfall depth-duration distributions for the MD 175 infiltration basin site and Oregon Ridge (reference site) for August 2009 to August 2012 period.

The test showed that the rainfall distributions at the two sites were statistically different for two (out of seven) duration categories in the (0.254-2.54 *cm*) and three (out of seven) duration categories in the (0.636-1.28 *cm*). The storm proportions were statistically similar for the (0.0254 -0.254 *cm*), (1.28-2.54 *cm*) and (> 2.54 *cm*) depth-duration categories. Since the statistical test showed similar proportions for a majority of the depth-duration categories, the overall rainfall distributions at the study and reference site can be considered to be similar.

The flow magnitudes at the infiltration basin site and Pond Branch were normalized by their respective total drainage areas and were expressed in $mm\ day^{-1}$. The Pond Branch stream maintains baseflow between storm events. The mode streamflow rate at Pond Branch was 0.49 $mm\ day^{-1}$ for the period Jan 2009 to August 2012. This mode value was selected as the baseflow and was subtracted from all recorded streamflow values. However, baseflow between storm events were not the same and this method of removing baseflow did not consistently eliminate baseflow. This resulted in very small flow values in the stream during dry periods. The flow durations at the Pond Branch stream were much longer compared to the infiltration basin site and these small flows were part of the tail end of the curve. Hence, this method was acceptable in the larger context. The reference flow duration curves were developed after removing baseflow from the streamflow data.

2.4.1.4 Estimation of Evapotranspiration

Evapotranspiration is a seasonal process and its effect on the water balance of the infiltration basin was examined. The evapotranspiration (ET) was estimated on a daily basis using the Blaney-Criddle formula (Blaney and Criddle 1962; Brouwer and Heibloem 1986):

$$ET_0 = p\ (0.46\ T_{mean} + 8) \qquad (3)$$

where, ET_0 ($mm\ day^{-1}$) is reference crop evapotranspiration, p is the mean daily percentage of annual daytime hours, and T_{mean} (°C) is the mean daily temperature. The mean daily temperature data were obtained from a weather station located 4.8 km from the infiltration basin site. The data are accessible via web (<http://www.wunderground.com/cgi-

bin/findweather/getForecast?query=21045>). The approximate values of *p* for the location of the study site are provided in Table 3.

Table 3. Mean daily percentage of annual daytime hours (*p*) for the study site location.

Latitude	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
39.24 N	0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21

(Source: Brouwer and Heibloem 1986)

The Blaney-Criddle formula is a simple temperature-based method. While the Blaney-Criddle method has been widely used to estimate evapotranspiration and crop irrigation needs, the reported reliability of this method has been mixed. Some research studies reported good correlation between predicted and measured ET values (or consumptive use) as well as predictions better than other temperature-based ET methods including Thornthwaite and Hargreaves Samani (Stephens and Stewart 1963; Hobbs and Krogman 1966; Cruff and Thompson 1967; Tabari *et al.* 2011; Xu and Singh 2011).

Tabari *et al.* (2011) reported 1.17% error of estimate ($r^2 = 0.99$; root mean square error of 0.33 $mm\ day^{-1}$) for the Blaney-Criddle predictions when compared to that of Penman-Monteith FAO 56 model for a mild-humid region in Iran, based on data for the period 1965 – 2005 for that region. Xu and Singh (2011) reported (-9) to (+20)% error of estimate for the monthly ET predictions (June to September for 10-year data set) using Blaney-Criddle when compared to pan evaporation data for a region in Ontario, Canada. The potential evapotranspiration computed by the Blaney-Criddle method at 15 sites in the sub-humid and modified arid environments of Florida, yielded values within ±22% of the adjusted pan evaporation based on one-year data (Cruff and Thompson 1967).

Few other studies reported poor performance of Blaney-Criddle method with over-prediction of the ET (Tukimat *et al.* 2012) or underestimation of crop ET in semiarid, high-elevation environments (Juday *et al.* 2011). In general, radiation-based methods have been found to perform better in comparison to temperature-based methods. It has been suggested that the Blaney-Criddle method provides only a rough estimation of ET and can be highly inaccurate for extreme climatic conditions (windy, dry, and sunny (underestimated by 60%) vs. calm, humid, and clouded (overestimated by 40%)) (Brouwer and Heibloem 1986).

The Penman-Monteith method has been found to provide the most reliable predictions of ET close to field observations (Allen *et al.* 1996; Tukimat *et al.* 2012). However, this method requires extensive data and is not feasible for use in data scarce regions. The meteorological inputs for this method were unavailable for the study site. Hence, the scope of this research was limited to employ the Blaney-Criddle method for evapotranspiration estimation at the infiltration basin site.

2.4.2 Water Quality Data Evaluation and Performance Metrics

2.4.2.1 Pollutant Mass Removal and Event Mean Concentration

For each pollutant, the total mass (M) was calculated as:

$$M = \int_0^{T_d} Q\, C\, dt \qquad (4)$$

In Equation 3, C is the measured pollutant concentration in each sample. Substituting corresponding values of Q and C for inflow and outflow, the inflow and outflow mass loadings during an event were obtained, respectively.

During a few storm events, the runoff flows at the infiltration basin continued beyond the water quality sampling period. While performing pollutant mass loading calculations, concentration of the unsampled runoff volume was assumed to be equal to half the concentration of the last sample collected, as a conservative estimate. In the event that the sampling duration covered only a portion of the hydrograph, the water quality data collected was considered non-representative of the storm event and the water quality data was excluded from analysis.

Mass removal efficiency for a pollutant was calculated as:

$$M_R = \frac{(M_{in} - M_{out})}{M_{in}} \tag{5}$$

where, M_{in} and M_{out} are the inflow and outflow pollutant mass loadings calculated using Equation 3. The total pollutant mass loadings and removals were evaluated for each storm event. In cases where the entire inflow volume was assimilated by the infiltration basin and no measurable outflow was produced, the removal efficiency for all target pollutants was 100% for that event.

The event mean concentration (EMC) was calculated as:

$$EMC = \frac{M}{V} = \frac{\int_0^{T_d} C\,Q\,dt}{\int_0^{T_d} Q\,dt} \tag{6}$$

where, V is the stormwater runoff volume. Since EMC weights discrete concentrations with flow volumes, EMCs were used to compare pollutant concentrations of inflow and discharge for different events. For composite water sampling, the EMC was directly obtained as the measured concentration of a pollutant in the composite sample. When a composite sample was taken, the pollutant mass was obtained by multiplying the measured EMC with the total runoff volume for that storm event. For storm events without outflow, a value of zero was assigned for discharge EMC for statistical purposes.

2.4.2.2 Probability Exceedence and Water Quality Goals

Percent pollutant removal may not be an accurate representation of the performance of a SCM since it depends on the influent pollutant concentrations (Strecker *et al.* 2001). Therefore additional metrics were utilized to evaluate the water quality performance of the infiltration basin. The inflow and outflow concentrations were statistically characterized through probability exceedence distributions (Li and Davis 2009). The effluent pollutant concentrations were compared to appropriate water quality targets (Table 4).

Table 4. Criteria for various water quality parameters**.** All concentrations are in mg L^{-1}.

Pollutant	TSS	TP	Nitrate (as N)	Nitrite (as N)	TKN (as	TN (as	Lead	Copper	Zinc	Chloride
Water quality criterion	25[a]	0.05[a]	0.20[a]	1[c]	-	-	0.065[b]	0.013[b]	0.12[b]	250[c]

[a] Criterion for excellent water quality in the Potomac River Basin (Davis and McCuen 2005)
[b] Acute toxicity level (COMAR 2006)
[c] Secondary drinking water regulation (US EPA 2009)

The selected water quality criteria in Table 4 are based on the water quality goals outlined in the bioretention research study by Li and Davis (2009). The criteria were derived from various local, state, and federal regulations; threshold levels of TSS, TP, and nitrate are local quantitative water quality designations (Davis and McCuen 2005); total heavy metal criteria are acute toxicity levels for freshwaters in Maryland (Code of Maryland Regulations (COMAR) 2006); and the threshold nitrite and chloride levels are federal secondary drinking water regulation (US EPA 2009).

2.4.2.3 Pollutant Duration Curve

Pollutant duration curves (as in Stagge *et al.* 2012) were developed for each pollutant based on 27 discrete-sample monitored storm events. Composite sampling was performed during the 11 excluded storm events. The curves illustrate the cumulative duration of a pollutant concentration flowing into the infiltration basin, the maximum pollutant concentrations discharged, cumulative duration of concentrations discharged, and their exceedence in comparison to water quality targets.

2.4.2.4 Statistical Evaluation

A non-parametric statistical method, the Wilcoxon matched-pairs signed-ranks test (McCuen 2005), was used to determine if the outflow EMCs were significantly lower than the inflow EMCs ($EMC_{out} < EMC_{in}$) for all pollutants (TSS, TP, TKN, NO_x, Pb, Cu, Zn, and chloride). Two separate statistical tests were performed to determine the effectiveness of the infiltration basin in providing water quality benefit. In the first test, inflow and outflow EMCs of all 38 sampled storm events were compared to determine the overall water quality performance of the infiltration basin. For events with no outflow, an EMC value of zero was used. In the second test, EMCs of only the 15 storm events with both measurable inflow and outflow were compared. This test was performed to determine the effectiveness of the basin from a treatment perspective.

Both hydrology and water quality performances of the infiltration basin were evaluated on an event basis as well as on seasonal basis. The classification followed was: September to November as fall, December to February as winter, March to May as spring, and June to August as summer.

Chapter 3: Hydrologic Performance of the Infiltration Basin

A total of 188 rainfall events were recorded at the infiltration basin site for the period August 2009 to August 2012. Details of rainfall depth and duration, antecedent dry period, and runoff inflow and outflow volumes recorded during each storm event are summarized in Table A-1 in Appendix A. All rainfall events with 0.0254 *cm* rainfall depth were ignored from the data collected because 0.0254 *cm* rainfall depth corresponds to one rain gauge tip and this could occur due to moisture or wind conditions. Also, no hydrology data are available for select winter periods (late Dec 2009 through early Mar 2010; late Dec 2010 until early Feb 2011) when accumulation of snow and/or presence of ice cover at the weir rendered flow measurements impossible.

3.1 Characterization of Monitored Storm Events

Table 5 shows the rainfall depth-duration frequency distribution of the 188 rainfall events recorded at the MD 175 infiltration basin site. Also included in Table 5 is the historical rainfall distribution for Maryland (Kreeb 2003) for comparison. The two rainfall distributions were compared using the hypothesis test for single proportion (McCuen 2005). The equality of the proportions of rainfall events observed at the study site and that expected for Maryland for each depth-duration category were verified at a 5% level of significance ($\alpha = 0.05$).

Table 5. Rainfall distribution for the MD 175 infiltration basin site and historical data for Maryland (Kreeb 2003). 'MD175 Sum' represents the column or row total for each depth-duration category.

	Total Rainfall Depth (*cm*)						
Rainfall Duration	**0.0254 - 0.254**	**0.255-0.635**	**0. 636-1.27**	**1.28-2.54**	**> 2.54**	**MD 175 Sum**	**Historical data**
0-2 hr	0.0479	0.0745	0.0266	0.0160	0.0053	**0.1702**	**0.3289**
2-3 hr	0.0479	0.0266	0.0160	0.0160	0.0000	**0.1064**	**0.0756**
3-4 hr	0.0266	0.0372	0.0532	0.0053	0.0160	**0.1383**	**0.0627**
4-6 hr	0.0319	0.0319	0.0798	0.0160	0.0000	**0.1596**	**0.1233**
7-12 hr	0.0266	0.0585	0.0638	0.0532	0.0213	**0.2234**	**0.1818**
13-24 hr	0.0000	0.0106	0.0426	0.0585	0.0319	**0.1436**	**0.1617**
24< hr	0.0000	0.0000	0.0053	0.0106	0.0426	**0.0585**	**0.0659**
MD 175 Sum	**0.1809**	**0.2394**	**0.2872**	**0.1755**	**0.1170**	**1.000**	**1.000**
Historical Data	**0.3287**	**0.1461**	**0.2130**	**0.1747**	**0.1374**	**1.000**	

The major differences in the two distributions were for the low rainfall depth (0.0254 – 0.254 and 0.255 – 0.635 *cm*) and duration categories. These categories were under-represented at the MD175 site and were statistically different from the MD distribution. As will be discussed later, all rainfall events of depth (< 0.255 *cm*) and some events of depth (0.255 – 0.635 *cm*) did not generate runoff to the site and were ignored for all volumetric analyses. The effect of these storms on the performance of the infiltration basin can thus be considered insignificant. The rainfall proportions were similar for rainfall depths (0. 636 – 1.27 *cm*) and larger (1.28 – 2.54 and >2.54 *cm*) for most storm depth-duration categories (α = 0.05). These categories represent about 80% of the storm events that produced runoff to the infiltration basin. Therefore, the overall rainfall distribution at the study site was in good agreement with the historical data.

3.2 Results and Discussion

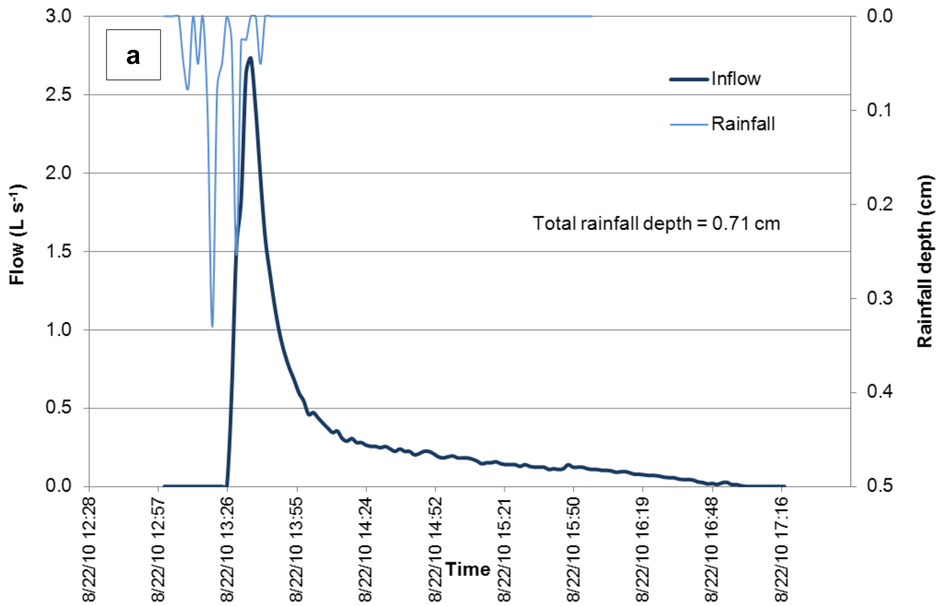
Of the total 188 monitored rainfall events, 54 events (mostly < 0.255 *cm*) did not produce any inflow to the site. These events were excluded from all hydrologic performance analyses. After eliminating events which did not produce any inflow to the site and then combining events when flows overlapped, the sample size of rainfall events was reduced from 188 to 120 events. The hydrologic performance metrics were computed based on these 120 events.

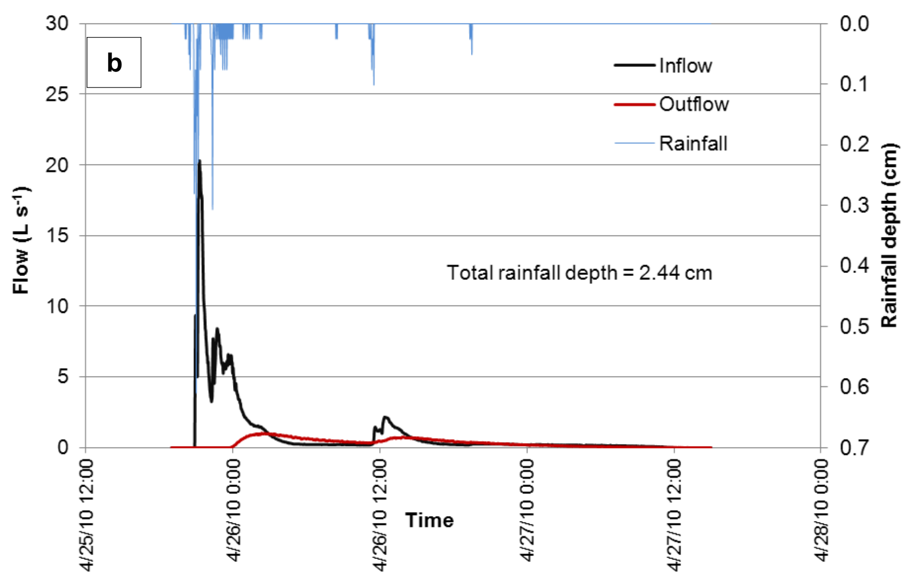
3.2.1 Hydrographs

Figure 8 shows sample inflow and outflow hydrographs recorded during rainfall events of different sizes and seasons. The inflow represents the rate of runoff flow from the drainage area to the infiltration basin based on the temporal variations in the rainfall intensity during that event. The outflow represents the dynamic response of the infiltration basin to the runoff inflow.

Figure 8a is hydrograph recorded in summer. During this event, the infiltration basin retained the entire inflow runoff and no discharge was observed (100 % volume reduction). These observations were common to several small (25 events of <0.636 *cm* rainfall depth) during all seasons and some moderate rainfall events (25 events of 0.636 – 1.27 *cm* rainfall depth).

Figure 8b is a hydrograph recorded during a moderate rainfall event (rainfall depth = 2.44 *cm*) in spring 2010. The reduction in peak flow, delayed outflow, reduced volume leaving the system (67% volume reduction), and longer outflow recession limb can be seen in the sample hydrograph presented in Figure 8b. For similar rainfall events during which outflow occurred, the infiltration basin was capable of delaying the discharge from the basin, ranging from one hour up to more than one day after the onset of inflow. The peak flow was reduced and the water was discharged at lower flow rates spread over several hours.





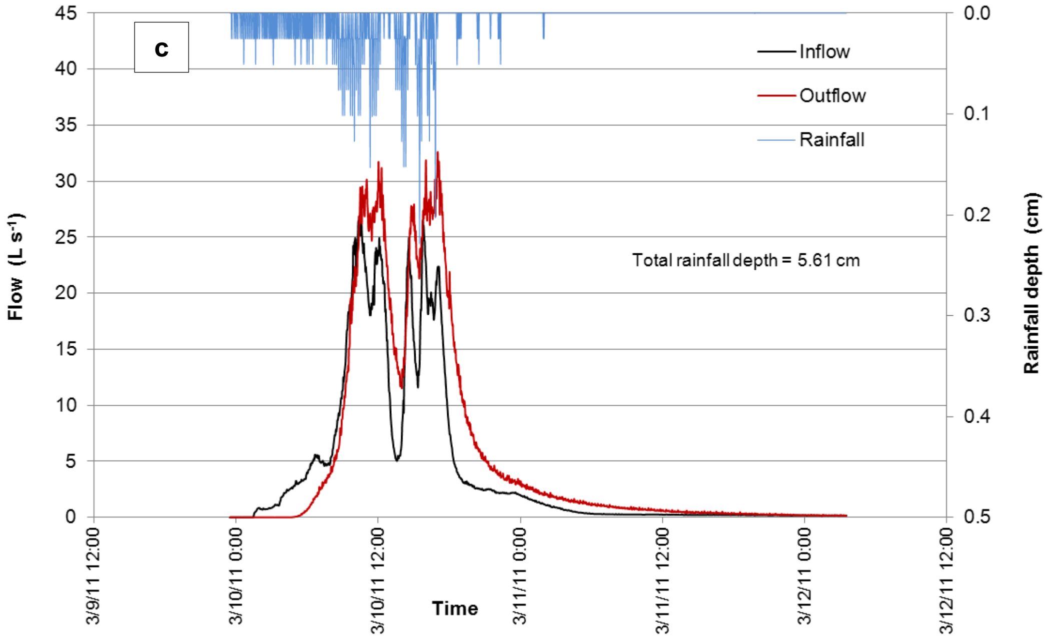


Figure 8. Hydrographs recorded during rainfall events on **a.** Aug 22, 2010 (no outflow) **b.** April 26, 2010 **c.** March 9, 2011 at the MD175 infiltration basin site.

The hydrograph in Figure 8c, recorded during a large rainfall event in spring 2011, shows no runoff volume reduction and no net peak flow attenuation. In fact, discharge volume in excess of the inflow volume was noted during this event. Similar observations were especially made during large and extreme rainfall events and extended wet periods at the site. The additional volume of water was possibly contributed by direct flow from the banks of the infiltration basin. Also direct input of rainfall to the infiltration basin could be significant during very large rainfall events.

3.2.2 Peak Flows and Peak Reduction Ratio

Since high runoff flow rates have implications in erosion and sediment transport, reduction of peak flows achieved through the infiltration basin was assessed. The peak inflows ranged between 1.9 and 272 L s^{-1} (median = 7 L s^{-1}). For the rainfall events producing outflow from the infiltration basin, the peak discharges ranged between 0.10 and 223 L s^{-1} (median = 4.8 L s^{-1}).

The probability plot for peak flows recorded during the entire monitoring duration is shown in Figure 9. The distribution of peak flows clearly depicts the attenuation of peak flows facilitated by the infiltration basin. While the median inflow peak flows was 7 L s^{-1}, the outflow peak flow was 0 L s^{-1} (no discharge).

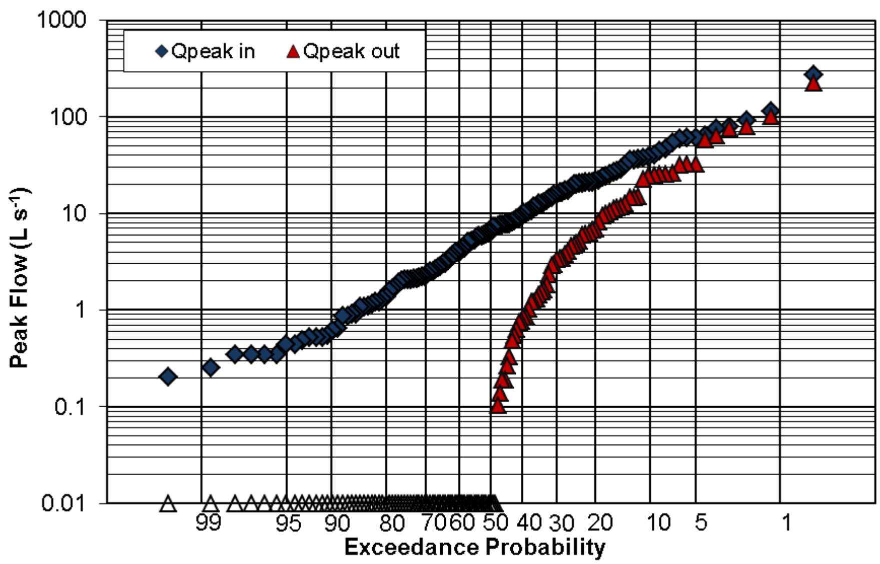


Figure 9. Probability plot for peak flows recorded at the MD175 infiltration basin site for the entire monitoring duration. Hollow points represent rainfall events with no discharge (complete capture of inflow).

For each rainfall event, the maximum inflow and outflow rates were compared using the peak flow ratio, R_{peak}, computed as:

$$R_{peak} = \frac{Q_{peak-out}}{Q_{peak-in}} \quad (7)$$

where, $Q_{peak-in}$ and $Q_{peak-out}$ are the measured peak stormwater runoff flow rates at the inlet and outlet, respectively, during the rainfall event. For the 53 events that produced outflow, the R_{peak} ranged between 0.01 and 1.2; the mean R_{peak} was 0.48 and the median was 0.44. Peak flow reductions were observed during all rainfall events of rainfall depth < 1.27 *cm* and most moderate rainfall events (rainfall depth < 2.54 *cm*). Negligible or no peak reduction ($R_{peak} \geq 1$) was characteristic of large and extreme events (rainfall depth > 4.57 *cm*).

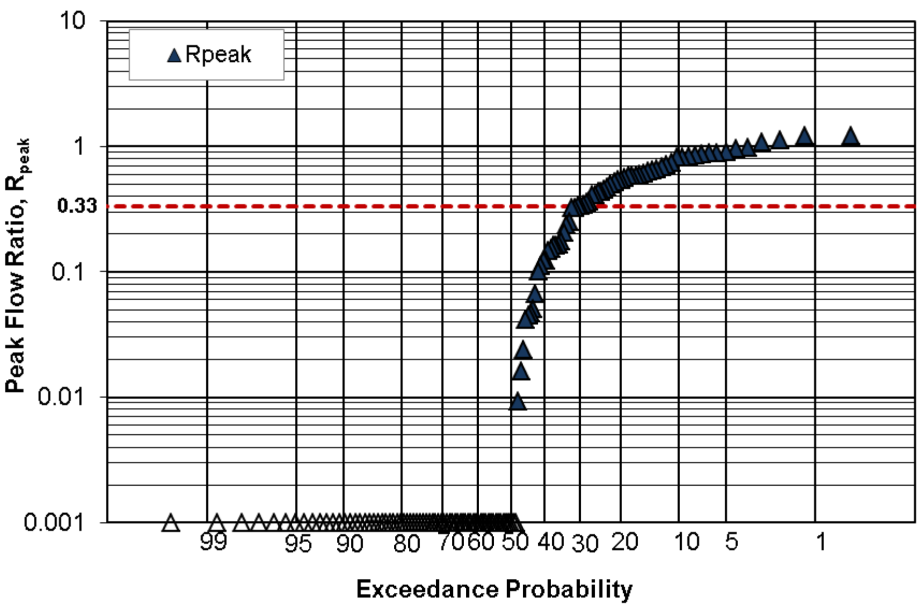


Figure 10. Probability plot for peak flow ratios (R_{peak}) for 120 rainfall events recorded at the MD175 infiltration basin site. Hollow points represent rainfall events with no discharge (complete capture of inflow).

The probability plot for R_{peak} for all 120 rainfall events is shown in Figure 10. The infiltration basin is expected to reduce the outflow peak ($R_{peak} < 1$) 96% of the time. A target peak ratio of 0.33 was used, which is simply the ratio of rational method coefficient (c) for undeveloped land ($c = 0.3$) and impervious area ($c = 0.9$) (Davis 2008). The R_{peak} criterion of 0.33 is expected to be met 69% of the time at the infiltration basin site.

3.2.3 Volumetric Performance

3.2.3.1 Runoff Volume Reductions

Of the 120 monitored rainfall events, outflow was produced during 53 events only. The infiltration basin assimilated the entire inflow volume and did not produce any outflow (100% volume reduction) for the remaining 67 events. For the 53 events during which outflow occurred, the outflow volumes were lower than the inflow volumes for 40 events. The reduction in volume ranged between 4 and 82% for these events; the median reduction in runoff volume was 28%.

Outflow volumes exceeding the inflow volumes (2 to 39%) were recorded during 13 rainfall events, four of which were large events (rainfall depth > 3.94 *cm*), two were extreme events (Tropical Storm Lee and Hurricane Irene), and the remaining occurred in winter or followed extended wet days (rainfall depth 1.07 – 2.08 *cm*). The source of additional volume of water was attributed to the direct flow from the banks of the infiltration basin and direct precipitation input, that can be significant during high rainfall volumes and extended wet periods.

The contribution of direct precipitation input was estimated for the range of rainfall depths recorded at the infiltration basin site. Although the pre-event storage volume varied prior to each event, the direct contribution of rainfall on to the surface of the infiltration basin was estimated assuming the infiltration was half-full, as a conservative estimate. The estimated contribution of direct rainfall input varied from 5 m^3 (rainfall depth = 0.76 *cm*) up to 47 m^3 (rainfall depth = 7.29 *cm*). For the 13 events producing higher outflow volumes (rainfall depths 1.6 to 22 *cm*), the direct precipitation accounted for 13 to 100% of the observed excess outflow volume. The remaining unaccounted excess volume must be contributed by direct bank flow from area surrounding the infiltration basin.

Statistically, the discharge volumes observed for the 53 events were significantly lower than the inflow volume (α = 0.01). The volume decreases observed for all 120 events were also significant at α = 0.01, suggesting that the infiltration basin is effective in reducing runoff flow volumes.

The overall volumetric performance of the infiltration basin is shown in Figure 11. The data are differentiated with different colors and symbols based on seasons. A 1:1 line is also plotted in the figure. The plot shows that the small runoff volumes were completely captured within the basin. In Figure 11, flow volumes from eight large storm events are off the chart. Of these eight events, discharge volumes exceeding the inflow volumes were recorded during four events.

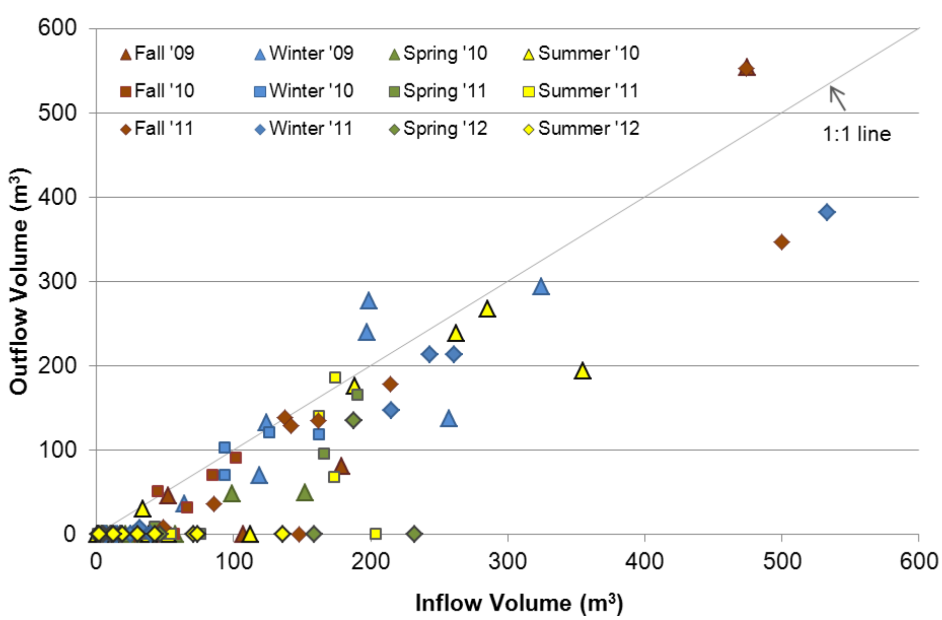


Figure 11. Inflow-outflow characteristics for 112 rainfall events recorded at the MD175 infiltration basin site from August 2009 to August 2012. (Eight large storm events were excluded to clearly show the distribution of the other data points).

In Figure 11, most of the data points lie below the 1:1 line suggesting that reduction in runoff volume was achieved for those events. The percent reductions, however, varied for different events and seasons. For the same inflow runoff volume, the volume reduction achieved in spring and summer was higher than that in late fall or winter. For instance, while 27% volume reduction was observed during a winter storm event (inflow volume = 163 m^3; rainfall depth = 1.96 *cm*), 100% volume capture occurred for a similar rainfall event (inflow volume = 159 m^3; rainfall depth = 2.64 *cm*) in summer. This can be attributed to the larger volume available for storing the incoming runoff during the warmer months compared to other months. Hence, greater volume reductions were observed in summer compared to other seasons. As noted earlier, discharge volumes greater than that of inflow were recorded when large events and extended wet periods occurred, represented by the points above the 1:1 line.

A probability plot for the inflow and outflow runoff volumes is shown in Figure 12. The probability plot clearly shows that the discharge volume was reduced by the infiltration basin, except for the largest flow volumes. The median discharge volume is zero, which corresponds to a volume reduction of 100% at the infiltration basin site.

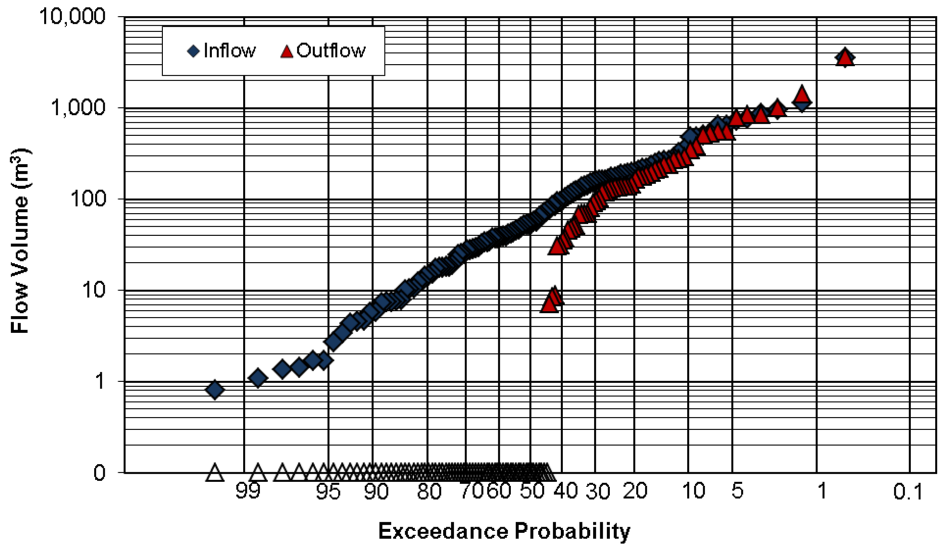


Figure 12. Probability plot for runoff flow volumes recorded during 120 rainfall events at the MD175 infiltration basin site from August 2009 to August 2012. Hollow points represent rainfall events with no discharge (complete capture of inflow).

The total inflow and outflow volumes recorded for 120 storm events were 20,123 and 16,425 m^3, respectively. Normalizing the volumes over the entire drainage area, this corresponds to total runoff depth of 27 inches input and 22 inches discharged from the infiltration basin. The cumulative runoff volume reduction was thus 18% for the three-year period.

3.2.3.2 Volume Reduction-Infiltration Basin Design Relationship

The volumetric performance was related to the existing design of the infiltration basin. The design storage capacity of the infiltration basin (S_T) is 650 m^3, as indicated in the original construction plans. The storage capacity of the infiltration basin estimated using the water level data is in agreement with this value as well. The ratio of measured inflow runoff volume at the site (V_{IN}) to the total design (S_T) was computed for each monitored storm event and their exceedence probabilities computed. The probability plot for this volume ratio ($\frac{V_{IN}}{S_T}$) is shown in Figure 13. The data are differentiated for storm events with outflow and without measurable outflow.

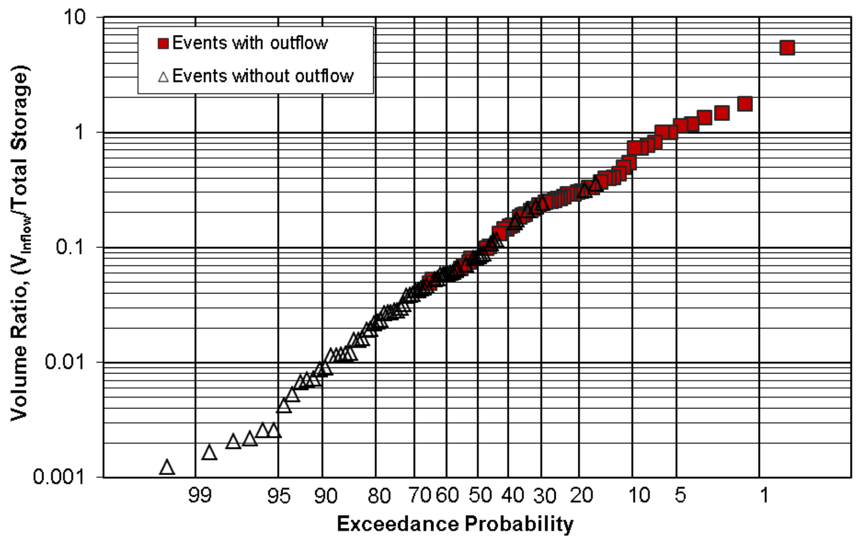


Figure 13. Probability plot for ratio of runoff inflow volume to design storage capacity of the infiltration basin for all rainfall events at the MD175 infiltration basin site. Data points are differentiated for rainfall events with and without outflow.

The probability plot shows that the rainfall events produced runoff volumes greater than the storage capacity of the infiltration basin about 7% of the time. As expected, discharge was produced for these events. Most runoff volumes lesser than 10% of the storage capacity were fully captured within the basin.

Variable performances were observed for volume ratios ranging between 0.25 and 0.09. As will be discussed later, the available storage in the infiltration basin varied during a year, influenced by rainfall characteristics and meteorological parameters. The available storage is likely to be higher in summer due to longer dry periods and higher water losses due to evapotranspiration when compared to cooler periods. This explains the response of the infiltration basin to differing runoff volume inputs during the year. This also explains the reason for a small runoff volume input to produce discharge from the infiltration basin on those occasions when the infiltration basin is already at its near-full capacity prior to the event, irrespective of the season.

3.2.3.3 Rainfall Size-Volume Reduction Relationship

The recorded hydrographs and flow volumes showed the varying volumetric performance of the infiltration basin based on the size of the storm event. Smaller runoff volumes were completely captured and no discharge occurred. Moderate to large rainfall events exhibited partial runoff capture resulting in some volume reduction. The largest events did not show net volume reductions. This relationship between rainfall and volumetric performance of the infiltration basin was examined in detail (Table 6). In Table 6, the number of rainfall events monitored in each rainfall depth-duration category is given. The number of monitored storms that were completely captured is indicated within brackets for each category. The cells have been shaded to show three categories: all storms completely captured, storm categories with a few events completely captured and with measurable discharge; storm categories with measurable discharge observed for all events.

Table 6. The relationship between rainfall depth-duration and volume reduction for the 120 rainfall events recorded at the MD 175 infiltration basin site. In each cell, total number of storms monitored in that category is given. The values within brackets represent the number of events completely captured in that category. Boxes are shaded as: storm categories completely captured (grey); storm categories with a few events completely captured and with outflow (white); storm categories with discharge observed for all events (shaded with dark outline).

	Total Rainfall Depth (*cm*)					
Rainfall Duration	**0.0254 -0.254**	**0.255-0.635**	**0. 636-1.27**	**1.28-2.54**	**> 2.54**	**Sum**
0-2 hr	0 (0)	4 (4)	3 (3)	3 (2)	1 (1)	**11 (10)**
2-3 hr	2 (2)	2 (2)	2 (1)	3 (3)	0 (0)	**9 (8)**
3-4 hr	0 (0)	4 (3)	6 (5)	2 (2)	3 (1)	**14 (10)**
4-6 hr	1 (1)	2 (2)	7 (4)	2 (1)	1 (1)	**13 (9)**
7-12 hr	1 (1)	7 (7)	10 (7)	9 (1)	5 (0)	**31 (15)**
13-24 hr	0 (0)	3 (3)	7 (4)	10 (1)	5 (0)	**25 (8)**
24< hr	0 (0)	0 (0)	1 (1)	3 (2)	11 (2)	**15 (5)**
Sum	**4 (4)**	**22 (21)**	**36 (25)**	**32 (12)**	**26 (5)**	**120 (67)**

Based on Table 6, runoff produced by all smaller rainfall events of rainfall depth < 0.635 *cm* of any duration can be expected to be completely captured (100 % volume reduction) in the infiltration basin. In Table 6, one rainfall event in the (0.255 – 0.635 *cm*) range produced outflow. This event followed three rainfall events (total rainfall depth = 3.07 *cm;* antecedent dry period = 0.67 days) and runoff from all three events were fully captured by the infiltration basin. As supported by the water level data, the infiltration basin was at its near-full capacity after these three rainfall events. Hence, outflow was produced from the additional runoff input from the subsequent smaller event (rainfall depth = 0.609 *cm* only).

Based on the rainfall data for the entire monitoring duration, events of rainfall depth (0.636 – 2.54 *cm*) occur more frequently (68 events out of 120 total storm events). These rainfall events are expected to produce discharge on most occasions. However varying, reduction in runoff volumes (even up to 100%) can be expected to occur for these storm event categories. The large rainfall durations (rainfall depth > 2.54 *cm*), which comprise 22% of rainfall events that occurred (26 events out of 120 total storm events), are likely to produce discharge for almost all events. This is supported by the previous volume reduction discussion.

The relationship between rainfall and hydrologic response of the infiltration basin was further investigated using a probability plot for the fraction of runoff volume produced per unit rainfall volume over the drainage area, as shown in Figure 14. The data are differentiated for events with outflow and without measurable outflow. The runoff-rainfall volume ratio ranged between 0.002 and 0.895, the median being 0.155. As expected, the maximum volume ratio was lower than one due to the initial abstraction of runoff from the drainage area during a storm event.

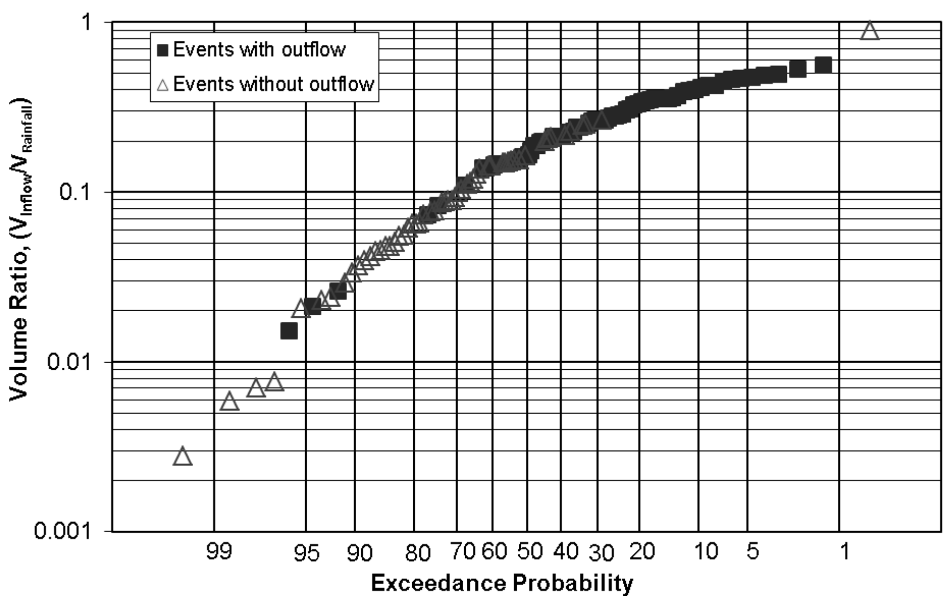


Figure 14. Probability plot for ratio of runoff flow volume to rainfall volume for 120 rainfall events recorded at the MD175 infiltration basin site. Hollow points represent rainfall events with no discharge (complete capture of inflow).

The effect of seasons was observable in the ratios; ratios lower than the median value were characteristic of several small (rainfall depths < 0.636 *cm*) and moderate rainfall events (rainfall depth 0.636 – 1.27 *cm*) in late spring and summer periods. During these warmer periods, relatively higher proportion of runoff was abstracted compared to cooler months. This was evident in the total runoff volume to the site for the same rainfall depth depending on the season. A large fraction of these rainfall events did not produce discharge from the infiltration basin. Figure 14 shows that a volume ratio of 0.27 and greater is likely to occur around 30% of the time and produce discharge from the infiltration basin. These observations are in agreement with the earlier results from analysis of rainfall and volume reduction characteristics.

The results suggest that the characteristics of the drainage area (percent pervious vis-à-vis impervious) and connectivity of the drainage area to the SCM facility can influence its hydrologic behavior. In the current study, the drainage area consisted of disconnected impervious surface (highway) and grassy area directly connected to the infiltration basin. Runoff from the entire drainage area concentrated into the grassy area and then flowed into the infiltration basin. The initial abstraction volume and the total runoff generated thus depended on the soil moisture conditions of the grassy area, which in turn influenced the hydrologic behavior of the infiltration basin. Different results may be produced for different drainage area characteristics. For instance, if the infiltration basin were to receive runoff only from impervious area, less variation and effect thereof of the inflow volumes would occur.

3.2.4 Water Balance for the Infiltration Basin

The hydrologic performance of the infiltration basin can be explained by its water balance. Figure 15 depicts the components of the hydrological inputs and outputs at the infiltration basin system. Water inputs to the infiltration basin are from runoff (weir flow and bank flow) and direct precipitation on the surface of the basin. Outflow occurs depending on the total volume of runoff received and the available storage in the infiltration basin. Water losses from the basin occur via evapotranspiration; evaporation driven by solar radiation and transpiration from vegetation in the infiltration basin, and by infiltration into the soil underneath.

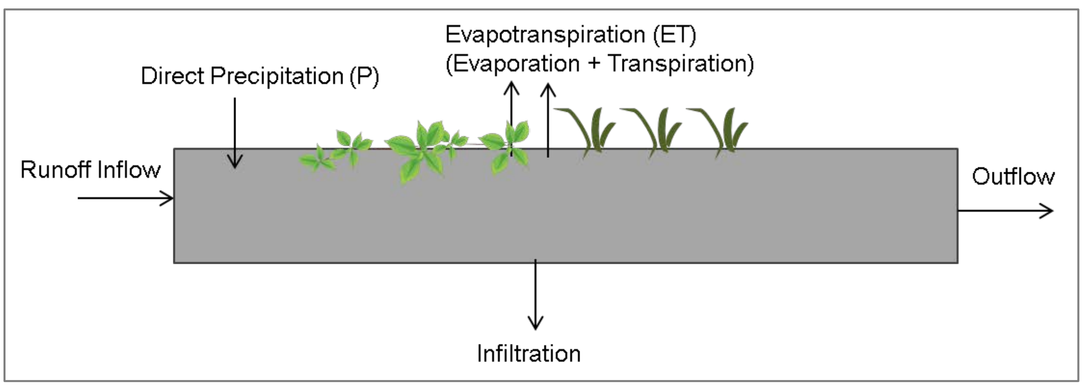


Figure 15. Schematic of water balance in the infiltration basin.

Accounting for all the water flows and losses in the infiltration basin, the water balance for the infiltration basin system (Figure 15) at any time *t* is:

$$\text{Change in storage}_{(t)} = \text{Inflow}_{(t)} + (PA)_{(t)} - \text{Outflow}_{(t)} - ET_{(t)} - \text{Infiltration}_{(t)} \qquad (8)$$

where, A is the surface area of the infiltration basin.

The varying hydrologic behavior of the infiltration basin during different rainfall events can be explained by the combined influence of factors such as rainfall intensity and duration, antecedent dry period, and season, on the water balance of the infiltration basin. The antecedent dry period and season influenced the volume of runoff to the site. For instance, a few rainfall events, especially in summer (June and July 2010, 2011, and 2012), produced smaller or no runoff flows to the facility owing to long dry periods between the events. Depending on the pre-event storage volume and the input runoff volume, the infiltration basin was capable of reducing the discharge volume. While the entire runoff volume from most small rainfall events (rainfall depth < 0.635 *cm*) was thus captured within the infiltration basin, varying volume reductions were observed during other moderate and large rainfall events.

The volume of water detained in the system was also influenced by the effects of evapotranspiration and infiltration from the system. Loss of water by evapotranspiration and infiltration can be important in summer (Lott and Hunt 2001; Braga *et al.* 2007). The existing vegetation also have an effect on the evapotranspiration from the basin (Lott and Hunt 2001). Braga *et al.* (2007) observed higher infiltration rates during warmer periods compared to other seasons in an infiltration trench which they attributed to temperature effects on the viscosity of water.

The water level in the infiltration basin was lowered significantly in summer (average water level in the basin < 0.304 *m* only) owing to high air temperatures and scant rainfall. Therefore, the available storage in the infiltration basin was higher, resulting in higher volume reductions during warmer periods. In colder periods, the presence of ice cover changed the hydraulics of the infiltration basin by reducing the available storage. Water losses due to evapotranspiration were also lower during cold periods. These changes caused the infiltration basin to act as a flow-conveyance facility and offer negligible or no reduction of runoff flow volumes.

3.2.4.1 Water Levels and Water Losses at the Infiltration Basin

The water level in the infiltration basin was continuously monitored from April 2010 through August 2012. Data are unavailable for a brief period in June 2010 and June to July 2011 when the water level in the infiltration basin dropped below the probe until the probe was re-installed at a different location within the basin. Also, measurements made during winter periods when the surface of the infiltration basin was frozen were not utilized towards any calculations.

Based on the two-year continuous measurements, the water level in the infiltration basin ranged from ~ 0.18 *m* (during dry-weather) up to 1.2 *m* (during storm event). Figure 16 shows the water level recorded at the infiltration basin for Dec 2011. During a storm event, the water level increased due to runoff input and then decreased as outflow from the infiltration basin occurred. After the storm passed and discharge ceased, the water level continued to gradually decrease due to water losses by ET and infiltration from the infiltration basin.

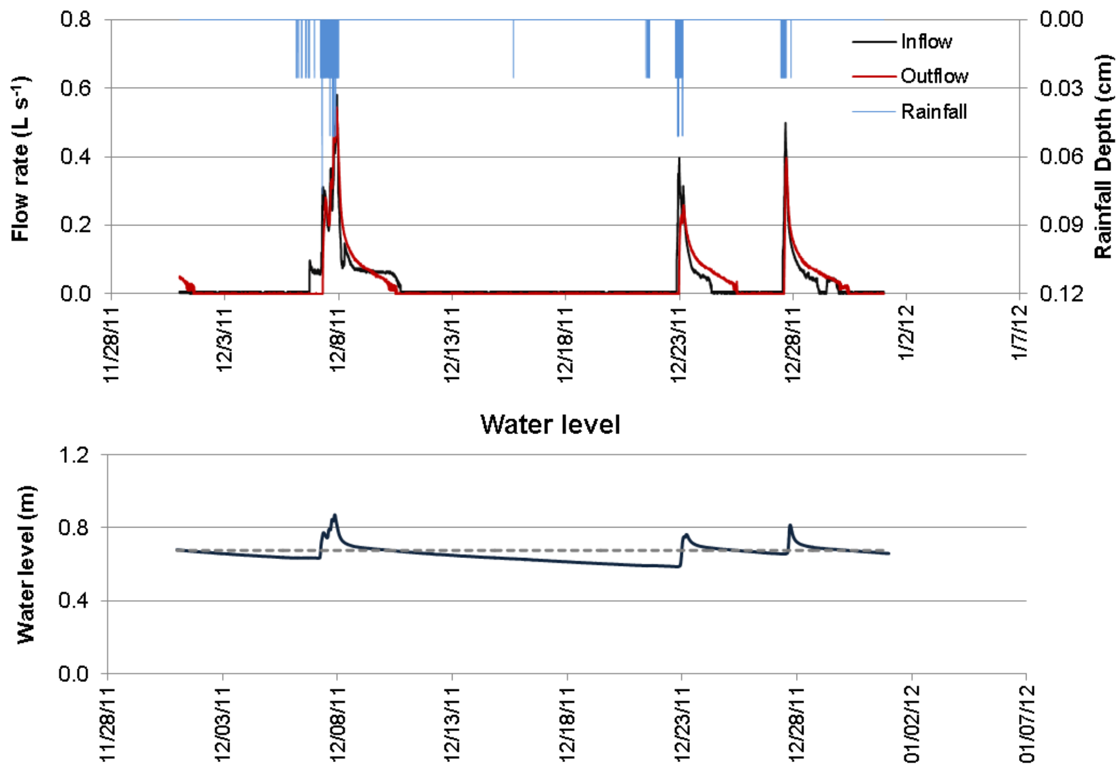


Figure 16. Water level in the infiltration basin in Dec 2011. Dashed line represents the invert of the outlet weir. Top figure shows the rainfall depth, inflow and outflow hydrographs for the month.

The water level data was used to estimate the water loss from the infiltration basin on each day. The daily water loss was calculated as the decrease in water level in 24 hours for a dry day. The water loss was not computed on a wet day if inflow and outflow occurred during a significant part of the day. The water loss was computed on a wet day only if the event occurred very early (midnight-5 am) or very late (after 9 pm) in the day in some cases.

Figure 17 shows the water loss for April 2012 computed from the water level data collected. The estimated ET from Blaney-Criddle formula is also plotted in Figure 17. The water loss on a wet day has been differentiated from the dry days (darker square markers) in the plot. Figure 17 shows that the calculated daily water losses from the infiltration basin matched well with the estimated ET for the dry days for April 2012.

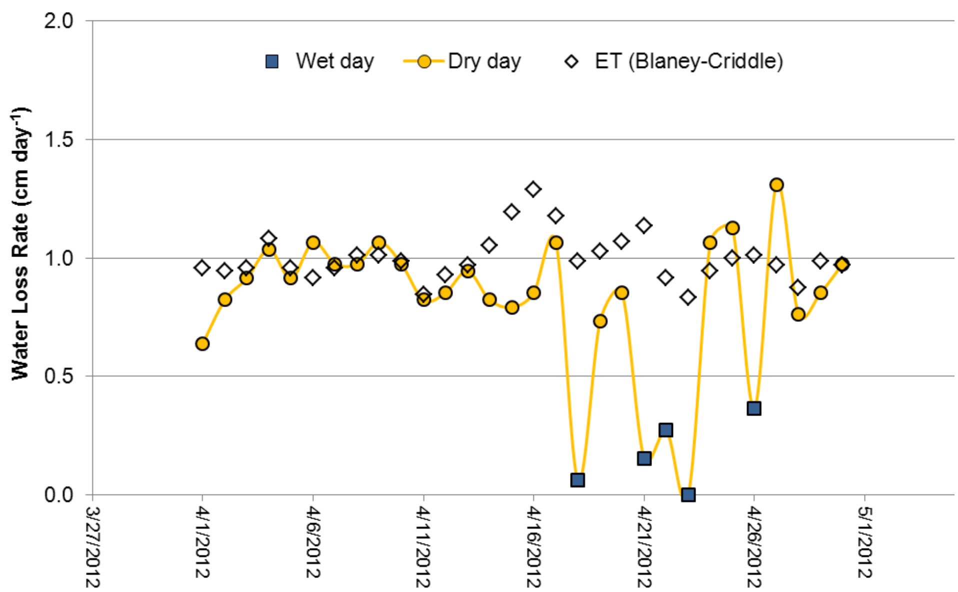


Figure 17. Measured and calculated water loss at the infiltration basin in April 2012. Estimated ET (based on Blaney-Criddle equation) has also been plotted.

The mean daily water loss rate, and monthly water loss and evapotranspiration totals for the dry days from April 2010 through August 2012 are summarized in Table 7. The water loss rate was highest in summer and decreased in the following months. This is expected since evaporation, infiltration, and transpiration rates increase during warmer periods compared to other seasons (Lott and Hunt 2001; Braga *et al.* 2007).

Table 7. Summary of water loss and evapotranspiration estimates at the infiltration basin site from April 2010 through August 2012.

Column (1)	*Column (2)*	*Column (3)*	*Column (4)*	*Column (5)*	*Col (5) /Col (4)*
Month of year	**Number of dry days**	**Mean dry day water loss rate (*cm day*$^{-1}$)**	**Dry day water loss total (*cm*)**	**Dry day ET* total (*cm*)**	$ET/_{Water\ loss}$
Apr-10	25	1.143	28.45 ± 1.293	26.16	0.92
May-10	26	1.268	32.98 ± 1.319	31.96	0.97
Jun-10	24	n/a	n/a	n/a	n/a
Jul-10	20	1.457	30.82 ± 1.157	31.56	1.02
Aug-10	19	1.425	27.07 ± 1.127	25.69	0.95
Sept-10	24	1.007	25.18 ± 1.267	27.35	1.09
Oct-10	20	1.151	23.01 ± 1.157	17.42	0.76
Nov-10	24	0.758	18.20 ± 1.267	14.80	0.81
Dec-10	26	0.752	16.55 ± 1.319	12.80	0.77
Feb-11	17	0.697	30.12 ± 1.066	26.43	0.88
Mar-11	22	1.320	26.40 ± 1.213	15.26	0.58
Apr-11	17	1.129	22.59 ± 1.066	20.92	0.93
May-11	24	1.320	34.32 ± 1.267	32.55	0.95
June+ 2011	22	1.221	24.41 ± 1.213	12.78	0.52
July+ 2011	20	1.273	28.01 ± 1.157	14.87	0.53
Aug-11	19	1.519	28.86 ± 1.127	25.18	0.87
Sept-11	18	1.048	18.87 ± 1.097	19.76	1.05
Oct-11	19	0.988	18.78 ± 1.127	16.35	0.87
Nov-11	21	0.755	15.85 ± 1.185	14.19	0.90
Dec-11	22	0.752	16.55 ± 1.213	12.80	0.77
Jan-12	24	0.742	17.80 ± 1.267	13.21	0.74
Feb-12	23	0.635	14.60 ± 1.240	14.94	1.02
Mar-12	25	0.914	22.76 ± 1.293	22.15	0.97
Apr-12	26	0.889	23.22 ± 1.319	25.10	1.08
May-12	24	1.126	27.04 ± 1.267	30.18	1.12
Jun-12	25	1.334	33.35 ± 1.293	35.39	1.06
Jul-12	27	1.318	39.81 ± 1.344	43.07	1.08
Aug-12	28	1.223	29.35 ± 1.369	31.86	1.09
TOTAL			**674.9** ±6.497	**617.6**	**0.92**

*ET estimated using Blaney-Criddle equation (Equation 8); n/a: no data; +excluding days on which data was unavailable

Table 7 shows that the estimated ET (using Blaney-Criddle equation) predicted 53 to 97% (although sometimes >100%) of the total water loss from the infiltration basin during the dry periods for the monitoring duration. The total estimated ET accounted for 92% of the total water loss from the infiltration basin for the dry periods considering the entire monitoring duration. Based on the reported accuracy of Blaney-Criddle method in literature, the error in predicted ET was assumed as ±20% in the current study. Using this error on the cumulative ET totals, the estimated ET still accounts for at least 73% of the cumulative water loss from the infiltration basin. Hence, it appears that evaporation is the major component of water loss from the infiltration basin and infiltration appears to be negligible.

The infiltration rate of the native soil at the infiltration basin site, as reported in the construction plans, is 1.32 $cm\ hr^{-1}$. One foot of sand media was placed in the basin to infiltrate water into the underlying native soil. Assuming that the sand media has a high hydraulic conductivity and offers no resistance to flow through the media, the infiltration rate in the basin can be expected to be the same as that of the native soil (1.32 $cm\ hr^{-1}$). Compared to the measured mean water loss of 1.1 $cm\ day^{-1}$ over the research period, it can be deduced that the present infiltration rate at the infiltration basin is much lower than the expected original infiltration rate. Hence, it can be concluded that the infiltration is negligible at the infiltration basin, as predicted by the ET and water loss computations.

3.2.5 Flow Durations

The cumulative duration of runoff flows at the study site are illustrated using a flow duration curve. The flow durations show the magnitude of all flows, not just the peak flows, at the infiltration basin site for the entire monitoring duration.

Figure 18 shows the inflow and outflow durations at the infiltration basin for the three-year monitoring duration. Although the two curves show minimal differences overall, the infiltration basin reduced the flow magnitudes as wells as the durations. While the peak inflow was 809 *mm day*$^{-1}$, the peak outflow was 662 *mm day*$^{-1}$. The total discharge duration about 2.9 days shorter than the total inflow runoff duration, considering the entire three-year period.

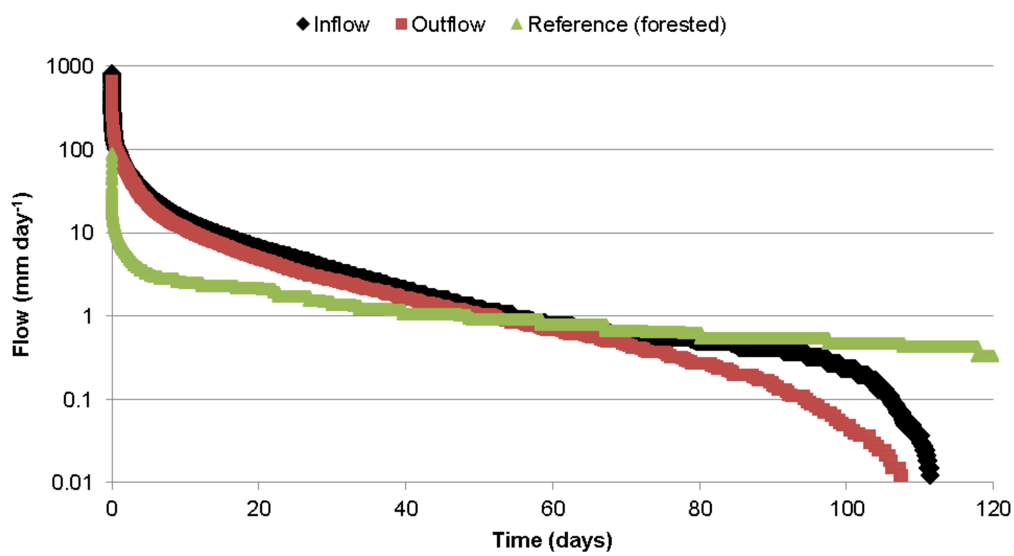


Figure 18. Flow duration curves at the MD 175 infiltration basin site for three-year monitoring duration. The plots also show the flow durations at the Pond Branch forested stream (reference site) only for the duration of flows at the MD 175 site.

The flow durations at Pond Branch, a 100% forested watershed located in Baltimore County, Maryland, was used as the reference in Figure 18. When compared to the forested site, the discharge flow magnitudes at the infiltration basin were higher throughout the three-year period. The discharge peak flow was much higher at the study site (122 *mm day*$^{-1}$ at Pond Branch compared to 662 *mm day*$^{-1}$ discharge at infiltration basin).

Shields *et al.* (2008) designated low- to moderate-flow conditions as < 1 *mm* day^{-1} in their study on nitrogen export from urban and rural catchments and Pond Branch was used as the reference watershed in their study. For the total flow duration of 112 days at the infiltration basin, the discharge magnitudes were at the low-flow values for 61 days. For comparison, the flows at Pond Branch were above the low-flow values for about 49 days during the same period.

3.2.5.1 Seasonal Flow Durations

The flow durations exhibited strong differences when examined on a seasonal basis. Figure 19 illustrates the flow durations observed at the study site along with the reference flow durations for the four seasons. The flow data from the three-year research period were combined on a seasonal basis to derive the flow durations in Figure 19.

First, the inflow and outflow durations at the study site were compared (Figure 19). The magnitudes and durations of flows at the infiltration basin exhibited differences during all seasons. Reduction of peak flows and overall magnitude of flows occurred during all seasons. However, differences in flow magnitudes observed during fall and winter were moderate when compared to spring. Figure 19c shows that during winter, the inflow and outflow magnitudes were similar for most of the period until the flow magnitude fell below 0.6 *mm* day^{-1}. This observation was common to the wet periods in both fall and winter. During spring and summer, there were fewer storm events and long intermittent dry periods. Thus the infiltration basin was able to manage the runoff flows by assimilating most of the inflow, resulting in lower outflow magnitudes and much shorter flow duration (Figure 19d).

Occurrence of large and extreme storm events had an impact on the flow duration at the site. Large rainfall events (rainfall depth ~ 5 *cm*) (Oct 2009, Sept 2010, March and Dec 2011 and Feb, June, and July 2012) and extreme events such as Hurricane Irene (Aug 2011) and Tropical Storm Lee (Sept 2011) were recorded during the monitoring period. Effects of these events are visible in Figure 19a and Figure 19b, which show high inflow and outflow magnitudes and long total flow durations. For instance, no discharge was observed during June and July 2011. The flows observed in summer 2011 were flows generated mostly from Hurricane Irene that occurred in Aug 2011. As discussed in the volumetric performance section, the infiltration basin provided only marginal control of high runoff flows during the largest storm events. Therefore, the largest flows were reduced only to a smaller extent. The infiltration basin, however, reduced the lower-magnitude flows and their durations.

Figure 19a and Figure 19b also show that the duration of outflow was higher than the duration of runoff to the site. Using the criterion of < 1 $mm\ day^{-1}$ for low- to moderate flow conditions (Shields *et al.* 2008), outflow magnitudes lower than 1 $mm\ day^{-1}$ at the infiltration basin site can be considered as low flows in Figure 19. Long duration of low flows is acceptable from a pre-development hydrology perspective, as suggested by DeBusk *et al.* (2011). DeBusk *et al.* (2011) compared the bioretention outflows with inter-event flows in a stream draining an undeveloped watershed located in North Carolina. The study results indicated that the bioretention outflow rates mimicked the shallow interflow to streams after a storm event, thereby suggesting that the low outflow rates from a bioretention need not be considered as 'runoff'. The same argument can be applied to the infiltration basin where low discharge flows are observed, even though the outflow occurs for extended time periods in comparison to the inflow durations.

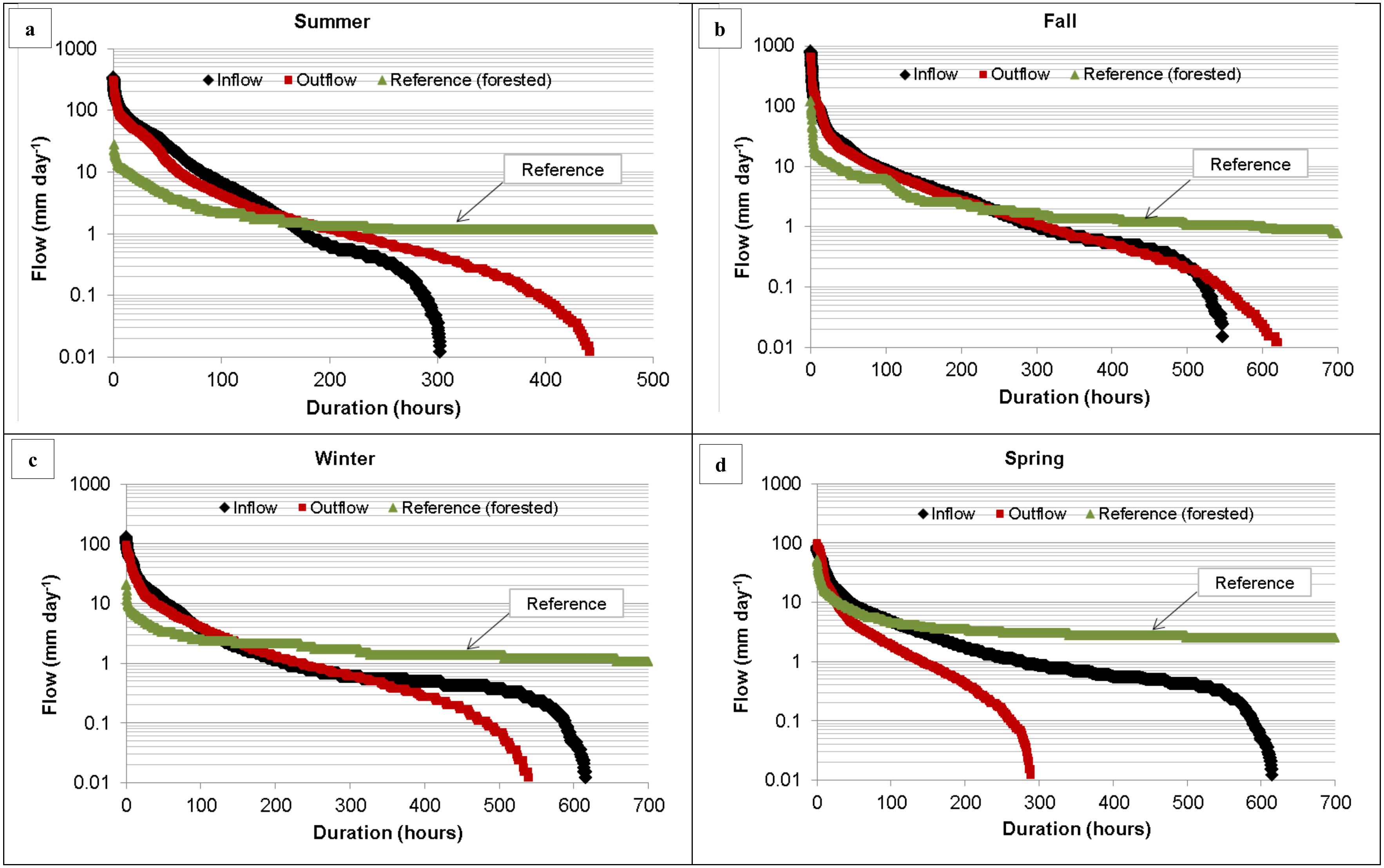


Figure 19. Flow duration curves for **a.** Summer (Jun to Aug) **b.** Fall (Sept to Nov) **c.** Winter (Dec to Feb) and **d.** Spring (Mar to May) at the MD 175 infiltration basin site for 2009 to 2012 period. Flow durations at the Pond Branch forested stream (reference site) are also included.

The infiltration basin outflow durations were compared with Pond Branch flow durations to determine the ability of the infiltration basin to mitigate urban runoff flows to forested (pre-development) conditions. Overall, the infiltration basin peak outflow magnitudes (normalized per drainage area) were much higher than the Pond Branch peak flows during all seasons. Pond Branch flows were at least one order magnitude lower than that of the infiltration basin discharges.

Given the difference in sizes of the drainage areas and absence of baseflow at the study site, the flow duration at Pond Branch was much longer compared to the flow duration at the study site. The forested watershed had an overall effect of dampening flows during storm events and maintained low flows for the most of the period. The streamflow was continuous for about 5914 hours at Pond Branch (PB) compared to 291 hours only for outflow from the infiltration basin in spring, for three years combined. While PB flow magnitudes were below 1 $mm\ day^{-1}$ for 3324 hours, the infiltration basin outflow magnitudes remained lower than 1 $mm\ day^{-1}$ for 149 hours (out of 291 hours total duration) for this period.

Thus, it can be concluded that flow durations in forested streams, although very long, are in low- to moderate- flow condition for majority of the time periods. This is expected for a "natural" hydrologic condition. The infiltration basin was able to attenuate the runoff flows from the highway during storm periods and discharged water at lower rates that extended over a longer period of time. However, the discharge flow magnitudes at the infiltration basin were higher than that of Pond Branch which suggests that the infiltration basin may not be performing well in comparison to a forested site.

3.2.5.2 Flow Durations Based on Rainfall Characteristics

Results from rainfall and volumetric performance data were used to evaluate the flow duration patterns for different rainfall sizes. Smaller rainfall depth events were fully captured in the infiltration basin. In fact, all runoff inflows were detained within the infiltration basin for an entire month in summer (May 2010, June 2010, June 2011, July 2011, April 2012, May 2012, and August 2012). Hence, for smaller runoff flows, the flows are expected to be completely reduced and no discharge would occur.

It was observed that a higher proportion of moderate and all large rainfall events produced discharge from the infiltration basin (Table 6). Peak flow and volume attenuation were observed during most of these events due to some capture of runoff. Hence, smaller discharge magnitudes and shorter discharge durations are expected to be produced for moderate rainfall events.

However, the infiltration basin was unable to manage very high runoff volumes produced during the largest and extreme rainfall events (10 events measuring rainfall depths > 4.8 *cm*). The large flows from these events resulted in high outflow magnitudes and durations longer than the inflow to the site. A research study on performance of grass swales by Stagge *et al.* (2012) also observed that the swales offered almost no protection against very high runoff flows. Therefore, it can be concluded that the infiltration basin cannot provide a significant impact during very large and extreme rainfall events which are, however, relatively rare in occurrence (10 out of 188 storms recorded).

3.3 Hydrologic Performance Summary

The effectiveness of a failed infiltration basin in mitigating stormwater runoff flows and volume from a highway area was evaluated over a three-year monitoring period. The runoff inflows and outflows were monitored during 188 rainfall events to quantify the hydrologic performance of the infiltration basin. Hydrographs and metrics such as peak reduction and total volume reduction, flow durations, and their statistical characterizations were used to evaluate the hydrologic performance. The rainfall depth-duration distribution monitored at the study site followed the expected distribution for Maryland.

Overall, the results indicate that the infiltration basin was capable of attenuating the hydrologic impacts of highway stormwater runoff. The infiltration basin attenuated peak flows, delayed outflow, and reduced the discharge volume during most rainfall events (101 out of 120 events). The observed volume reductions varied during different rainfall sizes and seasons. The smallest storm events were completely captured (100% volume reduction), the moderate events were attenuated to varying degree (4 to 100%), and the larger storm events were controlled to the least extent (-32 to 100%). For the same rainfall depth, the volume reductions achieved during warmer periods were higher than at other times.

The cumulative flow magnitudes and their durations at the infiltration basin were evaluated and compared to a forested site. The infiltration basin attenuated the peak flows from the highway and discharged water at lower flow rates. The duration of flows were reduced due to capture of runoff within the infiltration basin. The infiltration basin was more effective in reducing runoff flow magnitudes and minimizing flow durations for smallest and moderate rainfall events compared to the largest events. On a seasonal basis, the flow magnitudes and durations were attenuated more effectively in summer compared to the wetter periods in other seasons. However, the discharge flow magnitudes were higher compared to the forested site suggesting that the infiltration basin was unable to reduce the urban runoff flows to pre-development forested conditions.

Rainfall size, antecedent dry period, and meteorological factors influenced the hydrologic responses of the infiltration basin. Warmer months were characterized by longer dry periods and significant water loss via evapotranspiration and, to a lesser extent, infiltration. During colder periods, the presence of snow and ice cover modified the hydraulics of the infiltration basin and water losses were low. Hence, the infiltration basin provided the least hydrologic benefits during colder months compared to other periods.

Based on the hydrologic analyses, it can be concluded that the failed infiltration basin effectively controls the runoff flows, as it exists. The existing infiltration basin configuration allows for significant reduction of runoff volumes during most storm events, except the largest and extreme events. The occurrence of extreme events is relatively infrequent and hence management of very high flows during these events need not be considered critical. Therefore, the infiltration basin is hydrologically functional from a stormwater management perspective.

Chapter 4: Water Quality Performance of the Infiltration Basin

The second objective of this research study was to quantify the water quality performance of the transitioning infiltration basin. Since several research studies demonstrated the water quality benefits provided by stormwater infiltration basins, wetlands, and wetponds, this research hypothesized that a failed infiltration basin, naturally transforming into a wetland or wetpond, can provide functions of pollutant removal and enhancement of the quality of runoff.

The performance of the infiltration basin in removing total suspended solids (TSS), nitrate, nitrite, total Kjeldahl nitrogen (TKN), total phosphorus, total copper, total lead, total zinc, and chloride from the highway runoff was evaluated over a three-year period.

In total, 38 storm events were monitored and sampled for water quality. For 27 storm events, the sampling program was designed to collect multiple samples spread over the entire hydrograph. Flow-weighted composite samples were collected during the remaining 11 storm events. Also, 54 dry-weather sampling excursions were performed for the entire monitoring duration. Of the 38 storm events sampled for water quality, only 14 events produced measurable outflows. Runoff inflow to the infiltration basin was completely captured within the basin for the remaining 24 events. The pollutant mass removal efficiencies for these 24 storm events were, hence, 100 %.

The comprehensive data of event mean concentrations (EMCs) and percent pollutant mass removals for each storm event are presented in Table B-1 in the Appendix B. For the dry-weather samples, average concentration in the collected samples, along with the standard deviation are reported in Table B-1. Water quality data for individual storm event are presented in Table B-2 in the Appendix B. The hydrology data (rainfall depth and flow volumes) for the storm events sampled for water quality are included in Table A-1 in the Appendix A. No hydrology and water quality data are available for winter periods (late Dec 2009 through early Mar 2010; late Dec 2010 until early Feb 2011) when flow measurements were impossible due to snow and/or ice cover on the weirs at the study site. Also, grab samples were not collected when the water in the infiltration basin was frozen during colder periods.

4.1 Characterization of Storm Events Monitored for Water Quality

A detailed analysis on the rainfall depth-duration distribution of the 38 storm events sampled for water quality at the infiltration basin site was conducted and is presented in Table 8. The depth-duration frequencies of all 183 storm events recorded at the study site and the historic distribution for Maryland (Kreeb 2003) are also included in Table 8.

Table 8. Rainfall depth-duration distribution of 38 storm events sampled for water quality at the MD 175 infiltration basin site. Distribution of all 183 storm events recorded at the infiltration basin site and historical data for Maryland (Kreeb 2003) are also included.

	Total Rainfall Depth (*cm*)							
Rainfall Duration	**0.0254 - 0.254**	**0.255-0.635**	**0. 636-1.27**	**1.28-2.54**	**> 2.54**	**Sum**	**MD 175**	**Historical Data**
0-2 hr	0.0000	0.0000	0.0000	0.0526	0.0263	**0.0789**	**0.1702**	**0.3289**
2-3 hr	0.0263	0.0000	0.0000	0.0263	0.0000	**0.0526**	**0.1064**	**0.0756**
3-4 hr	0.0263	0.0000	0.0526	0.0000	0.0263	**0.1053**	**0.1383**	**0.0627**
4-6 hr	0.0000	0.0000	0.0526	0.0000	0.0000	**0.0526**	**0.1596**	**0.1233**
7-12 hr	0.0000	0.0526	0.0526	0.1316	0.0263	**0.2632**	**0.2234**	**0.1818**
13-24 hr	0.0000	0.0263	0.1316	0.1053	0.1053	**0.3684**	**0.1436**	**0.1617**
24< hr	0.0000	0.0000	0.0000	0.0263	0.0526	**0.0789**	**0.0585**	**0.0659**
Sum	**0.0526**	**0.0789**	**0.2895**	**0.3421**	**0.2368**	**1.000**		
MD 175	**0.1809**	**0.2394**	**0.2872**	**0.1755**	**0.1170**		**1.000**	**1.000**
Historical Data	**0.3287**	**0.1461**	**0.2130**	**0.1747**	**0.1374**		**1.000**	

The proportion of sampled events in the rainfall depth categories (0.0254 – 0.254 and 0.255 – 0.635 *cm*) were under-represented compared to the overall MD 175 site and historic MD frequencies. Correspondingly, frequencies of rainfall depth categories (1.28 – 2.54 and > 2.54 *cm*) sampled for water quality were higher compared to the site data as well as the expected MD data. The frequencies in the duration categories were well representative of both MD175 site and expected distributions.

As discussed in the hydrologic performance chapter, response of the infiltration basin to a storm event with respect to stormwater runoff capture and discharge characteristics, varied during different storm sizes and seasons. Most storm events of very small rainfall depths (< 0.635 *cm*) did not produce runoff to the infiltration basin. Therefore, these smaller storm events were less likely to be sampled for water quality, apparent by the under-represented categories in Table 8. Also, it took storm events of greater rainfall depths (> 1.27 *cm*) to produce outflow from the infiltration basin, especially during warmer months. Therefore, such larger storm events were more likely to be targeted in order to collect both inflow and discharge samples.

For the 38 storm events sampled for water quality, only 14 events produced outflow from the infiltration basin. This represents 37% storm events with outflow that were sampled for water quality in comparison to 47% of storm events producing outflows from the infiltration basin, based on the overall hydrology data for the MD 175 study site. In Table 8, distribution of these 15 sampled events with outflow is indicated by shaded cells. The overall distribution of storm events that produced outflow from the infiltration basin for the entire monitoring period was presented in Table 6 in the chapter 3 on 'Hydrologic Performance'. From Table 6 it was evident that most of the smaller events (< 0.635 *cm*) were fully captured. The likelihood of storm events producing outflows was higher in the 1.28 -2.54 *cm* range and much higher in the > 2.54 *cm* category. Therefore, the overall distribution of the water quality events can be considered to be representative of the storm event characteristics recorded at the infiltration basin site.

The water quality results are presented and discussed in two sections: the first section is on TSS, metals, and chloride and the second section is on nutrients phosphorus and nitrogen.

4.2 Water Quality Performance for TSS, Metals, and Chloride

4.2.1 Introduction and Background

Urban storm water runoff contains pollutants like suspended solids, heavy metals copper, lead, and zinc, and chloride. Suspended solids in road runoff originate from pavement wear, vehicles, atmospheric deposition, maintenance activities, and wash off from local soils (Sansalone *et al.* 1998). The expected concentration of total suspended solids (TSS) in highway runoff is 10 – 500 mg L^{-1} (Wu *et al.* 1998). The particle size distribution of solids in highway runoff is of hetero-disperse nature, with particle sizes ranging from 1 μm to greater than 24,500 μm (Kim and Sansalone 2008). High levels of suspended solids in runoff are attributed to coarser fractions (Furumai *et al.* 2002). While suspended solids are pollutants themselves, nutrients and heavy metals can be associated with the particles (Guo 1997; Herngren *et al.* 2005).

Heavy metals such as copper, lead, and zinc are introduced into runoff from vehicles, tires, brake wear, and by atmospheric deposition (Davis *et al.* 2001a). Heavy metal concentrations in runoff are of concern since their bioavailability can impart toxicity (Herngren *et al.* 2005). In general, the metal concentrations in urban runoff are: copper 5 – 200 µg L^{-1}, lead 5 – 200 µg L^{-1}, and zinc 20 – 5000 µg L^{-1} (Davis *et al.* 2001a). The metals can be present in both dissolved and particulate forms in stormwater runoff. A study conducted by Furumai *et al.* (2002) observed higher particle-bound fractions of Zn, Pb, and Cu than their dissolved forms in runoff from a highway in Switzerland. Particle-size distribution studies of highway runoff found that most metals have a greater affinity for smaller particles and hence metal concentrations generally increase with decreasing particle size (Furumai *et al.* 2002; Herngren *et al.* 2005).

Chloride in urban runoff is mainly introduced from the use of deicing salts for road maintenance during winter (Marsalek 2003; Semadeni-Davies 2006). Research by Kaushal *et al.* (2005) showed long-term increase in chloride concentrations in urban streams of the northeastern U.S. due to use of road salts. The streams draining urban and suburban areas contained chloride concentrations 100 times greater than streams draining forested and agricultural watersheds. Peak stream chloride concentration as high as 5 g L^{-1} (25% of sea water concentration) was reported in this research study.

Chloride pollution can have several human and ecological implications including potential threats to availability of freshwater for consumption, degradation of aquatic habitat, and alteration of ecosystem structure in wetlands and detention ponds (Marsalek 2003; Kaushal *et al.* 2005; Semadeni-Davies 2006; Van Meter *et al.* 2011a; Van Meter *et al.* 2011b). For instance, elevated chloride levels (650 mg L^{-1}) can induce changes in the composition of algae and zooplankton grazers, by negatively impacting zooplanktons (Van Meter *et al.* 2011a). Under elevated chloride concentrations in stormwater ponds, metamorphed amphibians such as American toads were favored and detrimental effects on gray tree frogs and wood frogs were observed in a study conducted by Van Meter *et al.* (2011b) in Baltimore, Maryland.

Good removal efficiencies of suspended solids and metals have been reported for infiltration basins, wetponds and wetlands. Birch *et al.* (2005) studied the efficiency of an infiltration basin, located in Sydney (Australia), in removing pollutants from urban stormwater runoff and reported reductions in TSS (50%), and trace metals Cu (68%), Pb (93%) and Zn (52%), respectively. Removal efficiencies of metals in wetponds and wetlands were reported as (80-90%) TSS, (45-65%) Cu, (33%-75%) Pb, and (31-61%) Zn (Wu *et al.* 1996; Carleton *et al.* 2000; Shutes *et al.* 2001; Mallin *et al.* 2002; Birch *et al.* 2004; Brydon *et al.* 2006). These studies on wetponds and wetlands were conducted in the U.S. (Wu *et al.* 1996; Carleton *et al.* 2000; Mallin *et al.* 2002), Canada (Brydon *et al.* 2006), Australia (Birch *et al.* 2004), and U.K. (Shutes *et al.* 2001). Chloride retention up to 80% was observed in a stormwater pond during winter periods in Sweden (Semadeni-Davies 2006). The chloride retention was, however, temporary and flushing of chloride was observed in baseflow and subsequent storm events.

Figure 20 illustrates the possible removal mechanisms of suspended solids, metals, and chloride in infiltration facilities, wetponds, and wetlands. The primary removal mechanism of suspended solids in runoff is by sedimentation in detention basins, wetlands, and wetponds (Kadlec and Knight 1996; Wu *et al.* 1996). Removal mechanisms of heavy metals include sedimentation, filtration, chemical precipitation and adsorption, microbial interactions, and uptake by vegetation (Walker and Hurl 2002; Yeh 2008). The chloride ion is extremely mobile and since it is a conservative dissolved parameter, its mobility is based on physical processes such as transport and dilution (Marsalek 2003). Therefore, reduction in chloride can be due to dilution and wash out after input of new water, and release into the ground via infiltration.

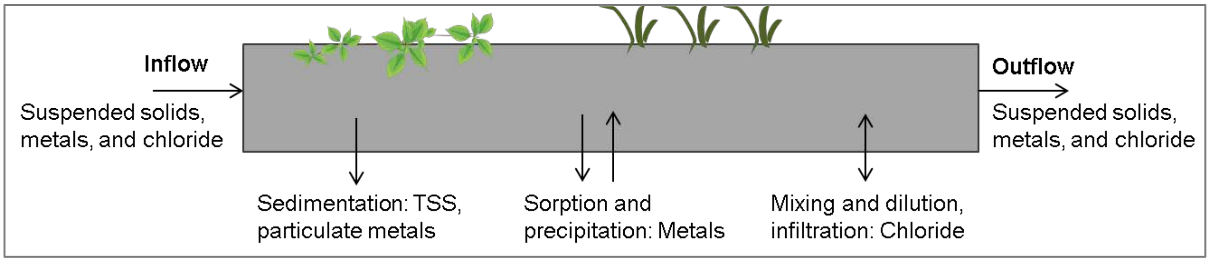


Figure 20. Schematic of expected pollutant (TSS, metals, and chloride) removal mechanisms in stormwater infiltration basins, wetponds, and wetlands.

Factors such as residence time, presence and type of vegetation, and surface area can influence the removal of pollutants in these stormwater treatment systems. Longer residence time provides opportunity for constituents to be acted upon either chemically or biologically (Wadzuk *et al.* 2010). Presence of vegetated regions increases the residence time and promotes sedimentation (Nepf 1999; Serra *et al.* 2004; Wadzuk *et al.* 2010). A study by Wu *et al.* (1996) showed that in wet detention ponds, a surface area ratio (ratio of pond area to drainage area) of 1-2% can provide adequate area for high removal of total suspended solids and other pollutants like metals associated with the solids via sedimentation.

4.2.2 Results and Discussion

The summary statistics (mean, median, and range) of event mean concentrations (EMCs) of TSS, total Cu, Pb, Zn, and chloride for 38 storm events monitored for water quality at the infiltration basin site are shown in Table 9. The water quality criteria (from Table 4 in 'Materials and Methods' chapter) for each pollutant are also included in the table. In Table 9, statistically significant EMCs for the 14 storm events with both inflow and outflow have also been indicated. Table 10 shows the summary statistics (mean, median, and range) of pollutant mass observed during the 38 sampled storm events.

Table 9. Mean, median, and range of pollutant event mean concentrations (EMCs) for storm events monitored for water quality at the infiltration basin from August 2009 to August 2012.

Pollutant	Water quality criteria	n	EMCin			EMCout		
			Mean	Median	Range	Mean	Median	Range
TSS * (mg L^{-1})	25	37	89	49	13 –510	5	NF	NF – 32
Total Copper * (µg L^{-1})	13	38	10	9	(< 2) –26	< 2	NF	NF – 6
Total Lead ** (µg L^{-1})	65	38	5	4	(< 5) – 22	< 5	NF	NF – 7
Total Zinc * (µg L^{-1})	120	37	40	41	(< 25) – 103	< 25	NF	NF – 43
Chloride (µg L^{-1})	250	37	434	52	5 – 6423	57	NF	NF – 702

n = number of events sampled; **NF** = no flow
* α = 0.01; ** α = 0.05 (where, α = level of significance)

Table 10. Mean, median, and range of pollutant mass for storm events monitored for water quality at the infiltration basin from August 2009 to August 2012. Negative values indicate export of pollutant.

Pollutant	n	Mass in (*kg*)			Mass out (*kg*)			Mass removal (%)	
		Mean	Median	Range	Mean	Median	Range	Mean	Range
TSS	37	18	5.1	0.34 – 272	1.9	NF	NF – 32	95	67 – 100
Total Copper	38	~1.4	~0.07	~0.018 – 13	~0.41	NF	NF – 3.4	86	(-8) – 100
Total Lead	38	~0.70	~0.36	~0.027 – 5.9	~0.29	NF	NF – 1.9	76	(-62) – 100
Total Zinc	37	~6.3	~2.4	~0.24 – 49	~2.8	NF	NF – 37	81	(-13) – 100
Chloride	37	23	3	0.26 – 156	13	NF	NF – 138	65	(-253) – 100

n = number of events sampled; **NF** = no flow

4.2.2.1 Total Suspended Solids (TSS)

A first flush phenomenon was observed in a majority of the rainfall events where high inflow TSS concentrations were recorded in the beginning of the event. Also, the TSS concentration and the rainfall intensity profiles correlated (Figure 21). The suspended solids concentrations flushed into the infiltration basin increased when the rainfall intensity and runoff flow rates increased. However, no notable flushing trends were observed in the discharge from the infiltration basin; the TSS concentrations were mostly similar in all discharge samples for a storm event.

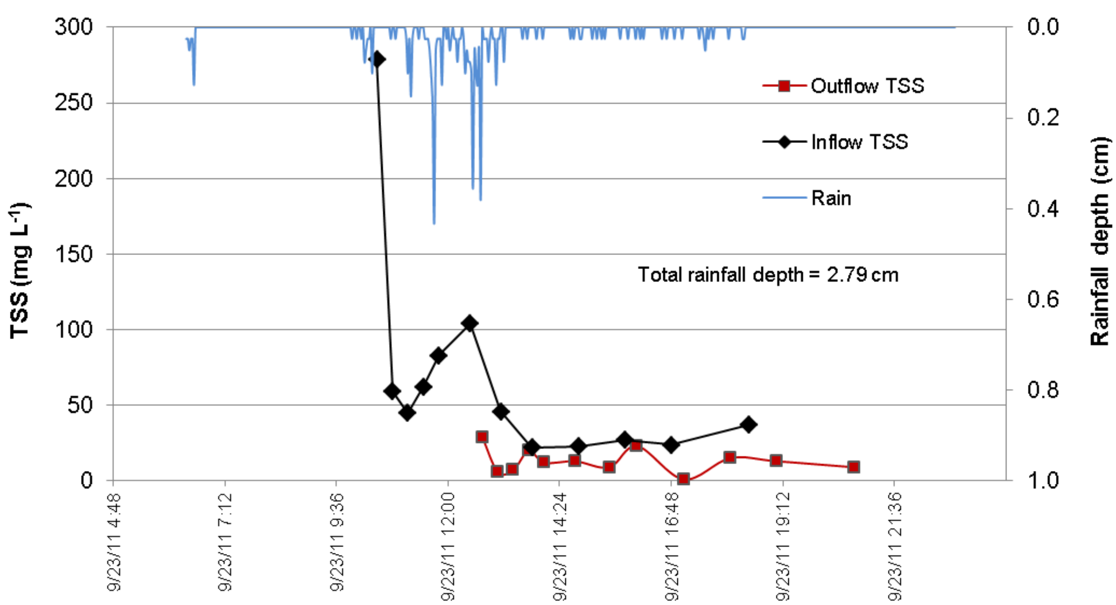


Figure 21. Pollutograph of inflow and outflow total suspended solids (TSS) recorded during the Sept 23, 2011, rainfall event at the infiltration basin.

A typical pollutograph recorded during a storm event on Sept 23, 2011 is depicted in Figure 21. During this rainfall event, the EMC of the inflow was 50 mg L^{-1} and the outflow EMC was 10 mg L^{-1}. Outflow occurred two hours after the onset of inflow and during this period most of the solids in the inflow runoff apparently settled, resulting in a total mass removal efficiency of 82% for this event. Similar observations were made during other storm events, with no particular seasonal patterns associated with TSS loadings and removals during the monitoring period.

The infiltration basin exhibited large removal of TSS from the stormwater runoff, both with respect to event mean concentration (EMC) (Table 9) and total mass (Table 10). The inflow EMCs ranged between 800 and 30 mg L^{-1} (median EMC = 49 mg L^{-1}). The discharge EMCs ranged between 32 and 2 mg L^{-1} (median EMC = 0 mg L^{-1}; no discharge) and were lower than the inflow EMCs for all storm events. The decrease in EMC was statistically significant (level of significance $\alpha = 0.01$), considering all 38 events as well as for the 14 events with outflow.

High TSS mass reductions ranging between 67 and 100% (median = 100%) were observed for the 38 storm events. These values are comparable to the observed 50 to 90% TSS mass removal efficiencies in infiltration basins, wetponds, and wetlands (Wu *et al.* 1996; Carleton *et al.* 2000; Mallin *et al.* 2002; Birch *et al.* 2004; Birch *et al.* 2005, Brydon *et al.* 2006).

The excellent TSS removals are supported by the probability exceedence plot (Figure 22) and pollutant duration plot (Figure 23) for the infiltration basin. The probability plot was developed using TSS EMC data of all sampled storm events. The water quality target level of 25 mg L^{-1} was used for comparison.

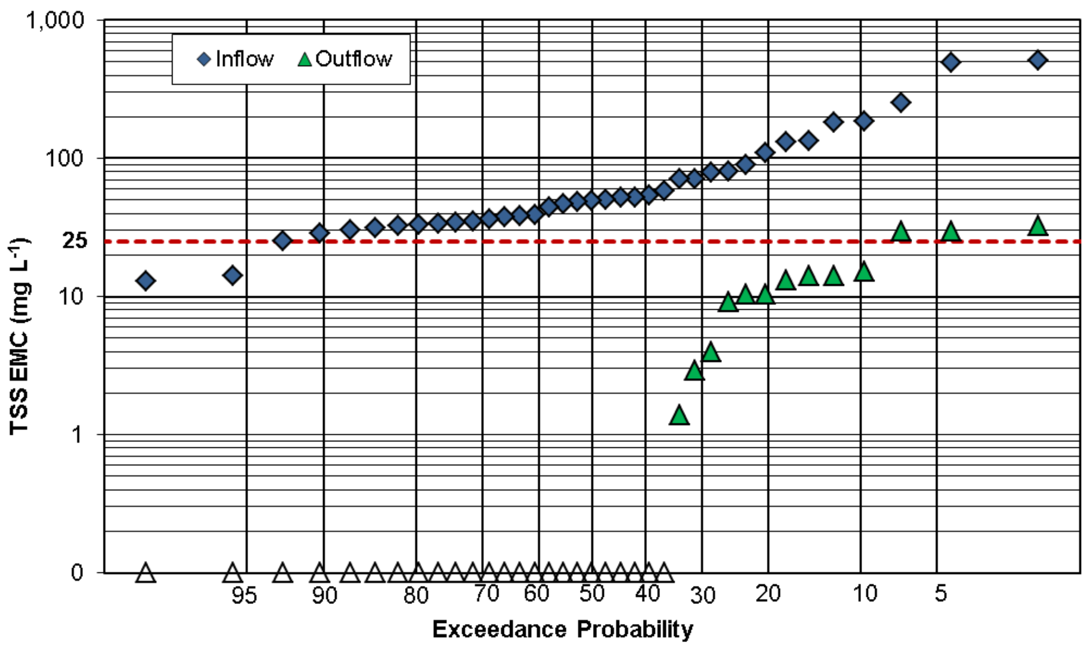


Figure 22. Probability plot for total suspended solids (TSS) EMCs at the infiltration basin. Open symbols represent storm events with no outflow. Dashed line represents the TSS water quality target criterion (25 mg L^{-1}).

Figure 22 shows that the median discharge TSS value is zero mg L^{-1}, resulting from no discharge. The discharge TSS concentrations were consistently lower than the influent for the remaining events as well as the water quality goal. About 90% of the discharge TSS concentrations are expected to meet the target value of 25 mg L^{-1}.

The instantaneous TSS inputs to and discharges from the infiltration basin are illustrated by the TSS pollutant duration in Figure 23. While the highest measured instantaneous inflow TSS concentration was 1771 mg L^{-1}, the peak discharge concentration was 48 mg L^{-1}. Also, the duration of TSS discharged was shorter owing to capture of runoff volume during 63% of the sampled events. The inflow exceeded the water quality criterion of 25 mg L^{-1} for 199 hours compared to 28 hours only for the discharge from the infiltration basin.

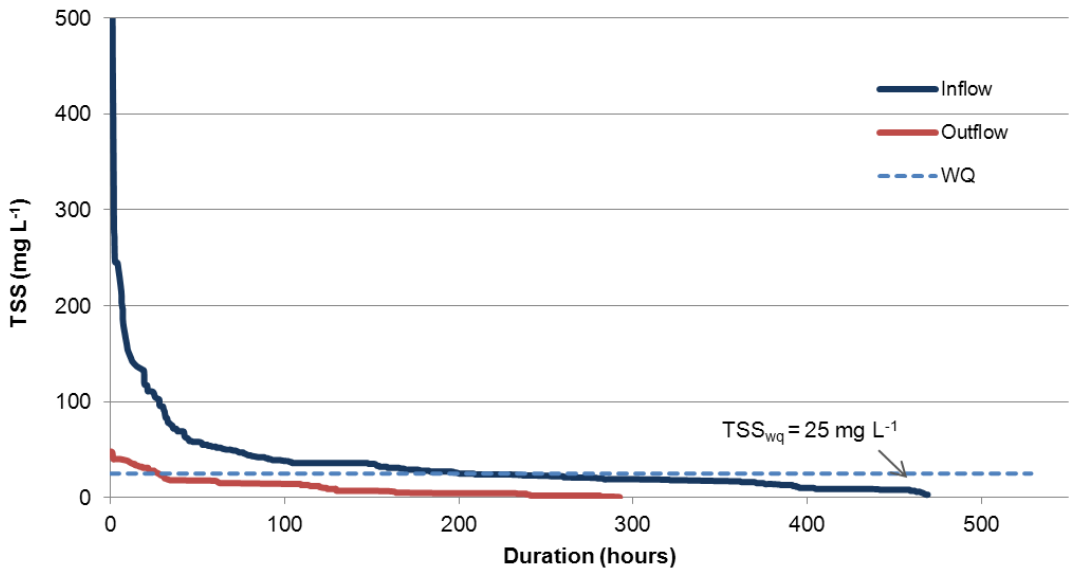


Figure 23. Pollutant duration curve for total suspended solids (TSS) at the infiltration basin for the monitoring duration. Dashed line represents the TSS water quality criterion (25 mg L^{-1}). The y-axis has been truncated at 500 mg L^{-1} in order to show the outflow pollutant duration clearly; the maximum value is 1771 mg L^{-1}.

4.2.2.1.1 TSS Removal Mechanism

Based on the TSS water quality data, it can be deduced that the suspended solids are primarily removed through sedimentation. Several other research studies have identified sedimentation as the primary removal mechanism for solids in infiltration basins, wetponds, and wetlands (Wu *et al.* 1996; Kadlec and Knight 1996; Guo 1997; Reddy and D'Angelo 1997; Comings *et al.* 2000; Mallin *et al.* 2002; Herngren *et al.* 2005). The pollutographs and observed flow delays suggest that detention (and or retention) of runoff enabled the suspended solids to settle within the infiltration basin, resulting in reduced discharge TSS concentrations and high TSS mass removals.

A simple analysis was performed to estimate the theoretical detention time during a storm event. A set of runoff flows consisting of highest, moderate, and low inflows recorded at the site, ranging from 272 to 0.52 $L\ s^{-1}$, was chosen. This corresponds to runoff depths of

0.021 to 34 $mm\ hr^{-1}$ over the total drainage area to the infiltration basin. Given the volume of the infiltration basin (V), these flows (Q) were used to derive a distribution of detention times (t). As examples, the detention times in the infiltration basin were distributed between 347 hours for very small flow rates (0.52 $L\ s^{-1}$), 36 hours for low flow rates (5 $L\ s^{-1}$); 4 hours for moderate flow rates (40 $L\ s^{-1}$), and 0.6 hours for the highest flow rate values (272 $L\ s^{-1}$).

The theoretical detention times were used to compute particle settling velocities as the ratio of depth of the infiltration basin to detention time. These settling velocities were in turn used to estimate the range of particle sizes that are expected to settle in the basin. For the detention times estimated for the different detention times, the settling velocities were: (0.531 x 10^{-3}) $mm\ s^{-1}$ for 347 hours detention (very small flow rates); (5.12 x 10^{-3}) $mm\ s^{-1}$ for 36 hours detention (low flow rates); 0.0409 $mm\ s^{-1}$ for 4 hours detention (moderate flow rates); and 0.278 $mm\ s^{-1}$ for 0.6 hours detention (very high flow rate values). The corresponding particle sizes were: 31 μm (silt particle range) for very small flow rates; 96 μm (very fine sand particle range) for low flow rates; 270 μm (medium sand particle range) for moderate flow rates, and 705 μm (medium sand particle range) for the highest flow rate values.

Therefore, particle sizes ranging between medium sand and silt particles (0.5 mm to 3.9 μm) can be expected to settle for the flow rates observed at the infiltration basin. The solid particle sizes range from 1 μm to greater than 24,500 μm in highway runoff (Kim and Sansalone 2008). This suggests that the infiltration basin is large enough to provide a detention period that will allow most of the suspended solid particles in typical roadway runoff to be removed via sedimentation during flow periods.

The removal of suspended solids from the runoff by sedimentation is also supported by the TSS levels in the grab samples collected during the inter-storm periods. Based on the data collected, water stored in the infiltration basin for a relatively long dry period (~10 days) contained a TSS concentration between 10 and 20 mg L^{-1} (Table B-1 in Appendix B). As an example, an inflow EMC of 185 mg L^{-1} was recorded during the April 25, 2010 event. Grab samples were taken one day prior to the storm (pre-event) and one week after the storm (post-event). Comparing the pre-event (16 mg L^{-1}), outflow EMC (29 mg L^{-1}), and post-event (9 mg L^{-1}) TSS levels, it can be deduced that some mixing and settling occurred during the event and given enough detention time (one week), the solids settled within the infiltration basin.

In wet detention ponds, a surface area ratio (ratio of pond area to drainage area) of 1 to 2% is expected to provide high mass removal efficiencies of total suspended solids (up to 80%) (Wu *et al.* 1996). In the current study, the surface area of the infiltration basin is about 3% of the total drainage area and high removals of TSS (67 – 100%) were achieved. This suggests that the sizing of the infiltration basin is adequate for achieving high mass removals of suspended solids.

The cumulative TSS mass input to and output from the infiltration basin for the 38 monitored events were 656 and 71 *kg*, respectively. This corresponds to a TSS mass removal efficiency of 89% for the three-year period. While part of this removal is attributed to 30% volume reduction during the 38 monitored storm events, sedimentation of suspended solids during the storm events contributed to the high removal efficiency.

The long-term effect of sedimentation of solids on the depth of the infiltration basin was assessed. For the three-year research period, the total sediment mass captured was 589 *kg*, which corresponds to 282 $kg\ ha^{-1}\ yr^{-1}$, normalized by drainage area. Assuming a dry bulk density of 1500 $kg\ m^{-3}$ for the sediment, the infiltration basin would have accumulated approximately 0.393 m^3 of sediments. For the bottom surface area of 450 m^2, this corresponds to a sediment accretion rate of 1.14 $mm\ yr^{-1}$ in the infiltration basin. Decrease in infiltration abilities of infiltration facilities due to deposition of sediments from urban stormwater runoff have been reported in several studies (Dechesne *et al.* 2005; Emerson *et al.* 2010). The estimated accumulation rate should not impact the depth of the infiltration basin over the course of the study. However, in the long-term, the sediment accumulation in the infiltration basin may have an effect on the structure of the basin.

4.2.2.2 Heavy Metals: Copper, Lead, and Zinc

The levels of total copper, lead, and zinc in the runoff were measured for 38 storm event samples and 54 grab samples collected during dry periods. In general, the heavy metal concentrations were low in the roadway runoff (inflow EMCs of total Cu < 26 μg L^{-1}; total Pb < 22 μg L^{-1}; total Zn < 103 μg L^{-1}). The average metal concentrations in the grab samples were also low (total Cu < 6 μg L^{-1}; total Pb < 7 μg L^{-1}; total Zn < 45 μg L^{-1}).

4.2.2.3 Copper

The EMCs of inflow total copper ranged between (< 2) and 26 μg L^{-1} (median EMC = 9 μg L^{-1}) and that of outflow between (< 2) and 6 μg L^{-1} (median EMC = 0 μg L^{-1}; no discharge). The non-exceedence probability for total copper above the target water quality (13 μg L^{-1}) is thus > 99% (Figure 24). The outflow EMCs were significantly lower than that of the inflow ($\alpha = 0.01$) for all 38 events as well as for the 14 events with outflow. The total copper mass removals ranged between -8 and 100 % (median = 100%) for the 38 sampled storm events (Table 10). The mass export of copper occurred during one winter event (8% for January 2010 event).

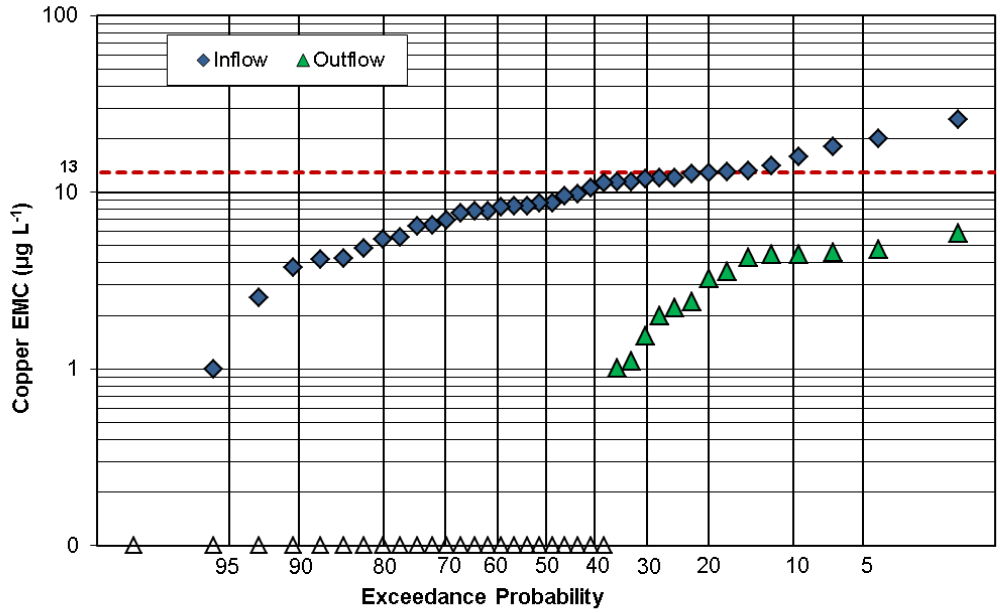


Figure 24. Probability plot for total copper EMCs at the infiltration basin. Open symbols represent storm events with no outflow. Dashed line represents the copper water quality target criterion (13 µg L^{-1}).

4.2.2.4 Lead

Total lead concentrations in the influent runoff were also very low. The inflow EMCs ranged between <5 µg L^{-1} and 22 µg L^{-1} (median EMC < 5 µg L^{-1}) (Table 10). The discharge samples contained Pb levels usually around or below their detection limits (median EMC = 0 µg L^{-1}; no discharge). Although the discharge EMC was higher than that of influent for one storm event, the discharge concentrations were much lower than the 65 µg L^{-1} target for all storm events. The exceedence probability of discharge Pb concentrations above the water quality goal of 65 µg L^{-1} is, thus, < 0.1%. Statistically, the outflow EMCs were significantly lower than the inflow EMCs both from a treatment (14 events; $\alpha = 0.05$) and performance perspective (38 events; $\alpha = 0.01$). The total Pb mass removal efficiencies ranged between -28 and 100% (median = 100%) for 38 events (Table 10). Mass export of Pb was observed during three storm events, two of which were during winter (28% on January 2010 and 13% on Dec 2011 events).

4.2.2.5 Zinc

Sample zinc concentrations were above detection limit in influent samples more frequently compared to Pb and Cu. The influent EMCs ranged between < 25 and103 μg L^{-1} (median = 41 μg L^{-1}) (Figure 25). The discharge EMCs ranged between < 25 and 43 μg L^{-1} (median EMC = 0 μg L^{-1}; no discharge). The discharge EMCs were statistically significantly lower than the inflow EMCs (α = 0.01).

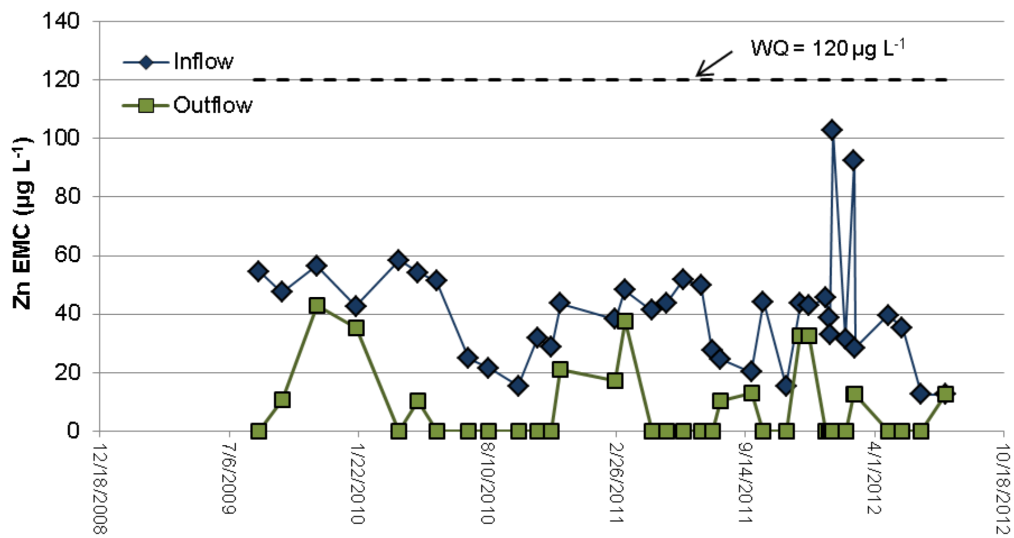


Figure 25. Event mean concentrations of zinc in the inflow and outflow at the infiltration basin during the three-year monitoring period. Open squares denote storm events with no outflow. Dashed line represents the zinc water quality target criterion (120 μg L^{-1}).

Similar to other heavy metals, non-exceedence probability for discharge Zn to be higher than the target water quality level is > 99%. The Zn mass removal efficiencies ranged between (-13) and 100%; the median being 100% (Table 10). The mass export of Zn occurred during two events (13% on January 2010 and 1% on March 2011 events).

Since the concentrations of all three heavy metals were low in the highway runoff for most periods, the instantaneous outflow pollutant concentrations at the study site were also much lower than the water quality goals for all there heavy metals for the entire duration.

Although no particular trend was associated with heavy metal loading to the infiltration basin, the highest inflow EMCs for all three metals were recorded during a winter storm in 2012. Accumulation of metals in snow and subsequent introduction of high pollutant loads through snowmelt from urban highway have been reported (Sansalone and Glenn 2002; Glenn and Sansalone 2002; Vollertsen *et al.* 2009). The inflow EMC measurements showed mixed levels during the other seasons.

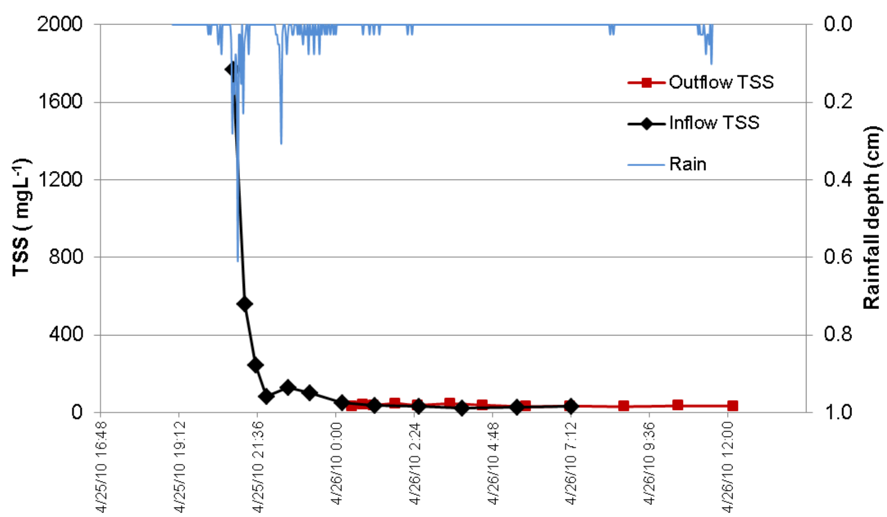
However, a seasonal trend was evident with respect to metal mass removal efficiency. As discussed earlier, two winter storm events showed export of pollutant mass for all three heavy metals. This can be attributed to minimal treatment provided by the infiltration basin during winter periods. The presence of ice-cover on the surface of the infiltration basin modified the hydraulics of the infiltration basin. Also, the ice cover prevented active removal of pollutants through sedimentation or adsorption. Poor performance of stormwater detention ponds during winter compared to other seasons have been reported by other studies as well for the same reasons (German *et al.* 2003; Semadeni-Davies 2006; Vollertsen *et al.* 2009).

The cumulative pollutant mass into and out of the infiltration basin were calculated for the 38 monitored events. For Cu, the mass input was 0.054 *kg* and output was 0.014 *kg*. For Pb, the mass input was 0.027 *kg* and output was 0.010 *kg*. For Zn, the mass input was 0.23

kg and output was 0.10 *kg*. This shows that the input pollutant loads were reduced by the infiltration basin for all the metal pollutants. The metal mass removal efficiency for the entire monitoring duration was: 73% total Cu, 63% total Pb, and 55% total Zn. Part of this removal is attributed to 30% runoff volume reduction during the 38 monitored storm events

4.2.2.5.1 Heavy Metals Removal Mechanism

One observation noticeable during several storm events was that the inflow concentration profiles of total copper, lead, and zinc correlated with that of TSS, exhibiting a first flush behavior. As an example, Figure 26 shows the pollutographs of TSS, Cu, Pb, and Zn for the April 26, 2010, storm event. The inflow TSS and metal concentration profiles exhibited a similar trend with high initial concentration (first-flush) and decrease in concentrations afterwards. Similar to outflow TSS, the outflow metal concentrations did not exhibit any first-flush trend and remained more or less uniform throughout the storm event.



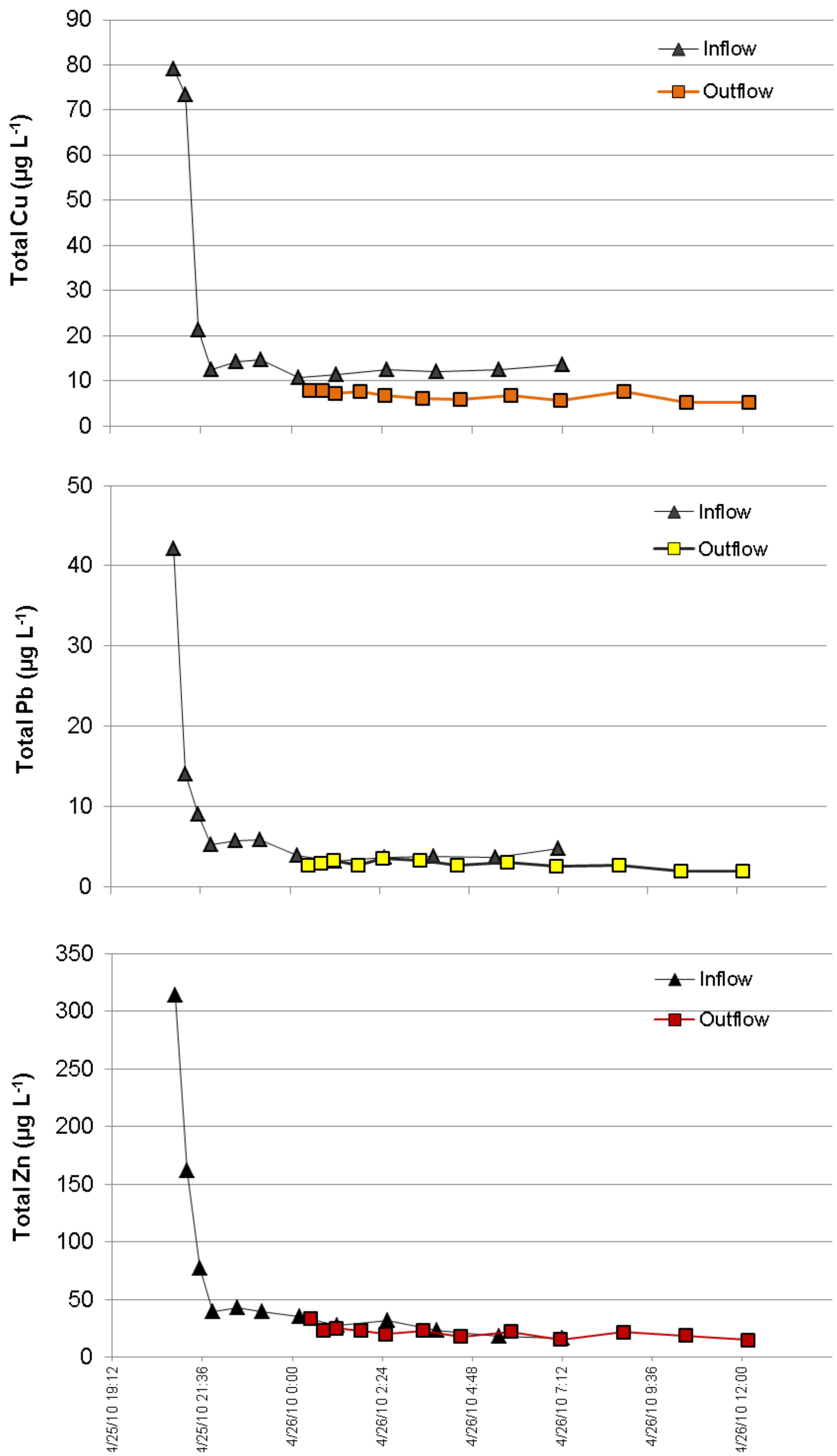


Figure 26. Pollutographs of inflow and outflow total suspended solids (TSS), total copper, lead, and zinc recorded during the April 25, 2010, rainfall event at the infiltration basin.

Based on the observed similarity in the TSS and heavy metals pollutographs (Figure 26), the correlations between TSS and metal concentration trends were examined (Figure 27). The concentrations of TSS and metals measured in the individual water samples collected during each storm event were used to develop the plot. Correlation between pollutant mass load and EMC was not performed. This is because both mass load and EMC quantities involve the volume term in their computation and regression between two quantities involving the same parameter may yield high linear correlation, leading to erroneous conclusions.

In the case of inflow concentrations, the TSS and metal concentrations exhibited very good linear correlations (Pb: 0.59; Cu: 0.60; and Zn: 0.64) (Figure 27). This suggests that a higher fraction of the total metal was in the particulate form in the inflow runoff for all three heavy metals. This is in agreement with research studies by Guo (1997), Pettersson (1998), and Herngren *et al.* (2005), who found that metals were mostly associated with particulates. Also, a study conducted by Furumai *et al.* (2002) observed higher particle-bound fractions of Zn, Pb, and Cu than their dissolved forms in runoff from a highway in Switzerland.

However, the outflow TSS and metal concentrations showed poor linear correlations (Pb: 0.019; Cu: 0.19; and Zn: 0.0005) (Figure 27). As discussed earlier, the total metal concentrations in the outflow samples were often below detection limits for Cu, Pb, and Zn. Also, assuming most of the inflow particulate metals were removed via sedimentation, most of the outflow metals must be in the dissolved form. Thus, no linear trend was detectable between outflow TSS and metal concentrations.

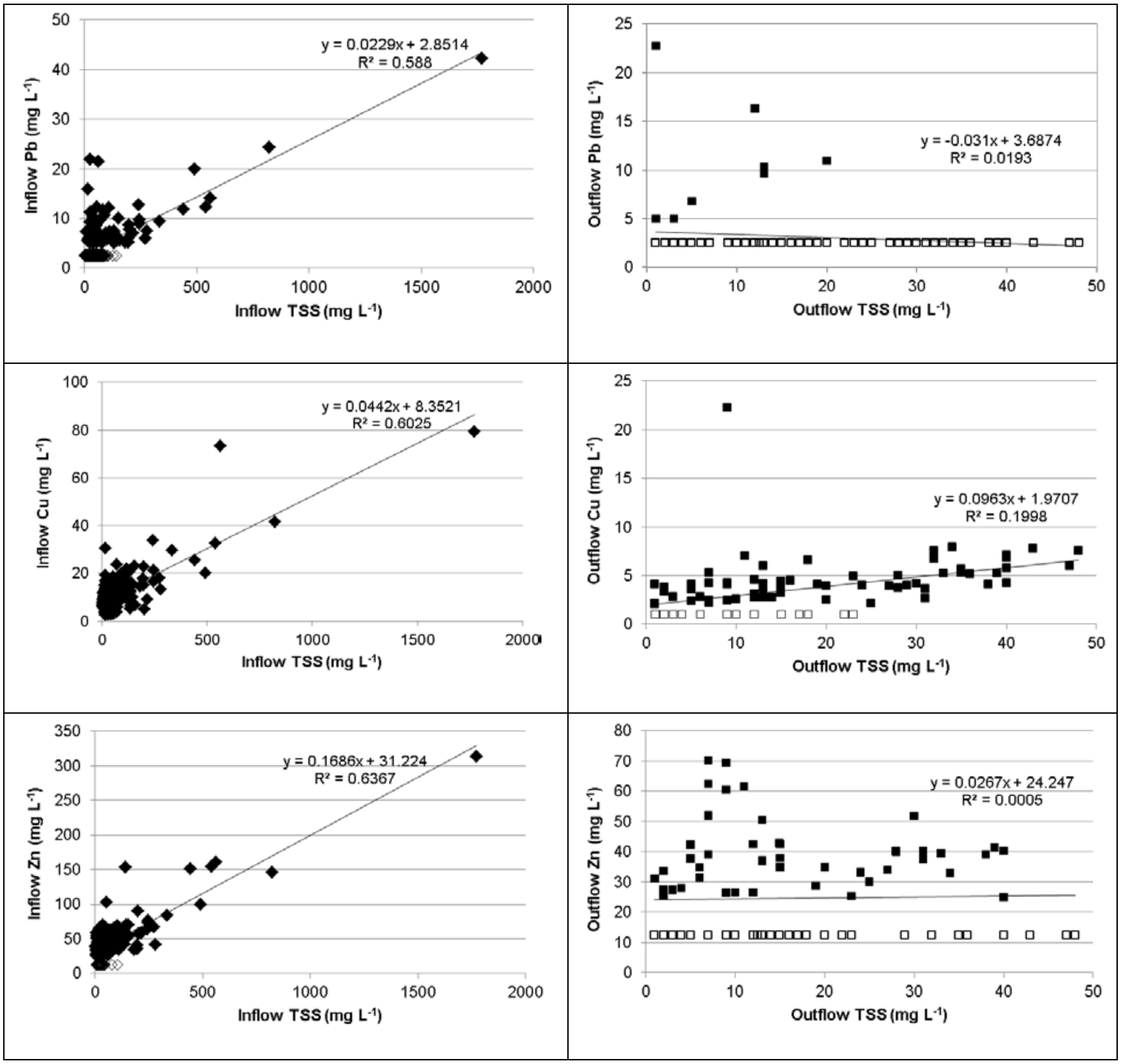


Figure 27. Correlations between TSS and metal concentrations in inflow and outflow for all storm events sampled for water quality at the infiltration basin site. Open symbol represents sample concentration measured below the analytical detection limit and assigned a value of half the detection limit.

Since speciation of metal (particulate vis-à-vis dissolved) was not performed, the fraction of metal associated with particulates in the inflow and outflow could not be quantified. However, based on the inflow and outflow metals concentrations and their respective linear relationship with the TSS concentrations, it can be deduced that the particulate metals in the inflow runoff settle out with solids. The high TSS mass removals (67 – 100%) via sedimentation and high mass removal efficiencies for the three metals during storm events are in support of the hypothesis.

Removal of metals by sedimentation is supported by the low water column concentrations of total Cu, Pb, and Zn in the grab samples (Table B-1 in Appendix B). The average concentration of total Cu ranged between < 2 and 7 μg L^{-1}; total Pb < 5 and 7 μg L^{-1}; and total Zn < 25 and 45 μg L^{-1} in the grab samples, based on54 dry-weather samplings Copper and lead levels were mostly below or around detection limit in the grab samples. Average zinc concentration was above detection in only 10 out of the 54 grab sample sets. Therefore, it can be deduced that the removal of particulate metal species occurred via sedimentation during the inter-event periods. The dissolved metal species could have been removed via adsorption, thereby resulting in overall low water column concentrations for all three metals.

4.2.2.6 Chloride

Chloride concentrations in the roadway runoff exhibited strong seasonal trends during the three-year research period. The highway runoff contained high levels of chloride during winter storm events when application of road salts for deicing was common. Chloride pollutograph and photographs of the ice-covered infiltration basin and the adjoining highway with road salt applied one day prior to the Jan 18, 2010, rainfall event are shown in Figure 28. Stormwater runoff sample contained chloride concentration as high as 2445 mg L^{-1} in this event. The inflow and outflow EMCs were 766 and 631 mg L^{-1}, respectively, for this event. The chloride mass removal efficiency for this event was -18% (mass export).

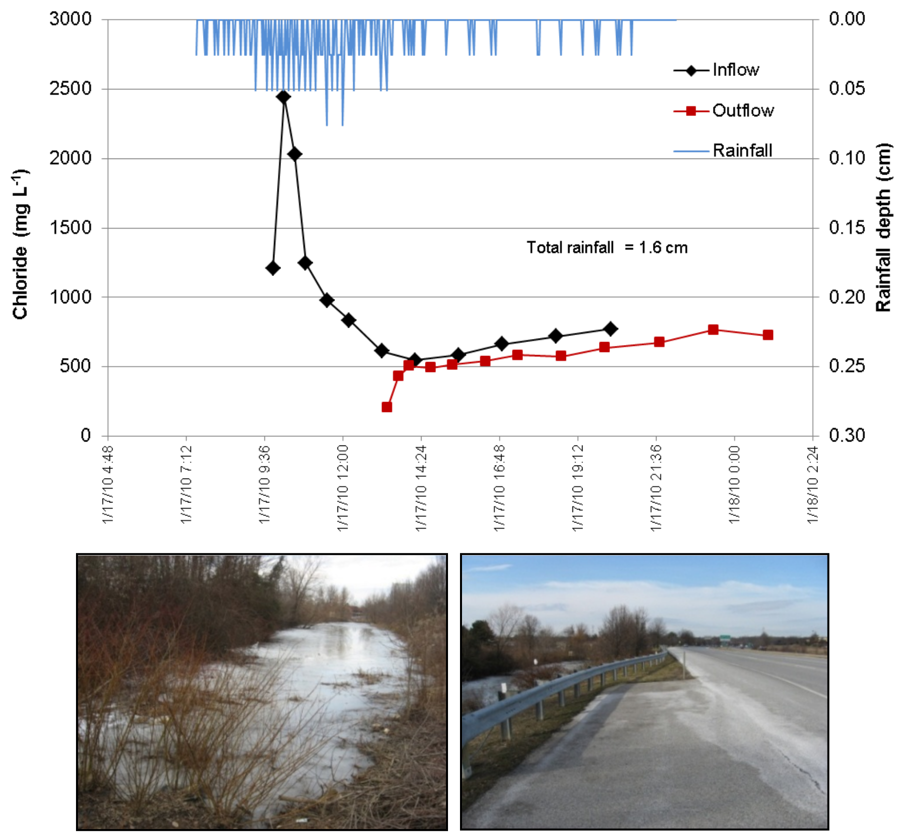


Figure 28. Pollutographs of inflow and outflow chloride during the Jan 17, 2010, rainfall event at the infiltration basin site. Photographs show the ice-covered infiltration basin (left) and the adjoining highway (right), one day prior to the event.

Figure 29 shows the inflow and discharge chloride EMCs observed at the infiltration basin for the entire monitoring duration. The inflow EMCs ranged from 5 to 6423 mg L^{-1} (median = 52 mg L^{-1}). The outflow EMCs varied between 6 and 702 mg L^{-1} (median = 0 mg L^{-1}; no discharge). As seen in Figure 29, the highest inflow EMCs were recorded during winter storm events. The maximum inflow EMC of 6423 mg L^{-1} was observed during the Jan 21, 2012, storm event. Correspondingly, the outflow EMCs were higher in winter and spring compared to other seasons. The inflow chloride EMC levels gradually decreased during the following seasons. In Figure 29, four inflow EMCs greater than 1000 mg L^{-1} are off the chart (1251 mg L^{-1} on Feb 24, 2011, 6423 mg L^{-1} on Jan 21, 2012 , 3126 mg L^{-1} on Jan 23, 2012, and 1326 mg L^{-1} on Feb 16, 2012 storm events).

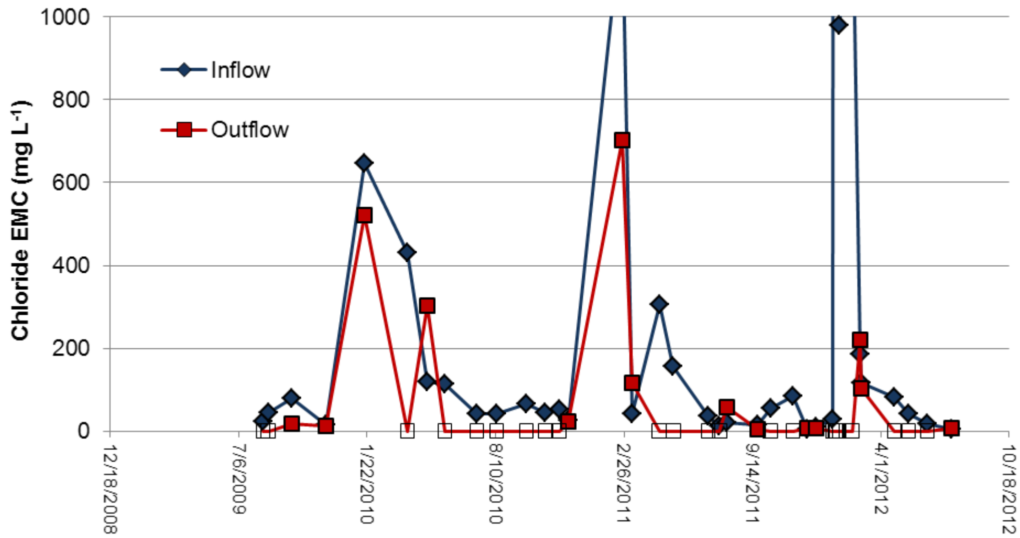


Figure 29. Event mean concentrations of chloride in the inflow and outflow observed at the MD175 infiltration basin site during the monitoring period. Open squares denote storm events with no outflow. In this plot, four inflow EMCs greater than 1000 mg L^{-1} are off the chart (1251 mg L^{-1} on Feb 24, 2011; 6423 mg L^{-1} on Jan 21, 2012; 3126 mg L^{-1} on Jan 23, 2012; and 1326 mg L^{-1} on Feb 16, 2012, storm events).

The large chloride inputs from winter storms resulted in elevated chloride levels in the water stored within the infiltration basin which is supported by the grab samples data (Figure 29). The grab samples collected after winter storm events showed high levels of chloride, ranging between 286 and 825 mg L^{-1} and remained elevated through spring (101 to 408 mg L^{-1}) (Figure 30).

The conductivity values measured within the infiltration basin also fluctuated throughout the year due to chloride input and subsequent wash out (Figure 30). The conductivity values increased from ~30 $\mu S\ cm^{-1}$ in Fall 2011 to up to 1000 $\mu S\ cm^{-1}$ in Feb 2012. The conductivity values remained in the 600 – 300 $\mu S\ cm^{-1}$ range in spring 2012 and decreased

~150 $\mu S\ cm^{-1}$ by end of summer 2012. As a comparison, the conductivity measured in runoff samples collected during winter and spring seasons ranged from 17.6 to 438 $mS\ cm^{-1}$ at two stormwater wet detention ponds treating runoff from a commercial/residential area in Bellevue, Washington (Comings *et al.* 2000).

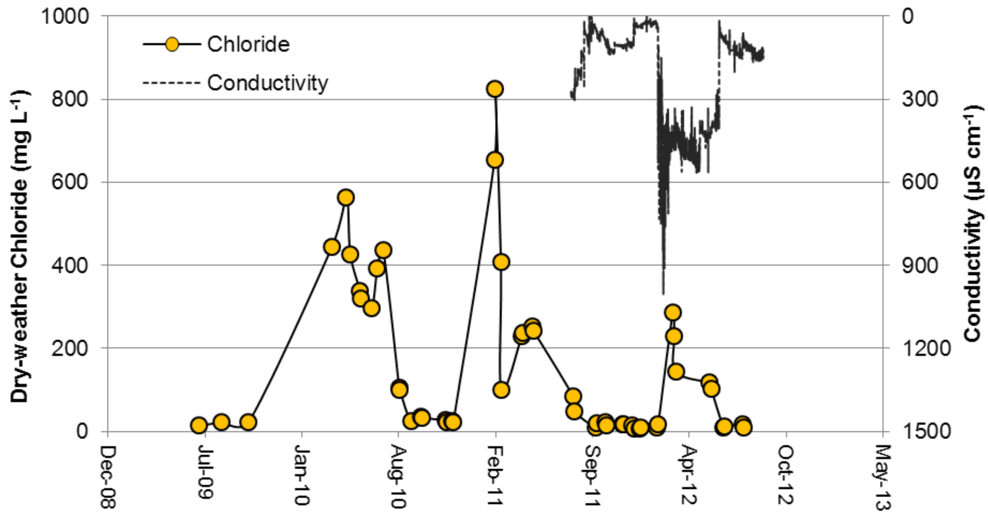


Figure 30. Concentration of chloride in the infiltration basin during dry-weather periods from June 2009 to Aug 2012. Conductivity measured in the infiltration basin during the period Aug 2011 to Aug 2012 is also shown.

As a conservative dissolved pollutant, chloride concentrations are expected to decrease through dilution and wash out during subsequent storm events (Semadeni-Davies 2006). As can be seen in Figure 30, the chloride concentration (and conductivity) in the water stored in the infiltration basin gradually decreased during summer and fall after input of new runoff during subsequent storm events.

As the chloride retained in the infiltration basin was diluted by runoff input and flushed out during subsequent storm events, it sometimes resulted in increased discharge EMC and/or export of chloride mass during storm events in early spring, that immediately followed winter periods. Five storm events in spring recorded discharge EMCs higher than the inflow EMCs (Figure 29) and three of these events showed chloride mass exports (from 10 up to 253%) (Table B-1 in Appendix B). Export of chloride mass (11 to12%) was observed during two other large events (rainfall depth > 2.54 *cm*) in summer.

Reductions in influent chloride EMCs and masses were observed during the remaining nine events that had measurable outflow. This reduction in concentration can be attributed largely to dilution. The chloride mass removals ranged between 13 and 100% for these nine events. However, the outflow EMCs were not significantly lower than inflow EMC for the 14 storm events with measured outflow (rejection probability > 95%). The outflow EMCs were statistically lower than the inflow EMCs ($\alpha = 0.01$) considering the EMCs of all 38 events, where 63% events did not have outflows.

Based on the chloride pollutant duration at the site, the inflow chloride concentrations exceeded the water quality criterion of 250 mg L^{-1} for 130 hours out of 529 hours total inflow duration. The peak discharge concentration (942 mg L^{-1}) was much lower than the inflow (3398 mg L^{-1}). The cumulative discharge duration was 176 hours shorter than the inflow duration. However, the discharge concentrations exceeded the water quality goal for about 124 hours out of the 353 hours of total discharge duration.

The probability exceedence for chloride is shown in Figure 31. The median concentration is zero mg L^{-1} owing to no discharge. The discharge chloride concentrations exceeded the water quality criterion of 250 mg L^{-1} for about 10% of the time.

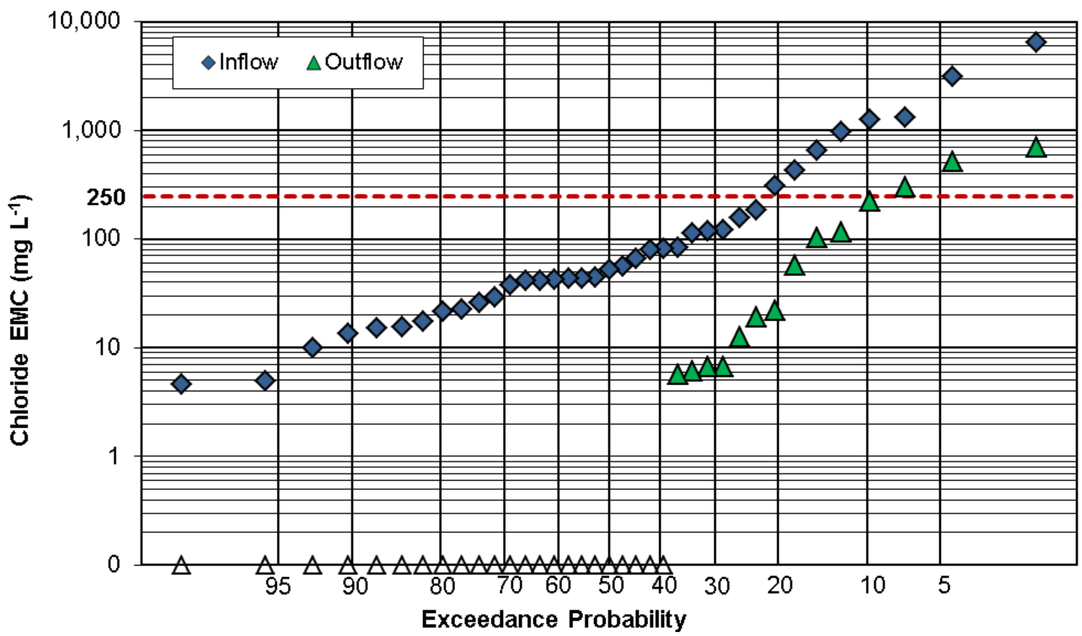


Figure 31. Probability plot for chloride EMCs at the infiltration basin site. Open symbols represent storm events with no outflow. Dashed line represents the chloride water quality target criterion (250 mg L^{-1}).

The observed chloride concentration trend is supported by a research study conducted by Kaushal *et al.* (2005) that showed long-term increase in chloride concentrations in urban and sub-urban streams of the northeastern US, due to the application of deicing salts during winter. Also, the study noted that the chloride concentrations remained elevated through spring, summer, and autumn in urban streams when compared to un-impacted forested streams.

In the current study, although the residence time of chloride was not estimated, flushing out of chloride was observed from winter through summer. As a comparison, Shaw *et al.* (2012) studied the steady, decades-long (1972 to 2003) increase in stream chloride concentration in Fall Creek near Ithaca, New York, due to road salt application. The average residence time of road salt in the watershed was estimated to be approximately 50 years (40 to 70 years considering uncertainty), suggesting that the stream chloride concentrations may not level out for decades. Several research studies have highlighted that high salinity levels caused by road salts can indirectly induce stress and alter the structure of the primary producer and consumer communities in the stormwater ponds, wetland ecosystems, and streams (Marsalek 2003; Kaushal *et al.* 2005; Semadeni-Davies 2006; Van Meter *et al.* 2011a; Van Meter *et al.* 2011b). Chloride concentration of 650 mg L^{-1} caused mortality of zooplankton grazers (copepods) and this concentration was sub-lethal to gray tree frog larvae in a pond mesocosm study conducted by Van Meter *et al.* (2011a) in Baltimore, MD.

In another field study, the relationship between specific conductance levels (99 to 19,320 $\mu S\ cm^{-1}$) and assemblages of zooplankton grazers and algae producers were studied in eight stormwater ponds receiving road salt deicers in Baltimore, MD (Van Meter *et al.* 2011b). The algal biomass and zooplankton community composition changed with salinity, with declining zooplankton grazers and thus increasing algal biomass in high specific conductance waters and the vice-versa in low to medium specific conductance ponds. These research studies suggest that the observed high chloride levels at the infiltration basin may have ecological implications on the invertebrate and amphibian populations in the infiltration basin.

The cumulative chloride mass input and output during the 38 monitored events were 850 and 467 kg, respectively, which corresponds to a chloride mass removal efficiency of 45% for the entire monitoring duration. The 30% volume reduction achieved during the 38 monitored storm events contributed to this mass removal. Thus, the chloride water quality data suggest that the overall performance of the infiltration basin in reducing chloride levels in the highway runoff was moderate. Since dilution is the only mechanism of decrease in concentration, the runoff capture and volume reduction during storm events influenced the chloride removal efficiencies.

4.2.2.7 Annual Pollutant Mass Loads

Annual pollutant mass load per unit drainage area is an important parameter employed towards design of a SCM in a watershed (Li and Davis 2009). The annual pollutant mass load per unit drainage area (L, in *kg ha*$^{-1}$ *yr*$^{-1}$) was estimated using Equation 9:

$$\boldsymbol{L = \frac{M}{A} \times \frac{P_{average}}{P_{observed}}} \qquad (9)$$

In Equation 9, M_{in} is the overall pollutant mass (in *kg*), A is the drainage area of the infiltration basin (in *ha*), $P_{average}$ $P_{average}$ is the average annual precipitation [1067 *mm yr*$^{-1}$ for the State of Maryland; MDE 2000], and $P_{observed}$ $P_{observed}$ is the observed cumulative precipitation during the monitoring duration (in *mm*). $P_{observed}$ for the 38 monitored events was 762 *mm*. The annual pollutant mass input L_{in} and discharge L_{out} from the infiltration basin were obtained using the input (M_{in}) and output (M_{out}) masses, respectively.

Table 11 shows the annual pollutant mass input and discharge load at the infiltration basin for the entire monitoring period. The difference between annual input and output masses ($L_{in} - L_{out}$) is the effect of the infiltration basin in reducing the annual pollutant loads. Table 11 shows that the annual pollutant mass discharged from the infiltration basin was much lower than the annual pollutant input load for all pollutants. The mass removals were 89% TSS, 73% copper, 63% lead, 55% zinc, and 45% chloride. The infiltration basin was, thus, effective in reducing pollutant mass loads and thus improving the discharge water quality.

Table 11. Annual pollutant mass input and discharge load of TSS, metals, and chloride for 38 storm events recorded at the infiltration basin from August 2009 to August 2012. Annual pollutant mass input and discharge values for a bioretention, as reported by Li and Davis (2009), are also included.

Pollutant	Annual Pollutant Mass Load (*kg ha^{-1} yr^{-1}*)			
	MD 175 Infiltration Basin		Bioretention[a]	
	Input (L_{in})	Output (L_{out})	Input	Output
TSS	323	35	570	38
Total Lead	0.013	~ 0.005	0.03	0.015
Total Copper	0.026	~ 0.007	0.12	0.045
Total Zinc	0.115	~ 0.052	0.36	0.017
Chloride	421	231	320	25

[a] Li and Davis (2009)

The annual pollutant input loads at the infiltration basin were compared to the values published for a bioretention facility by Li and Davis (2009) (Table 11). The bioretention facility, managing parking lot runoff, is located in Silver Spring, MD, and has a drainage area of 0.9 *ha* (90% impervious). This is in comparison to the 2.9 *ha* (33% impervious) drainage area to the infiltration basin. While the annual TSS and metal loads to the infiltration basin were relatively lower than at the bioretention, the chloride load at the infiltration basin was greater than the bioretention. The difference in pollutant loadings to the two SCMs is attributed to the land use of the contributing drainage areas.

On a performance perspective, the efficacy of the infiltration basin in removing the annual pollutant loads was quite comparable to that of the bioretention facility. The annual mass load removal efficiencies of the bioretention were 93% TSS, 50% copper, 63% lead, 95% zinc, and 92% chloride and this is comparable to the performance data for the infiltration basin: 89% TSS, 73% copper, 63% lead, 55% zinc, and 45% chloride removals.

4.2.3 Performance Summary for TSS, Metals, and Chloride

Performance of the infiltration basin in removing TSS, metals (Cu, Pb, Zn), and chloride from the runoff was evaluated for 38 storm events. Also, grab samples were collected from the infiltration basin during the dry periods before and after a storm event. The water quality data, collected over a three-year period, suggest overall improvements in the runoff water quality during both storm events and dry-weather periods.

The discharge event mean concentrations (EMCs) of TSS and metals (copper, lead, and zinc) were significantly lower ($\alpha = 0.01$) than those of inflow for the 14 storm events which produced outflow and considering all 38 storm events. The discharge EMCs of TSS exceeded the selected water quality criteria during three storm events (90% non-exceedence probability). The discharge EMCs of copper, lead and zinc satisfied the selected water quality criterion for all the events monitored (> 99% non-exceedence probability).

High mass removal efficiencies were observed for TSS and metals. The mean mass removal efficiencies were 95% TSS, 86% copper, 76% lead, and 81% zinc at the infiltration basin. The TSS and metals mass removal efficiencies of the infiltration basin were comparable to other SCMs. Removal efficiencies of 50-90% TSS, (45-65%) Cu, (33%-75%) Pb, and (31-61%) Zn have been reported for infiltration basins, wetponds, and wetlands by other research studies (Wu *et al.* 1996; Carleton *et al.* 2000; Mallin *et al.* 2002; Birch *et al.* 2004; Birch *et al.* 2005; Brydon *et al.* 2006).

Pollutant removal efficiencies for metals were poorest in winter compared to other seasons. Export of pollutant mass was observed for Pb (13 – 28%), Cu (8%), and Zn (1 – 13%) during two winter storm events. This observation is consistent with the poor metal removal performance of stormwater ponds during winter than in summer (German *et al.* 2003; Semadeni-Davies 2006; Vollertsen *et al.* 2009).

While no particular seasonal trends were visible for TSS and metal input loadings to the infiltration basin, chloride concentrations exhibited very strong seasonal patterns. The highest inflow EMCs (up to 6423 mg L^{-1}) were recorded during winter storm events. Correspondingly, the grab samples showed higher chloride levels in winter and spring periods due to the large chloride input. Discharge EMCs (up to 702 mg L^{-1}) recorded during winter and spring storm events were higher than the EMCs for storm events occurring in other seasons.

The high mass loads of chloride washed into the infiltration basin were gradually flushed out during subsequent storm events in spring, sometimes resulting in export of chloride mass (up to 253%) during these events. Reductions in chloride concentrations and masses were observed during the remaining nine storm events, largely due to dilution. However, the discharge EMC was not statistically lower than the inflow EMC for the 14 storm events with outflow, but significant ($\alpha = 0.01$) considering all 38 storm events. The discharge EMCs exceeded the chloride water quality target during 10% of the time.

Based on the wet- and dry-weather TSS water quality data for the infiltration basin, sedimentation was identified as the main removal mechanism. The detention time during a storm event and inter-event periods allowed the suspended solids to be removed via settling. The good linear correlation between TSS and metal mass loads suggested that most of the metals were attached to particulates. Higher fractions of particle-bound Zn, Pb, and Cu compared to their dissolved forms in highway runoff have been observed in other studies (Furumai *et al.* 2002). The grab samples also contained very low metal concentrations. This explained the observed high mass removals for heavy metals during storm events and dry-periods mainly via sedimentation. In the case of chloride, reduction in EMC observed during storm events and inter-event periods should occur largely by dilution of chloride concentration.

The pollutant removal efficiencies for chloride and metals were poorest in winter compared to other seasons. During colder periods, the surface of the infiltration basin was frozen. The formation of ice cover changed the conditions in the infiltration basin by reducing the available detention volume and deterring sedimentation. Based on the hydrologic performance data for the infiltration basin, the infiltration basin acted as a flow-through facility during colder periods due to the presence of ice-cover. The water losses were also lower (at least 45%) in winter compared to warmer months. Since volumetric reduction is an important consideration for pollutant mass removal, the overall pollutant removal efficiency of the infiltration basin can be expected to be worse during colder periods compared to other seasons

4.3 Water Quality Performance for Nitrogen and Phosphorus

4.3.1 Introduction and Background

Nutrients (nitrogen and phosphorus) are introduced into urban runoff through decomposing organic matter, human and pet wastes, fertilizers, and atmospheric deposition. Urban runoff containing elevated levels of nutrients can enrich and cause hypoxia in the receiving waters. The resulting conditions degrade the water quality and other ecosystem services of the streams (Kaushal *et al.* 2008). In particular, excess nutrients have been identified as the main issue in the decline of the Chesapeake Bay (Boesch *et al.* 2001; Shields *et al.* 2008).

Nitrogen in runoff is speciated into various forms: ammonium, nitrate, nitrite, and organic nitrogen. Taylor *et al.* (2005) characterized the composition of nitrogen in urban stormwater runoff in a study conducted in Australia and found that total dissolved nitrogen is a larger portion (~80%) of total nitrogen (TN) of the runoff. The study also revealed that organic nitrogen is the major (> 50%) and ammonia is the least-abundant (~11%) constituent of TN in stormwater runoff. Phosphorus occurs in both organic and inorganic forms that can be either dissolved or particulate in nature. The typical concentrations of the various nitrogen and phosphorus species in urban stormwater runoff are: nitrate 0.01 – 5 mg L^{-1}; TKN 1 – 50 mg L^{-1}; and total phosphorus 0.5 – 20 mg L^{-1} (Lee *et al.* 2003; Stagge 2006).

Figure 32 illustrates the possible fate and transformations of nutrients in a wetpond or wetland-like environment. The biochemical reactions are governed by the presence of aerobic or anaerobic conditions in the system, which create redox gradients in the soil and water columns. Redox conditions are influenced by hydrological fluctuations, the presence of electron acceptors (O_2, NO_3^- SO_4^{2-}), and transport of oxygen by plants into the root zones

(Reddy and D'Angelo 1997). Since nutrients can be associated with suspended solids, removal mechanism of suspended solids is also included in Figure 32.

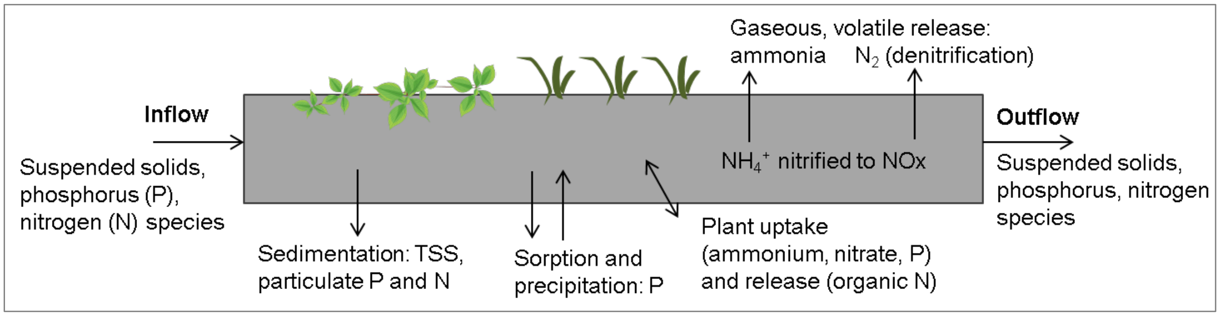


Figure 32. Schematic of possible pollutant (TSS, nitrogen, and phosphorus) removal mechanisms in stormwater infiltration basins, wetponds, and wetlands.

In a wetpond or wetland environment, nitrogen and phosphorus are utilized via complex biogeochemical cycling, which involves many pathways, sinks and sources (Kadlec and Knight 1996). The species are partitioned into particulates, dissolved in water, sorbed, and exist in biomass phases. The nitrogen species transform from organic to inorganic and vice-versa via chemical and biologically-mediated transformations, as shown in Figure 32. Ammonium nitrogen (NH_4^+-N) is transformed into oxidized nitrogen (NO_x) by nitrifying bacteria. Some NH_4^+-N is lost through volatilization. Under saturated conditions, reducing (anoxic) conditions likely develop in the soil and diffusion of the water into the anoxic soil zone favors denitrification to convert NO_x species to N_2 or NH_4^+-N (Reddy and D'Angelo 1997; Galloway *et al.* 2003; Vymazal 2007). Additionally, microbes can take up N for carrying out energy-generating reactions. Plants can assimilate N into their tissues and their senescence can release nitrogen back to the water column (Vymazal 2007; Fennessey *et al.*

2008). Temperature can significantly affect mineralization, nitrification, and denitrification processes (Kadlec and Knight 1996).

Phosphorus is regulated via various abiotic and biotic processes such as sedimentation, adsorption, plant uptake, and microbial reactions. Mineralization of plant litter and soil organic-P can release P into the water. Precipitation and dissolution of the nitrogen and phosphorus species are influenced by factors such as redox potential, temperature of the sediment and water, and pH (Reddy and D'Angelo 1997).

The removal of pollutants in a wetpond, wetland, or detention basin is a function of residence time, which is defined as the mean time spent by a flow parcel in the basin (Walker 1998; Wang *et al.* 2004; Wadzuk *et al.* 2010). Extended residence time provides opportunity for components to be acted upon either biologically or chemically. Presence of vegetated regions can impart a baffle-effect that can increase the residence time and promote sedimentation and other biological reactions (Nepf 1999; Serra *et al.* 2004). Wind and submerged vegetation can also play a role in the mixing of water in free water surface wetland (Kadlec 2003).

Birch *et al.* (2005) studied the efficiency of an infiltration basin, located in Sydney (Australia), in removing pollutants from urban stormwater runoff and reported reduction in total suspended solids (TSS) (50%), total phosphorus (TP) (51%), and total Kjeldahl nitrogen (TKN) (65%). But increased NO_x levels were observed in the outflow due to presence of aerobic conditions in the sand filter of the infiltration basin, facilitating oxidation of organic nitrogen to ammonia and subsequently to nitrate.

Both wetponds and wetlands have been found to be effective in removing pollutants from urban stormwater runoff. Removals in the range of 80 – 90% for TSS, 21 – 50% TKN, 22 – 58% NO_x, 16 – 48% TN, and 19 – 65% TP were reported (Wu *et al.* 1996; Carleton *et al.* 2000; Comings *et al.* 2000; Mallin *et al.* 2002; Birch *et al.* 2004; Brydon *et al.* 2006; Vymazal 2007). These research studies were conducted in the U.S. (Wu *et al.* 1996; Comings *et al.* 2000; Carleton *et al.* 2000; Mallin *et al.* 2002), Canada (Brydon *et al.* 2006), and Australia (Birch *et al.* 2004). In the research studies on wetponds, highly variable removal efficiencies were reported for phosphorus, generally <50%, sometimes exhibiting phosphorus export. Also, wetponds performed poorly when removing dissolved constituents, whose removals occur via adsorption to sediments or biological uptake (Comings *et al.* 2000).

The previous research studies on stormwater infiltration basins, wetlands, and wetponds demonstrate abilities of these systems to transform and remove phosphorus and nitrogen species. Thus, it was hypothesized that a 'transforming' infiltration basin with characteristics of wetland or wetpond will provide an environment for pollutants to undergo transformations and thus enhance the quality of the stormwater runoff.

As a second objective of this research, performance of the transitioning infiltration basin in removing nutrients from the roadway runoff was quantified. Concentrations of various nitrogen and phosphorus species in the inflow runoff and discharge were monitored for several storm events and for periods between storm events. The quality of the water discharged from the facility was evaluated based on established water quality goals and various performance metrics. Trends in water quality performances associated with season and rainfall characteristics were also determined.

4.3.2 Results and Discussion

In total, 38 storm events were monitored and sampled for water quality at the infiltration basin from August 2009 to August 2012. The distribution of the storm events sampled for water quality was representative of the overall rainfall distribution at the infiltration basin site. Also, 54 dry-weather samplings were performed during the entire monitoring duration.

All water samples were analyzed for total phosphorus, nitrate, nitrite, and TKN. In some cases, measurements for ammonium and dissolved phosphorus were additionally performed. Mean, median, and range of EMCs and masses of phosphorus (total and dissolved), and nitrogen species (nitrate, nitrite, TKN, and ammonium) for the sampled storm events have been summarized in Table 12 and Table 13, respectively. The water quality criteria (from Table 4 in "Materials and Methods" chapter) for each pollutant are also included in the table. In Table 12, statistically significant EMCs for the 14 storm events with both inflow and outflow have been indicated.

Table 12. Mean, median, and range of pollutant event mean concentrations (EMCs) for storm events monitored for water quality at the infiltration basin from August 2009 to August 2012.

Pollutant	Water quality criteria (mg L^{-1})	n	EMCin (mg L^{-1})			EMCout (mg L^{-1})		
			Mean	Median	Range	Mean	Median	Range
Total phosphorus*	0.05	38	0.31	0.29	0.050 – 0.60	0.046	NF	NF – 0.21
Total dissolved phosphorus *	0.05	15	0.15	0.12	0.039 – 0.45	0.032	0.01	NF – 0.11
Nitrate (as N) *	0.2	32	0.46	0.38	(< 0.10) – 1.2	< 0.10	NF	NF – 0.30
Nitrite (as N) *	1.0	36	~0.016	~0.014	(< 0.01) – 0.042	< 0.01	NF	NF – 0.032
TKN (as N) *	-	37	1.6	1.5	0.96 – 3.2	0.34	NF	NF – 1.2
Ammonium (as N) **	-	9	0.45	0.28	0.05 – 1.2	< 0.14	< 0.14	NF – 0.28
Total N[b]	-	32	2.1	1.9	1.2 – 4.1	0.40	NF	NF – 1.3

n = number of events sampled; **NF** = no flow; $*\alpha = 0.01$; $**\alpha = 0.05$ (α = level of significance)
[b]Total N = (Nitrate + Nitrite + TKN)

Table 13. Mean, median, and range of pollutant mass for storm events monitored for water quality at the infiltration basin from August 2009 to August 2012. Negative values indicate export of pollutant.

Pollutant	n	Mass in (*kg*)			Mass out (*kg*)			Mass removal (%)	
		Mean	Median	Range	Mean	Median	Range	Mean	Range
Total phosphorus	38	0.040	0.025	0.001 – 0.026	0.016	NF	NF – 0.18	82	(-16) – 100
Total dissolved phosphorus	15	0.022	0.02	0.001 – 0.075	0.011	0.002	NF – 0.064	76	(-18) –100
Nitrate (as N)	32	0.072	0.028	0.002– 0.738	0.015	NF	NF – 0.18	88	20 – 100
Nitrite (as N)	36	~0.002	~0.001	~(10^{-3}) – 0.009	~0.001	NF	NF – 0.009	77	(-25) – 100
TKN (as N)	37	0.21	0.11	0.015 – 1.3	0.1	NF	NF – 0.87	77	(-13) – 100
Ammonium (as N)	9	0.060	0.039	0.015 – 0.19	0.032	0.015	NF – 0.12	63	(-13) – 100
Total N	32	0.28	0.15	0.025 – 1.7	0.10	NF	NF – 1.1	82	6 – 100

n = number of events sampled; **NF** = no flow

4.3.2.1 Phosphorus

The infiltration basin exhibited good removal of phosphorus (Table 12 and Table 12). In the 38 sampled storm events, the total phosphorus (TP) EMC levels in the inflow runoff were between 0.10 and 0.60 mg L^{-1} (median = 0.29 mg L^{-1}). The outflow EMCs ranged between 0.06 and 0.21 mg L^{1} (median = 0 mg L^{-1}; no discharge). Although the outflow EMCs were significantly lower than inflow EMCs during all 14 events (α = 0.01), the discharge TP concentrations exceeded the stringent water quality criterion of 0.05 mg L^{-1} during all 15 storm events with outflow.

Figure 33 shows the probability exceedence plot for TP based on EMC data of 38 sampled storm events.

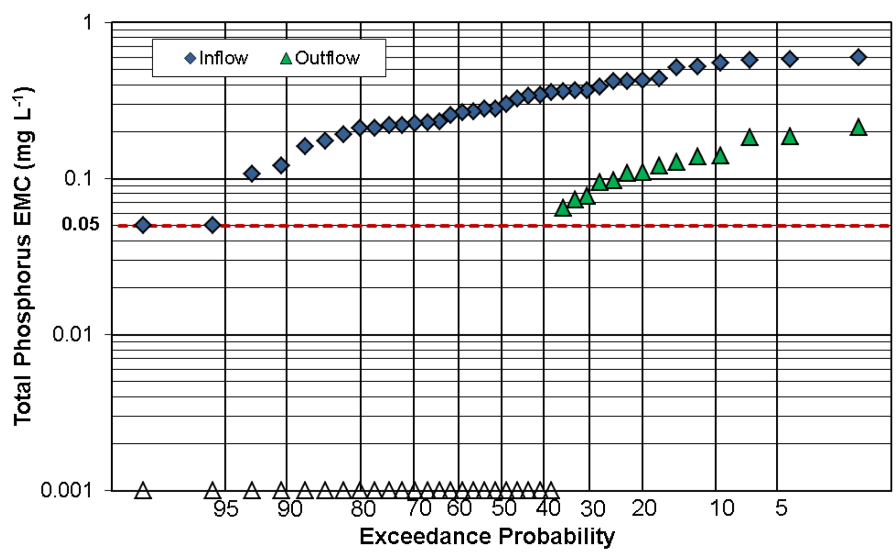


Figure 33. Probability plot for total phosphorus EMCs at the MD175 infiltration basin site. Open symbols represent storm events with no outflow. Dashed line represents the water quality target criterion (0.05 mg L^{-1}).

The inflow TP levels exceeded the water quality target value of 0.05 mg L^{-1} greater than 95% of the time. Although all measured discharge TP EMC values were greater than the water quality goal, the median discharge TP value is zero mg L^{-1} resulting from no discharge. About 40 % of the discharge TP EMCs are expected to exceed the stringent target value of 0.05 mg L^{-1}.

Figure 34 shows the duration of instantaneous total phosphorus input and discharge from the infiltration basin. Both inflow and outflow TP levels exceeded the stringent water quality criterion of 0.05 mg L^{-1} during most of the period. While the inflow concentration exceeded the water quality criterion for 466 hours, the discharge exceeded the water quality criterion for 284 hours.

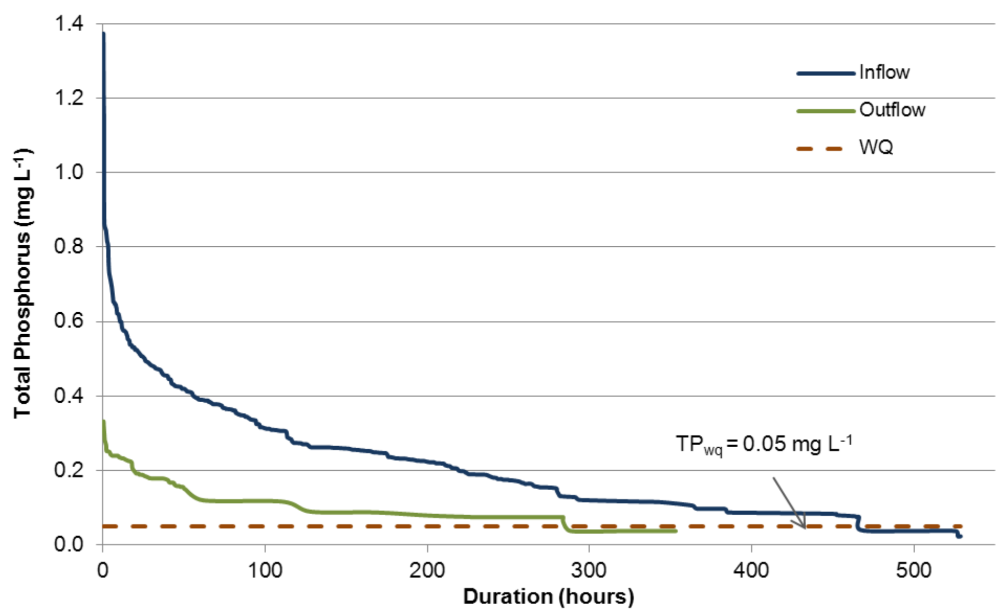


Figure 34. Pollutant duration curve for total phosphorus (TP) at the infiltration basin for the entire monitoring duration. Dashed line represents the water quality criterion (0.05 mg L^{-1}).

Efficiency of the infiltration basin in removing the TP mass varied between (-16) and 100% (median = 100%) during the 38 sampled storm events (Table 12). Phosphorus mass export occurred during a winter storm event (Jan 18, 2010) and a large storm event (rainfall depth = 5.61 *cm*) in spring (March 9, 2011). Both these events recorded outflow volumes in excess of the inflow volumes (32 and 39%, respectively). Also, these storm events recorded high outflow EMCs of 0.19 mg L^{-1} and 0.18 mg L^{-1}, respectively.

The cumulative total phosphorus mass input and output for the 38 monitored events were 1.5 and 0.6 *kg*, respectively. This shows that the total input TP mass reduction achieved through the infiltration basin was 61% for the monitoring duration. Since the cumulative volume reduction (31%) was observed for the 38 monitored storm events, a part of the cumulative TP mass removal can be attributed to the water volume reduction.

4.3.2.1.1 Phosphorus Speciation

In order to understand the phosphorus removal mechanism in the infiltration basin, selected samples were analyzed for dissolved phosphorus (DP) in addition to total phosphorus (TP). Particulate phosphorus (PP) levels were determined as the difference between total and dissolved phosphorus levels. A total of 15 storm events were tested for DP, of which eight storm events produced outflow.

Figure 35 shows the particulate (PP) and dissolved phosphorus (DP) pollutographs for the Sept 23, 2011, rainfall event. The inflow and outflow PP EMCs were 0.097 and 0.056 mg L^{-1}, respectively. The inflow and outflow DP EMCs were 0.168 and 0.072 mg L^{-1}, respectively. The PP and DP mass removal efficiencies for this event were 52% and 64%, respectively. For this event, most of the phosphorus in the inflow was in the dissolved form (63% by mass). In the outflow, 56% of total P was in dissolved form.

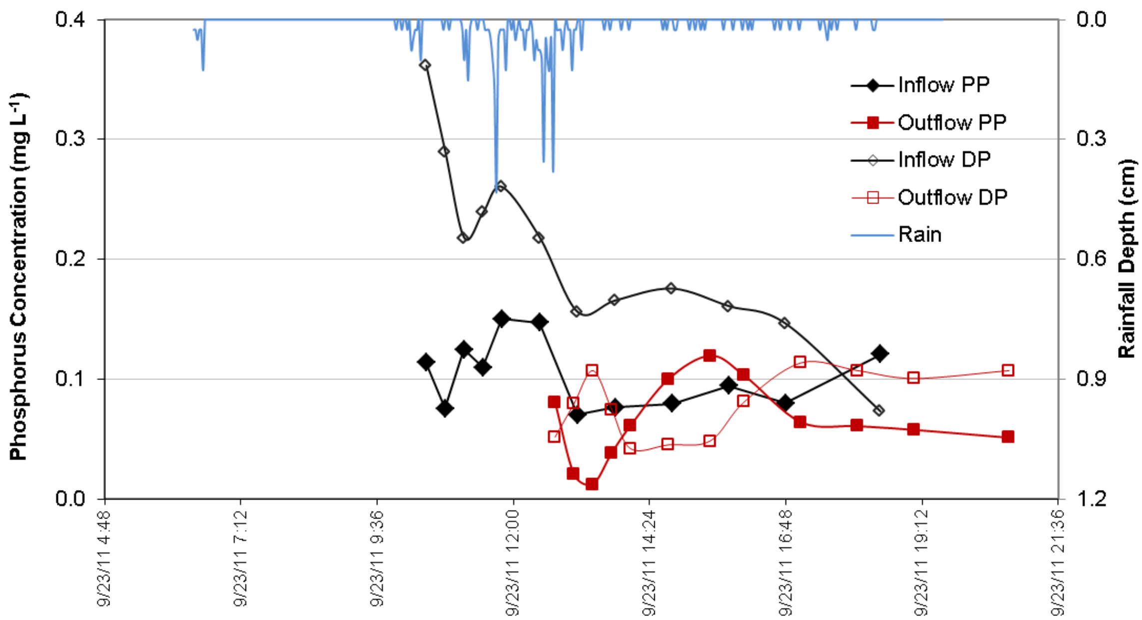


Figure 35. Concentrations of inflow and outflow particulate phosphorus (PP) and dissolved phosphorus (DP) recorded during the Sept 23, 2011 rainfall event.

For the 15 sampled events, the inflow particulate phosphorus (PP) EMCs ranged between 0.067 and 0.33 mg L^{-1} (median = 0.12 mg L^{-1}). This corresponds to 22 to 86 % of inflow TP levels (median = 46%). The outflow PP EMCs ranged between 0.040 and 0.103 mg L^{-1}(median = 0.07 mg L^{-1}), which is 41 to 87% of outflow TP levels (median = 46%) for the eight events with outflow data. The discharge PP EMCs were less than the inflow PP EMCs for all eight events. The mass removals of PP ranged between 14 and 100% (median = 77%).

The inflow DP event mean concentrations ranged between 0.039 and 0.45 mg L^{-1} (median = 0.12 mg L^{-1}); which is 14 to 78 % of inflow TP levels (median = 54%) for the 15 sampled storm events. The outflow DP EMCs ranged between 0.010 and 0.11 mg L^{-1} (median = 0.01 mg L^{-1}); which corresponds to 13 to 59% of outflow TP levels (median = 54%) for the eight events with outflow data. Although no export of PP mass was observed during any storm event, export of dissolved phosphorus mass (18%) occurred during one winter storm event (Dec 8, 2011). Also, the discharge DP EMC (0.08 mg L^{-1}) was higher than the inflow DP EMC (0.07 mg L^{-1}) for this event. Export of dissolved phosphorus from two wetponds in fall and winter was noted in a study conducted by Comings *et al.* (2000). The DP mass removals in the infiltration basin ranged between 22 to 90% for the remaining seven events. The DP EMCs exceeded the selected water quality criterion of 0.05 mg L^{-1} during five storm events.

While the DP and PP EMCs showed the variability involved in the nature and removal of the phosphorus species loading to the infiltration basin, the analysis of the individual sample concentrations of dissolved and particulate phosphorus in the inflow and outflow samples presented some interesting results. The sample concentrations of inflow dissolved phosphorus ranged between 0.04 – 0.65 mg L^{-1} (median = 0.17 mg L^{-1}) and that of outflow dissolved phosphorus ranged between 0.01 – 0.11 mg L^{-1} (median = 0.08 mg L^{-1}). The inflow particulate phosphorus sample concentrations ranged between 0.05 – 0.59 mg L^{-1} (median = 0.11 mg L^{-1}). The outflow particulate phosphorus sample concentrations ranged between 0.01 – 0.20 mg L^{-1} (median = 0.09 mg L^{-1}). These data suggest that both PP and DP levels in the inflow runoff were variable. However, the variability associated with the outflow DP concentrations was less when compared to the outflow PP levels. Comparison of the storm event DP and PP data with the grab sample data yielded more information on the possible removal mechanism of phosphorus in the infiltration basin.

4.3.2.1.2 Grab Sample Water Quality

Figure 36 shows the average total phosphorus levels in the grab samples collected during the inter-event periods at the infiltration basin. The TP concentrations ranged between 0.06

and 0.45 mg L^{-1}(median = 0.14 mg L^{-1}). Speciation of phosphorus into particulate and dissolved forms was performed for 21 grab sample sets. The particulate phosphorus concentration ranged between 0.01 – 0.19 mg L^{-1} (median = 0.06 mg L^{-1}) and the dissolved phosphorus concentrations ranged between 0.01 – 0.09 mg L^{-1} (median = 0.05 mg L^{-1}) in these 21 sample sets.

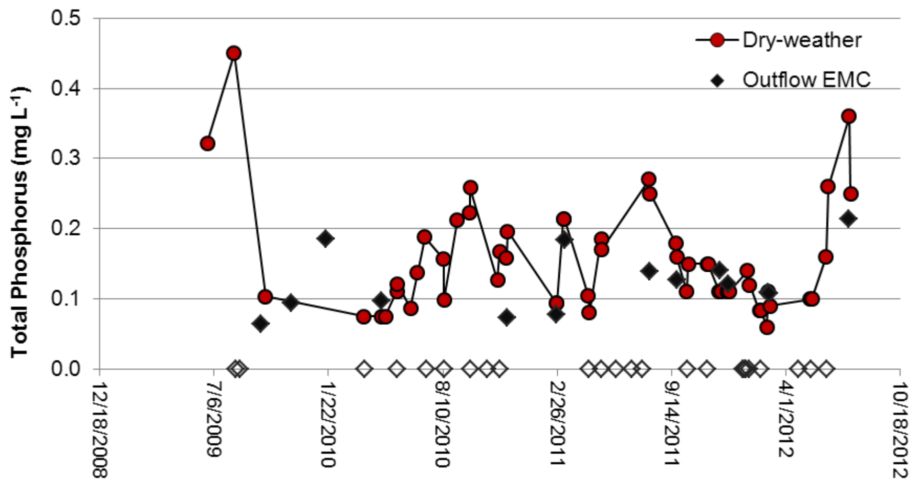


Figure 36. Concentrations of total phosphorus in the dry-weather samples collected at the infiltration basin site from June 2009 to Aug 2012. The outflow EMCs for the storm events are also plotted. Open symbols represent storm events with no outflow.

Interestingly, the grab sample DP levels are similar to the DP concentrations in the outflow samples (0.01 – 0.11 mg L^{-1}; median = 0.08 mg L^{-1}). Based on the concentration ranges, it can be deduced that while the dissolved P levels were more uniform in the grab samples, the particulate P levels in the grab samples were mixed. The more or less uniform DP levels in the stored water suggest that this DP must be recalcitrant or represents a background phosphorus level, as observed in treatment and vegetated wetlands (Kadlec and Knight 1996; Juston and DeBusk 2011).

4.3.2.1.3 Phosphorus Removal Mechanism

Figure 37 shows the inflow pollutographs of TSS and TP during a sample storm event. Similar to TSS, a first flush phenomenon was observed in the inflow runoff and the concentration profiles of the two pollutants matched for the majority of the storm events. The similarity in profiles suggests a strong relation between TSS and phosphorus that could be associated with the suspended solids.

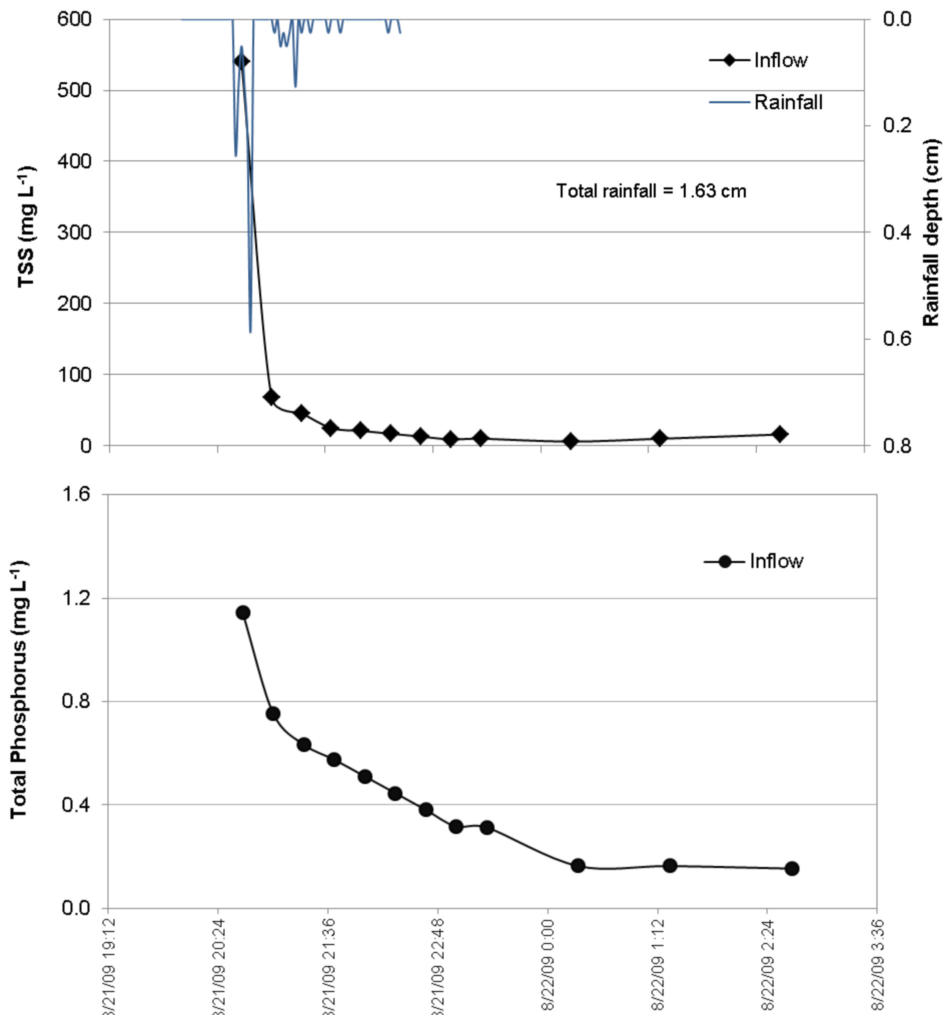


Figure 37. Inflow total suspended solids (TSS) and total phosphorus (TP) concentration profiles recorded during the Aug 21, 2009, rainfall event.

The relationship between TSS and phosphorus constituents was further analyzed by determining the correlation between TSS and particulate phosphorus (PP) concentrations (Figure 38). The individual sample concentrations of TSS and PP measured for all storm events were used in this plot. As expected, a good linear correlation ($R^2 = 0.49$) between the inflow TSS-PP concentrations was observed. Positive correlations between TSS and phosphorus levels in stormwater runoff have been observed in other research studies (Wu *et al.* 1996; Mallin *et al.* 2002). The linear correlation between the outflow TSS and PP was, however, poor ($R^2 = 0.098$).

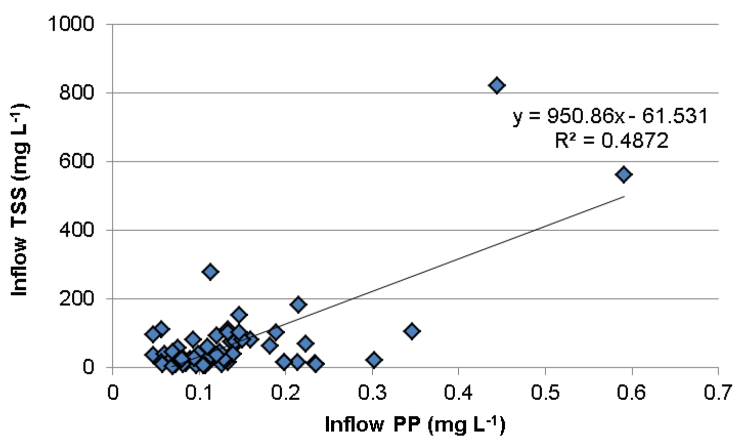


Figure 38. Correlations of TSS and particulate phosphorus concentrations in inflow runoff to the infiltration basin site.

The phosphorus removal mechanisms can be deduced based on the concentration of particulate and dissolved P in the inflow, outflow, and grab samples and the relationship between TSS and PP. The decrease in TP concentration through the infiltration basin can be partly attributed to settling of particulate phosphorus during the course of the storm event. Removal of the TSS by sedimentation during the detention period will contribute to the removal of the any phosphorus associated with the settling solids. Removal of particulate phosphorus by sedimentation has been reported by other studies as well (Wu *et al.* 1996; Reddy and D'Angelo 1997). The dissolved P can be removed via adsorption to sediments or biological uptake or simply by dilution. The similarity in the dissolved P levels in the outflow samples (median = 0.08 mg L^{-1}) and grab samples (median = 0.05 mg L^{-1})suggest that while a portion of the inflow DP could be removed via adsorption/biological uptake during a storm event, a part of the DP in the outflow is the recalcitrant DP flushed out from the infiltration basin.

There is no evidence of internal loading of phosphorus from sediments between storm events since the inter-event grab samples showed small variation in the phosphorus levels. The average total phosphorus level in the 54 grab sample sets was 0.16 ± 0.07 mg L^{-1}. The mean inter-event dissolved phosphorus level was 0.05 ± 0.02 mg L^{-1}. This suggests that the water in the infiltration basin contains a background phosphorus concentration which can consist of both bioavailable and recalcitrant compounds (Kadlec and Knight 1996; Juston and DeBusk 2011).

4.3.2.2 Nitrogen

Nitrogen species nitrate, nitrite, and total Kjeldahl nitrogen (TKN) were analyzed for all water quality samplings. Nine composite sample sets collected were analyzed for ammonium-N in addition to other nitrogen species. Due to equipment failure, nitrate-N data are unavailable for the period February through July 2011. Samples collected during this period were analyzed for nitrite-N and TKN only.

4.3.2.2.1 Nitrite

In general, nitrite-N concentrations were low in the water samples collected during storm events. In the inflow, individual sample concentrations of nitrite-N ranged between (< 0.01) and 0.09 mg L^{-1}. Sample outflow nitrite-N levels were around or below the laboratory detection limit of 0.01 mg L^{-1}. The inflow nitrite-N EMCs ranged between (< 0.01) and 0.042 mg L^{-1}. The discharge nitrite-N EMCs ranged between (< 0.01) and 0.032 mg L^{-1}. The discharge nitrite-N EMCs were always lower than the inflow EMCs during all storm events. The discharge EMCs of nitrite-N were much lower than the water quality criterion of 1 mg L^{-1} in all 15 events that produced outflow. The nitrite mass removals varied between (-25) and 100 %, with mass exports occurring during two winter events (Jan 18, 2010, and Dec 8, 2011). The median mass removal efficiency was 100% for 36 sampled storm events.

4.3.2.2.2 Nitrate

EMCs of nitrate-N ranged between (<0.10) and 1.2 mg L^{-1} in the influent (median = 0.38 mg L^{-1}) and between (<0.10)5 and 0.30 mg L^{-1} in the outflow (median = 0 mg L^{-1}; no discharge) (Table 12). The discharge EMC levels were less than that of influent in all events. The discharge nitrate EMCs exceeded the water quality criterion of 0.20 mg L^{-1} during 3 winter events (Jan 18, 2010, Dec 8, 2011, and Feb 29, 2012). The highest outflow EMC of 0.30 mg L^{-1} NO_x-N was recorded during the Jan 18, 2010 storm event. The nitrate mass removals varied between 20 and 100% (median = 100%) for 32 sampled events (Table 12). Although no net export of nitrogen mass was observed during any storm event, reduced mass removals were observed during winter periods.

The discharge NO_x (nitrate +nitrite) EMCs were lower than that of inflow in all 32 sampled events. The statistics tests showed that the outflow NOx EMCs were significantly lower than the inflow EMCs both from an overall performance (32 storm events) and treatment (14 storm events) perspectives (α = 0.01).

4.3.2.2.3 TKN

The inflow TKN EMCs ranged between 0.96 and 3.2 mg L^{-1} and the outflow EMC levels were between 0.43 and 1 mg L^{-1} (Table 12). The TKN outflow EMCs were lower than the inflow EMCs during 36 storm events, the exception being one winter event (Feb 24, 2011). Based on all 14 sampled events with outflow, the outflow EMC values were significantly lower than inflow EMCs (α = 0.01).

As noted for nitrate and nitrite, the worst removal of TKN was observed during the winter rainfall events (Jan 18, 2010, Feb 24, 2011, and Dec 8, 2011) and during a large storm event (rainfall depth = 5.61 *cm*) on March 9, 2011. During these events, export of TKN mass was observed (13 to 0.37%). Excluding these four storm events, the TKN mass removal efficiencies ranged between 5 and 100% (Table 12).

The pollutant duration curves for TKN and NO_x-N species are shown in Figure 39. With respect to the water quality criterion for NO_x-N (1.2 mg L^{-1}), the runoff flowing into the infiltration basin contained NO_x levels greater than 1.2 mg L^{-1} for a duration of 15 hours. However, the runoff discharged met the 1.2 mg L^{-1} water quality criterion for NO_x the entire duration.

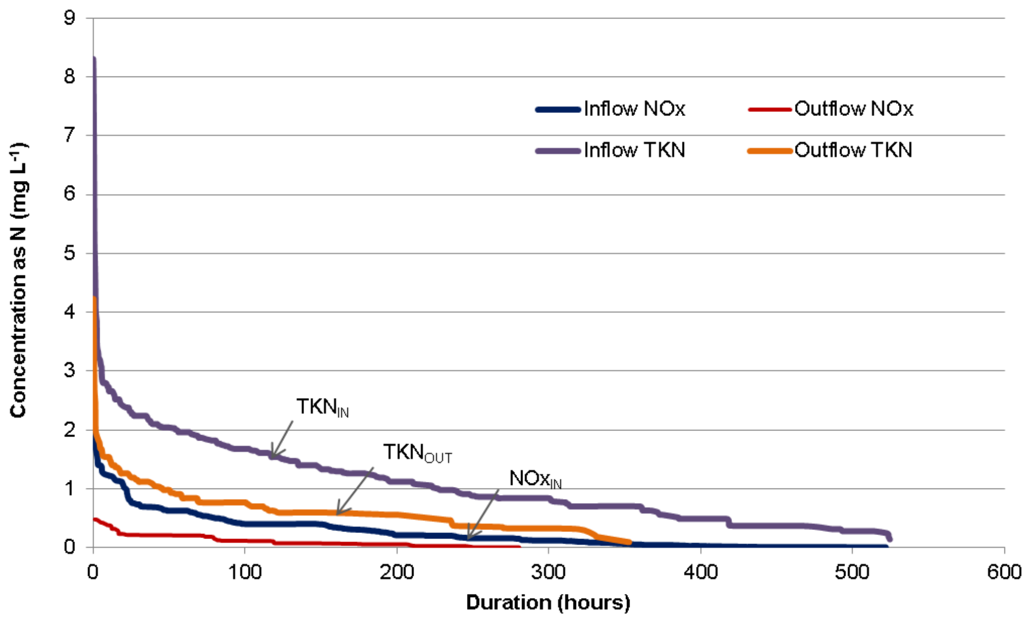


Figure 39. Pollutant duration curves for nitrogen species (TKN and NO_x-N) at the infiltration basin site for the entire monitoring duration.

Total nitrogen (TN) was determined as the sum of nitrogen species: nitrate, nitrite, and TKN (TN = NO_3-N + NO_2-N + TKN-N). Based on data available for all nitrogen species, the TN event mean concentrations in the runoff to the infiltration basin ranged between 1.2 and 4.1 mg L^{-1} during 32 storm events (Table 12). The discharge TN EMCs ranged between 0.59 and 1.3 mg L^{-1}. The mass removal efficiency for TN varied between 6 and 100 % (median = 100 %) for the 32 storm events. Thus, the infiltration basin exhibited good removal of TN from the highway runoff.

4.3.2.2.4 Nitrogen Speciation

In order to analyze the characteristics of nitrogen in the runoff and to understand the nitrogen dynamics in the infiltration basin, a comprehensive analysis was performed to speciate the runoff samples into the various nitrogen species (nitrate, nitrite, TKN, and ammonium) for selected rainfall events.

Excluding six storm events with no nitrate data, TKN was found to be the largest portion of TN in both inflow (median = 81%; 32 storm events) and outflow (median = 87%; 12 storm events). This observation is in agreement with the study by Taylor *et al.* (2005) in which TKN was found to be the major constituent (~70%) of total nitrogen in urban stormwater runoff.

Ammonium-N concentrations were determined for nine storm events. Organic nitrogen level was obtained as the difference between TKN and ammonium levels. Comparing the organic nitrogen and ammonium-N concentrations in these samples, organic nitrogen was the dominant fraction of TKN in both inflow and outflow samples. While organic nitrogen (ON) concentrations were 54 – 96% of TKN in inflow, outflow TKN consisted of 70 – 92% organic-N. The median ON concentrations in the inflow and discharge were 1.2 and 0.65 mg L^{-1}, respectively. For comparison, the median organic-N (ON) concentrations in the inflows and discharges were 1.09 and 0.78mg L^{-1}, respectively, at seven stormwater wetlands in North Carolina (Moore *et al.* 2011). The median ON:TN ratios for inflow and outflow at the infiltration basin facility were 0.82 and 0.89, respectively. This is in comparison to the median ON:TN ratios of 0.66 and 0.75 in the inflow and discharge, respectively, in stormwater wetlands (Moore *et al.* (2011).

Overall, the concentrations of nitrogen species observed at the infiltration basin are in agreement with the median concentrations of various nitrogen species observed in stormwater runoff from a variety of urban land uses (Taylor *et al.* 2005; Collins *et al.* 2010, and Moore *et al.* 2011).

The cumulative pollutant mass inputs and outputs (in *kg*) for all nitrogen species measured for the 38 events are summarized in Table 14. These correspond to mass removal efficiencies of 79% nitrate-N, 52% nitrite-N, 79% NOx-N (nitrate + nitrite), 51% TKN, and 64% total N, for the entire monitoring duration. This shows that the nutrient input pollutant loads were reduced by the infiltration basin. The 30% volume reduction observed during the 38 monitored storm events partially contribute towards the mass removals.

Table 14. Total pollutant mass input and output at the infiltration basin for 38 monitored rainfall events from August 2009 to August 2012.

Pollutant	Mass Input (*kg*)	Mass Output (*kg*)
Nitrate (as N)	2.3	0.47
Nitrite (as N)	0.063	0.03
NOx (as N)	2.4	0.5
TKN (as N)	7.6	3.7
Total N	9.0	3.2

4.3.2.2.5 Nitrogen Removal Mechanisms

For the 38 storm events sampled for water quality, the volume reductions ranged between 6 and 100 % during 34 storm events (as discussed in the 'Hydrologic Performance' chapter). While a part of the removal of nitrogen mass can be attributed to the observed volume reductions during these storm events, the physical and biological processes aiding N removal in the infiltration basin were specifically identified based on the concentrations of various nitrogen species in the water. Nitrate and nitrite are primarily dissolved components in the water (Taylor *et al.* 2005). Removal of NO_x must occur through conversion of nitrite to nitrate and denitrification of nitrate to N_2 for complete removal of NO_x (Reddy and D'Angelo 1997).

The nitrate and nitrite levels in the grab samples collected between storm events were usually around or below their respective detection limits (Table B-1 in Appendix B) (nitrite detection limit = 0.01 mg L^{-1}; nitrate detection limit = 0.1 mg L^{-1}). The NO_x concentrations ranged between (< 0.06) and 0.21 mg L^{-1} in the grab samples collected. The NO_x levels in the samples collected before and after a storm event were usually less than 0.06 mg L^{-1}. This suggests that the conditions in the infiltration basin enabled removal of NO_x during inter-storm periods.

The oxidation-reduction potential (ORP) measurements of the water in the infiltration basin support processing of NO_x through denitrification during storm events and dry periods. Figure 40 shows the ORP measurements taken during December 2011.

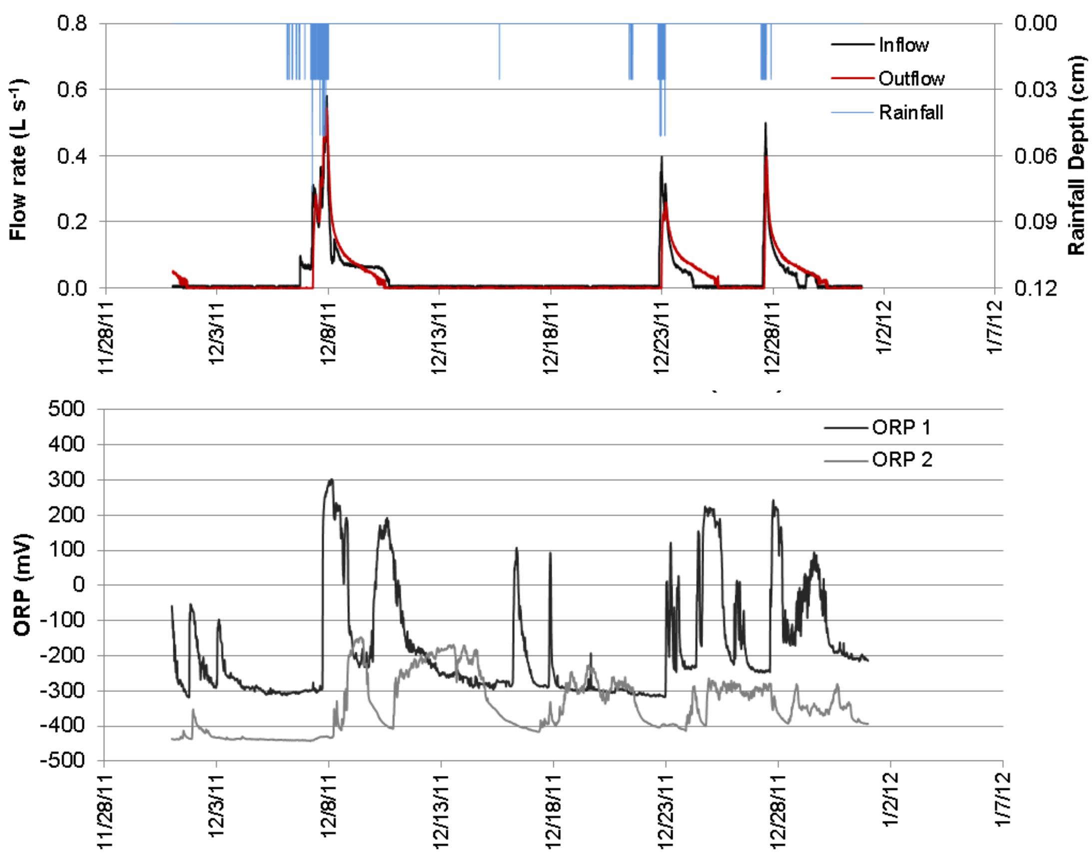


Figure 40. Oxidation-reduction potential measured in the infiltration basin during Dec 2011. ORP 1 and ORP 2 were recorded near the inlet and outlet sides of the infiltration basin, respectively. Also included are the inflow and outflow hydrographs for the month (top figure).

The ORP of the water column remained largely negative (-100 to -400 *mV*) during dry periods. During a storm event, ORP increased to more positive values due to fresh input of runoff into the infiltration basin.

As can be seen in Figure 40, the ORP values measured by the two probes were different. One reason could be because probes were installed in two different locations in the infiltration basin. The second reason could be due to the fluctuation observed in the overall accuracy of ORP probes (50 – 100 *mV* margin), in general.

Based on the one-year continuous measurements, the ORP of the water column remained low positive to large negative (-400 to 200 *mV*) in the anoxic/anaerobic range during most dry periods. The presence of anoxic conditions within the infiltration basin is conducive for nitrate removal through denitrification during inter-storm periods (Kadlec and Knight 1996; Reddy and D'Angelo 1997). The pH of the water remained within the 6 to 8 range for most periods, which falls within the optimal pH range of 7 to 8.5 for denitrification (Kadlec and Knight 1996).

The existing vegetation at the infiltration basin also provided evidence of prevalence of wetland-like conditions at the site. The emergent vegetation (softstem bulrush) established at the fringe of the infiltration basin, and floating vegetation (floating primrose-willow) were identified as 'obligate' wetland plants that are found in wetlands only. The wetland conditions support the hypothesized nitrate removal mechanism via denitrification. The details on all vegetation types identified at the infiltration basin are presented in the 'Ecological Value of the Infiltration Basin' chapter. Removal of nitrate during a storm event could largely be due to dilution and volume reduction.

While NO_x removals were very good, removal of TKN was moderate and mixed in the infiltration basin. This can be attributed to the removal mechanisms governing each component of TKN in the runoff. TKN primarily consists of dissolved and particulate organic-N and a small portion of dissolved ammonium in urban stormwater runoff (Taylor *et al.* 2005). Although the ammonium concentrations were found to low in the water samples, removal of ammonium must occur through nitrification and plant uptake (Reddy and D'Angelo 1997).

The dry-weather monitoring showed that the TKN concentration ranged between 0.30 and 3.7 mg L^{-1} (median = 1.1 mg L^{-1}) in the inter-storm periods. Speciation of TKN was not performed for the grab samples. However, the TKN levels in the water stored in the infiltration basin in between storm events were around the same concentration (~1 mg L^{-1}).

Based on the concentrations of TKN in the inflow, outflow, and dry-weather samples, it was deduced that most of the TKN in the infiltration basin water was organic nitrogen. Given the location of the infiltration basin, the source of organic-N in the runoff must be from plants in the upstream swale area. The recorded pollutographs of inflow TKN showed stronger first flush behavior compared to nitrate and nitrite during several storm events. If the particulate organic-N can be assumed to follow the TSS trend, some removal of TKN can be expected to occur by sedimentation of the particulate organic-N component.

The dissolved organic-N (DON) in marine and aquatic systems was historically considered to consist of refractory compounds that are resistant to biological degradation and unavailable as N source to organisms (Berman and Bronk 2003). However, several studies have recognized that DON can provide a source of nitrogen to phytoplanktons and bacteria in aquatic ecosystems (Stepanauskas *et al.*, 1999; Berman and Bronk 2003; Seitzinger *et al.*

2002; Kaushal and Lewis 2005; Wiegner *et al.* 2009). The bioavailability of dissolved organic-N varies depending on the source. For instance, research by Seitzinger *et al.* (2002) showed that about 59±11% of org-N was bioavailable in stormwater runoff from urban watersheds compared to 30±14% for agricultural and 23±19% for forested watersheds.

Moderate removal of TKN, consistent TKN levels (~1 mg L^{-1}) in the water stored in the infiltration basin during inter-storm periods, and predominance of organic-N in the inflow and outflow, suggest the organic-N in the discharge from the infiltration basin consists of both recalcitrant and bioavailable portions. Similar to a natural wetland, stormwater wetlands were found to contain a consistent background organic-N concentration and limited organic-N removal, likely attributed to internal loading from plants (Moore *et al.* 2011). In the current study, plants growing within the infiltration basin can assimilate N into their tissues and their senescence can release nitrogen back to the water column (Fennessey *et al.* 2008).

4.3.2.3 Annual Pollutant Mass Loads

Annual pollutant mass load per unit drainage area are important parameters employed towards design of a SCM in a watershed (Li and Davis 2009). The annual pollutant mass load per unit drainage area (L, in *kg* ha^{-1} yr^{-1}) was estimated for each pollutant using Equation 10:

$$L = \frac{M}{A} \times \frac{P_{average}}{P_{observed}} \qquad (10)$$

In Equation 10, M_{in} is the overall input pollutant mass (in *kg*), A is the drainage area of the infiltration basin (in *ha*), $P_{average}$ is the average annual precipitation [1067 *mm* yr^{-1} for the State of Maryland; MDE 2000], and $P_{observed}$ $P_{observed}$ is the observed cumulative precipitation during the monitoring period (in *mm*). $P_{observed}$ for the 38 monitored events was 762 *mm*.

The annual pollutant mass input (L_{in}) and discharge (L_{out}) at the infiltration basin are summarized in Table 15. The annual pollutant mass discharged from the infiltration basin was lower than the annual pollutant input load for both phosphorus and nitrogen. The annual mass removals were 61% TP, 79% nitrate, 53% nitrite, 78% NO_x, 51% TKN, and 64% total N. This suggests that the infiltration basin effectively reduced pollutant loads and provided an overall improvement in water quality of the water discharged from the facility.

Table 15. Annual pollutant mass input and discharge load of phosphorus and nitrogen based on 38 storm events recorded at the infiltration basin from August 2009 to August 2012. Annual pollutant mass input and discharge values for a bioretention, as reported by Li and Davis (2009), are also included.

Pollutant	Annual Pollutant Mass Load (*kg ha*$^{-1}$ *yr*$^{-1}$)			
	MD 175 Infiltration Basin		Bioretention[a]	
	Input (L_{in})	Output (L_{out})	Input	Output
Total Phosphorus	0.73	0.29	0.9	0.38
Nitrate (as N)	1.3	~ 0.27	3.7	~ 0.19
Nitrite (as N)	~ 0.032	~ 0.015	0.2	~ 0.06
NO_x (as N)	1.3	~ 0.28		
TKN (as N)	3.8	1.8	6.0	3.6
Total Nitrogen	5.1	1.8	9.6	3.6

[a] Li and Davis (2009)

The annual pollutant input loads at the infiltration basin were compared to values for a bioretention facility located in Silver Spring, MD (Li and Davis 2009) (Table 14). The bioretention has a drainage area of 0.9 *ha* (90% impervious) and manages runoff from a parking lot. Comparing the annual pollutant loads at the two SCMs, the mass loads to the bioretention were greater than those to the infiltration basin for nitrogen. Phosphorus loadings were similar at the two sites.

Although the infiltration basin and bioretention SCMs are structurally different and operate on different science, the performances of the two facilities were compared. Based on the annual loading and removal, the annual mass load removal efficiencies of the bioretention were 53% TP, 98% nitrate, 70% nitrite, 40% TKN, and 63% TN. The performance data of the infiltration basin are comparable to the bioretention data: 61% TP, 79% nitrate, 53% nitrite, 51% TKN, and 64% total N removals. Since annual mass loads are important parameters for TMDL models, the infiltration basin research data contribute towards the determination of loads for these models.

4.3.3 Performance Summary for Nutrients

Water quality data from 38 storm events and 54 dry-weather samplings showed overall improvements in the runoff water quality for nutrients. The event mean concentrations (EMCs) of the measured pollutants in the outflow were significantly lower ($\alpha = 0.01$) than those of inflow in all events for both phosphorus and nitrogen species. The outflow EMCs of nitrite-N satisfied the water quality target during all 14 events. The discharge nitrate-N EMC exceeded the selected water quality criteria for 3 out of the 12 monitored events. However, the discharge TP EMCs exceeded the stringent water quality goal of 0.05 mg L^{-1} during all events.

Average mass removal efficiencies of 82% TP, 77% TKN, and 86% NO_x-N 86% were observed at the infiltration basin. This is in comparison to mass removals in the range of 35 – 65% TP, 21 – 50% TKN, 22 – 58% NO_x, and16 – 48% TN, that have been reported for wetponds and wetlands (Wu *et al.* 1996; Carleton *et al.* 2000; Mallin *et al.* 2002; Birch *et al.* 2004; Brydon *et al.* 2006). As observed in the other research studies (Comings *et al.* 2000; Birch *et al.* 2005), highly variable removal efficiencies of nitrogen and phosphorus, sometimes exhibiting phosphorus and nitrogen exports were observed.

Speciation analyses of phosphorus (dissolved vis-à-vis particulate) showed that the particulate P ranged between 22 and 86% of inflow TP levels and 41 to 87% of outflow TP levels. While removal of particulate P ranged between 14 and 100%, export (18%) of dissolved P was observed during one winter storm event. The PP and DP levels were more variable in the inflow runoff than in the outflow.

The speciation analysis and good linear correlation between TSS and particulate P mass loads, along with the grab sampling data, showed that most of the phosphorus removal occurred via sedimentation of particulate P in the infiltration basin. Removal of dissolved P should occur via adsorption and biological uptake. There is no evidence of phosphorus release from the sediments during inter-event periods.

The nitrogen water quality data showed that the infiltration basin is effective in removing the oxidized nitrogen species (NO_x) through denitrification. This is supported by the low oxidation-reduction potential measured in the water column of the infiltration basin and NO_x concentrations below detection limit especially during the dry periods between storm events. The presence of wetland plants also confirm the presence of wetland conditions at the infiltration basin.

TKN (ammonium-N + organic-N) was only partially removed. The speciation analyses showed that majority of the TKN was in the form of organic-N in both inflow and outflow samples. Based on the inter-event TKN levels (~1 mg L^{-1}) and predominance of organic N in discharge (70-90% of TKN), it was deduced that the majority of the TKN was in the organic N form in the water stored between events. While the particulate fraction of organic-N is expected to settle with the solids, a fraction of the dissolved organic-N (DON) may be available for biological uptake. The presence of organic-N in the discharge (median = 0.65 mg L^{-1}) suggests that a background concentration of organic-N will persist in the water, likely due to recalcitrant DON and/or contribution from plants in the basin, as observed in natural wetlands and constructed stormwater wetlands (Seitzinger *et al.* 2002; Moore *et al.* 2011).

With respect to overall performance, the treatment efficiency of the infiltration basin showed seasonal differences. The mass removals ranged between 17 – 100% for total phosphorus, 23 – 100% for TKN and 20 – 100% for NO_x during storm events in spring, summer, and early fall. The poorest nutrient removal performance was observed during the coldest months and this trend repeated each seasonal year. Export of total phosphorus (3 – 16%), nitrite (13 – 25%) and, TKN (0.32 – 13%) masses and low nitrate mass removals (23%) were observed during winter storm events. Similar observations were made in other research studies where performances of wetpond, wetland, and infiltration basin SCMs were observed to be worse during winter than in summer (Oberts 1994; Marsalek 2003; German *et al.* 2003; Semadeni-Davies 2006; Emerson and Traver 2008; Vollertsen *et al.* 2009; Wadzuk *et al.* 2010).

During colder periods, water in the infiltration basin was frozen forming a sheet of ice on the surface which reduced the available detention volume. Also, water losses through evapotranspiration and infiltration were lower during winter (at least 45%) compared to warmer months. The hydrology data indicated that the infiltration basin provided least water quantity control during colder periods due to presence of ice cover. Also, cold temperatures arrest biological activity which affects the water quality performance of the system. Runoff volume reduction is an important consideration for pollutant mass reduction. Changes in the physical and biological processes within the infiltration basin, combined with changes in hydraulic behavior, can impact the overall water quality performance of the infiltration basin. Hence, during the coldest temperatures, the infiltration basin is expected to act as a flow-through system and provide the least benefits, as evident by the poor nutrient removal performance.

Chapter 5: Ecological Value of the Infiltration Basin

The third objective of this research study was to evaluate the ecological value of the infiltration basin. In addition to monitoring hydrology and water quality functions, the vegetation and wildlife at the infiltration basin were recorded throughout the three-year monitoring period. The goal was to collectively qualify the hydrologic, water quality, and habitat conditions at the infiltration basin site in terms of their ecological significance.

5.1 Vegetation and Animals Observed at the Infiltration Basin Site

First, the plants and animals occurring at the MD175 infiltration basin site are described. Figure 41 and Figure 42 show the various species of flora and fauna observed at the infiltration basin site during the three-year research period.

The *2012 National Wetland Plant List* (PLANTS, USDA 2012) of the U.S. Department of Agriculture (USDA) for wetland indicator statuses was utilized to characterize the plants identified at the infiltration basin site. The USDA 2012 PLANTS database replaced the 1988 U.S. Fish and Wildlife Service's National list of plant species that occur in wetlands (Reed 1988) for use under the Clean Water Act, Swamp Buster, and National Wetland Inventory programs. The plant species are classified into five indicator categories based on their preference for occurrence in wetland or upland: *obligate wetland* (occur almost always in wetlands; estimated probability (p) > 99%), *facultative wetland* (usually occur in wetlands, p = 67 - 99%, but occasionally found in nonwetlands), *facultative* (equally likely to occur in wetlands or nonwetlands; p = 34 - 66%), *facultative upland* (usually occur in nonwetlands, p = 67 - 99%, but occasionally found in nonwetlands), and *obligate upland* (occur almost always under natural conditions in nonwetlands; p > 99%) (Reed 1988).

Figure 41. Photographs showing the vegetation at the MD175 infiltration basin site for the period 2009 to 2012. (Plants not labeled were not identified)

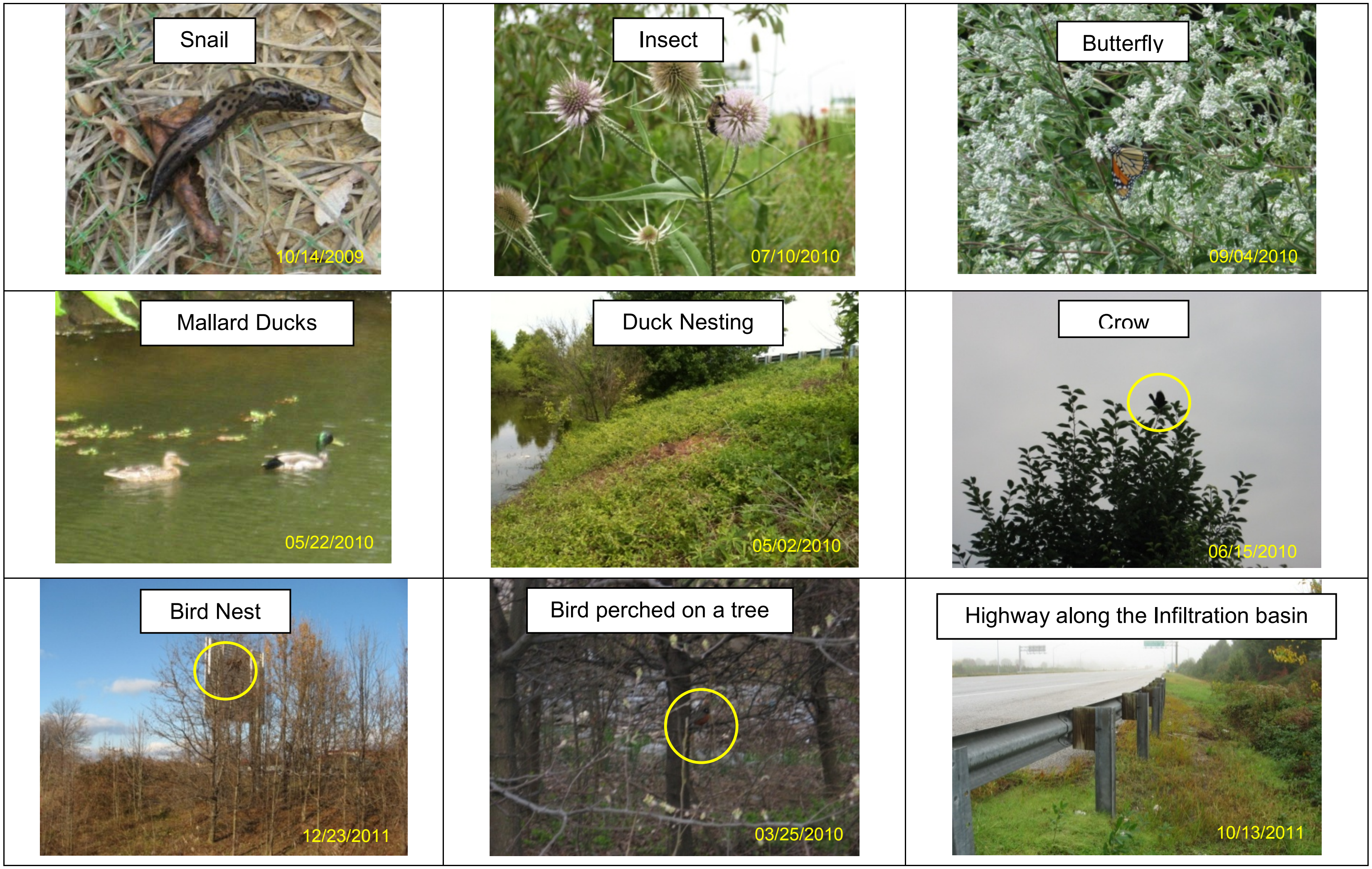


Figure 42. Photographs showing the wildlife observed at the MD175 infiltration basin site during the period 2009 to 2012.

The vegetation at the infiltration basin site consisted of submerged and floating species in the water, emergent plants along the edges of the infiltration basin, and shrubs and trees upland of the infiltration basin site. Some of the plants were identified with the help of Dr. Andrew Baldwin of University of Maryland (personal communication).

The submerged aquatic vegetation was identified as water-nymph (*Najas* spp.), an obligate wetland plant that can tolerate anaerobic conditions (PLANTS, USDA 2012). This plant was found to be actively growing and blooming in the spring and summer of 2009 and 2010 (Figure 41).

The floating macrophyte, floating primrose-willow (*Ludwigia peploides*), was observed to be growing in the infiltration basin water (Figure 41). This perennial aquatic weed is also an obligate wetland species that has been deemed as an invasive plant displacing native species in wetland ecosystems (Tiner 2009; PLANTS, USDA 2012). Known to grow and spread very fast, this plant covered nearly 70% of the water surface in spring, summer, and fall of 2010 - 2012. It was observed that floating primrose-willow displaced the water-nymph plants in 2011. Another obligate floating wetland plant, duckweed (*Lemna spp.)*, was observed in the shallow water regions on both inlet and outlet sides of the infiltration basin.

The emergent vegetation at the site consisted of colonies of softstem bulrush (*Schoenoplectus tabernaemontani*), established in shallow water along the edges of the infiltration basin (Figure 41). The softstem bulrush is an obligate wetland plant belonging to the sedge family (Tiner 2009; PLANTS, USDA 2012) and the plants were actively growing in spring, summer, and fall seasons throughout the research period.

Some of the upland shrubs and trees at the site include oxeye daisy (*Chrysanthemum leucanthemum*), blackberry, honeysuckle, black chokeberry, and dogwood (Figure 41).

These plants and trees followed their growing and blooming cycle from spring through fall. Several other upland weed plants, shrubs, and trees were growing at the infiltration basin site but were not identified by their names. The upland weeds and shrubs provided a continuous cover of vegetation in the area surrounding the infiltration basin in the growing season.

The fauna spotted at the infiltration basin site ranged from macroinvertebrates, frogs, toads, terrestrial insects and butterflies, and terrestrial animals such as raccoons, mice, ducks, and birds (Figure 42). The presence of water and vegetation cover provided a potential source of food, water, and shelter for these animals belonging to different trophic levels.

The water in the infiltration basin contained a few macroinvertebrates. The only macroinvertebrate identified at the infiltration basin site was snail. Although, benthic macroinvertebrates and amphibians are indicator organisms of the environmental condition of the water in an ecosystem (Micacchion 2004), biotic sampling was not performed in this research study.

The infiltration basin provided habitat for amphibians and rodents, which are animals with limited mobility and small home ranges (Micacchion 2004). Presence of both open water and vegetation is important for amphibians (toads and frogs) for breeding, feeding, and shelter. Although the stagnant water is a breeding ground for mosquitoes, which is a prevalent problem in in wetlands (Dale and Knight 2008), the amphibians feed on mosquito and their larvae, and other invertebrates in the water. Although the upland weeds growing at the infiltration basin site hold limited value as a habitat, they provided food and cover for terrestrial species such as raccoons and rodents. The vegetation cover continuity at the site provided a hiding and resting site for these animals.

Mallard ducks were often spotted swimming in the infiltration basin water. The vegetation cover around the basin also provided a nesting habitat for the ducks (Figure 42). The upland trees and woody vegetation provided a nesting habitat for birds and acted as perch sites for small birds (crows, others not identified) (Figure 42). The abundance of insects, amphibians, and plants is a source of food for the ducks and birds. As an example, the hard coated fruits of softstem bulrush growing at the site are food for ducks and raccoons (Neill and Cornwell 1992; Dick *et al.* 2004; PLANTS, USDA 2012).

Since the infiltration basin is located along a highway in a suburban area (Figure 42), the habitat value of the infiltration basin site is expected to be limited. The increased level of human activity in the area including automobiles on the highway, surrounding developed areas (shopping mall and hotel), and the noise associated with all these activities limit the use of the infiltration basin site as a habitat for small animals, birds, amphibians, and invertebrates. However, the infiltration basin site must be considered a valuable habitat to these animals in an urban setting.

5.2 Assessment of the Ecological Value of the Infiltration Basin Site

5.2.1 Wetland Assessment Methods

Under the U.S. Environmental Protection Agency's (EPA) National Wetland Program, wetland monitoring and assessment programs have been developed to evaluate the ecological conditions of wetlands (U.S. EPA 2002; U.S. EPA 2003). The purpose of these programs is to assess the ambient wetland resources, for regulatory purposes, and for assessing mitigation and restoration project success. These monitoring and assessment methods vary in scale and intensity, ranging from broad landscape-level assessment (level 1), rapid field methods (level 2) to rigorous physico-chemical and biological measurements (level 3).

The wetland assessment methods embed the classification of wetlands so that scores for two wetlands in the same class can be compared. Two wetland classification systems are widely accepted: The U.S. Fish and Wildlife Service's wetland classification system, in which wetlands are defined by plants (hydrophytes), soils (hydric soils), and frequency of flooding (Cowardin *et al.* 1979); and the hydrogeomorphic (HGM) classification of wetlands which is based on the wetland hydrogeomorphic properties of geomorphic setting, water source, and hydrodynamics (Brinson 1993).

Smith *et al.* (1995) proposed an approach for assessing wetland functions based on HGM classification, centered on the fact that the interdependency of geomorphic setting, water source, and hydrodynamics reveal the functions that the wetlands are likely to perform. The overall wetland assessment approach is to identify the functions of the wetland based on its existing condition (taking into consideration all the disturbances), recognize a reference wetland (least disturbed wetland) belonging to the same HGM class, assign scores to the identified functional values in comparison to the reference wetland and develop the functional capacity index for the wetland (Bartoldus 1994; Smith *et al.* 1995).

The wetland assessment methods are comprised of various indicators and metrics related to hydrology, soils, and biotic communities for evaluating the wetland condition and functions. Some methods employ the index of biotic integrity (IBI) that utilize fish, amphibians, invertebrates, and vegetation assemblages as indicators of the overall biological condition of a wetland (Mack 2004; Micacchion 2004).

Rapid assessment methods have been widely used for wetland assessment and monitoring projects since they provide sound quantitative information on wetland conditions for the small amount of time and effort invested (Fennessey *et al.* 2004). Fennessey *et al.*

(2004) reviewed the existing rapid assessment methods developed by various U.S. State programs and summarized the strongest metrics related to hydrology, soil conditions, vegetation, and landscape setting that measure and provide quantitative information of the wetland resources.

5.2.2 Site Assessment Plan for the Infiltration Basin

The rapid assessment method is a tool applicable towards evaluating the condition of stormwater control measures (SCMs) as well (Fennessey *et al.* 2004). A rapid assessment plan was designed to evaluate the ecological value of the infiltration basin site. For the current research study, scope of the rapid assessment plan was limited to identifying and describing the hydrologic, water quality, and habitat functions observed at the site. Although no overall scoring and comparisons to reference wetland conditions were performed, the existing conditions and identified functions were qualified in terms of the ecosystem services provided by the infiltration basin.

Table 16 shows the hydrology, water quality, and habitat criteria/indicators for the rapid assessment of the MD 175 infiltration basin. The selected criteria/indicators were derived from several wetland assessment methods from literature (Fennessey *et al.* 2004; Smith *et al.* 1995). The hydrology criteria include stormwater control, source of water to the infiltration basin, and hydroperiod and water level fluctuations, which influence the soil and vegetation conditions at the site. For water quality, reduction and removal of pollutants (solids, nutrients, and metals) were mainly considered. Under habitat characteristics, maintenance of representative vegetation and wildlife habitat at the infiltration basin site were evaluated. The monitoring method, and functions and benefits corresponding to each criterion are summarized in Table 16.

Table 16. Assessment plan for evaluating the ecological value of the infiltration basin site.

Characteristics	Criteria/Indicator	Measurement/ Monitoring	Observations	Functions/Benefits/Ecosystem Services
Hydrology	Source of water		Surface runoff from impervious and grassy areas; direct precipitation	Stormwater runoff management
Hydrology	Stormwater runoff control	Continuous rainfall depth, runoff inflow and outflow measurements; Continuous water level monitoring	• Runoff flow and volume attenuation • Peak flow attenuation • Short-term and long-term storage of runoff	• Slow runoff flows • Reduced discharge volumes and peak flows • Flood attenuation • Flood storage potential • Erosion control • Possible improved downstream water quality • Maintenance of habitat
Maintenance of hydrologic regime	Hydroperiod	Continuous water level monitoring	• Permanently flooded (water present in all seasons) • Open water and partially vegetated water surface (spring to fall seasons)	• Increased evapotranspiration • Maintenance of vegetation • Maintenance of habitat • Groundwater recharge through infiltration
Maintenance of hydrologic regime	Water level fluctuation	Continuous water level monitoring	• Up to 0.6 m	• Storage of runoff
Water Quality	Removal of pollutants on a short- and long-term basis	Water quality sampling during 38 storm events; Grab sampling during inter-event periods; Continuous water temperature, pH, redox potential monitoring	• Removal of suspended solids, nitrogen, phosphorus, heavy metals (copper, lead, and zinc) through physical, chemical, and biochemical processes • Retention of particulate pollutants • Improved discharge water quality	• Reduced downstream particulate loading • Reduced pollutant concentrations (solids, nutrients, and metals) Transformation of pollutant species to innocuous forms • Reduced downstream pollutant mass loading • Possible improved downstream water quality • Nutrient cycling • Maintenance of habitat

Characteristics	Criteria/Indicator	Measurement/ Monitoring	Observations	Functions/Benefits/Ecosystem Services
Water Quality	Presence of algae (or signs of eutrophication)	Visual inspection year-round	None	• Nutrient cycling • Reduced downstream nutrient loading • Possible improved downstream water quality
Habitat	Maintenance of plant communities	Visual inspection year-round	• Obligate wetland plants (submerged, floating, and emergent hydrophytes) • Upland weeds, shrubs, and trees	• Habitat for wildlife (invertebrates, amphibians, ducks, birds) • Nest, shade and food for wildlife
Habitat	Maintenance of animal communities	Visual inspection year-round	• Presence of invertebrates, amphibians, insects, ducks, and birds	• Habitat for wildlife
Habitat	Vegetation alterations (mowing, toxicity)	Visual inspection year-round	None	
Other – SCM facility settings	Sensitivity to stormwater/urban development		• Ratio of facility area to drainage area = 3% • Land use of watershed = sub-urban (buildings, highway, and roads) • Position of the facility in the watershed = along a highway • Connectivity and proximity to surface water = outflow from facility discharged into a storm drain	
Other	Aesthetics, recreation, education, cultural uses		• Education uses	• Provide research opportunities

The runoff flow and water level data collected over the three-year research period were utilized to assess the hydrology characteristics. Results from water quality samplings performed during storm events and dry-weather period were utilized for water quality characteristics. The detailed methodology of measurements and samplings were presented in the 'Materials and Methods' chapter. The results of the hydrology and water quality analyses were presented in the 'Hydrology Performance' and 'Water Quality Performance' chapters.

For the biota (vegetation and animals) category, biosurveys or any other intensive field samplings were beyond the scope of this research work. Hence, measures such as number of species, richness, and diversity were not employed to evaluate the biota composition and condition at the site. As a simple approach, the plants and animals occurring at the infiltration basin site were identified and the potential for wildlife habitat (nests, shade, and open water) was assessed.

The infiltration basin facility is expected to provide stormwater runoff flow and volume control, and reduce the runoff pollutant loads to improve the discharge water quality. The assessment of the hydrology, water quality, and habitat conditions at the infiltration basin site show that the infiltration basin provides these ecosystem services. Also, the infiltration basin site supports vegetation and provides habitat for amphibians, birds, and small animals. Several of these functions of the infiltration basin site are similar to the ecosystem services provided by natural and constructed wetlands that include flood control, groundwater recharge, water quality regulation, nutrient cycling, habitat for plants, animals and micro-organisms, wildlife conservation, and recreational opportunities (Kadlec and Knight 1996; Fisher and Acreman 2004; Vymazal 2007; Blackwell and Pilgrim 2011).

As indicated earlier, the infiltration basin is located in a suburban setting and can be considered to have a high degree of human disturbance. It is important to recognize that the infiltration basin holds a high value as a stormwater quantity and quality control structure as well as value as a habitat for the animals. Van Meter *et al.* (2011) have noted that stormwater detention ponds have emerged as important manmade aquatic ecosystems that support birds, amphibians, small mammals, and invertebrates, in urban areas which are heavily influenced by anthropogenic factors. Given the limited number of wetlands in urban areas, location of the infiltration basin in a disturbed area makes it a valuable habitat to the different organisms living at the site.

5.3 Indicators of Functionality of the Infiltration Basin

The hydrology and water quality performance monitoring and evaluation showed that the transitioning infiltration basin facility is effective in managing runoff flows and improving the runoff water quality. In addition to providing water quantity and quality benefits, the infiltration basin provides ancillary benefits such as wildlife habitat.

The research information obtained from this three-year research study was utilized to identify the 'indicators of functionality' of the infiltration basin under investigation. The aim of this task was to select indicators that can predict the existence of conditions that allow the desired functions to be performed by the transitioning infiltration basin. Ultimately, the goal is employ the derived set of indicators of functionality to evaluate similar failed and transitioning infiltration basins.

The wetland classification systems and assessment methods are based on the idea that the ecological conditions and functions of a wetland are a consequence of the ecosystem processes governed by the factors of geomorphic setting, hydrodynamics, soils, and vegetation (Smith *et al.* 1995). Since vegetation provides important clues of the hydrogeomorphic forces at work in a wetland ecosystem, vegetation-based assessment tools have been used for assessing wetland conditions (Brinson 1993; Tiner 1993a; Tiner 1993b; Mack 2004). In fact, the U.S. Fish and Wildlife Service's wetland classification system (Cowardin *et al.* 1979) relies largely on vegetative cover for determining the wetland type.

The aquatic plants or hydrophytes found in wetlands are adapted to the conditions of prolonged inundation/soil saturation (classified as obligate, facultative, facultative wetland; PLANTS, USDA 2012). The plants supported by the hydric soils in wetlands are characterized by the presence of aerenchyma tissue, which are internal spaces in the stems and rhizomes that allow atmospheric oxygen to be transported to the root zones (Kadlec and Knight 1996). Hydric soils develop under 'conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part' (U.S. Army Corps of Engineers Environmental Laboratory 1987). An area with hydric soils, wetland-adapted plants, and the presence of water for at least a portion of the year is considered to be a wetland.

In the current research study, at least three obligate wetland plants namely, softstem bulrush, floating primrose willow, and water nymph, were observed at the infiltration basin site. The wetland plant softstem bulrush belongs to the sedge family of plants that thrive in hydric soil conditions. These observations strongly suggest that wetland conditions prevail at the infiltration basin.

Given that wetland conditions exist at the infiltration basin, the environmental conditions must facilitate biogeochemical processes like nutrient cycling. The nitrogen water quality data along with the oxidation-reduction potential trends support that conditions favoring denitrification exist at the infiltration basin. The water level data and hydrology data also showed that the infiltration basin remained inundated throughout the year, which support the presence of hydric soils and hydrophytic vegetation onsite. Thus, there is sufficient evidence to support the research hypothesis that the failed infiltration basin is evolving into a wetland-like practice.

This knowledge gained was utilized to develop a simple method to assess a failed and transitioning infiltration basin SCM facility (Table 17).

Table 17. Indicators of functionality for evaluating a failed stormwater infiltration basin facility.

Indicator	Measure	Monitoring/Measurement
Source of water	Runoff/precipitation/baseflow	Visual inspection
Hydroperiod	Permanent inundation/seasonal/saturated/drained	Visual inspection (watermarks, sediment deposition, wetness of soil)
Water level	Standing water (percent area inundated)	Visual inspection (watermarks, sediment deposition, wetness of soil)
Vegetation	Maintenance of plant community characteristic of wetlands • floating leaved community dominated by: • submerged aquatic community dominated by: • emergent community dominated by: • upland vegetation:	Refer 2012 PLANTS database (PLANTS, USDA 2012)
Soil conditions	Presence of hydric soil	Visual inspection (rotten-egg odor, organic material accumulation). Refer NRCS hydric soil field guide (USDA NRCS 2010)
Habitat	• Vegetation cover (aquatic, emergent, upland shrub and woody vegetation) • Animals supported	Visual inspection
Design features	• Size relative to drainage area • Location in watershed • Watershed characteristics	Visual inspection

The indicators presented in Table 17 are simple visual measures that can be employed during a field-scale inspection of the facility. For an intensive assessment, physical and chemical measurements must be taken at the site in addition to the field inspection. Although a detailed procedure for an intensive assessment method is not presented in this section, the research methodology described in the 'Materials and Methods' chapter can be used a reference for conducting rigorous physico-chemical monitoring and measurements at the site.

For the indicators presented in Table 17, the visual inspection must be carried out seasonally. This is because periods immediately after a storm event may cause temporary inundation at the site, whereas the water conditions might be different a few days after the storm event which can lead to different set of conclusions about hydroperiod and water level criteria.

Presence of saturated soil conditions and hydrophytic vegetation are strong indicators of the presence of wetland condition. Therefore, the type of the vegetation in terms of probability of occurrence in wetlands or upland (obligate and/or facultative) must be determined (PLANTS, USDA 2012). Based on the adaptation and tolerance of the plants (pH, alkalinity, soil type, water levels), it can be confirmed if wetland conditions prevail. Subsequently, functions typically associated with wetlands, like nutrient cycling and other pollutant removals, can be expected to occur.

Hydric soils that are usually associated with wetland areas are strongly influenced by the presence of water (U.S. Army Corps of Engineers Environmental Laboratory 1987). A simple visual inspection of the soil can reveal if hydric soil conditions are present. As an example, hydrogen sulfide is formed under reducing conditions due to prolonged inundation/soil saturation, which yields a rotten-egg odor to the soil. Presence of organic material represented by a darker color surface layer is a sign of hydric soil (U.S. Army Corps of Engineers Environmental Laboratory 1987). For detailed information, the NRCS field guide for hydric soils (USDA NRCS 2010) must be used for hydric soil identification.

Ancillary benefits like wildlife habitat can be assessed based on the vegetation structure and composition. The vegetation plays a fundamental role in providing habitat for birds, mammals, and other groups. The wildlife present at the site can be determined by visual inspection. It must be reiterated that SCM facilities are typically located in urban areas that feature roads and large areas of development. The presence of these urban features creates limited but valuable vegetation and habitat conditions that can be associated with urban SCM facilities.

5.4 Summary

Some plants and animals occurring at the infiltration basin site were identified and recorded over the three-year research period. The plants were established in the various regions of the site: submerged, floating and emergent plants in the wetter areas, and shrubs and woody vegetation in the upland areas. The submerged, floating, and emergent species were hydrophytes, the majority of which were identified as obligate wetland plants that occur in wetlands only. This confirmed the presence of wetland conditions at the infiltration basin site. The upland vegetation consisted of weedy species, shrubs, and trees. The water and vegetation at the infiltration basin site provided a foraging and nesting habitat for animals such as invertebrates, amphibians (frogs and toads), insects, raccoons, mice, ducks, and birds.

The ecological value of the infiltration basin was assessed based on the hydrologic, water quality, and ancillary benefits provided by the facility using a simple assessment plan. The infiltration basin was capable of slowing runoff, reducing the peak flows and total runoff volumes, and reducing the pollutant concentrations and loads. Some of the benefits associated with these functions are flood attenuation and control, erosion control, improved discharge water quality, and thus possible improved downstream water quality. The maintenance of plant and animal communities presented a potential habitat for small animals at the infiltration basin site.

The research information obtained from the hydrology, water quality, and field observations were utilized to identify existing conditions favoring the functional performance of the infiltration basin, especially pollutant removal functions of the facility. The indicators of functionality were developed based on the hydroperiod, soil, and vegetation characteristics at the facility. Since vegetation characteristics are dependent on both water and soil conditions, presence of vegetation native to wetlands is a strong biotic indicator of wetland-like conditions and hence the associated beneficial functions. A simple visual assessment plan was devised using these indicators for use with any failed infiltration basin evaluation.

Chapter 6: Conclusions and Recommendations

This research study fully monitored, researched, and documented the functionality of a failed stormwater infiltration basin managing highway runoff. The research hypothesis was that a separate ecological function may develop in the failed infiltration basin with time. The failed infiltration basin can gradually transform into or may possess qualities of a wetland or wetpond-like practice.

The hydrology and water quality at the infiltration basin were monitored during many storm events and for periods between storm events, over a period of three years. Trends in hydrology and water quality performances associated with season and rainfall characteristics, and the controlling mechanisms were determined. Ancillary benefits such as wildlife habitat were also recorded. The rainfall distribution monitored at the infiltration basin site was well-representative of the historical rainfall distribution for Maryland.

6.1 Hydrologic Performance

The effectiveness of the infiltration basin in mitigating runoff flows and volumes was evaluated based on the flow responses, i.e., hydrographs, and performance metrics such as total volume reduction, peak flow attenuation, and flow duration for the 120 monitored rainfall events. Dynamic reduction in flow magnitudes, decrease in peak flows, delay in discharge of runoff, and net reduction in total volume were observed during the majority of storm events. Overall, the total volume reductions ranged between 4 and 100% (median = 100%) and peak flow reductions ranged between 1 and 100% (median = 100%), excluding a few large events that produced higher peak flows and no net volume reductions. The decrease in runoff volume achieved was statistically significant for the entire monitoring duration (α = 0.01).

The hydrologic performance of the infiltration basin showed distinct trends based on the rainfall characteristics. The smallest storm events (rainfall depth < 0.636 *cm*) were fully captured within the infiltration basin, resulting in 100% volume reduction. For moderate rainfall events (rainfall depth < 2.55 *cm*), significant reduction in total volume discharged and dynamic flow attenuation were observed. The hydrographs indicated that the infiltration basin detained the inflow runoff initially thereby delaying the discharge, and subsequently discharged water at reduced flow rates, resulting in overall total volume reduction (1 – 100%) as well as peak flow reduction for these events (5 – 100%).

The hydrologic performance of the infiltration basin was less efficient for the large storm events (rainfall depths > 2.54 *cm*). The higher runoff volumes from these large rainfall events overwhelmed the storage capacity of the infiltration basin, resulting in only small reduction of the total runoff volume and flow magnitudes. Negligible volume reductions and no net peak flow reductions were observed for the largest and extreme storm events (rainfall depths > 5 *cm*), during which the infiltration basin acted merely as a flow-conveyance facility.

The rainfall size, evapotranspiration, infiltration, and antecedent dry period produced a combined effect on the volume capture/attenuation through the infiltration basin. Assessment of the influence of these factors on a seasonal basis showed some interesting observations about the hydrologic behavior of the infiltration basin. During warmer months, the inter-event dry periods were longer compared to other seasons. The rainfall events thus contributed lesser runoff volume to the infiltration basin due to higher initial abstraction.

Loss of water through evapotranspiration and infiltration was also higher due to warm temperatures. As a result, the effective volume available in the infiltration basin was higher and this allowed capture of inflow runoff more effectively. During winter periods, the smaller water loss and periodic ice cover modified the hydraulics of the infiltration basin. Therefore, for the same inflow runoff volume, the volume reductions achieved during warm periods were higher than that during colder months. The runoff volume reductions directly contributed to total pollutant mass reductions through the facility.

The overall magnitude and total duration of discharge were reduced by the infiltration basin with a strong seasonal pattern associated with this performance. The effectiveness of the infiltration basin was strongest for the smaller to moderate flows, when runoff retention/capture and flow attenuation allowed discharge flows of smaller magnitude and shorter flow durations. The highest flows were partially reduced, explained by the hydrologic response of the infiltration basin to large and intense rainfall events during any season. In terms of matching the hydrologic regime to pre-development conditions, the effect of the infiltration basin was less effective when compared to a forested condition, as expected. Matching flows at the infiltration basin to forested condition is an ambitious target and consideration must be given to the overall impact of the infiltration basin in attenuating runoff flows from the highway area.

It can be concluded that the infiltration basin is effective as a stormwater runoff control practice as it exists, providing significant runoff flow attenuation, volume reduction, and reduced flow durations. The size of the facility is adequate to provide substantial hydrologic benefits for the more frequent smaller and moderate rainfall events, and least hydrologic benefits during the occasional largest and extreme rainfall events. No modifications to the existing design of the facility are necessary.

6.2 Water Quality Performance

The effectiveness of the infiltration basin in improving the water quality of the highway runoff was quantified based on 38 storm event and 54 dry-weather samplings. Water quality of the runoff inflow and discharge were monitored for a suite of pollutants: total suspended solids (TSS), total phosphorus (TP), nitrate, nitrite, TKN, total lead, copper, zinc, and chloride. Measurements for ammonium and dissolved phosphorus were additionally performed on some occasions. Performance efficiency for the infiltration basin was evaluated based on pollutant mass removal efficiency, effluent pollutant concentrations, pollutant durations, and probability exceedence distributions with appropriate water quality targets.

Overall, the infiltration basin reduced the mean pollutant concentrations and pollutant mass for all water quality parameters. The discharge event mean concentrations (EMCs) of TSS, metals (copper, lead, and zinc), total phosphorus (TP), TKN, NO_x-N (nitrate + nitrite), and chloride were statistically significantly lower than those of inflow considering all 38 storm events ($\alpha = 0.01$). The discharge EMCs of TSS, metals, and NO_x-N satisfied their respective water quality criterion for all the events monitored, except for total phosphorus.

Excellent reductions in TSS mass were observed during all storm events. Metal mass removals were also high for most storm events, except for three winter events that showed export for all three metals. The removal of nitrogen and phosphorus was mixed, effective for the majority of storm events and showing export during certain winter events. The inorganic nitrogen mass (nitrite and nitrate) was consistently removed and TKN removal was moderate. Chloride mass removal and discharge concentration decrease were partial, with increased discharge concentrations and mass export during winter and spring storm events due to the high input chloride pulses during winter.

The cumulative mass removal efficiencies were 89% TSS, 61% TP, 79% NO_x-N, 51% TKN, 64% total nitrogen, 73% total Cu, 63% total Pb, 55% total Zn, and 45% chloride. The annual mass load input and discharge from the infiltration basin were determined, which are critical input parameters for TMDL models. The annual pollutant mass data showed that the infiltration basin reduced the input loads for all water quality parameters.

6.2.1 Controlling Mechanisms

The water quality data from storm event and inter-event periods were utilized to determine the controlling mechanisms in the infiltration basin. Figure 43 exemplifies the physical, chemical, and biological mechanisms governing the pollutant removals and transformations in the infiltration basin.

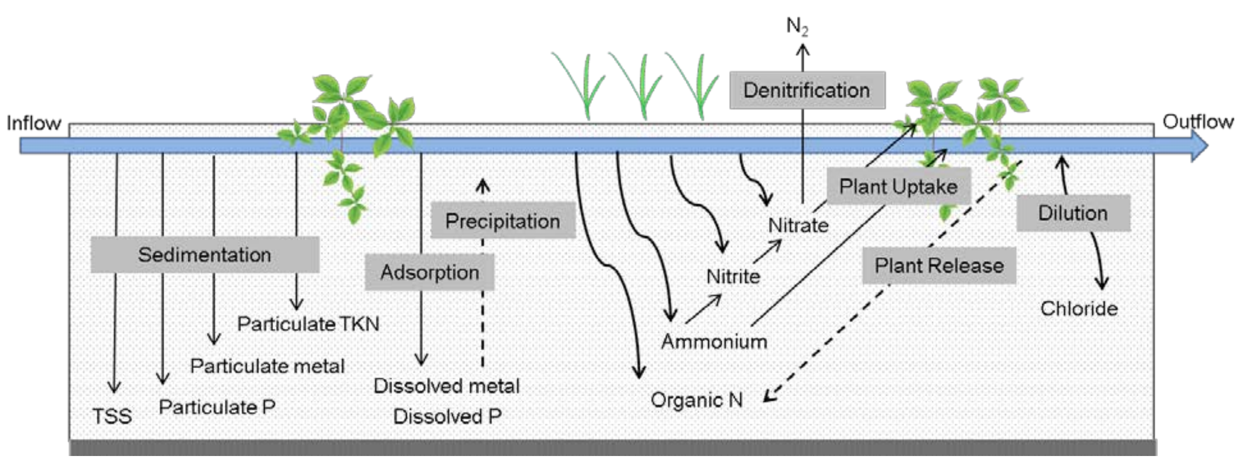


Figure 43. Schematic of controlling mechanisms in the transforming infiltration basin.

The infiltration basin acted as a sedimentation basin to effectively remove the suspended solids in the runoff. The particulate fractions of phosphorus, TKN, metals also settled with the solids. This behavior of the infiltration basin is similar to that of a stormwater detention pond.

In a research study on performance of stormwater wet detention ponds, utilizing 1-2% of the watershed area for the development of the ponds was recommended to achieve high pollutant mass removal efficiencies for TSS, TP, and metals (Wu *et al.* 1996). In the current study, the surface area of the infiltration basin was 3% of the total drainage area and high removals of TSS, TP, and metals were achieved. Although mass removal efficiency is not a good measure of performance, this suggests that the sizing of the infiltration basin is adequate for achieving high mass removals of suspended solids and pollutants associated with the solids.

The infiltration basin provided very good removals of inorganic nitrogen, which is not typically expected in detention ponds. The nitrogen processing ability is attributed to the separate wetland-like ecological function developed in the transitioning infiltration basin facility. Several floating and emergent macrophytes were observed within and at the periphery of the infiltration basin during the growing season. All of these established hydrophytes were identified as 'obligate' wetlands plants that occur in wetlands only (> 99% probability of occurrence). The oxidation reduction potential measurements in the water column confirmed the existence of anoxic/anaerobic conditions, especially during inter-event periods. The wetland environmental conditions thus favored denitrification to occur to effectively process nitrogen.

The presence of vegetation in the basin also aided in slowing the water and increasing sedimentation. The removal of dissolved phosphorus and metal components was possibly through adsorption or biological uptake. Chloride reduction occurred largely through mixing and dilution.

Figure 44 shows the year-round view of the infiltration basin, starting spring 2009 through summer next year. As can be seen in Figure 44, productivity of the infiltration basin changed as the seasons changed, which had implications for both hydrology and water quality at the site. The basin consisted of both open water, and transpiring floating and emergent vegetation during the growing season, which enabled loss of water by evapotranspiration. This contributed to the water balance in the basin by increasing the volume available for runoff retention. Correspondingly, good pollutant removals occurred, supported by the active physico-chemical and biological processes during the warm periods.

As fall progressed, the plants began to perish, decreasing transpiration but evaporation continued to occur from the open water. During winter, the water surface was completely frozen and was devoid of any transpiring plants. The ice cover resulted in minimal volume reduction and jointly influenced by the reduced biological activity in cold temperatures, resulted in poor removals of nitrogen, phosphorus, and heavy metals during winter storm events.

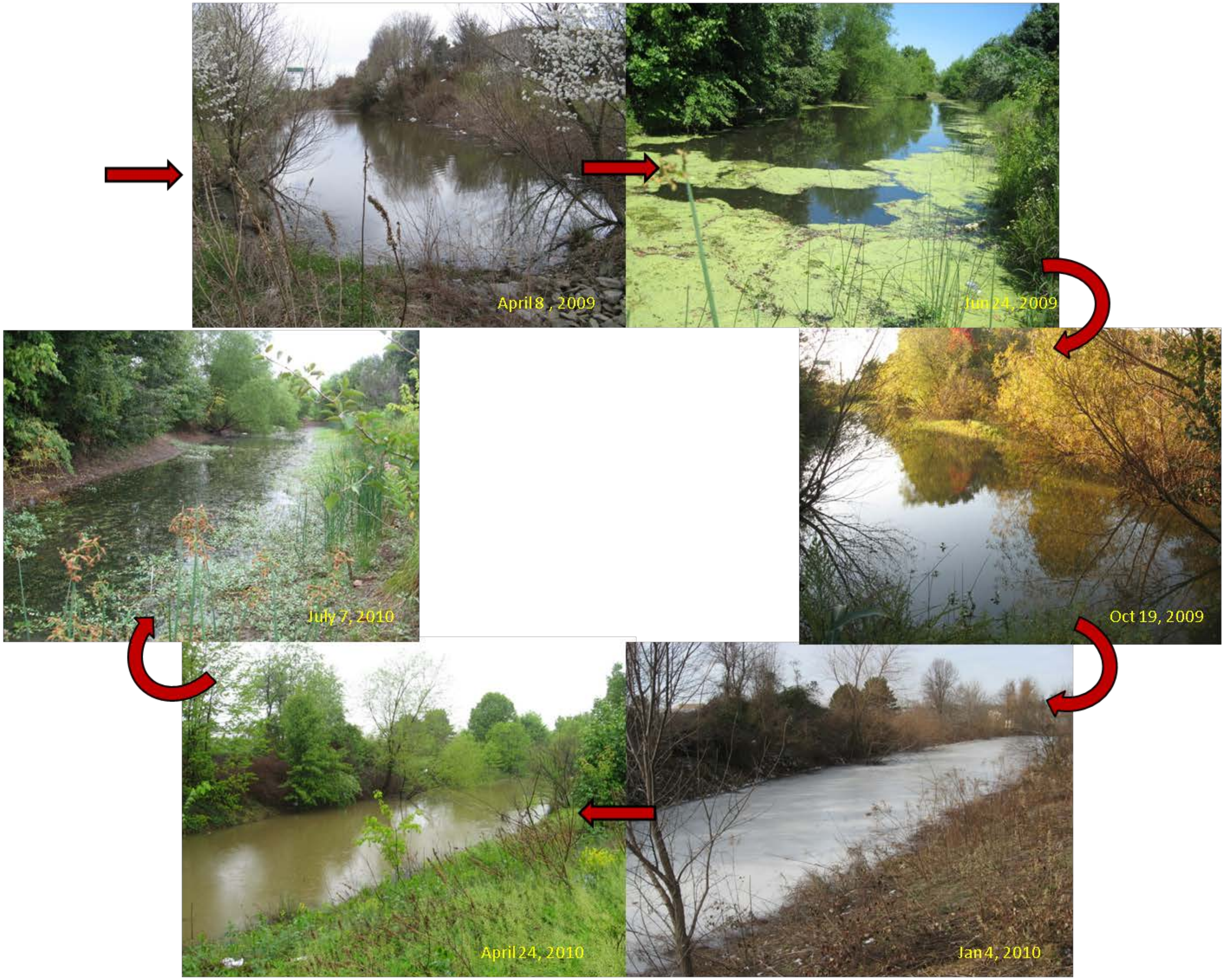


Figure 44. Photographs showing the infiltration basin from April 2009 through July 2010.

6.3 Recommendations and Future Work

This research study clearly showed that a failed stormwater infiltration basin can naturally transform into a wetlands/wetpond site, possessing both hydrologic management and water quality functions. Additionally, the site can provide ancillary benefits such as habitat for wildlife. In the current study, the presence of water and vegetation cover presented a potential source of water, food, and shelter for animals such as invertebrates, amphibians, mice, raccoons, ducks, and birds, which added an overall ecological value to the infiltration basin site. Therefore, rather than failure, such transforming infiltration basins must be considered as innovative stormwater management practices that provide valuable habitat for animals in the urban areas.

Research results obtained from this study are directly applicable to similar failed infiltration basins. A failed infiltration basin is primarily characterized by inappropriate ponding of water. In the current study, the water level in the infiltration basin fluctuated between partially to completely full (0.3 to 0.91 *m*), but a pool of water persisted throughout a year. The soil in the shallower areas of the basin remained moist, if not completely wet. The prolonged inundation likely developed anaerobic conditions and formed hydric soils, which are characteristic of wetlands, over a period of time. Although the original infiltration capacity may be lost over time, the inundation of water due to reduced infiltration can potentially create wetland and/or wetpond conditions in the meanwhile, which together add functionality to an otherwise failed infiltration facility. Also, the ponding of water increases evaporation/transpiration (ET). This is only a modification to the original hydrologic cycle at the infiltration basin; water loss to the atmosphere via ET instead of groundwater recharge via infiltration.

It is recommended that such transforming infiltration basins be permitted to remain on site. These new wetland-like SCMs may in fact provide better functionality than the original infiltration basin by providing stormwater control and treatment in urban areas as well as providing habitat to wildlife. By allowing these SCMs to remain, the cost required to remove these facilities or restore the SCM to the original infiltration basin can be avoided.

The set of indicators of functionality developed in this research can be utilized as a guide to evaluate the existence of functional conditions in a hypothetically transforming infiltration basin. However, it must be pointed out the evolution of an infiltration basin facility into a wetland/wetpond involves time and the effectiveness of the facility during the transitioning period may or may not satisfy all stormwater management goals, especially water quality targets.

As an extension of this research, a water budget model for the infiltration basin can be developed. One application of the model could be to predict the hydrologic behavior/efficacy of the infiltration basin for different storm event characteristics given a geographical region and then assess the likely impact on the hydrologic and water quality performances of the infiltration basin. This model is also important in light of the fact that rainfall patterns are expected to be altered due to climate change and this can have implications on the hydrologic and water quality behaviors and thus the design of a SCM facility (Pyke *et al.* 2011).

With respect to water quality, phosphorus reduction achieved through the infiltration basin was moderate and the discharge phosphorus concentrations did not satisfy the water quality goal. As a future work, research on enhanced phosphorus removal within a transforming infiltration basin can be conducted. Research on bioretention soil mixture amended with water treatment residual has shown promising results of increased phosphorus adsorption (O'Neill and Davis 2012). Similarly, the soil media can be amended in selected locations within the infiltration basin and its effect on phosphorus removals can be explored.

The scope of incorporating a infiltration basin, naturally transforming into a new wetland/wetpond facility, as a part of a stormwater treatment train can be investigated. Since the transitioning infiltration basin was successful in removing TSS, nitrogen and metals, the discharge from the infiltration basin can be subsequently treated in a SCM facility such as a bioretention amended for enhanced phosphorus removal. Alternatively, discharge from a SCM such as a wetpond that has inferior inorganic nitrogen removal capability, can be introduced into the transitioning infiltration basin with wetland features so that complete removal of nitrogen through denitrification can be achieved.

Research on these areas can provide improved understanding of SCM designs and contribute towards novel stormwater management technologies. With improved understanding, more widespread and reliable implementation of SCM facilities can be exercised to mitigate the negative impacts of urban stormwater runoff and hence protect the surface waters and the health of natural ecosystems.

Appendices

Appendix A

Table A-1. Hydrology data recorded at the MD 175 infiltration basin site from August 2009 to August 2012.

Event date	Antecedent dry period (days)	Rainfall depth (cm)	Rainfall duration (hours)	Inflow volume (m^3)	Outflow volume (m^3)
8/13/2009[a]	2	2.388	1.1	107	0
8/21/2009[a]	2	1.626	15.0	41	0
9/26/2009[a]	1	3.251	16.6	179	81
10/15/2009[a]	17	7.290	71.6	649	502
10/24/2009	6.3	1.016	8.1	52	46
10/27/2009	2.1	4.623	33.4	475	554
11/1/2009	3.4	1.143	12.3	119	70
11/11/2009	10.3	2.845	36.6	257	137
11/13/2009	0.7	0.914	1.9	64	37
11/19/2009[a]	6	1.549	8.5	124	133
11/23/2009	3	2.108	22.1		
11/25/2009	0.7	0.432	10.8	325[++]	294[++]
11/26/2009	0.9	0.305	5.0		
11/30/2009	3.3	0.559	7.1	34	0
12/2/2009	1	2.083	19.3	197	240
12/5/2009	2	0.356	6.2	0	0
12/7/2009	1	0.406	4.4	0	0
1/17/2010[a]	16	1.600	13.4	199	277
3/25/2010	3.3	0.762	11.13	35	0
3/28/2010[a]	2.4	1.270	10.97	99	48
3/30/2010[a]	1.3	0.254	3.5	18	0
4/21/2010	7.0	0.762	3.0	3	0
4/25/2010	4	2.438	15.4	152	50
5/3/2010	6	0.584	2.70	8	0
5/11/2010	7	0.686	8.03	0	0
5/12/2010	1	1.194	1.60	57	0
5/18/2010	0.5	0.457	9.83	7	0
5/23/2010[a]	4	1.016	3.47	28	0

Event date	Antecedent dry period (days)	Rainfall depth (cm)	Rainfall duration (hours)	Inflow volume (m^3)	Outflow volume (m^3)
5/27/2010	4	0.940	2.30	21	0
6/3/2010	2	0.635	0.90	1	0
6/6/2010	2	0.305	0.53	0	0
6/9/2010	2	0.229	1.83	0	0
6/28/2010	19	1.219	0.53	0	0
7/10/2010	10	0.813	5.37	0	0
7/12/2010	2	1.397	0.80	11	0
7/12/2010	0.25	2.438	1.57	52	0
7/13/2010	0.75	4.318	7.27	355[++]	194[++]
7/14/2010	0.29	0.279	1.17		
7/18/2010	4.5	0.432	0.67	0	0
7/25/2010	6.5	0.991	0.33	1	0
8/4/2010	9.6	1.803	1.77	39	0
8/5/2010	0.83	0.203	3.67	0	0
8/12/2010[a]	8.1	2.692	0.93	113	0
8/13/2010	0.67	2.642	6.37	262	238
8/15/2010	2.2	0.838	3.13	34	31
8/18/2010	2.6	2.438	6.47	189	176
8/22/2010	4.1	0.711	0.47	4	0
8/23/2010	0.79	2.946	2.67	285	268
9/12/2010	19	1.067	11.97	0	0
9/16/2010[a]	4	0.737	14.13	0	0
9/26/2010	9.8	2.337	25.63	57	0
9/29/2010	2	9.398	25.30	958	845
10/14/2010	9	2.261	6.23	102	91
10/19/2010	4	1.067	5.13	45	51
10/27/2010	7	1.549	12.00	66	31
11/3/2010	5	2.769	17.43	0	0
11/15/2010	10	1.981	31.67	85	70
11/25/2010	7	0.127	2.57	0	0
11/30/2010	4	0.152	4.40	0	0
12/1/2010	12	1.422	6.20	94	70
12/11/2010[a]	10	1.956	22.53	163	119
12/18/2010	6	0.076	1.87	0	0
2/24/2011[a]	1	1.092	14.17	126	121
2/28/2011	2	1.143	18.73	94	103
3/9/2011[a]	2	5.613	26.33	770	1013
4/5/2011	3	0.711	7.37	29	0

Event date	Antecedent dry period (days)	Rainfall depth (cm)	Rainfall duration (hours)	Inflow volume (m^3)	Outflow volume (m^3)
4/8/2011	2	0.838	12.13	52	0
4/12/2011	3	0.787	6.87	37	0
4/13/2011	0.5	0.457	11.33	38	0
4/16/2011	2	2.286	12.73	191	165
4/19/2011	2	0.279	5.00	0	0
4/22/2011[a]	2	0.838	23.53	24	0
4/24/2011	1	1.600	10.23	166	95
4/28/2011	3.3	0.279	1.63	2	0
5/1/2011	3	0.127	1.60	0	0
5/4/2011	8	0.864	11.03	37	0
5/14/2011[a]	9	0.965	3.17	17	0
5/16/2011	1.7	0.889	0.50	29	0
5/17/2011	0.5	0.686	5.63	76[++]	0
5/17/2011	0.25	0.432	1.60		
5/18/2011	0.42	0.102	1.07		
5/18/2011	0.67	0.610	2.60	43	9
5/19/2011	0.79	0.356	2.87	15	0
6/9/2011[a]	20	2.108	0.67	55	0
6/10/2011	0.75	0.533	0.50	8	0
6/12/2011	1	0.330	0.17	0	0
6/16/2011	5	0.279	0.37	0	0
6/18/2011	1.4	0.229	0.67	0	0
6/20/2011	1	0.254	4.90	0	0
6/21/2011	1.5	0.102	0.17	0	0
7/3/2011	13	0.787	2.87	0	0
7/3/2011	0.46	0.559	0.30	0	0
7/7/2011[a]	3	0.864	2.03	7	0
7/8/2011	0.67	1.118	2.23	39	0
7/11/2011	2	0.203	0.17	0	0
7/19/2011	5	0.406	0.57	0	0
7/25/2011[a]	5	4.623	2.33	204	0
8/1/2011	6	0.254	0.27	0	0
8/3/2011	1	0.889	0.70	0	0
8/6/2011[a]	2	2.388	6.43	174[++]	68[++]
8/7/2011	0.67	0.406	0.27		
8/9/2011	1	0.356	0.17	0	0
8/13/2011	3	0.889	3.53	10	0
8/14/2011	0.54	1.575	4.37	162[++]	140[++]

Event date	Antecedent dry period (days)	Rainfall depth (cm)	Rainfall duration (hours)	Inflow volume (m^3)	Outflow volume (m^3)
8/14/2011	0.39	1.041	3.53		
8/15/2011	0.45	0.330	4.87		
8/21/2011	5.3	0.610	0.30	1	0
8/21/2011	5	2.286	0.90	174	186
8/25/2011	3	0.406	2.03	3	0
8/27/2011	1	8.026	28.87	1148	1429
9/5/2011	7	21.666	91.10	3507	3674
9/5/2011	-	2.083	6.10	118	82
9/6/2011	-	2.438	21.93	221	279
9/7/2011	-	9.169	8.17	1856	1695
9/7/2011	-	3.962	0.57	693	853
9/8/2011	-	3.937	0.17	620	765
9/11/2011	1	3.937	9.03	474	553
9/20/2011	8	0.178	4.07	0	0
9/22/2011	1.7	0.406	0.23	0	0
9/23/2011[a]	11.3	2.794	12.00	162	135
9/28/2011	4	1.041	1.73	137	139
9/28/2011	0.44	1.016	2.13		
10/1/2011	2	0.787	10.13	49	9
10/3/2011	0.8	0.152	7.40	0	0
10/12/2011[a]	8	1.346	21.20	148[++]	0
10/13/2011	0.45	0.330	0.40		
10/14/2011	0.34	0.864	4.07		
10/19/2011	4	1.143	5.53	142	129
10/19/2011	0.29	0.762	7.70		
10/26/2011	6	0.152	0.63	0	0
10/27/2011	0.5	0.406	4.50	0	0
10/28/2011	9	2.134	19.73	215	178
11/16/2011	17	0.279	1.70	0	0
11/16/2011[a]	17	0.914	21.90	28	0
11/22/2011	5	3.505	20.80	500	347
11/29/2011	5	0.813	5.63	85	36
12/6/2011	6	0.330	18.57	8	0
12/7/2011[a]	0.5	5.436	19.53	736	834
12/22/2011[a]	14	2.083	7.87	215	147
12/27/2011	3	1.854	10.73	243	213
1/11/2012	10	2.438	16.77	261	214
1/16/2012[a]	3	0.381	16.27	25	0

Event date	Antecedent dry period (days)	Rainfall depth (cm)	Rainfall duration (hours)	Inflow volume (m^3)	Outflow volume (m^3)
1/21/2012[a]	3	0.559	9.00	18	0
1/23/2012[a]	1	0.152	1.80	40	0
1/27/2012[a]	3	0.660	2.40	32	7
2/4/2012	7	0.279	2.73	15[++]	0
2/5/2012	0.26	0.305	9.57		
2/8/2012	3	0.229	8.43	6	0
2/10/2012	2	0.178	2.60	25[++]	0
2/11/2012	0.29	0.406	2.43		
2/16/2012[a]	5	0.381	9.03	14	0
2/24/2012	7	0.406	6.83	6	0
2/29/2012[a]	4	4.547	15.40	533	381
3/2/2012[a]	1	1.397	15.63	188	135
3/19/2012	16.8	0.102	6.10	0	0
3/24/2012	4	0.940	26.40	18	0
4/1/2012	7	0.203	5.47	0	0
4/18/2012	16.5	0.483	10.60	0	0
4/21/2012	2	0.660	3.73	0	0
4/22/2012[a]	0.42	2.794	15.47	232[++]	0
4/23/2012	0.28	0.203	12.00		
4/26/2012	3	0.356	1.13	5	0
4/28/2012	1	0.203	9.37	0	0
5/2/2012	3	0.533	0.30	10	0
5/3/2012	1.7	0.127	0.77	0	0
5/8/2012	7.5	0.229	1.63	0	0
5/8/2012	0.29	0.432	6.23	5	0
5/9/2012	0.5	1.041	8.07	46	0
5/14/2012[a]	4	2.642	24.67	159	0
5/20/2012	5.9	1.092	15.20	18	0
5/24/2012	3	0.203	0.47	0	0
5/27/2012	3.8	0.305	2.17	0	0
5/29/2012	1.8	0.914	3.73	13	0
6/1/2012	2	5.690	8.08	873	789
6/12/2012[a]	10	1.575	11.47	19	0
6/22/2012	10	0.127	0.60	0	0
6/25/2012	3	0.127	0.27	0	0
6/29/2012	4	1.194	2.47	0	0
7/2/2012	1	0.076	2.90	0	0

Event date	Antecedent dry period (days)	Rainfall depth (cm)	Rainfall duration (hours)	Inflow volume (m^3)	Outflow volume (m^3)
7/9/2012	6	1.194	5.03	0	0
7/14/2012	4.5	2.134	2.23	71	0
7/15/2012	0.7	0.152	0.47	0	0
7/19/2012	4	3.404	3.50	136	0
7/20/2012[a]	0.83	5.283	24.17	651	522
7/26/2012	6	0.584	4.27	43	0
8/5/2012	9.63	0.940	4.57	0	0
8/9/2012	3.67	1.270	2.30	12	0
8/10/2012	0.29	1.295	4.77	74	0
8/11/2012	0.75	0.203	1.17	1	0
8/12/2012	0.75	0.152	2.97	0	0
8/14/2012	0.67	0.178	1.33	0	0
8/18/2012	3.5	0.813	11.50	2	0
8/20/2012	1.5	1.549	2.08	30	0

[a] Rainfall event sampled for water quality

[++]Flow volumes have been combined since continuous flow occurred during this period.

Appendix B

Table B-1. Water quality data of the 38 sampled rainfall events and 54 dry-weather samplings at the MD 175 infiltration basin site from June 2009 to August 2012.

Event	TSS			TP			TKN (as N)			Nitrite + Nitrate (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
6/24/2009 Dry-weather	65 ± 75			0.32 ± 0.23			2.5 ± 1.7			0.06 ± 0.0		
8/10/2009 Dry-weather	126 ± 107			0.45 ± 0.16			6.6 ± 4.1			0.08 ± 0.06		
8/13/2009 Storm event	181	0*	100	0.52	0*	100	1.5	0*	100	0.58	0*	100
8/21/2009 Storm event	44	0*	100	0.42	0*	100	2.6	0*	100	0.38	0*	100
9/26/2009 Storm event	39	1	98	0.43	0.06	93	1.5	0.93	72	0.96	0.05	97
10/04/2009 Dry-weather	7.6 ± 2.1			0.10 ± 0.06			1.5 ± 0.3			0.06 ± 0.0		
11/19/2009 Storm event	110	9	91	0.25	0.09	60	1.2	0.70	38	0.26	0.06	76
01/18/2010 Storm event	n/a~	n/a~		0.22	0.19	-16	1.3	0.92	-0.32	0.58	0.34	20
3/25/2010 Dry-weather	14 ± 2.1			0.08 ± 0.0			1.19 ± 0.10			0.07 ± 0.02		
3/26/2010 Storm event	72	0*	100	0.22	0*	100	2.1	0*	100	0.46	0*	100
4/24/2010 Dry-weather	16 ± 3.6			0.08 ± 0.0			1.4 ± 0.14			0.11 ± 0.03		
4/25/2010 Storm event	185	29	95	0.28	0.10	91	1.9	1.1	83	0.29	0.14	85
5/2/2010 Dry-weather	9 ± 1.5			0.08 ± 0.0			1.2 ± 0.3			0.22 ± 0.03		
5/22/2010 Dry-weather	15 ± 11			0.11 ± 0.06			0.49 ± 0.3			0.07 ± 0.03		
5/23/2010 Storm event	52	0*	100	0.34	0*	100	1.3	0*	100	0.18	0*	100
5/23/2010 Dry-weather	11 ± 6.6			0.12 ± 0.05			0.98 ± 0.2			0.06 ± 0.0		
6/15/2010 Dry-weather	6 ± 2.5			0.09 ± 0.01			0.89 ± 0.08			0.10 ± 0.05		
6/27/2010 Dry-weather	17 ± 3.3			0.14± 0.03			1.1 ± 0.06			0.06 ± 0.0		
7/9/2010 Dry-weather	44 ± 48			0.19 ± 0.07			2.1 ± 0.43			0.06 ± 0.0		
7/12/2010 Storm event	54	0*	100	0.58	0*	100	0.99	0*	100	0.86	0*	100

Event	TSS			TP			TKN (as N)			Nitrite + Nitrate (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
8/11/2010 Dry-weather	49 ± 30			0.16 ± 0.09			2.03 ± 0.89			0.06 ± 0.0		
8/12/2010 Storm event	47	0*	100	0.58	0*	100	1.39	0*	100	0.47	0*	100
8/12/2010 Dry-weather	9 ± 6			0.10 ± 0.04			1.33 ± 0.10			0.06 ± 0.0		
9/4/2010 Dry-weather	45 ± 28			0.21 ± 0.05			1.96 ± 0.0			0.05 ± 0.0		
9/26/2010 Dry-weather	45 ± 29			0.22 ± 0.14			2.08 ± 0.93			0.06 ± 0.0		
9/27/2010 Storm event	31	0*	100	0.44	0*	100	1.54	0*	100	0.32	0*	100
9/27/2010 Dry-weather	49 ± 23			0.26 ± 0.10			3.66 ± 0.34			0.06 ± 0.0		
10/27/2010 Storm event	35	0*	100	0.42	0*	100	1.57	0*	100	0.12	0*	100
11/14/2010 Dry-weather	2 ± 0.71			0.13 ± 0.05			0.52 ± 0.05			0.06 ± 0.0		
11/17/2010 Storm event	14	0*	100	0.37	0*	100	1.2	0*	100	0.18	0*	100
11/17/2010 Dry-weather	9 ± 6.8			0.17 ± 0.10			0.98 ± 0.40			0.06 ± 0.0		
11/29/2010 Dry-weather	10			0.16 ± 0.06			0.49 ± 0.30			0.06 ± 0.00		
12/1/2010 Storm event	25	3	92	0.34	0.07	85	1.25	0.64	65	0.08	0.05	60
12/1/2010 Dry-weather	4			0.20 ± 0.10			0.7 ± 0. 0			0.06 ± 0.00		
2/24/2011 Dry-weather	22			0.09			0.98			0.01 ± 0.00^{+}		
2/24/2011 Storm event	58	13	79	0.12	0.08	40	0.97	0.98	5	0.03^{+}	0.004^{+}	87
2/25/2011 Dry-weather	22 ± 19			0.06 ± 0.01			0.77 ± 0.10			0.01 ± 0.00^{+}		
3/9/2011 Dry-weather	23 ± 2.7			0.15 ± 0.10			1.26			0.01 ± 0.00^{+}		
3/9/2011 Storm event	130	32	68	0.23	0.18	-3	1.01	0.86	-11	0.011^{+}	0.009^{+}	-0.37
3/11/2011 Dry-weather	75			0.19 ± 0.03			0.98			0.01 ± 0.00^{+}		
4/21/2011 Dry-weather	13 ± 3.5			0.10 ± 0.02			0.98			0.01 ± 0.00^{+}		
4/22/2011 Storm event	28	0*	100	0.21	0*	100	1.93	0*	100	0.03^{+}	0*	100
4/23/2011 Dry-weather	12 ± 6.2			0.08 ± 0.07			1.12			0.01 ± 0.00^{+}		
5/14/2011 Dry-weather	20 ± 14			0.19 ± 0.02			1.68			0.01 ± 0.00^{+}		
5/14/2011 Storm event	34	0*	100	0.36	0*	100	2.28	0*	100	0.02^{+}	0*	100

Event	TSS			TP			TKN (as N)			Nitrite + Nitrate (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
5/15/2011 Dry-weather	25 ± 9.9			0.17 ± 0.04			1.82			0.01 ± 0.00[+]		
6/9/2011 Storm event	134	0*	100	0.60	0*	100	n/a~			n/a~		
7/7/2011 Storm event	48	0*	100	0.55	0*	100	2.18	0*	100	n/a~		
7/25/2011 Storm event	30	0*	100	0.37	0*	100	1.46	0*	100	0.03[+]	0*	100
8/5/2011 Dry-weather	14 ± 2.8			0.27 ± 0.03			1.49			0.01 ± 0.00[+]		
8/6/2011 Storm event	38	10	90	0.36	0.14	85	1.6	0.47	89	0.93	0.16	93
8/7/2011 Dry-weather	16 ± 4.9			0.25 ± 0.08			1.68			0.01 ± 0.00[+]		
9/21/2011 Dry-weather	60 ± 29			0.18 ± 0.03			0.91 ± 0.1			0.13 ± 0.00[+]		
9/21/2011 Storm event	58	9	91	0.27	0.11	76	1.4	0.81	67	0.4	0.2	58
9/23/2011 Dry-weather	11 ± 1.1			0.16 ± 0.03			0.98 ± 0.0			0.08 ± 0.00		
10/10/2011 Dry-weather	15 ± 4.2			0.11 ± 0.02			0.98			0.06 ± 0.00		
10/12/2011 Storm event	52	0*	100	0.32	0*	100	1.5	0*	100	0.32	0*	100
10/13/2011 Dry-weather	55 ± 27			0.15 ± 0.07			1.82			0.06 ± 0.00		
11/15/2011 Dry-weather	6 ± 3.1			0.15 ± 0.07			0.93			0.06 ± 0.00		
11/16/2011 Storm event	36	0*	100	0.51	0*	100	1.88	0*	100	0.07	0*	100
11/17/2011 Dry-weather	8 ± 1.2			0.15 ± 0.03			1.12			0.06 ± 0.00		
12/06/2011 Dry-weather	8			0.11 ± 0.07			1.31			0.06 ± 0.00		
12/07/2011 Storm event	90	14	82	0.19	0.14	17	1.23	1.22	-13	1.01	0.22	85
12/09/2011 Dry-weather	5 ± 1.5			0.11 ± 0.004			2.24			0.21 ± 0.11		
12/20/2011 Dry-weather	5 ± 2.5			0.11 ± 0.01			0.84 ± 0.2			0.06 ± 0.00		
12/22/2011 Storm event	49	4	94	0.17	0.12	52	1.28	1.00	46	0.25	0.05	85
12/23/2011 Dry-weather	8 ± 2.3			0.11 ± 0.02			0.84 ± 0.2			0.06 ± 0.00		
01/16/2012 Storm event	40	0*	100	0.24	0*	100	1.47	0*	100	1.03	0*	100
01/21/2012 Storm event	33	0*	100	0.04	0*	100	1.26	0*	100	0.65	0*	100
01/23/2012 Storm event	13	0*	100	0.08	0*	100	1.26	0*	100	1.18	0*	100
01/24/2012 Dry-weather	92			0.14			1.12			0.13		

Event	TSS			TP			TKN (as N)			Nitrite + Nitrate (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
01/27/2012 Storm event	490	0*	100	0.14	0*	100	3.16	0*	100	0.89	0*	100
01/28/2012 Dry-weather	6 ± 1.1			0.12 ± 0.01			0.75			0.08 ± 0.00		
02/14/2012 Dry-weather	10			0.08			0.93			0.06		
02/16/2012 Storm event	252	0*	100	0.11	0*	100	2.45	0*	100	0.58	0*	100
02/17/2012 Dry-weather	7 ± 3.2			0.08 ± 0.04			1.1 ± 0.05			0.26 ± 0.02		
02/27/2012 Dry-weather	7 ± 1.1			0.06 ± 0.02			0.56			0.06 ± 0.00		
02/29/2012 Storm event	510	30	96	0.39	0.11	80	2.43	0.93	72	0.77	0.28	73
03/1/2012 Dry-weather	24 ± 3.5			0.11 ± 0.01			0.75			0.06 ± 0.00		
03/2/2012 Storm event	80	15	86	0.16	0.11	52	1.49	0.93	55	0.24	0.15	55
03/4/2012 Dry-weather	13 ± 0.76			0.09 ± 0.00			0.93			0.08 ± 0.04		
04/22/2012 Storm event	79	0*	100	0.27	0*	100	1.03	0*	100	0.29	0*	100
05/13/2012 Dry-weather	17			0.10			0.56			0.06		
05/14/2012 Storm event	71	0*	100	0.23	0*	100	1.11	0*	100	0.13	0*	100
05/16/2012 Dry-weather	11 ± 0.71			0.10 ± 0.02			0.75			0.06 ± 0.00		
06/10/2012 Dry-weather	21 ± 3.5			0.16 ± 0.05			0.75			0.06 ± 0.00		
06/12/2012 Storm event	32	0*	100	0.30	0*	100	2.37	0*	100	0.15	0*	100
06/13/2012 Dry-weather	23 ± 13			0.26 ± 0.12			1.68			0.06 ± 0.00		
07/20/2012 Dry-weather	41 ± 46			0.36 ± 0.15			2.61			0.08 ± 0.03		
07/20/2012 Storm event	34	14	67	0.21	0.21	18	1.21	1.17	23	0.06	0.06	20
07/23/2012 Dry-weather	11 ± 11			0.25 ± 0.01			1.31			0.06 ± 0.00		

Table B-1. (Continued) Water quality data of the 38 sampled rainfall events and 54 dry-weather samplings at the MD 175 infiltration basin site from June 2009 to August 2012.

Event	Total Pb			Total Cu			Total Zn			Chloride		
	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
6/24/2009 Dry-weather	7 ± 2.7			6 ± 4			23 ± 13			13 ± 0.1		
8/10/2009 Dry-weather	4 ± 2.1			2 ± 2.8			13 ± 0.0			21 ± 0.14		
8/13/2009 Storm event	7	0*	100	11	0*	100	n/a~	0*		22	0*	100
8/21/2009 Storm event	5	0*	100	13	0*	100	55	0*	100	44	0*	100
9/26/2009 Storm event	2	2	48	10	2	93	47	11	90	79	19	89
10/04/2009 Dry-weather	3 ± 0.0			2 ± 0.0			n/a~			22 ± 0.55		
11/19/2009 Storm event	6	4	29	11	4	64	56	43	18	15	12	10
01/18/2010 Storm event	2	2	-28	5	4	-8	43	35	-13	647	522	-10
3/25/2010 Dry-weather	3 ± 0.0			3 ± 0.72			17 ± 9.1			444 ± 19		
3/26/2010 Storm event	6	0*	100	13	0*	100	58	0*	100	449	0*	100
4/24/2010 Dry-weather	3 ± 0.0			1 ± 0.7			13 ± 0.0			562 ± 86		
4/25/2010 Storm event	6	2	90	20	5	93	54	10	94	120	303	21
5/2/2010 Dry-weather	3 ± 0.0			1 ± 0.7			13 ± 0.0			427 ± 33		
5/22/2010 Dry-weather	3 ± 0.0			1 ± 0.93			21 ± 16			339 ± 14		
5/23/2010 Storm event	3	0*	100	16	0*	100	51	0*	100	113	0*	100
5/23/2010 Dry-weather	3 ± 0.0			1 ± 0.6			13 ± 0.0			320 ± 20		
6/15/2010 Dry-weather	3 ± 0.0			1 ± 0.7			13 ± 0.0			297 ± 6		
6/27/2010 Dry-weather	3 ± 0.0			2 ± 1.1			13 ± 0.0			392 ± 10		
7/9/2010 Dry-weather	5 ± 3.1			5 ± 3.5			13 ± 0.0			436 ± 13		
7/12/2010 Storm event	4	0*	100	13	0*	100	25	0*	100	42	0*	100
8/11/2010 Dry-weather	3 ± 0.0			3 ± 0.46			13 ± 0.0			106 ± 6		
8/12/2010 Storm event	4	0*	100	12	0*	100	22	0*	100	42	0*	100
8/12/2010 Dry-weather	3 ± 0.0			1 ± 0.67			13 ± 0.0			100 ± 11		
9/4/2010 Dry-weather	3 ± 0.0			3 ± 0.42			13 ± 0.0			25 ± 2.3		
9/26/2010 Dry-weather	3 ± 0.0			3 ± 1.9			13 ± 0.0			35 ± 4.1		

Event	Total Pb			Total Cu			Total Zn			Chloride		
	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
9/27/2010 Storm event	3	0*	100	11	0*	100	15	0*	100	66	0*	100
9/27/2010 Dry-weather	3 ± 0.0			3 ± 1.4			13 ± 0.0			33 ± 6.7		
10/27/2010 Storm event	3	0*	100	8	0*	100	32	0*	100	43	0*	100
11/14/2010 Dry-weather	4 ± 1.9			1.7 ± 1.0			17 ± 8.5			26 ± 0.66		
11/17/2010 Storm event	2	0*	100	7	0*	100	29	0*	100	52	0*	100
11/17/2010 Dry-weather	5 ± 1.9			3 ± 1.6			42 ± 4.9			23 ± 1.7		
11/29/2010 Dry-weather	3 ± 0.0			1.3 ± 0.64			38 ± 7.6			25 ± 1.1		
12/1/2010 Storm event	3	2	39	4	1	82	44	21	67	26	22	42
12/1/2010 Dry-weather	3 ± 0.0			1.7 ± 1.3			34 ± 4.8			23 ± 1.9		
2/24/2011 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			655		
2/24/2011 Storm event	3	2	32	6	1	83	38	17	58	1251	702	47
2/25/2011 Dry-weather	3 ± 0.0			1 ± 0.67			26 ± 11			825 ± 51		
3/9/2011 Dry-weather	3 ± 0.0			5 ± 0.63			31 ± 4.4			408 ± 74		
3/9/2011 Storm event	5	2	37	6	4	11	48	38	-1	43	117	-253
3/11/2011 Dry-weather	3 ± 0.0			5 ± 0.83			40 ± 5.9			101 ± 15		
4/21/2011 Dry-weather	3 ± 0.0			1 ± 0.59			13 ± 0.0			229 ± 3.7		
4/22/2011 Storm event	4	0*	100	11	0*	100	41	0*	100	307	0*	100
4/23/2011 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			238 ± 3.0		
5/14/2011 Dry-weather	3 ± 0.0			1 ± 0.0			27 ± 0.33			252 ± 12.5		
5/14/2011 Storm event	3	0*	100	13	0*	100	44	0*	100	157	0*	100
5/15/2011 Dry-weather	3 ± 0.0			2 ± 1.3			13 ± 0.0			243 ± 3.8		
6/9/2011 Storm event	4	0*	100	18	0*	100	52	0*	100	n/a~		
7/7/2011 Storm event	4	0*	100	14	0*	100	50	0*	100	37	0*	100
7/25/2011 Storm event	3	0*	100	8	0*	100	28	0*	100	14	0*	100
8/5/2011 Dry-weather	4 ± 2.01			3 ± 0.01			13 ± 0.0			84 ± 5.2		
8/6/2011 Storm event	4	2	80	9	3	89	25	11	84	21	58	-12

Event	Total Pb			Total Cu			Total Zn			Chloride		
	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_R$ (%)	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_R$ (%)	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_R$ (%)	EMC$_{in}$ (mg L^{-1})	EMC$_{out}$ (mg L^{-1})	M$_R$ (%)
8/7/2011 Dry-weather	4 ± 2.2			7 ± 5.3			13 ± 0.0			49 ± 32		
9/21/2011 Dry-weather	4 ± 2.5			6 ± 0.69			13 ± 0.0			8 ± 0.36		
9/21/2011 Storm event	5	6	28	8	3	77	19	12	63	15	6	68
9/23/2011 Dry-weather	3 ± 0.0			5 ± 1.3			13 ± 0.0			19 ± 10		
10/10/2011 Dry-weather	3 ± 0.0			1 ± 0.0			41 ± 0.1			23 ± 0.79		
10/12/2011 Storm event	2	0*	100	8	0*	100	44	0*	100	56	0*	100
10/13/2011 Dry-weather	3 ± 0.0			1 ± 0.0			45 ± 1.7			15 ± 2		
11/15/2011 Dry-weather	3 ± 0.0			2 ± 1.7			13 ± 0.0			18 ± 0.39		
11/16/2011 Storm event	5	0*	100	9	0*	100	15	0*	100	73	0*	100
11/17/2011 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			18 ± 2.1		
12/06/2011 Dry-weather	3 ± 0.0			4 ± 1.7			13 ± 0.0			15 ± 1.5		
12/07/2011 Storm event	2	1	-13	5	2	48	44	33	16	5	6	-50
12/09/2011 Dry-weather	3 ± 0.0			2 ± 1.1			30 ± 2.6			7 ± 5.2		
12/20/2011 Dry-weather	3 ± 0.0			1 ± 0.0			18 ± 8.6			6 ± 3.1		
12/22/2011 Storm event	3	3	32	4	2	67	43	33	48	10	7	54
12/23/2011 Dry-weather	3 ± 0.0			2 ± 0.84			33 ± 3.4			8 ± 1.4		
01/16/2012 Storm event	9	0*	100	4	0*	100	46	0*	100	30	0*	100
01/21/2012 Storm event	3	0*	100	1	0*	100	39	0*	100	6423	0*	100
01/23/2012 Storm event	3	0*	100	1	0*	100	33	0*	100	3126	0*	100
01/24/2012 Dry-weather	6			3			13			8		
01/27/2012 Storm event	13	0*	100	6	0*	100	103	0*	100	979	0*	100
01/28/2012 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			18 ± 4.8		
02/14/2012 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0					
02/16/2012 Storm event	3	0*	100	3	0*	100	32	0*	100	1326	0*	100
02/17/2012 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			172 ± 31		
02/27/2012 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			286 ± 39		

Event	Total Pb			Total Cu			Total Zn			Chloride		
	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_R$ (%)	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_R$ (%)	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_R$ (%)	EMC$_{in}$ (mg L^{-1})	EMC$_{out}$ (mg L^{-1})	M$_R$ (%)
02/29/2012 Storm event	11	3	84	26	6	84	93	13	90	185	220	15
03/1/2012 Dry-weather	3 ± 1.6			5 ± 0.74			17 ± 8.3			229 ± 41		
03/2/2012 Storm event	7	3	72	8	4	62	28	13	68	118	104	37
03/4/2012 Dry-weather	3 ± 0.0			4 ± 0.27			13 ± 0.0			143 ± 9.1		
04/22/2012 Storm event	9	0*	100	10	0*	100	40	0*	100	81	0*	100
05/13/2012 Dry-weather	5			7			13			117		
05/14/2012 Storm event	8	0*	100	12	0*	100	35	0*	100	42	0*	100
05/16/2012 Dry-weather	4 ± 2.1			3 ± 2.3			20 ± 10			103 ± 8		
06/10/2012 Dry-weather	3 ± 0.0			3 ± 0.56			13 ± 0.0			10 ± 1.9		
06/12/2012 Storm event	22	0*	100	12	0*	100	13	0*	100	18	0*	100
06/13/2012 Dry-weather	3 ± 0.0			2 ± 1.2			13 ± 0.0			11 ± 1.1		
07/20/2012 Dry-weather	7 ± 5.7			5 ± 3.7			23 ± 14			17 ± 3.5		
07/20/2012 Storm event	3	3	20	8	5	52	13	13	20	5	7	-11
07/23/2012 Dry-weather	4 ± 2.1			4 ± 0.43			21 ± 11			8 ± 0.88		

EMC = Event mean concentration (as defined in Equation 5); **M$_R$** = Mass removal efficiency (as defined in Equation 4);
*Entire inflow runoff volume assimilated
$^+$ Nitrite only
n/a Not applicable
n/a~ No data due to lab accident and/or equipment failure

Table B-1. (Continued) Water quality data of the 38 sampled rainfall events and 54 dry-weather samples at the MD 175 infiltration basin site from June 2009 to August 2012.

Event	Dissolved P			Ammonium (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} mg L^{-1})	M_R (%)
3/25/2010 Dry-weather	0.01 ± 0.0			n/a		
3/26/2010 Storm event	0.12	0*	100	n/a		
4/24/2010 Dry-weather	0.018 ± 0.002			n/a		
5/23/2010 Storm event	0.15	0.057	89	n/a	n/a	
5/22/2010 Dry-weather	0.038 ± 0.006			n/a		
5/23/2010 Storm event	0.16	0*	100	n/a		
5/23/2010 Dry-weather	0.041 ± 0.008			n/a		
6/15/2010 Dry-weather	0.083 ± 0.002			n/a		
6/27/2010 Dry-weather	0.087 ± 0.033			n/a		
7/9/2010 Dry-weather	0.079 ± 0.012			n/a		
9/26/2010 Dry-weather	0.078 ± 0.016			n/a		
9/27/2010 Storm event	0.32	0*	100	n/a		
9/27/2010 Dry-weather	0.067 ± 0.009			n/a		
8/06/2011 Storm event	0.23	0.053	90	n/a		
9/23/2011 Storm event	0.17	0.072	64	n/a		
12/06/2011 Dry-weather	0.094 ± 0.005			n/a		
12/07/2011 Storm event	0.074	0.077	-18	0.14	0.14	-13
12/09/2011 Dry-weather	0.064 ± 0.006			n/a		
12/20/2011 Dry-weather	0.041 ± 0.011			n/a		
12/22/2011 Storm event	0.093	0.070	48	0.17	0.10	59
12/23/2011 Dry-weather	0.074 ± 0.008			n/a		
01/23/2012 Storm event	n/a			0.56	0*	100
01/24/2012 Dry-weather	0.080			n/a		
01/27/2012 Storm event	0.061	0*	100	1.21	0*	100
01/28/2012 Dry-weather	0.067 ± 0.014			n/a		
02/14/2012 Dry-weather	0.035			n/a		
02/16/2012 Storm event	0.039	0*	100	1.12	0*	100
02/17/2012 Dry-weather	0.030 ± 0.008			n/a		
02/27/2012 Dry-weather	0.016 ± 0.001			n/a		
02/29/2012 Storm event	0.054	0.023	70	0.37	0.19	64
03/1/2012 Dry-weather	0.033 ± 0.010			n/a		
03/2/2012 Storm event	0.040	0.014	74	0.28	0.28	28
03/4/2012 Dry-weather	0.019 ± 0.005			n/a		
04/22/2012 Storm event	0.14	0*	100	0.19	0*	100
07/20/2012 Storm event	0.12	0.11	22	0.047	0.093	30

Table B-2. Water quality data of measured sample pollutant concentrations for the 38 storm events sampled at the infiltration basin site from August 2009 to August 2012.

WATER QUALITY DATA FOR STORM EVENT ON 08/13/2009											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO2-N**	**NO3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
8/13/09 0:42	0	5.73	443	0.47	3.45	0.05	0.86	12	26	152	43
8/13/09 1:02	20	23.67	492	0.82	2.01	0.03	0.82	20	20	99	18
8/13/09 1:22	20	26.88	78	0.51	0.70	0.02	0.44	< 5	8	39	16
8/13/09 1:42	20	14.69	43	0.41	1.33	0.02	0.42	< 5	7	38	19
8/13/09 2:02	20	7.73	9	0.31	1.96	0.03	0.40	< 5	6	38	23
8/13/09 2:22	20	4.12	10	0.34	1.27	0.03	0.41	< 5	6	38	27
8/13/09 2:42	20	2.38	11	0.36	0.59	0.03	0.42	< 5	6	37	30
8/13/09 3:02	20	1.56	8	0.37	0.75	0.04	0.43	< 5	6	37	35
8/13/09 3:22	20	0.90	5	0.37	0.91	0.04	0.43	< 5	6	37	40
8/13/09 4:22	60	0.25	4	0.38	1.30	0.06	0.47	< 5	7	38	53
8/13/09 5:22	60	0.15	3	0.39	1.68	0.08	0.51	< 5	8	40	55
8/13/09 6:42	80	0.05	6	0.38	0.28	0.03	1.04	< 5	9	33	60

WATER QUALITY DATA FOR STORM EVENT ON 08/21/2009											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
8/21/09 20:46	0	1.38	540	1.14	3.35	0.03	1.19	12	33	154	38
8/21/09 21:06	20	3.54	68	0.75	2.44	0.02	0.71	< 5	13	62	47
8/21/09 21:26	20	5.31	46	0.63	6.87	0.02	0.52	< 5	10	67	30
8/21/09 21:46	20	4.10	25	0.58	1.70	0.01	0.38	< 5	10	62	35
8/21/09 22:06	20	2.86	21	0.51	2.23	0.02	0.35	< 5	10	59	42
8/21/09 22:26	20	2.06	17	0.45	2.76	0.02	0.33	< 5	10	56	49
8/21/09 22:46	20	0.30	13	0.38	3.29	0.03	0.30	< 5	10	53	57
8/21/09 23:06	20	0.97	9	0.32	3.82	0.03	0.27	< 5	9	51	64
8/21/09 23:26	20	0.63	10	0.31	2.78	0.03	0.27	< 5	9	40	67
8/22/09 0:26	60	0.24	6	0.16	1.74	0.01	0.25	< 5	12	59	80
8/22/09 1:26	60	0.16	10	0.16	1.93	0.01	0.28	< 5	11	54	88
8/22/09 2:46	80	0.27	16	0.15	2.11	0.01	0.23	16	31	58	81

WATER QUALITY DATA FOR STORM EVENT ON 09/26/2009											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
9/26/09 19:48	0	0.59	36	0.53	2.36	0.030	0.72	< 5	13	54	109
9/26/09 20:08	20	1.09	36	0.53	2.04	0.028	0.65	< 5	11	58	35
9/26/09 20:28	20	0.85	42	0.52	1.72	0.033	0.52	< 5	10	65	35
9/26/09 20:48	20	1.05	40	0.52	1.74	0.038	0.51	< 5	9	60	31
9/26/09 21:08	20	1.49	54	0.43	1.77	0.031	0.49	< 5	9	103	27
9/26/09 21:28	20	2.34	25	0.27	1.39	0.027	0.18	< 5	7	62	23
9/26/09 21:48	20	2.74	18	0.34	1.02	0.014	0.32	< 5	7	63	88
9/26/09 22:08	20	3.42	28	0.31	2.10	0.014	0.17	< 5	7	61	35
9/26/09 22:28	20	4.93	142	0.65	3.18	0.089	1.31	< 5	16	153	68
9/26/09 23:28	60	8.94	44	0.60	2.61	< 0.01	1.13	< 5	11	58	107
9/27/09 0:28	60	6.48	19	0.53	2.04	< 0.01	1.39	< 5	12	48	112
9/27/09 1:48	80	4.19	45	0.52	1.02	< 0.01	1.36	< 5	13	34	117
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
9/27/2009 1:46	0	0.46	7	0.11	1.56	< 0.01	< 0.10	< 5	5	39	22
9/27/2009 2:06	20	0.75	5	0.10	1.37	< 0.01	< 0.10	7	4	< 25	22
9/27/2009 2:26	20	1.18	3	0.10	1.18	< 0.01	< 0.10	5	3	< 25	22
9/27/2009 2:46	20	1.62	1	0.11	1.94	< 0.01	< 0.10	5	< 2	< 25	22
9/27/2009 3:06	20	2.05	2	0.09	2.70	< 0.01	< 0.10	< 5	< 2	< 25	22
9/27/2009 3:26	20	2.30	1	0.10	3.46	< 0.01	< 0.10	< 5	2	< 25	22
9/27/2009 3:46	20	2.51	3	0.10	4.23	< 0.01	< 0.10	< 5	< 2	< 25	22
9/27/2009 4:06	20	2.70	2	0.11	2.55	< 0.01	< 0.10	< 5	< 2	< 25	22
9/27/2009 4:26	20	2.97	2	0.10	0.87	< 0.01	< 0.10	< 5	< 2	< 25	22
9/27/2009 5:26	60	3.33	2	0.11	0.77	< 0.01	< 0.10	< 5	3	< 25	22
9/27/2009 6:26	60	3.03	1	0.11	0.66	< 0.01	< 0.10	< 5	2	< 25	22
9/27/2009 7:46	80	2.28	1	0.11	0.33	< 0.01	< 0.10	< 5	< 2	< 25	22

WATER QUALITY DATA FOR STORM EVENT ON 11/19/2009											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
11/19/2009 17:38	0	0.34	88	0.39	2.66	0.044	0.54	6	14	65	57
11/19/2009 17:58	20	0.52	55	0.38	2.87	0.055	0.50	5	13	56	43
11/19/2009 18:18	20	0.41	36	0.35	3.08	0.031	0.47	< 5	12	71	43
11/19/2009 18:38	20	0.32	27	0.35	2.52	0.028	0.42	6	12	57	45
11/19/2009 19:18	40	0.26	23	0.32	1.96	0.024	0.39	< 5	13	66	48
11/19/2009 19:58	40	0.24	22	0.27	1.54	0.025	0.37	< 5	11	48	49
11/19/2009 20:58	60	0.21	19	0.27	1.12	0.024	0.30	< 5	12	32	52
11/19/2009 21:58	60	1.03	25	0.23	1.26	0.025	0.26	11	17	56	51
11/19/2009 23:18	80	7.13	245	0.37	1.40	0.027	0.23	10	17	73	16
11/20/2009 0:38	80	8.77	117	0.22	1.33	0.032	0.16	7	9	59	7
11/20/2009 2:18	100	2.36	50	0.25	1.26	0.021	0.30	< 5	7	54	9
11/20/2009 3:58	100	1.15	41	0.21	0.63	0.019	0.40	5	6	48	12
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
11/19/2009 23:36	0	0.53	11	0.13	0.70	< 0.01	< 0.10	< 5	7	62	13
11/19/2009 23:56	20	2.00	9	0.13	0.77	< 0.01	< 0.10	< 5	22	70	14
11/20/2009 0:16	20	4.50	7	0.11	0.84	< 0.01	< 0.10	< 5	2	70	14
11/20/2009 0:56	40	7.86	5	0.12	0.91	< 0.01	< 0.10	< 5	2	38	14
11/20/2009 1:36	40	7.10	7	0.09	0.98	< 0.01	< 0.10	< 5	2	52	13
11/20/2009 2:36	60	4.34	12	0.11	0.77	< 0.01	< 0.10	< 5	5	42	13
11/20/2009 3:36	60	2.79	15	0.13	0.56	< 0.01	< 0.10	< 5	4	38	14
11/20/2009 4:56	80	1.96	15	0.14	0.66	< 0.01	< 0.10	< 5	3	43	13
11/20/2009 6:16	80	1.49	7	0.14	0.70	< 0.01	< 0.10	< 5	4	62	14
11/20/2009 7:56	100	1.11	15	0.17	0.77	< 0.01	< 0.10	< 5	4	43	13
11/20/2009 9:36	100	0.86	5	0.18	0.84	< 0.01	< 0.10	< 5	4	42	13
11/20/2009 11:16	100	0.68	13	0.24	0.42	< 0.01	0.12	< 5	4	37	13

WATER QUALITY DATA FOR STORM EVENT ON 01/17/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
1/17/2010 9:52	0	0.46	n/a	0.08	4.62	0.097	1.84	9	12	90	1211
1/17/2010 10:12	20	1.51	n/a	0.19	3.92	0.112	0.55	< 5	15	63	2445
1/17/2010 10:32	20	1.75	n/a	0.28	3.22	0.099	1.31	< 5	9	55	2030
1/17/2010 10:52	20	3.15	n/a	0.42	2.73	0.068	0.97	< 5	11	72	1245
1/17/2010 11:32	40	5.04	n/a	0.42	2.24	0.071	0.57	< 5	12	71	976
1/17/2010 12:12	40	6.96	n/a	0.42	1.93	0.062	0.48	< 5	11	66	835
1/17/2010 13:12	60	6.94	n/a	0.25	1.61	0.043	0.56	< 5	8	52	612
1/17/2010 14:12	60	5.30	n/a	0.24	1.37	0.038	0.50	< 5	7	48	546
1/17/2010 15:32	80	3.07	n/a	0.22	1.12	0.033	0.57	< 5	4	43	586
1/17/2010 16:52	80	2.20	n/a	0.23	1.30	0.029	0.64	< 5	4	59	663
1/17/2010 18:32	100	1.76	n/a	0.17	1.47	0.025	0.71	< 5	3	34	718
1/17/2010 20:12	100	1.88	n/a	0.17	0.74	0.024	0.78	< 5	3	36	774
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
1/17/2010 13:22	0	0.44	n/a	0.06	0.84	0.021	0.29	< 5	5	57	210
1/17/2010 13:42	20	1.04	n/a	0.16	1.26	0.037	0.35	< 5	5	40	432
1/17/2010 14:02	20	1.69	n/a	0.15	1.68	0.043	0.32	< 5	5	51	508
1/17/2010 14:42	40	2.51	n/a	0.24	1.40	0.042	0.34	< 5	7	50	496
1/17/2010 15:22	40	3.29	n/a	0.24	1.12	0.040	0.36	< 5	6	45	515
1/17/2010 16:22	60	3.96	n/a	0.24	1.16	0.040	0.39	< 5	5	48	542
1/17/2010 17:22	60	3.97	n/a	0.25	1.19	0.040	0.44	< 5	5	44	584
1/17/2010 18:42	80	4.10	n/a	0.23	1.37	0.055	0.42	< 5	7	43	577
1/17/2010 20:02	80	4.12	n/a	0.23	1.82	0.040	0.41	< 5	6	46	638
1/17/2010 21:42	100	4.38	n/a	0.24	1.54	0.040	0.38	< 5	6	47	675
1/17/2010 23:22	100	4.29	n/a	0.23	1.26	0.038	0.34	< 5	6	45	768
1/18/2010 1:02	100	3.91	n/a	0.23	0.63	0.038	0.37	< 5	4	41	725

WATER QUALITY DATA FOR STORM EVENT ON 03/26/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
3/26/2010 1:42	0	0.45	823	0.58	0.14	2.52	0.023	0.60	24	41	146	682
3/26/2010 2:02	20	0.57	154	0.28	0.14	2.56	0.025	0.54	10	23	70	569
3/26/2010 2:22	20	0.68	111	0.19	0.13	2.59	0.029	0.48	7	20	63	504
3/26/2010 2:42	20	0.51	72	0.27	0.13	2.03	0.047	0.46	5	18	56	499
3/26/2010 3:22	40	0.68	111	0.27	0.13	1.47	0.027	0.43	6	18	57	420
3/26/2010 4:02	40	0.81	77	0.27	0.14	2.07	0.027	0.42	6	17	62	368
3/26/2010 5:02	60	2.05	102	0.31	0.13	2.66	0.020	0.57	< 5	15	64	365
3/26/2010 6:02	60	1.40	37	0.16	0.11	2.17	0.018	0.47	< 5	10	55	431
3/26/2010 7:22	80	0.68	32	0.18	0.10	1.68	0.016	0.41	< 5	8	48	510
3/26/2010 8:42	80	0.36	28	0.16	0.08	2.04	0.016	0.40	< 5	10	49	560
3/26/2010 10:22	100	0.49	95	0.18	0.06	2.40	0.027	0.28	7	13	66	362
3/26/2010 12:02	100	0.55	27	0.17	0.04	1.20	0.016	0.32	< 5	9	48	571

WATER QUALITY DATA FOR STORM EVENT ON 04/25/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
4/25/2010 20:52	0	3.22	1771	1.37		8.30	0.028	0.35	42	79	313	172
4/25/2010 21:12	20	14.65	562	0.72	0.08	4.85	0.015	0.34	14	73	161	42
4/25/2010 21:32	20	13.83	246	0.40		1.40	0.014	0.33	9	21	77	54
4/25/2010 21:52	20	6.92	83	0.21	0.05	1.61	0.015	0.28	5	13	39	68
4/25/2010 22:32	40	6.31	133	0.26		1.82	0.016	0.27	6	14	43	82
4/25/2010 23:12	40	6.13	103	0.25	0.08	1.61	0.016	0.34	6	15	39	79
4/26/2010 0:12	60	4.52	51	0.18		1.40	0.015	0.32	< 5	11	35	80
4/26/2010 1:12	60	1.99	39	0.18	0.08	1.51	0.016	0.26	< 5	11	27	125
4/26/2010 2:32	80	1.23	32	0.20		1.61	0.011	0.28	< 5	12	32	143
4/26/2010 3:52	80	0.52	23	0.17	0.08	1.65	0.017	0.29	< 5	12	< 25	191
4/26/2010 5:32	100	0.24	28	0.15		1.68	0.018	0.32	< 5	12	< 25	315
4/26/2010 7:12	100	0.22	34	0.06	0.07	1.68	0.016	0.30	< 5	14	< 25	441
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
4/26/2010 0:30	0	0.45	34	0.09		1.40	< 0.01	0.23	< 5	8	33	379
4/26/2010 0:50	20	0.64	43	0.13	0.00	1.52	< 0.01	0.19	< 5	8	< 25	381
4/26/2010 1:10	20	0.79	40	0.14		1.59	< 0.01	0.21	< 5	7	25	379
4/26/2010 1:50	20	0.93	48	0.11	0.01	1.65	< 0.01	0.17	< 5	8	< 25	380
4/26/2010 2:30	40	0.98	40	0.14		1.40	< 0.01	0.22	< 5	7	< 25	382
4/26/2010 3:30	40	0.92	47	0.11	0.00	1.26	< 0.01	0.18	< 5	6	< 25	381
4/26/2010 4:30	60	0.79	40	0.11		1.12	< 0.01	0.21	< 5	6	< 25	386
4/26/2010 5:50	60	0.65	32	0.12	0.01	1.12	< 0.01	0.18	< 5	7	< 25	389
4/26/2010 7:10	80	0.53	35	0.04		1.12	< 0.01	0.18	< 5	6	< 25	397
4/26/2010 8:50	80	0.44	32	0.11	0.02	1.33	< 0.01	0.18	< 5	8	< 25	393
4/26/2010 10:30	100	0.36	36	0.13		1.54	< 0.01	0.12	< 5	5	< 25	404
4/26/2010 12:10	100	0.49	35	0.15	0.01	1.54	< 0.01	0.14	< 5	5	< 25	385

WATER QUALITY DATA FOR STORM EVENT ON 05/23/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
5/23/2010 4:30	0	0.54	69	0.40	0.18	1.39	0.042	0.27	< 5	24	47	231
5/23/2010 5:30	60	3.13	105	0.51	0.17	1.32	0.017	0.22	< 5	20	69	45
5/23/2010 6:30	60	2.18	24	0.25	0.16	1.26	0.012	0.11	< 5	12	40	84
5/23/2010 7:30	60	0.84	14	0.23	0.15	1.30	0.015	0.10	< 5	12	53	121
5/23/2010 8:30	60	0.32	16	0.19	0.13	1.33	0.016	0.08	< 5	13	34	148
5/23/2010 9:30	60	0.19	15	0.25	0.11	1.67	0.017	0.08	5	14	36	203
5/23/2010 10:30	60	0.15	16	0.21	0.10	2.00	0.016	0.09	< 5	14	42	264
5/23/2010 11:30	60	0.11	14	0.20	0.09	1.98	0.015	0.09	< 5	15	58	300
5/23/2010 12:30	60	0.07	29	0.19	0.09	1.96	0.016	0.11	< 5	14	44	350
5/23/2010 13:30	60	0.02	33	0.18	0.05	0.98	0.015	0.16	< 5	15	39	409

WATER QUALITY DATA FOR STORM EVENT ON 07/12/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
7/12/2010 16:08	0	0.33	96	0.50	0.45	2.30	0.042	0.55	6	16	37	73
7/12/2010 16:28	20	3.99	76	0.60	0.46	1.26	0.025	0.73	5	16	42	27
7/12/2010 16:48	20	2.47	40	0.60	0.46	1.46	0.031	0.99	< 5	12	< 25	34
7/12/2010 17:08	20	1.10	27	0.57	0.47	1.66	0.039	0.88	< 5	11	< 25	46
7/12/2010 17:28	20	0.46	20	0.58	0.47	1.68	0.042	0.83	6	11	< 25	59
7/12/2010 18:08	20	0.09	21	0.54	0.24	1.71	0.046	1.07	< 5	13	< 25	72

WATER QUALITY DATA FOR STORM EVENT ON 08/12/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
8/12/2010 7:14	0	4.81	196	0.84	1.96	0.032	0.65	5	18	35	51
8/12/2010 7:34	20	32.40	53	0.73	1.58	0.037	0.54	6	17	38	34
8/12/2010 7:54	20	26.61	31	0.50	1.19	0.052	0.35	< 5	10	< 25	36
8/12/2010 8:14	20	13.62	17	0.47	1.16	0.038	0.34	< 5	8	< 25	43
8/12/2010 8:34	20	7.20	6	0.42	1.12	0.046	0.38	< 5	9	< 25	45
8/12/2010 8:54	20	3.87	8	0.48	1.40	0.044	0.33	< 5	8	< 25	50
8/12/2010 9:14	20	2.13	9	0.49	1.68	0.041	0.31	< 5	11	< 25	58
8/12/2010 9:34	20	1.22	7	0.46	1.68	0.040	0.32	< 5	9	< 25	67
8/12/2010 9:54	20	0.65	8	0.42	1.68	0.036	0.31	< 5	9	< 25	75
8/12/2010 10:54	60	0.13	24	0.38	0.84	0.031	0.28	< 5	11	< 25	100

WATER QUALITY DATA FOR STORM EVENT ON 09/27/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
9/27/2010 4:58	0	1.44	182	0.86	0.65	2.28	0.019	0.61	5	15	34	52
9/27/2010 5:16	20	4.95	78	0.51		1.53	0.018	0.34	< 5	10	< 25	33
9/27/2010 5:36	20	8.99	41	0.47	0.37	0.79	0.013	0.37	< 5	12	< 25	27
9/27/2010 5:56	20	5.51	14	0.51	0.27	1.13	0.016	0.29	< 5	8	< 25	32
9/27/2010 6:36	40	2.68	17	0.43	0.23	1.47	0.010	0.24	< 5	13	< 25	50
9/27/2010 7:16	40	1.27	10	0.31	0.18	1.77	0.009	0.25	< 5	9	< 25	85
9/27/2010 8:16	60	0.96	15	0.46	0.24	2.07	0.013	0.29	< 5	13	< 25	100
9/27/2010 9:16	60	0.79	17	0.47	0.27	2.15	0.010	0.29	< 5	13	47	103
9/27/2010 10:36	80	0.24	10	0.36	0.31	2.24	0.009	0.38	< 5	13	< 25	161
9/27/2010 11:56	80	0.16	24	0.48	0.35	2.52	0.010	0.49	< 5	12	26	220
9/27/2010 13:36	100	0.25	25	0.49	0.38	2.80	0.019	0.49	6	18	35	217
9/27/2010 15:16	100	0.79	17	0.31		2.45	0.021	0.22	< 5	17	< 25	108

WATER QUALITY DATA FOR STORM EVENT ON 10/27/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
10/27/2010 3:58	0	0.30	133	0.43	8.07	0.020	0.43	7	12	41	95
10/27/2010 4:18	20	0.57	52	0.46	5.22	0.016	0.34	< 5	11	63	87
10/27/2010 4:38	20	0.41	35	0.30	2.38	0.013	0.27	< 5	9	34	90
10/27/2010 4:58	20	1.00	133	0.50	2.12	< 0.01	0.21	8	13	62	55
10/27/2010 5:18	20	1.39	71	0.48	1.87	< 0.01	0.20	< 5	9	39	45
10/27/2010 5:58	40	2.83	53	0.56	1.73	< 0.01	0.11	< 5	8	30	24
10/27/2010 6:38	40	3.32	28	0.43	1.58	0.014	0.07	< 5	7	30	33
10/27/2010 7:18	40	2.25	15	0.39	1.19	< 0.01	0.08	< 5	6	32	38
10/27/2010 8:18	60	1.19	10	0.31	0.80	< 0.01	0.09	< 5	10	< 25	45
10/27/2010 9:18	60	0.65	23	0.31	1.20	0.010	0.10	< 5	7	41	54
10/27/2010 10:18	60	0.33	14	0.35	1.60	0.010	0.09	< 5	7	33	69
10/27/2010 11:58	100	0.20	20	0.32	1.73	0.010	0.09	< 5	8	37	124

WATER QUALITY DATA FOR STORM EVENT ON 11/16/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
11/16/2010 10:34	0	0.32	59	0.40	1.54	0.016	0.35	< 5	8	36	88
11/16/2010 10:54	20	0.44	17	0.31	1.51	0.016	0.37	< 5	8	32	80
11/16/2010 11:14	20	0.38	11	0.29	1.47	0.013	0.30	< 5	7	13	81
11/16/2010 11:34	20	0.32	7	0.33	1.09	0.012	0.25	< 5	6	28	82
11/16/2010 12:14	40	0.25	13	0.34	0.70	0.011	0.19	< 5	7	27	85
11/16/2010 12:54	40	0.21	10	0.35	1.05	0.011	0.15	< 5	7	13	89
11/16/2010 13:54	60	0.22	8	0.35	1.40	0.011	0.12	< 5	8	36	92
11/16/2010 14:54	60	0.22	13	0.31	1.40	0.011	0.10	< 5	8	29	91
11/16/2010 16:14	80	0.77	10	0.25	1.40	0.012	0.20	< 5	7	29	58
11/16/2010 17:34	80	1.36	22	0.48	1.33	0.014	0.29	< 5	7	42	28
11/16/2010 19:14	100	1.02	13	0.37	1.30	0.010	0.15	< 5	8	28	57
11/16/2010 20:54	100	0.61	16	0.52	1.26	0.010	< 0.10	< 5	8	27	57

WATER QUALITY DATA FOR STORM EVENT ON 12/01/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
12/1/2010 5:46	0	0.69	132	0.83	2.33	< 0.01	0.22	5	11	62	83
12/1/2010 6:16	30	1.22	42	0.34	1.87	< 0.01	0.19	< 5	6	36	55
12/1/2010 6:56	40	0.99	31	0.35	1.40	< 0.01	0.16	< 5	5	34	45
12/1/2010 7:36	40	2.01	58	0.62	1.19	0.010	0.10	< 5	7	46	26
12/1/2010 8:36	60	2.88	31	0.55	0.98	< 0.01	< 0.10	< 5	6	44	30
12/1/2010 9:36	60	3.79	17	0.38	1.19	< 0.01	< 0.10	< 5	4	46	28
12/1/2010 11:06	90	5.87	25	0.23	1.40	< 0.01	< 0.10	< 5	4	47	12
12/1/2010 13:06	120	1.35	15	0.25	1.26	< 0.01	< 0.10	< 5	3	39	22
12/1/2010 15:06	120	0.39	16	0.21	0.84	< 0.01	< 0.10	< 5	3	36	35
12/1/2010 17:06	120	0.19	16	0.21	0.91	0.010	0.10	< 5	3	42	64
12/1/2010 19:36	150	0.07	14	0.18	0.98	0.010	< 0.10	< 5	4	45	127
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
12/1/2010 10:46	0	0.57	9	0.10	0.70	< 0.01	< 0.10	< 5	< 2	61	24
12/1/2010 11:16	30	1.35	4	0.21	0.72	< 0.01	< 0.10	< 5	< 2	< 25	24
12/1/2010 11:56	40	1.67	2	0.06	0.56	< 0.01	< 0.10	< 5	< 2	26	24
12/1/2010 12:36	40	1.75	1	0.06	0.74	< 0.01	< 0.10	< 5	< 2	31	24
12/1/2010 13:36	60	0.17	3	0.02	1.26	< 0.01	< 0.10	< 5	< 2	27	25
12/1/2010 15:06	90	1.30	4	0.14	0.93	< 0.01	< 0.10	< 5	< 2	< 25	24
12/1/2010 16:36	90	1.05	6	0.09	0.56	< 0.01	< 0.10	< 5	< 2	32	24
12/1/2010 18:36	120	0.86	1	0.02	0.59	< 0.01	< 0.10	< 5	< 2	< 25	24
12/1/2010 20:36	120	0.69	2	0.08	0.56	< 0.01	< 0.10	< 5	< 2	27	24
12/1/2010 23:06	150	0.54	4	0.09	0.63	< 0.01	< 0.10	< 5	< 2	28	24
12/2/2010 1:36	180	0.45	2	0.08	0.70	< 0.01	< 0.10	< 5	4	34	24
12/2/2010 4:36	180	0.36	4	0.08	0.70	< 0.01	< 0.10	< 5	< 2	< 25	24

WATER QUALITY DATA FOR STORM EVENT ON 02/25/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
2/25/2011 0:44	0	0.47	53	0.14	0.63	0.011	n/a	< 5	8	41	1072
2/25/2011 1:14	30	0.82	42	0.13	0.94	0.012	n/a	< 5	7	36	1057
2/25/2011 1:54	40	0.79	33	0.13	1.25	0.047	n/a	< 5	5	31	1933
2/25/2011 2:34	40	1.47	29	0.09	0.77	0.094	n/a	< 5	5	30	3398
2/25/2011 3:34	60	1.21	22	0.04	0.29	0.043	n/a	< 5	5	41	2204
2/25/2011 4:34	60	0.95	20	0.02	0.65	0.037	n/a	< 5	6	39	2378
2/25/2011 6:04	90	1.26	19	0.02	1.01	0.029	n/a	< 5	4	< 25	2350
2/25/2011 8:04	120	6.54	145	0.22	1.26	0.032	n/a	5	10	70	797
2/25/2011 10:04	120	2.67	49	0.15	1.12	0.022	n/a	< 5	5	42	801
2/25/2011 12:04	120	1.49	25	0.12	0.91	0.021	n/a	< 5	4	33	931
2/25/2011 14:34	150	0.80	38	0.10	0.70	0.018	n/a	< 5	4	29	1021
2/25/2011 17:34	180	0.38	18	0.05	0.98	0.016	n/a	< 5	3	< 25	1254
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
2/25/2011 7:40	0	0.46	31	0.25	2.43	< 0.01	n/a	< 5	3	40	472
2/25/2011 8:10	30	1.49	22	0.24	1.79	< 0.01	n/a	< 5	< 2	< 25	515
2/25/2011 8:50	40	2.47	23	0.19	1.26	< 0.01	n/a	< 5	< 2	25	552
2/25/2011 9:30	40	3.11	10	0.11	1.15	< 0.01	n/a	< 5	< 2	< 25	619
2/25/2011 10:30	60	3.01	17	0.08	1.05	< 0.01	n/a	< 5	< 2	< 25	730
2/25/2011 12:00	90	2.38	9	0.02	1.04	< 0.01	n/a	< 5	< 2	< 25	725
2/25/2011 13:30	90	1.85	18	0.07	0.98	< 0.01	n/a	< 5	< 2	< 25	911
2/25/2011 15:30	120	1.38	25	0.22	1.03	< 0.01	n/a	< 5	< 2	30	942
2/25/2011 17:30	120	1.08	15	0.09	0.98	< 0.01	n/a	< 5	< 2	< 25	906
2/25/2011 20:00	150	0.84	12	0.06	1.09	< 0.01	n/a	< 5	< 2	27	857
2/25/2011 22:30	150	0.67	10	0.04	0.77	< 0.01	n/a	< 5	< 2	27	883
2/26/2011 1:30	180	0.53	9	0.03	1.19	< 0.01	n/a	< 5	< 2	27	783

WATER QUALITY DATA FOR STORM EVENT ON 03/10/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
3/10/2011 1:36	0	0.41	95	0.41	1.68	0.014	n/a	< 5	9	59	762
3/10/2011 2:06	30	0.77	58	0.26	1.75	0.026	n/a	5	10	43	399
3/10/2011 2:46	40	0.80	31	0.23	1.82	0.022	n/a	< 5	9	51	392
3/10/2011 3:46	60	1.69	62	0.23	1.47	0.017	n/a	< 5	8	44	336
3/10/2011 4:46	60	2.71	44	0.14	1.12	0.014	n/a	< 5	8	41	227
3/10/2011 6:16	90	4.45	57	0.22	1.12	0.012	n/a	< 5	5	44	136
3/10/2011 8:16	90	7.58	58	0.20	1.12	0.013	n/a	< 5	5	46	86
3/10/2011 10:16	120	22.02	215	0.31	1.12	0.012	n/a	7	9	58	26
3/10/2011 12:46	120	14.50	158	0.25	0.98	0.011	n/a	6	7	54	20
3/10/2011 15:16	150	18.30	137	0.25	0.84	0.012	n/a	6	7	48	20
3/10/2011 17:46	150	11.93	134	0.18	0.98	0.010	n/a	6	5	48	16
3/10/2011 20:46	180	2.59	72	0.23	1.40	0.010	n/a	< 5	6	42	0
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
3/10/2011 5:46	0	0.46	30	0.33	1.68	< 0.01	n/a	< 5	4	52	365
3/10/2011 6:16	30	1.09	27	0.29	1.47	< 0.01	n/a	< 5	4	34	353
3/10/2011 6:56	40	2.18	20	0.25	1.68	< 0.01	n/a	< 5	4	35	348
3/10/2011 7:56	40	3.94	24	0.27	1.26	< 0.01	n/a	< 5	4	33	332
3/10/2011 9:26	60	14.13	19	0.19	1.12	< 0.01	n/a	< 5	4	29	310
3/10/2011 10:56	90	26.76	28	0.19	0.84	< 0.01	n/a	< 5	5	40	154
3/10/2011 12:56	90	20.58	38	0.20	0.84	< 0.01	n/a	< 5	4	39	83
3/10/2011 14:56	120	22.11	33	0.19	0.84	< 0.01	n/a	< 5	5	39	78
3/10/2011 17:26	120	23.87	40	0.18	0.84	< 0.01	n/a	< 5	4	40	74
3/10/2011 19:56	150	7.95	39	0.18	0.70	< 0.01	n/a	< 5	5	41	72
3/10/2011 22:56	180	3.50	31	0.18	0.91	0.012	n/a	< 5	4	38	83
3/11/2011 1:56	180	2.15	28	0.18	1.12	< 0.01	n/a	< 5	4	40	104

WATER QUALITY DATA FOR STORM EVENT ON 04/22/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
4/22/2011 20:16	0	0.43	40	0.24	2.66	0.036	n/a	< 5	15	41	0
4/22/2011 20:46	30	0.42	25	0.25	2.73	0.031	n/a	< 5	14	37	0
4/22/2011 21:26	40	0.37	31	0.25	2.80	0.028	n/a	< 5	12	39	0
4/22/2011 22:06	40	0.34	35	0.21	2.31	0.029	n/a	< 5	12	39	0
4/22/2011 23:06	60	0.36	39	0.22	1.82	0.029	n/a	< 5	13	42	0
4/23/2011 0:36	90	0.29	27	0.23	2.03	0.029	n/a	< 5	12	36	0
4/23/2011 2:06	90	0.28	30	0.23	2.24	0.029	n/a	< 5	13	46	0
4/23/2011 4:06	120	0.39	29	0.22	2.38	0.026	n/a	6	12	40	0
4/23/2011 6:06	120	0.48	24	0.19	1.96	0.034	n/a	< 5	8	41	0
4/23/2011 8:36	150	0.31	18	0.15	1.61	0.017	n/a	< 5	9	41	0
4/23/2011 11:06	150	0.20	24	0.22	1.26	0.012	n/a	6	10	43	0
4/23/2011 14:06	180	0.25	54	0.23	0.63	0.022	n/a	6	16	50	0

WATER QUALITY DATA FOR STORM EVENT ON 05/14/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
5/14/2011 22:56	0	0.54	118	0.57	4.34	0.042	n/a	6	22	64	207
5/14/2011 23:16	20	1.26	63	0.45	3.36	0.030	n/a	< 5	15	47	220
5/14/2011 23:36	20	1.53	33	0.42	2.38	0.027	n/a	< 5	14	40	224
5/15/2011 0:16	40	2.04	30	0.38	2.24	0.024	n/a	< 5	13	41	108
5/15/2011 0:56	40	1.32	30	0.34	1.82	0.022	n/a	< 5	12	50	118
5/15/2011 1:56	60	0.55	20	0.27	2.04	0.017	n/a	< 5	10	39	134
5/15/2011 2:56	60	0.23	24	0.26	2.27	0.017	n/a	< 5	12	44	197
5/15/2011 4:16	80	0.04	27	0.21	1.13	0.018	n/a	< 5	10	31	278

WATER QUALITY DATA FOR STORM EVENT ON 06/09/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
6/9/2011 20:16	0	7.68	335	0.58	n/a	n/a	n/a	9	30	83	n/a
6/9/2011 21:16	60	5.90	75	0.65	n/a	n/a	n/a	< 5	13	44	n/a
6/9/2011 22:16	60	1.61	22	0.54	n/a	n/a	n/a	< 5	14	30	n/a
6/9/2011 23:16	60	0.52	19	0.50	n/a	n/a	n/a	< 5	15	33	n/a
6/10/2011 0:16	60	0.10	17	0.65	n/a	n/a	n/a	< 5	19	43	n/a

WATER QUALITY DATA FOR STORM EVENT ON 07/07/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
7/7/2011 19:52	0	0.53	127	0.55	3.22	n/a	n/a	< 5	20	59	69
7/7/2011 20:12	20	0.52	81	0.41	2.24	n/a	n/a	< 5	18	44	90
7/7/2011 20:32	20	2.25	50	0.58	1.96	n/a	n/a	7	13	57	20
7/7/2011 20:52	20	1.31	41	0.57	2.10	n/a	n/a	< 5	13	51	25
7/7/2011 21:12	20	0.70	24	0.64	2.24	n/a	n/a	< 5	12	46	26
7/7/2011 21:32	20	0.39	18	0.57	2.38	n/a	n/a	< 5	13	50	34
7/7/2011 21:52	20	0.24	18	0.56	2.52	n/a	n/a	< 5	13	38	36
7/7/2011 22:12	20	0.14	38	0.62	2.38	n/a	n/a	< 5	14	44	29
7/7/2011 22:32	20	0.04	27	0.46	1.19	n/a	n/a	< 5	14	42	23

WATER QUALITY DATA FOR STORM EVENT ON 07/25/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
7/25/2011 15:16	0	15.19	54	0.54	1.82	0.028	0.74	< 5	8	29	18
7/25/2011 15:36	20	63.26	32	0.36	1.40	0.016	0.46	< 5	10	34	7
7/25/2011 15:56	20	35.93	31	0.31	1.26	0.022	0.35	< 5	8	30	11
7/25/2011 16:16	20	22.27	35	0.33	1.33	0.026	0.39	< 5	8	31	12
7/25/2011 16:36	20	13.59	13	0.34	1.40	0.031	0.30	< 5	7	< 25	14
7/25/2011 16:56	20	7.96	12	0.41	1.75	0.039	0.48	< 5	7	< 25	20
7/25/2011 17:16	20	4.76	10	0.38	2.10	0.045	0.48	< 5	9	< 25	33
7/25/2011 17:36	20	2.90	6	0.43	1.89	0.044	0.62	< 5	8	< 25	24
7/25/2011 17:56	20	1.71	7	0.39	1.68	0.043	0.66	< 5	9	26	38
7/25/2011 18:56	60	0.48	9	0.36	1.68	0.030	0.37	< 5	10	27	53
7/25/2011 19:56	60	0.08	12	0.36	1.68	0.023	0.29	< 5	11	< 25	57
7/25/2011 21:16	80	0.00	16	0.41	0.84	0.019	0.16	< 5	13	26	70

WATER QUALITY DATA FOR STORM EVENT ON 08/06/2011												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L s^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$\mu g L^{-1}$**	**$\mu g L^{-1}$**	**$\mu g L^{-1}$**	**$mg L^{-1}$**
8/6/2011 18:18	0	11.23	83	0.53	0.37	2.05	0.014	1.11	< 5	13	35	37
8/6/2011 18:38	20	53.36	64	0.39	0.21	1.87	< 0.01	1.22	< 5	12	46	12
8/6/2011 18:58	20	30.11	26	0.29	0.18	1.49	< 0.01	0.78	5	7	< 25	16
8/6/2011 19:18	20	16.68	11	0.28	0.21	1.40	0.011	0.74	7	6	< 25	26
8/6/2011 19:38	20	10.27	6	0.33	0.24	1.31	0.011	0.79	< 5	6	< 25	24
8/6/2011 19:58	20	6.09	9	0.35	0.27	1.31	0.010	0.65	< 5	7	< 25	27
8/6/2011 20:18	20	3.71	5	0.36	0.30	1.31	0.010	0.73	< 5	7	< 25	33
8/6/2011 20:38	20	1.98	8	0.37	0.27	1.03	0.010	0.62	< 5	6	< 25	29
8/6/2011 20:58	20	0.98	7	0.34	0.24	0.75	0.010	0.42	< 5	7	< 25	35
8/6/2011 21:58	60	0.12	11	0.35	0.12	0.37	0.011	0.48	< 5	9	< 25	41
8/6/2011 22:58	60	0.00										
8/7/2011 0:18	80	0.00										
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L s^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$mg L^{-1}$**	**$\mu g L^{-1}$**	**$\mu g L^{-1}$**	**$\mu g L^{-1}$**	**$mg L^{-1}$**
8/6/2011 19:08	0	0.51	13	0.28	0.09	1.49	< 0.01	0.31	< 5	6	50	75
8/6/2011 19:28	20	1.32	18	0.24	0.08	1.40	< 0.01	0.23	< 5	7	< 25	76
8/6/2011 19:48	20	1.84	12	0.24	0.08	1.31	< 0.01	0.39	< 5	3	< 25	73
8/6/2011 20:08	20	2.28	9	0.19	0.08	1.12	< 0.01	0.23	< 5	2	< 25	73
8/6/2011 20:28	20	2.17	12	0.16	0.08	0.93	< 0.01	0.31	< 5	3	< 25	73
8/6/2011 20:48	20	2.09	12.5	0.16	0.08	0.84	< 0.01	0.37	< 5	3	< 25	78
8/6/2011 21:08	20	2.24	13	0.18	0.07	0.75	< 0.01	0.29	< 5	3	< 25	75
8/6/2011 21:28	20	2.03	10	0.16	0.07	0.65	< 0.01	0.15	< 5	3	< 25	74
8/6/2011 21:48	20	1.79	16	0.17	0.08	0.56	< 0.01	0.18	< 5	4	< 25	73
8/6/2011 22:48	60	1.71	13	0.16	0.08	0.47	< 0.01	0.11	< 5	3	< 25	73
8/6/2011 23:48	60	1.49	12	0.16	0.08	0.37	< 0.01	0.23	< 5	3	< 25	73
8/7/2011 1:08	80	1.32	14	0.18	0.04	0.19	< 0.01	0.13	< 5	3	< 25	73

WATER QUALITY DATA FOR STORM EVENT ON 09/23/2011												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
9/23/2011 10:28	0	0.36	279	0.48	0.36	4.03	0.017	0.73	7	13	41	90
9/23/2011 10:48	20	0.52	59	0.37	0.29	3.13	0.013	0.81	< 5	13	27	107
9/23/2011 11:08	20	0.80	45	0.34	0.22	2.24	< 0.01	0.56	< 5	12	< 25	106
9/23/2011 11:28	20	1.22	62	0.35	0.24	1.77	< 0.01	0.27	21	11	26	84
9/23/2011 11:48	20	6.24	83	0.41	0.26	1.54	< 0.01	0.48	12	9	33	18
9/23/2011 12:28	40	12.61	104	0.37	0.22	1.31	< 0.01	0.34	< 5	13	< 25	16
9/23/2011 13:08	40	16.50	46	0.23	0.16	0.71	< 0.01	0.27	< 5	7	< 25	7
9/23/2011 13:48	40	7.70	22	0.24	0.17	0.80	< 0.01	0.52	< 5	5	49	8
9/23/2011 14:48	60	2.57	23	0.26	0.18	0.89	< 0.01	0.63	< 5	6	< 25	12
9/23/2011 15:48	60	1.87	27	0.26	0.16	1.00	< 0.01	0.63	< 5	7	25	21
9/23/2011 16:48	60	2.14	24	0.23	0.15	1.12	< 0.01	0.30	< 5	7	< 25	8
9/23/2011 18:28	100	2.11	37	0.19	0.07	0.56	< 0.01	0.40	< 5	6	< 25	28
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
9/23/2011 12:44	0	0.67	29	0.13	0.05	2.02	< 0.01	0.32	< 5	4	< 25	6
9/23/2011 13:04	20	4.19	6	0.10	0.08	1.43	< 0.01	0.23	< 5	3	35	5
9/23/2011 13:24	20	8.88	7	0.12	0.11	0.83	< 0.01	0.05	< 5	2	< 25	5
9/23/2011 13:44	20	8.60	20	0.11	0.07	0.73	< 0.01	0.18	11	3	< 25	6
9/23/2011 14:04	20	7.69	12	0.10	0.04	0.62	< 0.01	0.18	16	3	< 25	6
9/23/2011 14:44	40	5.16	13	0.15	0.05	1.01	< 0.01	0.21	10	4	< 25	7
9/23/2011 15:28	40	3.52	9	0.17	0.05	1.40	< 0.01	0.29	< 5	4	< 25	5
9/23/2011 16:04	40	2.71	23	0.18	0.08	1.01	0.013	0.26	< 5	5	< 25	8
9/23/2011 17:04	60	2.26	1	0.18	0.11	0.62	< 0.01	0.32	23	4	< 25	6
9/23/2011 18:04	60	2.08	15	0.17	0.11	0.92	< 0.01	0.31	< 5	4	35	7
9/23/2011 19:04	60	1.92	13	0.16	0.10	1.21	< 0.01	0.23	10	4	< 25	7
9/23/2011 20:44	100	1.51	9	0.16	0.11	0.93	< 0.01	0.21	< 5	4	< 25	7

WATER QUALITY DATA FOR STORM EVENT ON 10/12/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
10/12/2011 16:34	0	0.50	197	0.65	1.68	0.020	0.71	6	15	41	60
10/12/2011 16:54	20	1.15	199	0.24	1.68	0.021	0.55	9	23	91	54
10/12/2011 17:14	20	0.85	59	0.45	2.10	0.015	0.44	< 5	9	43	65
10/12/2011 17:34	20	1.27	90	0.32	2.52	0.014	0.37	< 5	10	48	63
10/12/2011 17:54	20	1.41	41	0.43	1.96	0.017	0.48	< 5	9	48	24
10/12/2011 18:34	40	0.83	40	0.39	1.40	0.018	0.54	< 5	8	49	33
10/12/2011 19:14	40	0.45	39	0.38	1.47	0.016	0.55	< 5	9	48	44
10/12/2011 19:54	40	0.27	49	0.39	1.54	0.011	0.48	< 5	12	49	56
10/12/2011 20:54	60	0.19	47	0.40	2.10	0.013	0.48	< 5	9	47	73
10/12/2011 21:54	60	0.20	42	0.44	2.66	0.010	0.39	< 5	10	54	94
10/12/2011 22:54	60	0.28	58	0.41	2.10	0.010	0.25	< 5	10	63	109
10/13/2011 0:34	100	0.44	47	0.38	1.54	0.011	0.12	< 5	9	55	99

WATER QUALITY DATA FOR STORM EVENT ON 11/16/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
11/16/2011 12:20	0	0.81	272	1.19	3.08	0.026	0.23	6	18	67	57
11/16/2011 12:50	30	0.97	59	0.80	2.24	0.015	0.17	5	10	34	72
11/16/2011 13:30	40	0.66	31	0.43	2.05	< 0.001	< 0.10	< 5	9	< 25	76
11/16/2011 14:30	60	0.90	23	0.85	1.87	0.017	0.13	< 5	8	< 25	29
11/16/2011 15:30	60	0.57	18	0.69	1.91	0.010	< 0.10	< 5	7	< 25	42
11/16/2011 17:00	90	0.37	28	0.47	1.96	< 0.001	< 0.10	6	8	< 25	60
11/16/2011 19:00	120	0.30	31	0.45	1.90	< 0.001	< 0.10	7	8	< 25	80
11/16/2011 21:00	120	0.31	39	0.43	1.84	0.010	< 0.10	5	10	< 25	96
11/16/2011 23:30	150	0.27	27	0.39	2.04	0.010	< 0.10	5	8	< 25	109
11/17/2011 2:00	150	0.22	22	0.33	2.24	0.010	< 0.10	5	8	< 25	122
11/17/2011 4:30	150	0.20	19	0.26	1.12	0.011	< 0.10	6	9	< 25	143
11/17/2011 7:30	180	0.18	26	0.23	0.56	< 0.001	< 0.10	5	8	< 25	174

WATER QUALITY DATA FOR STORM EVENT ON 01/17/2012											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
1/17/2012 9:46	0	0.47	203	0.42	1.68	0.010	1.28	8	5	57	28
1/17/2012 10:16	30	0.56	69	0.32	1.96	0.011	0.74	10	4	42	31
1/17/2012 10:56	40	0.42	42	0.20	1.86	0.010	0.73	7	3	44	28
1/17/2012 11:36	40	0.36	55	0.25	1.77	0.012	0.74	12	3	49	28
1/17/2012 12:36	60	0.31	27	0.26	1.62	0.010	1.11	9	3	45	29
1/17/2012 14:06	90	0.26	32	0.26	1.47	0.012	0.97	7	3	48	31
1/17/2012 15:36	90	0.23	25	0.28	1.51	0.010	1.15	22	3	48	33
1/17/2012 17:36	120	0.20	29	0.23	1.54	0.011	1.12	7	3	52	30
1/17/2012 19:36	120	0.19	29	0.31	1.68	0.010	1.20	7	3	59	32
1/17/2012 22:06	150	0.18	50	0.31	1.83	0.011	1.22	9	3	47	34
1/18/2012 0:36	150	0.18	35	0.26	0.91	0.010	1.51	8	4	62	36
1/18/2012 3:36	180	0.16	38	0.17	1.72	0.010	1.24	10	8	56	38

WATER QUALITY DATA FOR STORM EVENT ON 05/14/2012											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
5/14/2012 16:42	0	1.29	243	0.48	2.32	0.022	0.40	13	34	64	76
5/14/2012 17:12	30	1.58	91	0.32	1.79	0.015	0.26	11	20	54	56
5/14/2012 17:52	40	3.75	60	0.39	1.27	0.011	0.27	7	16	62	30
5/14/2012 18:52	60	1.93	47	0.25	1.30	< 0.001	0.11	7	14	35	58
5/14/2012 20:22	90	0.67	43	0.18	1.33	< 0.001	< 0.10	5	12	29	62
5/14/2012 21:52	90	0.43	53	0.23	1.49	< 0.001	0.12	9	19	35	79
5/14/2012 23:52	120	0.43	55	0.26	1.65	0.015	0.10	9	16	36	100
5/15/2012 1:52	120	0.69	52	0.27	1.26	0.014	< 0.10	9	15	38	91
5/15/2012 4:22	150	4.48	110	0.27	0.88	< 0.001	0.14	12	13	34	33
5/15/2012 6:52	150	6.81	69	0.16	1.17	< 0.001	0.12	6	8	33	22
5/15/2012 9:52	180	0.93	42	0.17	0.96	< 0.001	< 0.10	5	10	32	42
5/15/2012 12:52	180	0.24	48	0.26	0.48	< 0.001	< 0.10	6	9	31	61

n/a: No data;
Concentrations measured below laboratory detection limit are reported as '< (detection limit)'

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