ABSTRACT

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The impact of two management practices, gutter filters and bioinlets, on stormwater highway runoff quality at an ultra urban area in Mt. Rainier, MD, was evaluated. The analyses were divided into 3 phases: before construction (32 events) (Flint, 2004), gutter filters only (17 events) and gutter filters and bioinlets (14 events). Comparisons between phases 1 and 3 resulted in Total Suspended Solids (83%), cadmium (86-89%) and lead (84%) demonstrating statistically significant removal using the student's *t* test and the Mann-Whitney U test on the mean event mean concentration (EMC). Total Kjeldahl Nitrogen (12%), nitrite (42%) and copper (29%) demonstrated statistically significant removal, while Total Phosphorus (20-40%) indicated an increase in EMC by the Mann-Whitney U test after phase 3, but these values were insignificant based on the student's *t* test. Results support the application of these stormwater management practices in urban areas.

FIELD EVALUATION OF LOW IMPACT DEVELOPMENT PRACTICES FOR TREATMENT OF HIGHWAY RUNOFF IN AN ULTRA URBAN AREA

By

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Chapter 1

INTRODUCTION

The increase in the nature and extent of contamination by pollutants in surface runoff in urban areas and along highways has led to implementation of stormwater management practices. The problems associated with water quality as well as quantity have been the focus of stormwater management. A variety of anthropogenic activities and rainfall characteristics influence the pollutant concentrations in runoffs. Urbanization leads to changes in drainage patterns, replacement of pervious areas by impervious ones and removal of vegetation which eventually leads to modifications in the hydrologic cycle at a site (Goonetilleke, et al., 2005). A variety of pollutants find their way into stormwater runoff from construction sites, highways, and residential, commercial and industrial areas. Comparison between data obtained from wastewater treatment plants and from major industrial-process-wastewater discharges located in Washington D.C., Maryland and Virginia, provide an insight that the annual metal-element loadings from runoff are not only comparable to the contributions made from the industrial waste discharges, but also exceed those loadings in the effluent from the wastewater treatment plant by at least an order of magnitude (Sansalone, et al., 2005).

Over the years, regulations have been passed and technological solutions have been implemented on wastewater treatment facilities and industry, ensuring that these sources are less significant today as the cause of impairment of receiving waters (Swamikannu, et al., 2003). The data from the U.S. E.P.A.-funded Nationwide Urban Runoff Program (NURP) from 1978 to 1983 indicated that, on an annual loadings basis, suspended solids and Chemical Oxygen Demand from urban rainfall runoff are an equivalent magnitude to that of effluent from wastewater treatment plants receiving only primary treatment (Sansalone, et al., 2005). As a consequence, emphasis was laid on passing regulations and government policies on stormwater management. In order to achieve the desired result and compliance with the stormwater regulations, a number of stormwater management systems were implemented. Since highway runoff is generally similar to urban runoff, the same types of runoff controls used to treat urban stormwater runoff are also appropriate for treating stormwater discharges from highways (Barrett, et al., 1998).

Schueler (1987) listed some stormwater management practices referred to as Best Management Practices (BMPs). Various structural and non structural best management practices have been developed and used extensively for effective control of runoff flows and somewhat less effective control of stormwater quality (Viklander, et al., 2003). Detention basins, sand filters, grass swales, bioinlets, bioretention areas, hydrodynamic devices, infiltration trenches, porous pavements, wetland basins, media filters are some common stormwater BMPs.

The Low Impact Development (LID) approach incorporates such BMPs and is in contrast to conventional stormwater management practices which involve end-of-pipe solutions. LID practices in residential, commercial and industrial properties aim to achieve the same site conditions pre-development and post-development with respect to hydrology, soil and vegetation cover. In contrast to conventional stormwater management practices which emphasize transporting the runoff away from the site as quickly as possible, BMPs try to maintain the runoff around the site and use processes like infiltration, evapo-transpiration and rerouting runoff over pervious surfaces (Holman-Dodds, et al., 2003). Urban drainage systems should be designed not only with an adequate hydraulic capacity in mind but also to meet environmental quality objectives. The LID philosophy needs a multidisciplinary approach with contributions from engineers, landscape architects, ecologists and soil scientists to name a few (Landers, 2004).

Performance comparisons of BMPs would help in making judicious choices in implementing them at different sites. The effectiveness of a stormwater management practice can be determined by assessing its pollutant removal ability. Over the years, pollutant removal efficiency has been expressed as percent reduction in the concentration or load for the concerned pollutants using a statistical characterization based on flow weighted samples collected from the untreated and treated runoff (Barrett, 2005). Statistical characterization of the inflow and outflow concentrations is one of the techniques for estimating the pollutant reduction by BMPs. Assessment of the annual pollutant loadings and event mean concentrations (EMCs) also aid in establishing success in implementing BMPs for water quality improvement. It is imperative from a performance comparison point of view to determine the effectiveness of BMPs. However, comparison of various BMP studies requires consistent data reporting and incorporating key parameters (Urbonas, 1995). Due to the randomness in stormwater quality assessment and remediation, statistical approaches using probability distributions provide an effective tool to showcase the pollutant removal.

The current research undertaken is a before and after study for evaluation of LID practices implemented at a site in Mt. Rainier, MD on U.S. Rt. 1. The entire project has been divided into three phases. Phase 1: conventional (before construction), phase 2: gutter filters only, and phase 3: gutter filters and bioinlets. Water quality data of highway runoff were obtained when there was no treatment for phase 1 from June 2002–September 2003 (Flint, 2004), after gutter filter construction for phase 2 from November 2003-September 2004 and after complete implementation of LID practice (gutter filters + bioinlets) for phase 3 from October 2004–November 2005. Total Suspended Solids (TSS), Total Kjeldahl Nitrogen (TKN), nitrite (NO_2^-), nitrate (NO_3^-), Total Phosphorus (TP), chloride (Cl), cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn) were the target pollutants analyzed for water quality. Previous work (Flint, 2004) evaluated the highway runoff water quality at Mt. Rainier prior to construction of any stormwater management practice. The characterization of the water quality is used as an experimental control to the later 2 phases that have been completed in the current project. The present research involves the two later stages. Water quality data were collected after the construction of gutter filters on the east side of U.S. Rt. 1 (Phase 2). The water quality is obtained after treatment from the gutter filters alone. Further, there is another set of data collected after the construction of bioinlets on the west side of the highway. The stormwater sampled in this case (Phase 3) was after treatment of the highway runoff from gutter filters and bioinlets.

The goals for this project were to monitor storm water flows and quality, monitor rainfall, and analyze pollutant loadings at Mt. Rainier, MD. The objective was to quantify water quality improvements via the selected LID practices. Comparison of storm water runoff quality after construction of the gutter filters and the bioinlets with the previous results (Flint, 2004) obtained before construction of any treatment was carried out.

Within this goal, water quality improvements were correlated with LID practice information, land use/site characteristics, and wet weather characteristics. The research aims to shed light on the performance of the LID practices by statistical analyses on the event mean concentration of the pollutants. The focus of the statistical study (student's *t* test and the Mann-Whitney U test) is to establish a certain degree of confidence on whether the observed reduction is by chance or a true difference, which can be attributed to the treatment. The pollutant data sets in each of the 3 phases were examined for outliers by the Rosner's Outlier Test (sample size >25) and the Dixon-Thompson Test (sample size from 3-25). Tools such as the exceedence probability charts provide a pictorial representation of the pollutant concentrations in each phase of the project. The probability of when a particular pollutant concentration will be exceeded is obtained from these charts. As a result, with the data sets on three phases of the project, the water quality improvements can be quantified and documented and performance of the LID practices in place will be statistically defendable.

The project will aid in establishing the impact of the LID practices on water quality at Mt. Rainier. The data and the inferences from this project will provide guidelines for the Maryland State Highway Administration and other agencies to implement environmentally sound cost efficient stormwater management systems. The project aims to focus on the effectiveness of LID practices in treatment of highway water runoff and therefore try to alleviate the problems posed by urban non-point source pollution to surface waters.

Chapter 2

BACKGROUND

2.1. GENERAL OVERVIEW

Stormwater runoff and associated pollutant discharge causes flooding in urban areas and has adverse effects on receiving waters, causing flooding, erosion, nutrition enrichment, metal toxicity and dissolved oxygen depletion (Marsalek, 1998). Elevated concentrations of nutrients lead to eutrophication while particulate matter adds to turbidity. Pollutants of interest in stormwater runoff include Total Suspended Solids (TSS), Total Kjeldahl Nitrogen (TKN), nitrite (NO_2^-), nitrate (NO_3^-), total phosphorus (TP), zinc (Zn), copper (Cu), lead (Pb) and cadmium (Cd). The heavy metals, Zn, Cu and Pb are considered priority pollutants in highway runoff water (Federal Highway Administration (FHA) 1996, Barbosa and Jacobsen, 2001). Some major factors which influence the concentrations of these pollutants in stormwater are particle size distribution for TSS, traffic counts (Average Daily Traffic, ADT) and storm characteristics such as runoff volume, antecedent dry period, rainfall intensity and rainfall duration.

The immediate impacts of urbanization result in degradation of water quality, stream habitats and increase in flooding (Goonetilleke, et al., 2005). Figure 2.1 shows that a runoff peak flow rate from an informal developed area can be about four times, and from a formal developed area can be about three times that from an undeveloped (virgin) area. Informal developed areas are those which do not have utility services while formal developed areas refer to areas with sewer systems (Braune and Wood, 1999).

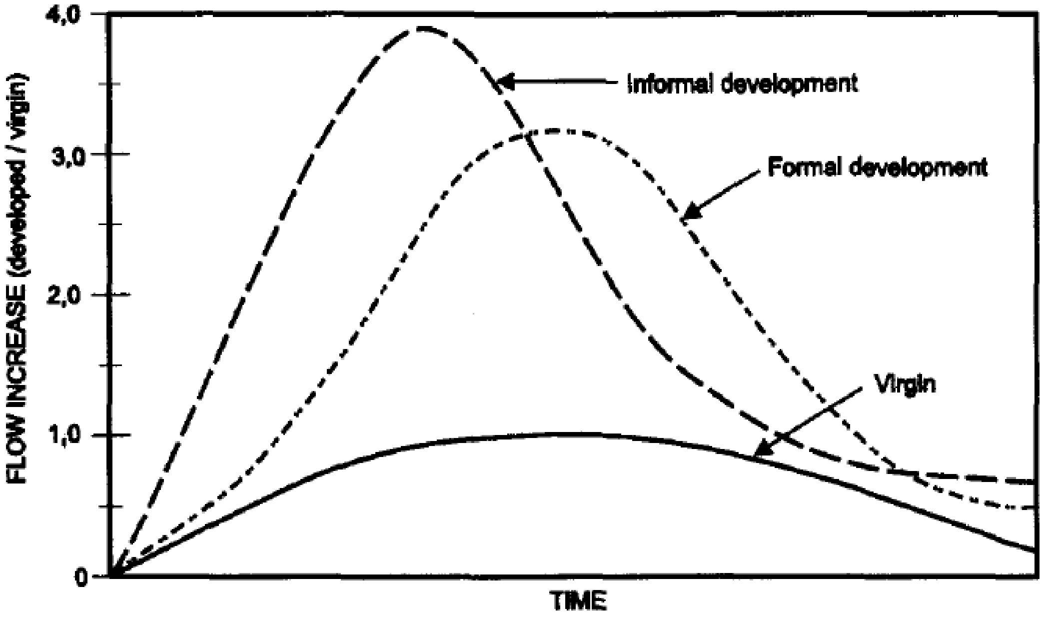


Figure 2.1. Impact of urbanization on runoff quantity (Braune and Wood, 1999) Representative figure not to scale.

2.2. POLLUTANTS

2.2.1. *Total Suspended Solids*

Total Suspended Solids (TSS) have been measured in stormwater at a concentration range of 1.0 to 36,200 mg/l. The means of suspended solids values range from 4 to 1223 mg/l (Makepeace, et al., 1995). Total suspended solids are operationally defined by the Standard Method as the particulate matter retained by a glass fiber filter with 0.45 μm pore size (APHA, 1995). However, some suspended solids have diameters smaller than 0.45 μm. Particulates deposit on impervious surfaces through a variety of pathways, such as dustfall, atmospheric deposition, wear of automobile parts and corrosion. Particles in highway runoff in particular arise from roadway maintenance operations, atmospheric deposition, corrosion and erosion and various kinds of traffic activities such as tire abrasion, vehicular wear, fluid leakage and pavement degradation

(Kobriger and Geinopolos, 1984; Thomson, et al., 1987; Legret and Pagotto, 1999; Grant et al., 2003; Li et al., 2005). Total suspended solids provide surface area for metals to be adsorbed. Therefore, the particle size distribution of TSS in runoff impacts the concentration of metal pollutants. Thus TSS is an important parameter for evaluating wet weather pollution.

2.2.2. *Metals*

Heavy metals are of particular interest in stormwater runoff due to their toxicity, ubiquity, and the fact that metals cannot be chemically transformed or destroyed. A variety of sources contribute to the presence of metals in the environment. For example, wear of tires and brake pads is a source of all four metals; Cd, Cu, Pb and Zn (Makepeace, et al., 1995).

Cadmium is toxic at concentrations as low as 0.0036 mg/L to rainbow trout at 50 mg/l hardness, and shows a chronic toxicity range from 0.00015 to 0.156 mg/l for different organisms (Makepeace, et al., 1995). The high toxicity of Cd combined with its tendency to remain as ionic species makes it a threat to receiving water body life (Morrison, et al., 1990). Sources of Cd are combustion of lubricating oils, metal finishing industrial emissions, agricultural use of sludge, fertilizers and pesticides (Makepeace, et al., 1995). Cd may enter water as a result of industrial discharges or the deterioration of galvanized pipe (APHA, 1995).

Copper is introduced in roadway runoff from brake pad materials, motor oil, and flashing used in buildings. Common sources of Cu in stormwater are corrosion of building parts; wear of bearings; bushings and other moving parts in engines;

metallurgical and industrial emissions; fungicides and pesticides (Makepeace, et al., 1995). Tire wear, motor oil and batteries are common sources of lead in roadway runoff. Zinc is generally found in stormwater from tire wear, brake pads, motor oil and grease, and zinc-coated building materials. Combustion of lubricating oils and corrosion of buildings and metal objects are also sources of Zn (Makepeace, et al., 1995).

Davis, et al., (2001) estimated metal loadings from individual components of automobiles and buildings with controlled experimental and sampling investigations. A percentage breakdown of the various sources for each of the metal loadings in urban runoff is indicated in Figure 2.2. It is evident from the figure that building sidings are the main source of Pb and Zn, brake wear for Cu and atmospheric deposition for Cd in urban runoff. Oil was not a significant source for any of the metals. The secondary sources were dry deposition for Pb, building sidings for Cu and Cd, and tire wear for Zn. Atmospheric deposition was the main source for Pb and tire wear for Zn when the building type was changed from brick to vinyl. The metal levels from vinyl sidings were lower than from the brick building sidings.

The percentage of metals associated to suspended solids is higher than the dissolved fraction (Barbosa and Jacobsen, 2001). Suspended solids provide surfaces for metals to be adsorbed and thus serve as carriers for metal pollutants. Heavy metals, polycyclic aromatic hydrocarbons (PAHs), phosphorus and organic compounds are adsorbed onto TSS (Rossi, et al., 2004). Metal concentrations increase with decreasing particle size. This is mainly because fine particles provide a greater surface area for adsorption and have a higher cation exchange capacity (Dong, et al., 1984; Ujevic, et al., 2000; Liebens, 2001; Herngren, et al., 2005).

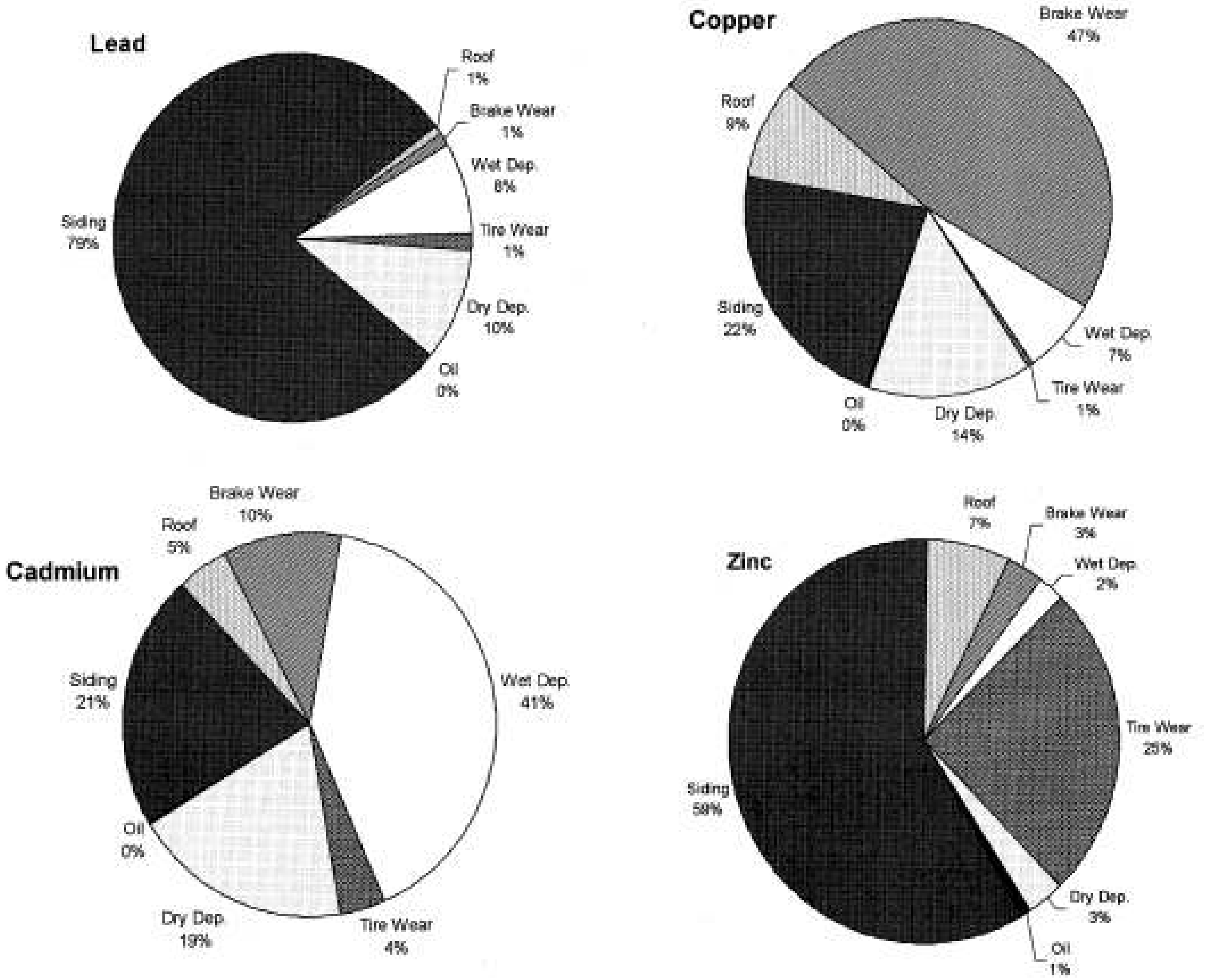


Figure 2.2. Estimated contributions of various sources of metals in urban residential stormwater runoff. Brick buildings. Total metal loadings: Pb = 0.069 kg/ha-yr, Cu = 0.038 kg/ha-yr, Cd = 0.0012 kg/ha-yr, Zn = 0.646 kg/ha-yr (Davis, et al., 2001).

2.2.3. *Nutrients*

Increase in impervious area results in a build up of nutrients on surfaces, leading to high pollution loads. Phosphorus and nitrogen are the nutrients of concern in stormwater. The presence of nitrogen and phosphorus compounds in excessive amounts leads to excessive growth of aquatic plants (eutrophication), surface algal scum, water discoloration, turbidity, odor, and low concentrations or fluctuations of dissolved oxygen. Nitrogen occurs as organic nitrogen, NH_4^+, NO_3^- and NO_2^-. Nitrate and NH_4^+ are the forms used by aquatic plants. Organic nitrogen and nitrite are also included in pollutant accounting because these forms can be converted to the available forms. In addition to nitrogen's function as a nutrient, the dissolved forms of nitrogen are also toxic to aquatic organisms. Nitrate is acutely toxic at concentrations as low as 5 mg/L to steelhead eggs, NO_2^- at 0.19 mg/L to rainbow trout, and NH_4^+ at 0.0017 mg/L to pink salmon (Makepeace, et al., 1995). Nitrogen sources are derived from decomposing organic matter, animal and human wastes and atmospheric deposition. Sources of nitrogen in stormwater are fertilizers, industrial cleaning operations, feed lots, animal excrement, and combustion of fuels (Makepeace, et al., 1995).

The sources of phosphorus are similar to nitrogen sources. Generally, tree leaves (Hodges, 1997), fertilizers and lubricants are sources of phosphorus (Makepeace, et al., 1995). Phosphorus occurs organically bound as orthophosphate or in the dissolved form as phosphate.

Vaze and Chiew (2004) showed that particulate TN and TP are associated with sediment size range of 11-150 μm in urban stormwater runoff. The dissolved components of TN and TP were 20-50% and 20-30%, respectively. Thus treatment facilities with design based on sediment sizes should be able to remove particles down to 11 μm for effective nitrogen and phosphorus removal.

2.2.4. *Chloride*

Chloride is another contaminant of concern in stormwater runoff. It has been found at a concentration range of 0.30 (snow) to 25,000 mg/l (Makepeace, et al., 1995); some of the high values were, however, associated with deicing of roads. An estimated 10 million tons of salt are applied to US roadways annually (Novotny, 1999, as referenced by Mangold, 2000). Application of deicing salts, mainly NaCl and $MgCl_2$, during winter months is the main contribution to elevated chloride levels in snowmelt. As a result, Na^+, Ca^{2+} and Mg^{2+} concentration measurements can be used as an indicator for Cl^- levels in stormwater runoff. Chloride is also introduced into stormwater runoff by tire road ballast, dust control, chemical manufacturing, wastewater treatment, fertilizers and insecticides (Makepeace, et al., 1995). The presence of chlorides creates two types of effects: those exerted directly by chloride toxicity, and those caused by toxicity of urban pollutants, which may be enhanced by the presence of chloride (e.g., leaching of contaminants or their increased bioavailability, Marsalek, et al., 2003). Chloride adversely affects soil fertility by affecting soil structure and water transport through the soil (Marsalek, et al., 2003).

2.3. EVENT MEAN CONCENTRATION

The event mean concentration (EMC) represents the concentration that would result if the entire storm event discharge was collected in one container. EMC weighs discrete concentrations with flow volumes; therefore it is generally used to compare pollutant concentrations among different events. Generally the constituent concentrations vary by orders of magnitude during a runoff event; hence the EMC is used to characterize concentrations (Sansalone, et al., 1997). The EMC represents a flow average concentration computed as the total pollutant load (mass) divided by the total runoff volume:

$$\text{EMC} = \overline{C} = \frac{M}{V} = \frac{\int_0^{tr} c(t)q(t)dt}{\int_0^{tr} q(t)dt} \tag{2.1}$$

where, M = total mass of constituent over entire event duration (M); V = total volume of flow over the entire event duration (L^3); q(t) = time variable flow, (L^3/T); c(t) = time dependent concentration (M/L^3), and t_r = duration of the storm event.

Barrett et al., (1998) measured the water quality characteristics for runoff samples as median EMCs and a coefficient of variance for each of the three sites in Austin, Texas. The sites exhibited different land use characteristics. The rural/ residential site had a drainage area of 526 m^2, commercial/ high density residential site had a drainage area of 104,600 m^2 and the commercial/ residential site had a drainage area of 5341 m^2. The characterization of the pollutant runoff at these sites indicated that TSS, Zn and Pb had the highest median event mean concentration in the commercial/ residential area followed by the rural/ residential area with the commercial/ high density residential area having the lowest concentration. In a study carried out by Wu et al., (1998), site mean EMCs were taken as the arithmetic average of all EMCs observed at three highway sites with drainage areas equal to 1497 m^2, 2307 m^2 and 4452 m^2 in Charlotte, NC. The characterization of the runoff at the three sites with respect to mean EMCs is presented in Table 2.1.

Table 2.1. Mean EMCs for 3 sites in Charlotte, NC for different pollutants (Wu et al., 1998).

Pollutants Site	TSS (mg/L)	TKN (mg/L)	TP (mg/L)	Cu (µg/L)	Pb (µg/L)
Site 1	283	1.4	0.43	24	21
Site 2	93	1.2	0.52	12	14
Site 3	30	1.0	0.47	4.6	6.5

Some statistical analyses was carried out on EMCs (Van Buren, et al., 1997, Sansalone, et al., 2004, Barrett, 2005) to determine the effectiveness of the Best Management Practices (BMPs) adopted for treatment of stormwater runoff and thus evaluate stormwater quality. Applications of log-normal distributions to stormwater quality were reported in literature (U.S. E.P.A., 1983; Marsalek, 1984; Harremoes, 1988; Van Buren et al., 1997). Van Buren, et al. (1997) obtained EMC data from parking lot inflow, creek inflow and pond outflow in Kingston Township, Ontario, Canada. The purpose of the research was to obtain a complete description of the cumulative distribution function for the runoff quality data. The results for suspended solids indicated that log-normal distribution of the EMCs was appropriate for all the data subsets except pond outflow. Organic contaminants, metals, nitrogen and phosphorus (which show a strong affinity for suspended solids) also exhibited log-normal distribution.

2.4. POLLUTANT LOADS

The annual pollutant load can be calculated using the Simple Method defined by Schueler (1987) and given by:

$$L = PP_j R_v (CF) C \tag{2.2}$$

where, L is the normalized annual pollutant load (kg/ha/yr or lb/ac/yr), P is the annual precipitation (cm/yr), P_j is the dimensionless correction factor that adjusts for storms without runoff, R_v is the dimensionless average runoff coefficient, CF is a conversion factor for matching appropriate units, and C is the flow weighted average concentration (mg/L). The pollutant loads are used a parameter to compare the pollutant removal efficency for a before and after study. The estimated annual pollutant load uses the flow weighted concentration as opposed to the EMC.

2.5. FIRST FLUSH CONCEPTS

The “First Flush” phenomenon is based on the reasoning that most of the pollutants are washed out in the initial stages of the stormwater runoff. However the amount of pollutant transported from the ground surface to the receiving waters can depend on a number of factors such as antecedent conditions, individual storm intensity patterns and site specific drainage characteristics (Ahlfield, et al., 2004). First flush implies a disproportionately high input of concentrations or pollutant mass in the initial portions of a rainfall-runoff event. Sansalone and Cristina (2004) employed two dimensionless parameters – normalized mass and volume to define a first flush in a storm event.

$$\text{Normalized mass} = m'(t) = \frac{m(t)}{M} = \frac{\int_0^k q(t)c(t)dt}{\int_0^n q(t)c(t)dt} \tag{2.3}$$

$$\text{Normalized volume} = v'(t) = \frac{v(t)}{V} = \frac{\int_0^k q(t)dt}{\int_0^n q(t)dt} \tag{2.4}$$

Normalized mass is the ratio of the instantaneous mass over the sum total of the mass of the pollutant at the end of the event, while normalized volume represents the ratio of the instantaneous volume over the cumulative rainfall volume. The parameter k represents any instant during the runoff between the initiation of the runoff (t=0) and the end of the runoff (t=n). $q(t)$ is a function denoting the measured hydrograph of a rainfall runoff event (flow rate). $c(t)$ represents the function denoting measured constituent concentration as a function of time.

In the literature, there have been three approaches to describing a first flush. Sansalone et al., (1997, 1998, 2003) adopted a qualitative approach to characterizing first flush. In this method the percent of the total mass that has been flushed at any time during the storm event must be equal to or greater than the percent of the total volume that has been washed from the system up to that time. In another variation to the definition, in a plot of $m'(t)$ on the dependent axis versus $v'(t)$, a line with a slope 1:1 is plotted and a first flush is considered if $m'(t)$ exceeds (lies above) the 45^o line (Geiger, et al., 1987).

Saget et al., (1995) and Bertrand-Krajewski et al., (1998) defined first flush as 80% of the pollutant mass in the initial 30% of the rainfall runoff volume.

The second and third criteria of first flush are quantitative and may be adopted for design purposes. First flush criteria have also been defined as the first 20 L of runoff from elevated bridge scuppers (Drapper, et al., 2000), the first 1.27 cm (0.5 in.) of runoff per contributing area (Grisham, 1995), the first 1.27 cm (0.5 in.) runoff per contributing impervious acre (first 3.14 cm per contributing hectare), the volume of runoff produced by a 0.1 in. storm (Schueler, 1987), or the volume of water obtained by a 1.9 cm (0.75 in.) rainfall event (State of California, 2001). First flush was also defined as the percentage of total event pollution load (FF_{20}) transported by the first 20% of storm runoff volume (Deletic, 1998). If the FF_{20} value of an event is significantly higher than 20%, a first flush is present in that event.

In the analysis of first flush by Sansalone and Cristina (2004), 16 rainfall events were categorized into mass-limited high runoff volume event or flow-limited low runoff volume event. Eight events prior to 2000 were monitored at Cincinnati, Ohio (asphalt paved section of I-75 with a drainage area = 300 m^2). The other 8 events were sampled along an elevated section of Portland cement concrete paved I-10 in urban Baton Rouge, LA (drainage area = 544 m^2). Five of the eight measured mass limited events at both the sites combined exhibited a strong decline in the concentration of suspended solids indicative of a concentration based first flush in which the concentration rapidly falls below 20% of the maximum concentration during the rising limb of the hydrograph for single peak events or during the first hydrograph for multiple peak events. Mass based first flush (MBFF) has been defined in literature in a number of ways. The dimensionless mass and volume curves (Figure 2.3) indicate that a MBFF for suspended solids was observed in all but one event at the Cincinnati site, while at the Baton Rouge site it was observed it in six out of eight events. The flow-limited events exhibit a MBFF for six of the eight examined events at both the sites together. However no first flush was observed at any site if the first flush was defined as 80% of the total mass in 20% of runoff volume.

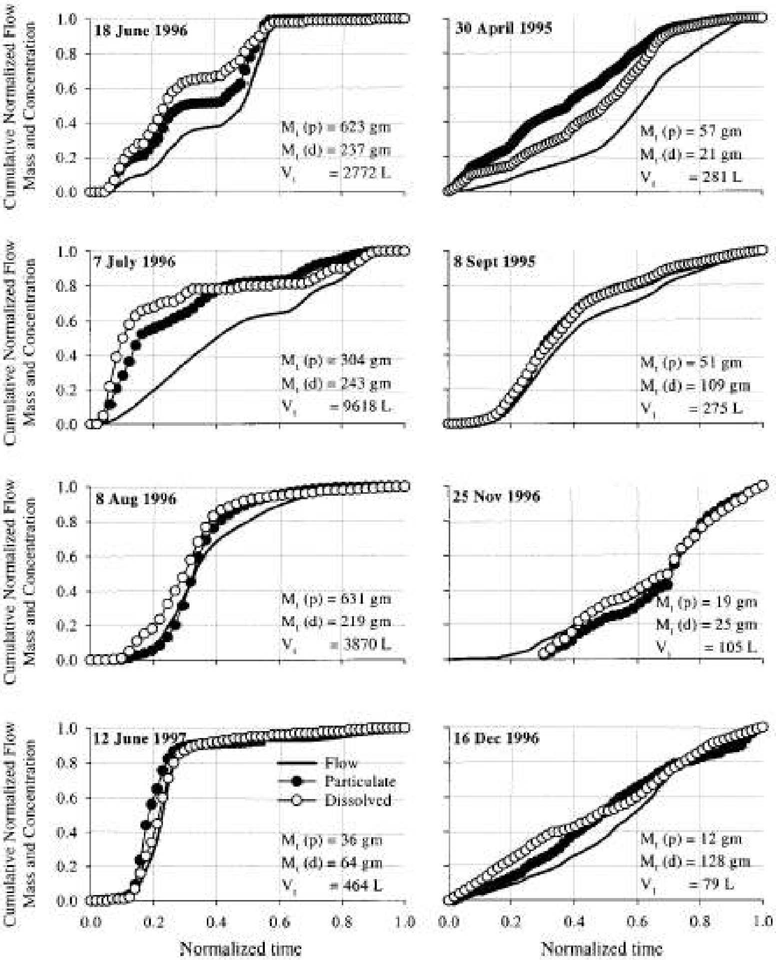


Figure 2.3. Mass based first flush plots at the Cincinnati site (Sansalone and Cristina, 2004). Plot for dimensionless curves of mass versus volume.

Lee and Bang (2000) characterized urban stormwater runoff in areas which could be characterized based on land use as residential, undeveloped and industrial watersheds

(Figures 2.4). The different sites were categorized on the basis of land use as high density residence with commercial activity (site-BBW-74.4 ha and MSW-86.5 ha), high density residence (site-YMW-230 ha), low density residence (site-GYW-557.9 ha) and undeveloped (site-YJW-348 ha). The first flush was dependent on the ratio of the dimensionless cumulative pollutant load and the dimensionless cumulative runoff (Equations 2.3 and 2.4). The dimensionless cumulative curves for some events are presented in Figure 2.5. Thus, if the pollutant loading is higher than that of the runoff volume, then the slope of the line will be more than 1 and is an indication of first flush. COD, n-Hexane extracts and PO_4-P exhibited a distinct first flush for the residential and industrial watersheds (a,d,e). NO_3-N does not show a first flush except at one particular site (CICW-3) where it shows a distinct first flush and Pb show a weak first flush at all sites studied (c, f). A general tendency of the first flush shows that the relative strength of the first flush is COD > n-hexane extracts > PO_4-P > NO_3^--N>Pb (Lee and Bang, 2000).

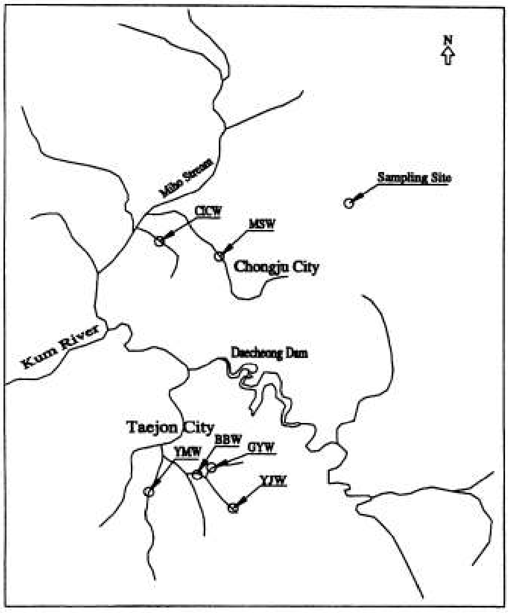
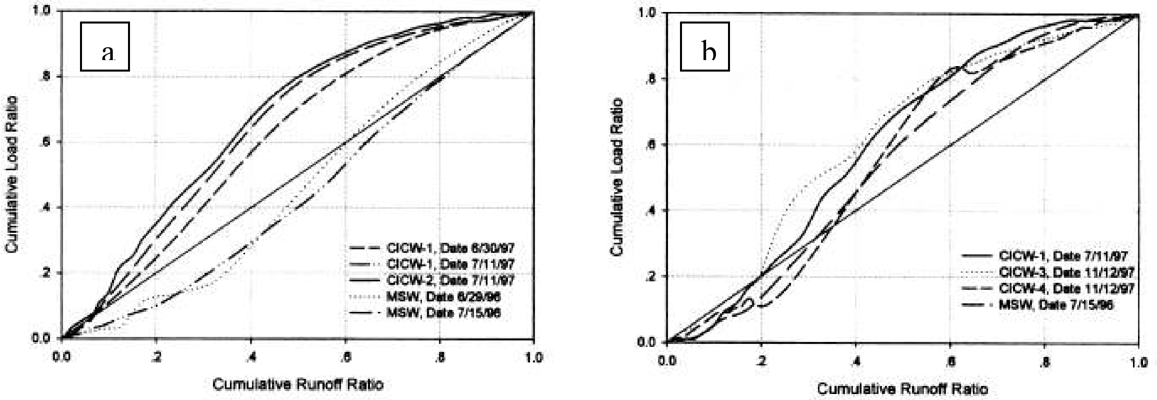
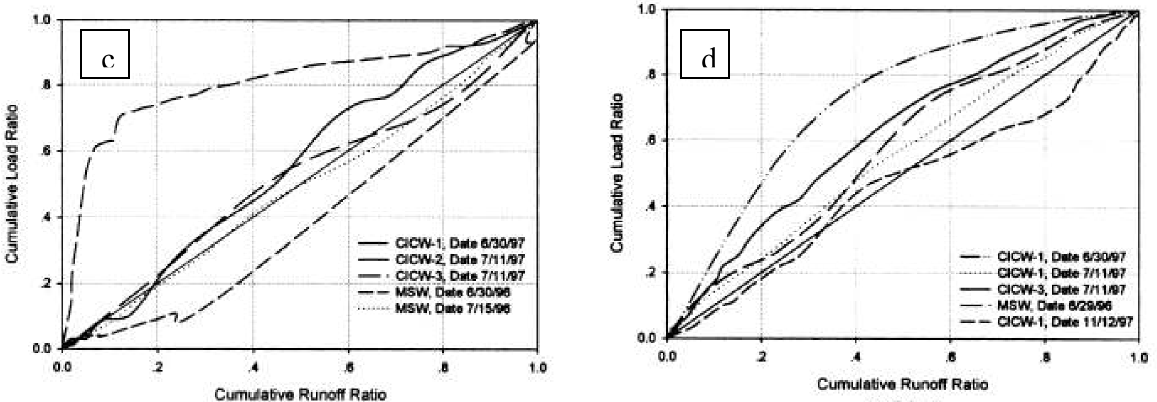


Figure 2.4. Locations of sites monitored by Lee and Bang (2000) in the watersheds of cities of Taejon and Chongju, Korea from June 1995 to November 1997.



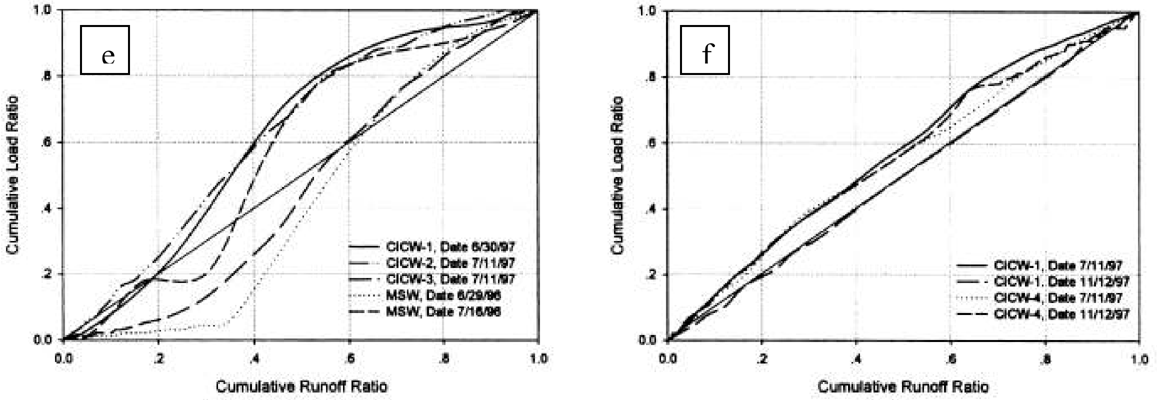
(a) COD

(b) SS



(c) NO_3-N

(d) PO_4-P



(e) n-Hexane extracts

(f) Pb

Figure 2.5. Dimensionless cumulative curves of mass versus volume for some events at the sites monitored in the watersheds of cities of Taejon and Chongju, Korea from June 1995 to November 1997 (Lee and Bang, 2000).

Different studies have been carried out to investigate the characteristics which influence the first flush phenomenon. Gupta and Saul (1996) showed that, in combined sewers, the first flush load of total suspended solids correlated well with the peak rainfall intensity, the storm duration, and the antecedent dry weather period. They developed a set of predictive equations for first flush load using linear regression. However, the study has limitations as the coefficients are catchment specific. In contrast, Saget et al., (1995) found no correlation between the shape of the cumulative load curves and catchment characteristics (area, time of concentration and average slope) or any rainfall characteristic (rainfall depth, maximum intensity and antecedent dry weather period).

2.6. LOW IMPACT DEVELOPMENT AND BEST MANAGEMENT PRACTICES

Stormwater Best Management Practices (BMPs) aid in addressing the water quality concerns to surface waters from runoff. A BMP is a structural or a non structural measure employed in stormwater management for stormwater quantity and quality control (Marsalek and Chocat, 2002). The BMPs, in contrast to end of pipe solutions, intercept the pollutants at the source and stormwater is discharged close to the point of rainfall (Barbosa and Jacobsen, 2001). The runoff controls used to treat urban stormwater runoff are similar to those for treating stormwater discharge from highways and thus highway runoff can be treated by analogous treatment measures (Barrett, et al., 1998).

Urban development directly affects natural processes like interception, infiltration and depression storage for a watershed (McCuen, 2003). Urban stormwater management infrastructure conventionally was designed to move runoff away from a developed area as quickly as possible: from impervious surfaces to stream discharge via gutters and storm drains (Davis, 2005). However, with the increased understanding of nonpoint source pollution, there is a need for executing a holistic design of urban stormwater management systems incorporating multiple purposes of controlling major and minor floods as well as stormwater pollution. It is important to not only consider suspended pollutants but also dissolved pollutants which exist in significant proportions while designing an urban stormwater management practice (Goonetilleke, et al., 2005). Low Impact Development (LID) in land development is directed to mitigating such problems.

"Smart growth" in urban planning incorporates LID and involves planned development strategies, controlled growth, the balance of multiple objectives, and use of best management practices for water and air quality enhancement (McCuen, 2003). The LID concept involves manipulating the layout of urbanized landscapes to disconnect impervious surfaces from streams. Non-structural and structural best management practices (BMPs) are intrinsic to Low Impact Development. The LID approach manages rainfall where it falls, through a combination of enhancing infiltration properties of pervious areas and rerouting impervious runoff across pervious areas to allow an opportunity for infiltration (Holman-Dodds et al., 2003). This can be accomplished by stormwater management practices such as pervious land cover, vegetation around the impervious surfaces, infiltration trenches, rain gardens, bioretention cells, sand filters and grass swales. Figure 2.6 indicates a comparison of traditional drainage practices with a structural BMP in the form of minimal directly-connected impervious area. Infiltration practices like grass swales, bioinlets, porous pavements, infiltration trenches are forms of structural BMPs which aid in stormwater runoff treatment (Urbonas, 1994). Media filters and retention ponds are also a part of this group and are used for non-point source pollution mitigation.

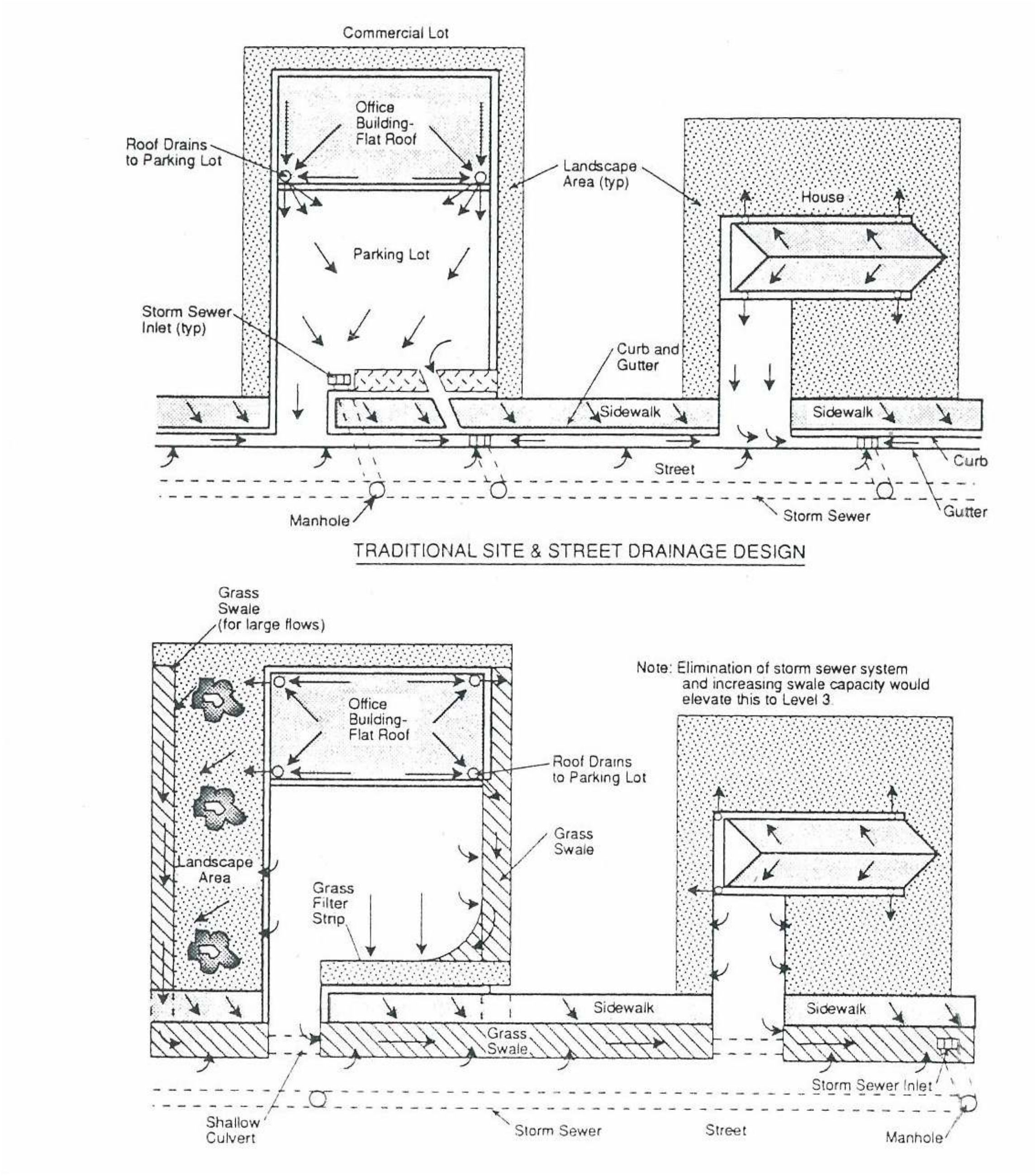


Figure 2.6. Comparison between conventional and LID treatment for drainage from a parking lot and a residence (Urbonas, 1994).

In addition to reducing the amount of surface runoff, LID also aids in recharging local ground water aquifers and streams, reduce erosion and stream widening, and improve stream water quality, all without the additional expense and maintenance associated with traditional engineered stormwater infrastructure (Prince George's County, 1999; Holman-Dodds, et al., 2003). Non-structural BMPs include public education on proper disposal of household waste (chemicals, paints, solvents, motor oils), detection and elimination of illicit discharges of wastewater connections and enforcing clear violations for pollution deposition on urban landscapes (Urbonas, 1994). Basically non-structural BMPs encourage good housekeeping measures.

The LID practices incorporated at Mt. Rainier, MD for the current study are gutter filters and bioinlets. The gutter filters are similar to sand filters (Figure 2.7) which work on the principle of sedimentation and filtration. They are constructed below grade and are especially an advantage in urban areas where land availability is at a premium. The filtered runoff is discharged to a storm drain or natural channel. Bioinlets are similar to bioretention areas (Figure 2.8) and aid in improving water quality by processes like sedimentation, filtration, soil adsorption, microbial decay processes and uptake of pollutants by plants. The soil layer and the microbes in the soil enhance infiltration, groundwater recharge and provide oxygen for plant root metabolism and growth. The vegetation in bioinlets is generally plants which are tolerant to varying hydrologic conditions, soil and pH requirements (FHWA, 2003).

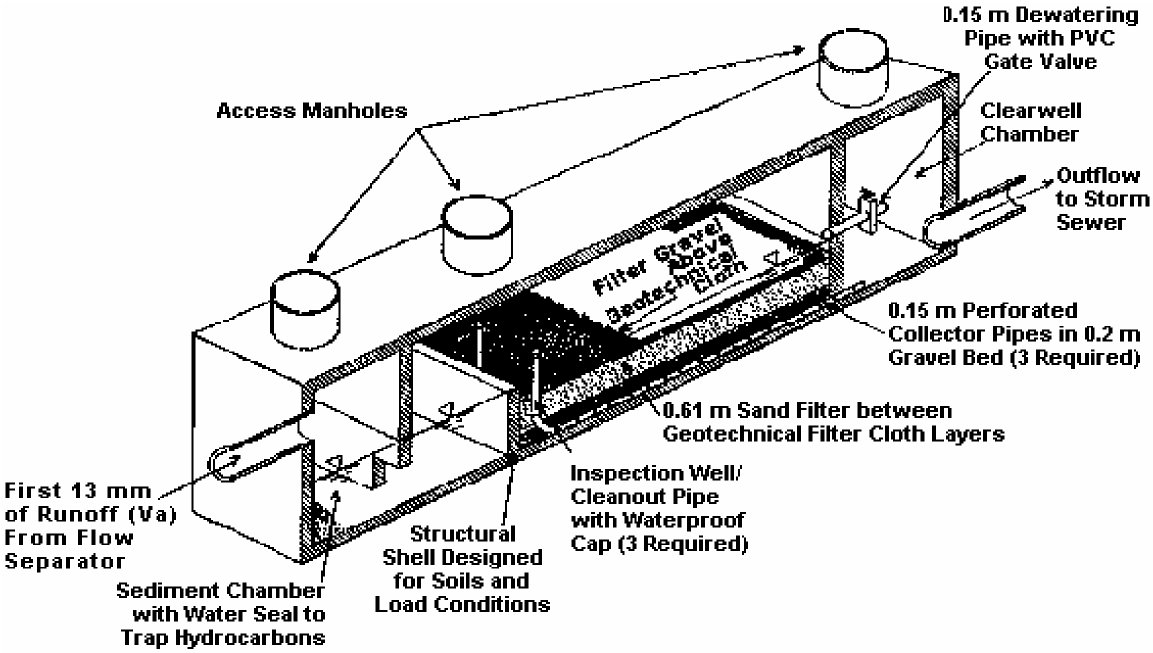
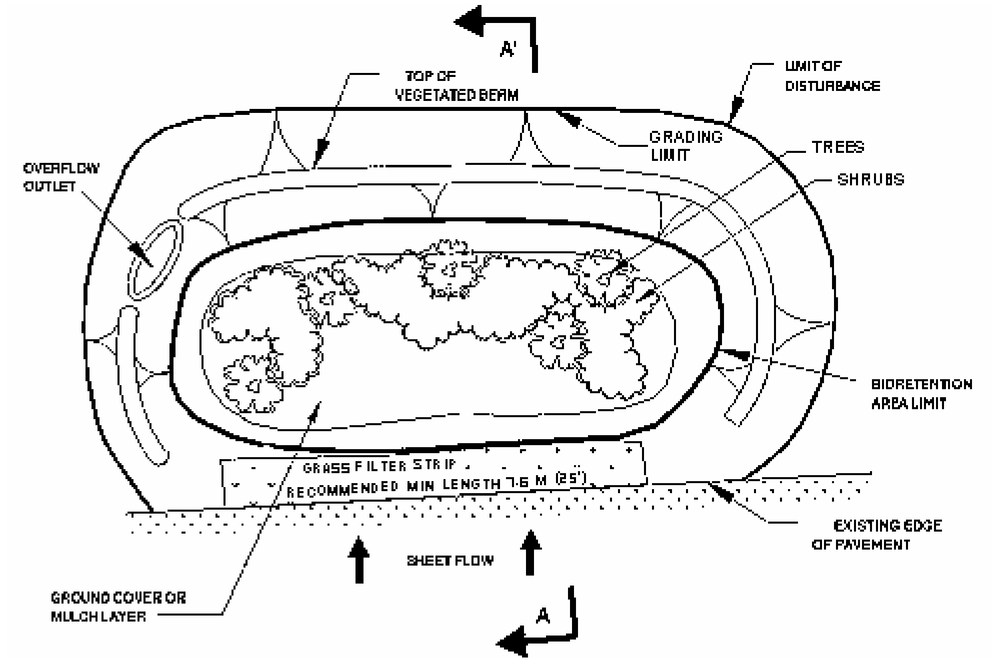


Figure 2.7. Original D.C. underground sand filter system (Young, et al., 1996).



PLAN VIEW
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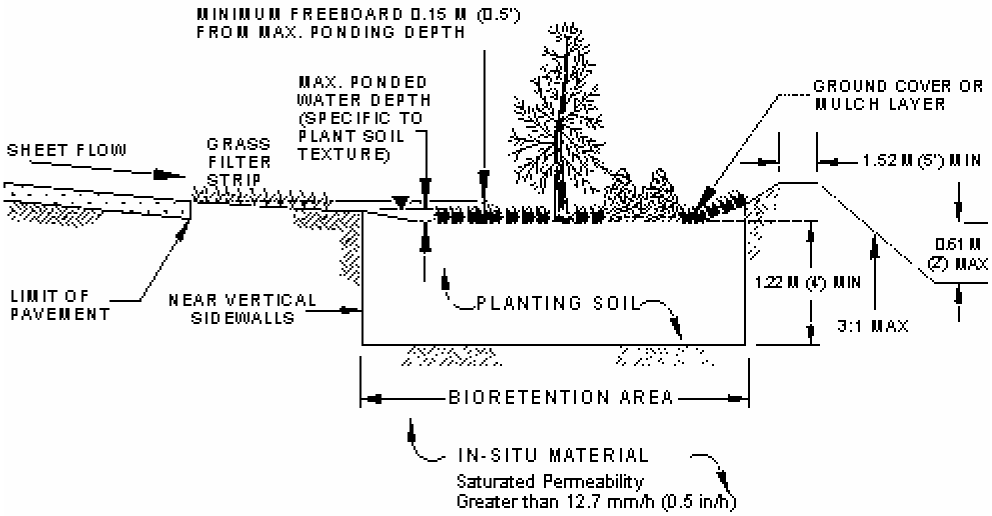


Figure 2.8. Parking edge and perimeter without curb (Bioretention area) (Prince George's county, MD, 1993).

The focus of LID is on stormwater management at micro levels (individual lots) and a cumulative impact is expected at a macro level (over the entire developed area) (Davis, 2005). Incorporating simple LID concepts into a site design can significantly reduce runoff flow and pollutant loads. For example, ammonia (80-85%), nitrate (66-79%), suspended solids (91-92%), copper (81-94%), iron (92-94%), lead (88-93%), manganese (92-93%), and zinc (75-89%) annual loads were decreased significantly by incorporating porous paving and swales into a parking lot of the Florida Aquarium in Tampa (Rushton, 2001). Water quality improvements due to bioretention have been found and were compared to the findings at Mt. Rainier, MD. A removal for TKN, ammonium and phosphorus in the range of 60-80% was observed in Bioretention box studies (Davis et al., 2001). In case of heavy metals, Cu, Pb and Zn removal of 90% was observed in laboratory bioretention systems from synthetic urban runoff and confirmed in field studies (Davis et al., 2003).

The evaluation of performance of a particular stormwater management practice is a complex process. The judicious choice of applying a particular BMP at a site depends on its effectiveness. The appropriate choice of a BMP can be determined by a two phase project, as illustrated in Figure 2.9. The elimination phase eliminates BMPs depending on their feasibility at a particular site. The decision phase allows the comparison of suitable scenarios in keeping with the demands and the aims of the project (Barraud et al., 1999).

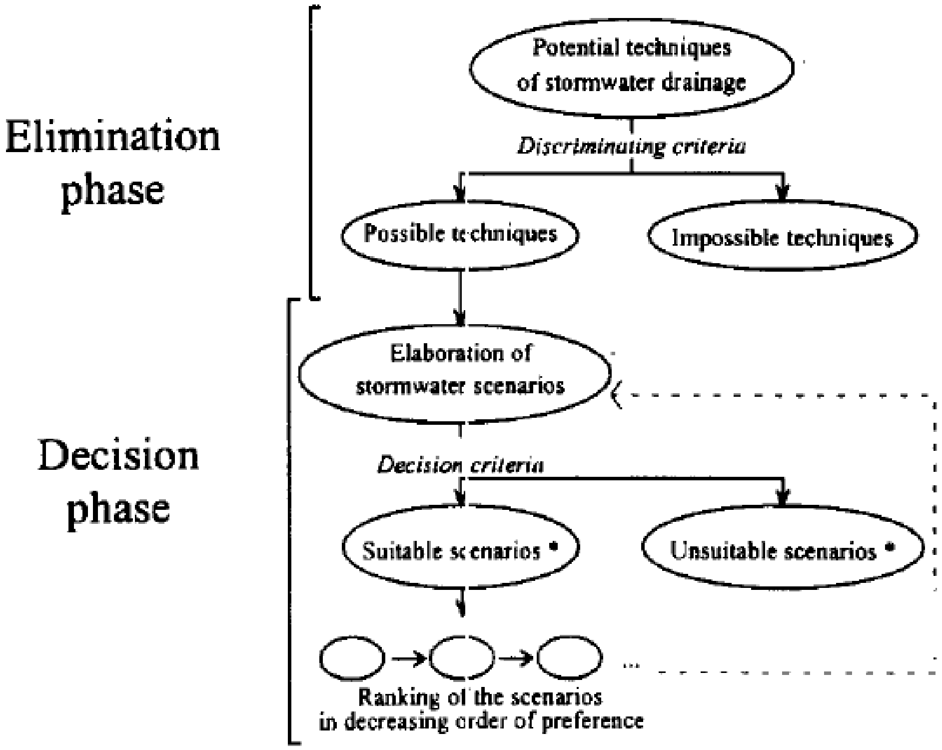
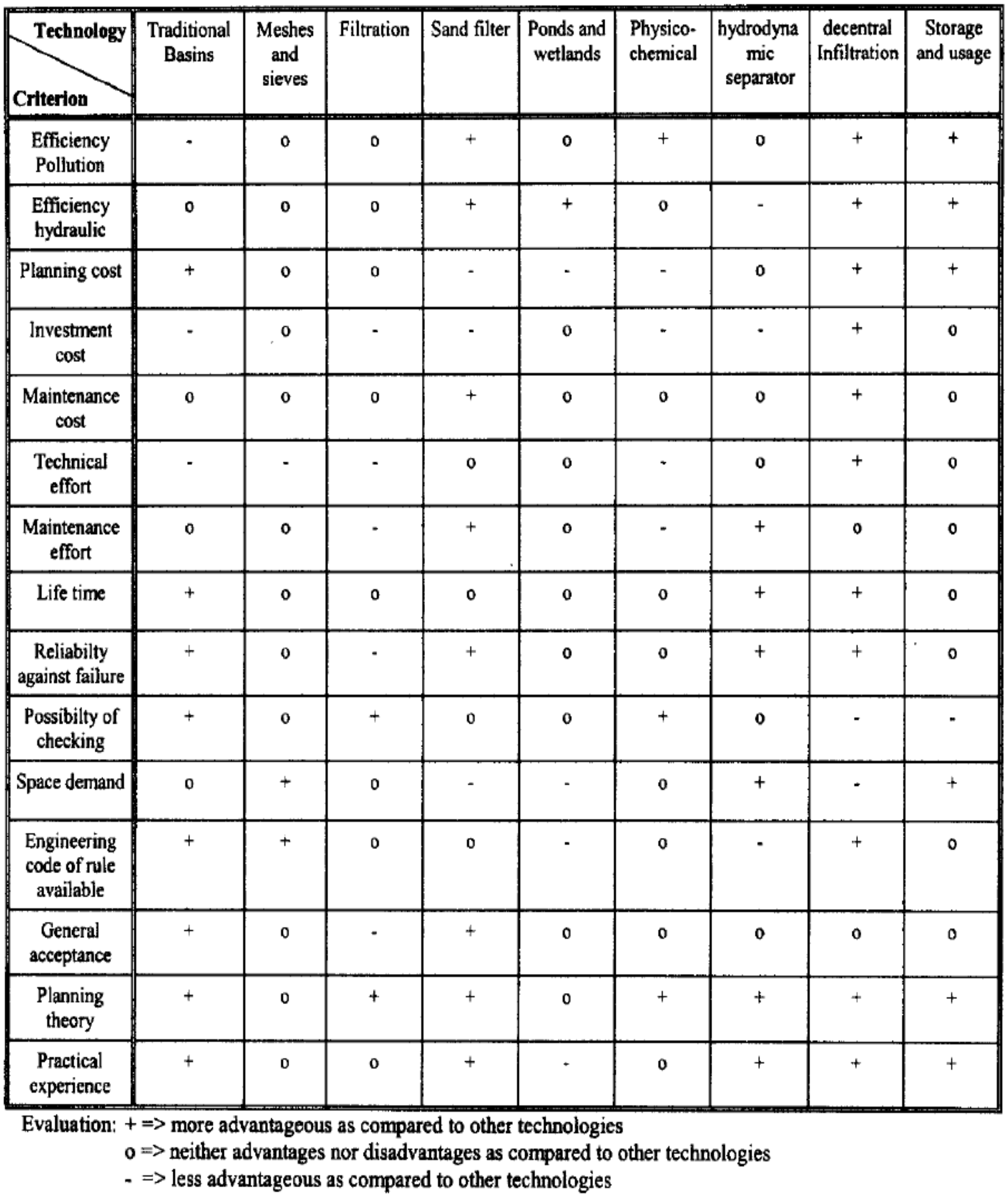


Figure 2.9. Overall view for decision making process in selection of a BMP in an ultra urban area (Barraud et al., 1999).

Mehler and Ostrowski (1999) focused on urban water resources planning and applied simulation models for the evaluation of stormwater management systems for the Chemical Oxygen Demand (COD) criteria. The advantages and disadvantages of different BMPs for certain predefined categories based on their literature review and multiple simulation runs are presented in Table 2.2. The catalogue was compiled based on a subjective analysis. It is observed from Table 2.2, that techniques involving sand filters, decentral infiltration and detention ponds (storage and usage) were advantageous for water quality (Efficiency pollution) and quantity (Efficiency hydraulic) over other technologies. Sand filters were also low on maintenance and had a wider acceptance.

Table 2.2. Comparative matrix for various Best Management Practices for stormwater treatment (Mehler and Ostrowski, 1999).



Technology / Criterion	Traditional Basins	Meshes and sieves	Filtration	Sand filter	Ponds and wetlands	Physico-chemical	hydrodynamic separator	decentral Infiltration	Storage and usage
Efficiency Pollution	-	o	o	+	o	+	o	+	+
Efficiency hydraulic	o	o	o	+	+	o	-	+	+
Planning cost	+	o	o	-	-	-	o	+	+
Investment cost	-	o	-	-	o	-	-	+	o
Maintenance cost	o	o	o	+	o	o	o	+	o
Technical effort	-	-	-	o	o	-	o	+	o
Maintenance effort	o	o	-	+	o	-	+	o	o
Life time	+	o	o	o	o	o	+	+	o
Reliabilty against failure	+	o	-	+	o	o	+	+	o
Possibilty of checking	+	o	+	o	o	+	o	-	-
Space demand	o	+	o	-	-	o	+	-	+
Engineering code of rule available	+	+	o	o	-	o	-	+	o
General acceptance	+	o	-	+	o	o	o	o	o
Planning theory	+	o	+	+	o	+	+	+	+
Practical experience	+	o	o	+	-	o	+	+	+

Evaluation: + => more advantageous as compared to other technologies
o => neither advantages nor disadvantages as compared to other technologies
\- => less advantageous as compared to other technologies

The performance of a BMP can be evaluated through input-output studies and before and after studies. Comparison of different BMPs at different sites can be carried out if common physical, chemical, climatic, geological, biological and meteorological parameters are reported (Urbonas, 1995). Statistical characterization of the data aids in assessing a BMP for removal efficiency for pollutants. One goal of the present study is to propose and demonstrate a robust statistical characterization tool.

The inherent variability of stormwater data due to the randomness of storm events, sampling and analysis methodology and the large number of independent variables and parameters make derivation of functional relationships between stormwater pollutant loadings and various independent variables difficult (Jewell and Adrian, 1982). Series of univariate statistical analyses with the mean and standard deviation undertook from the data obtained from 5 sites in Australia relating key pollutant parameters and rainfall characteristics (Goonetilleke, et al., 2005). They carried out multivariate techniques to identify the connection between various pollutant parameters and land use, and principal component analysis (PCA) for pattern recognition. The parameters of interest in modeling stormwater quality models are chosen such that they remain constant for storm to storm, but change depending on the site monitored (Jewell and Adrian, 1982).

Barrett (2005) adopted EMC data for performance evaluation of 13 different BMPs based on paired influent and effluent EMCs. He developed a linear relationship between the influent and the effluent EMCs:

$$C_{eff} = aC_{\inf} + b \tag{2.5}$$

where, C_{eff} = Predicted effluent EMC,

$C_{\inf}$ = Influent EMC,

a = slope of the regression line and

b = y intercept.

It is obvious from the above expression that at a very low influent concentration (close to 0); there will be a certain irreducible minimum effluent concentration (b). Similarly, for large influent concentrations,

$$C_{eff} \cong aC_{\inf} \tag{2.6}$$

The uncertainty in the location of the regression line was given by

$$t_{0.05}\, s\sqrt{\frac{1}{n}+\frac{\left(X-\overline{X}\right)^{(2)}}{\sum_{i=1}^{n}\left(X_i-\overline{X}\right)^{(2)}}} \tag{2.7}$$

where,

$t =$ value of the t statistic for the appropriate degrees of freedom (n-2),

$s =$ standard error of the regression,

$n =$ number of paired data points,

$X =$ average influent EMC at which the confidence interval is calculated,

$\overline{X} =$ mean of observed influent EMCs from monitoring data, and

$X_i =$ individual observed influent EMCs from monitoring data

The uncertainty in the location of the regression line implies the uncertainty in the predicted average effluent concentration for an influent concentration of interest. The results obtained from the regression analysis are tabulated in Table 2.3. It is observed that the predicted effluent EMC in some cases is independent of the influent EMC (in case of TSS for some BMPs) and in other cases supports the notion that the effluent concentrations not only depends on the BMP but also on the influent concentrations.

Table 2.3. Results of regression analysis for predicting effluent concentration from different BMPs by Barrett (2005).

x = influent EMC (units are consistent).

Upper number in each cell represents expected value and lower value is the uncertainty at 90% confidence level.

Results shown only for selected BMPs
MCTT = Multiple Chambered Treatment Train.

BMP	TSS (mg/L)	Nitrate (mg/L-N)	Orthophosphorus (mg/L)	Dissolved Zn (µg/L)	Dissolved Cu (µg/L)
Delaware Sand Filter	16.2 (5.6)	$0.96x + 0.47$ $0.96(\frac{1}{13} + \frac{(x-0.34)^2}{0.93})0.5$	$0.5x + 0.03$ $0.048(\frac{1}{8} + \frac{(x-0.08)^2}{0.042})0.5$	$0.054x + 1.0$ $7.62(\frac{1}{10} + \frac{(x-213)^2}{67096})0.5$	$0.52x + 0.53$ $3.09(\frac{1}{13} + \frac{(x-6.8)^2}{340})0.5$
MCTT	9.8(2.4)	$0.52x + 0.57$ $0.48(\frac{1}{16} + \frac{(x-0.41)^2}{2.69})0.5$	$0.55x + 0.05$ $0.10(\frac{1}{9} + \frac{(x-0.11)^2}{0.04})0.5$	$0.19x + 5.2$ $17.5(\frac{1}{17} + \frac{(x-73)^2}{35565})0.5$	$0.39x + 2.4$ $5.2(\frac{1}{17} + \frac{(x-6.1)^2}{456})0.5$
Wet Basin	11.8(4.0)	0.45 (0.25)	0.33 (0.28)	33 (7.8)	8.7 (3.1)
Austin Sand Filter	7.8(1.2)	$0.93x + 0.37$ $0.86(\frac{1}{64} + \frac{(x-0.67)^2}{24.01})0.5$	$0.62x + 0.02$ $0.14(\frac{1}{33} + \frac{(x-0.18)^2}{1.74})0.5$	$0.23x + 10.6$ $42.1(\frac{1}{63} + \frac{(x-92)^2}{296,910})0.5$	$0.76x + 1.62$ $6.27(\frac{1}{63} + \frac{(x-8.8)^2}{2195})0.5$

Extended Detention Basin	$0.11x + 23.6$ $30.9(\frac{1}{55} + \frac{(x-139)^2}{498318})0.5$	$0.74x + 0.19$ $0.77(\frac{1}{57} + \frac{(x-1.06)^2}{35})0.5$	$1.0x + 0.02$ $0.19(\frac{1}{31} + \frac{(x-0.11)^2}{0.166})0.5$	$0.57x + 19.1$ $44.1(\frac{1}{57} + \frac{(x-68)^2}{198956})0.5$	$0.91x + 1.3$ $5.3(\frac{1}{57} + \frac{(x-12.4)^2}{2310})0.5$
Swales	$0.42x - 11.0$ $54.6(\frac{1}{39} + \frac{(x-84.5)^2}{139{,}000})0.5$	$1.31x - 0.03$ $0.69(\frac{1}{38} + \frac{(x-0.71)^2}{6.1})0.5$	0.40 (0.12)	$0.40x + 7.7$ $58.6(\frac{1}{39} + \frac{(x-99)^2}{213{,}600})0.5$	$0.55x + 3.3$ $8.13(\frac{1}{39} + \frac{(x-16)^2}{4256})0.5$
Strips	$0.074x - 19.2$ $29.2(\frac{1}{27} + \frac{(x-101)^2}{200{,}000})0.5$	$1.31x - 0.03$ $0.59(\frac{1}{26} + \frac{(x-0.38)^2}{0.98})0.5$	0.50 (0.26)	$0.31x + 12.4$ $38.8(\frac{1}{26} + \frac{(x-68)^2}{35{,}000})0.5$	$0.11x + 4.6$ $8.57(\frac{1}{28} + \frac{(x-17)^2}{8421})0.5$

2.7. PERFORMANCE COMPARISON

Comparison of the performance of structural stormwater best management practices is complex as differences in monitoring strategies and data evaluation contribute significantly to the range of reported BMP effectiveness. There are inconsistencies in sample collection techniques (grab, composite, flow measurement), water quality constituents, analyses including chemical species, methods (detection limits), form (dissolved versus total versus total recoverable), treatment potential and data reporting on tributary watershed, and BMP design characteristics in the case of monitoring studies (Strecker, et al., 2001).

It is imperative to assess the effectiveness in terms of pollutant removal ability of a particular stormwater management technology before adopting it at a site. The effluent concentration alone need not always be a good indicator of the performance of the BMP; the corresponding influent concentration also plays a major role (Barrett, 2005). This is of particular relevance when the influent concentration is low or when the concentration of the BMP effluent is unrelated to influent concentration. Lower percent removal was reported for low influent concentrations in BMP monitoring studies (Horner and Horner, 1999 as referenced in Barrett, 2005). Pollutant removal efficiency has generally been described as percent reduction in the concentration or load for the pollutants concerned using statistical analysis on treated and untreated runoff.

Strecker et al., (2001) described four techniques for estimating the pollutant reduction of best management practices (BMPs). These include the statistical characterization of inflow and outflow concentrations, sum of loads, storm-by-storm comparison, and regression of loads. The statistical characterization defines removal as the ratio between the average influent and effluent concentrations. The sum-of-loads method takes the ratio of the sums of influent and effluent loads of the monitored events. The storm-by-storm procedure averages the ratio of influent to effluent concentration for individual events, while the regression of loads determines the removal by a regression analysis of paired influent and effluent loads. Comparison of input-output storm pollutant loading ratios for assessment of efficiency assumes that all storms are equal. It is, however, readily apparent that all storm volumes and their associated concentrations are not equal. In the case of BMPs such as wetland basins or retention ponds, comparing effectiveness on a storm by storm basis neglects that the outflow may have little or no relationship to the inflow for that same event. The effluent from retention ponds would give an assimilated concentration from different events if the influent volume is less than the total capacity of the retention pond/basin. It is therefore more appropriate to evaluate effectiveness by statistical characterization of the inflow and outflow concentrations (Strecker, et al., 2001). One can use the total loads in and out of the BMP to determine the removal efficiency in cases where all the storms are monitored.

The difficulties with the refinement of physically based descriptions of urban runoff quality led to statistical approaches to runoff quality and its impact on receiving waters (Van Buren et al., 1997). The lognormal distribution gave a good fit for the urban stormwater runoff EMCs (Van Buren, et al., 1997). The investigation for BMP effectiveness includes employing statistical and graphical tools (Strecker, et al., 2001) such as:

- Descriptive statistics of the influent and effluent EMCs with determination of the mean, median, standard deviation, variance and upper and lower confidence limits for mean and median and percent removals using the efficiency ratios.

- Parametric tests such as the student's *t* test and non-parametric tests such as the Mann-Whitney U test.
- Percentiles for influent and effluent EMCs.
- Normal probability plots of log transformed water quality data showing overlays of influent and effluent EMCs.
- Scatter plots showing percent removal as a function of ratio between mean runoff volume and storage volume.

A greater importance is attached to probability plots due to the limitations of the objective tests. The runoff quality and quantity data deal with randomness in rainfall events and various frequencies of occurrence of flows, concentrations and durations and loads and hence, the need to determine an accurate cumulative distribution. The probability plots have all the information on the agreement between the sample and the theoretical distributions and their visual inspection leads to sound conclusions (Van Buren, et al., 1997). The plotting position in such probability plots is given by the formula by Blom (1958),

$$F_i = \frac{(i-\alpha)}{(N+1-2\alpha)} \tag{2.8}$$

where $\alpha = \frac{3}{8}$ for a good approximation to the corresponding probability for normal distributions (constant in general plotting position formula) (Cunnane, 1978). In this equation:

i = serial number (rank) of ith smallest in sample of size N

N = sample size

F_i = plotting position of i^{th} smallest as a probability value

Equation 2.8 therefore reduces to

$$F_i = \frac{(i - \frac{3}{8})}{(N + \frac{1}{4})} \tag{2.9}$$

Variations in the efficiency estimation techniques and statistical validation of results also contribute to irregularity in performance comparisons of BMP studies as described in the literature. Urbonas (1995) has recommended a list of parameters which should be defined in stormwater management studies. The paper stresses the need to report a variety of physical, chemical, climatic, geological, biological, and meteorological parameters, along with pollutant concentration and loading data, in order to draw generalized conclusions on comparison of BMP studies at different locations. Thus, a consistent data set will provide reliable tools for the selection of structural BMPs. The American Society of Civil Engineers (ASCE) project team has developed a set of protocols and a database on BMP effectiveness studies (http://www.bmpdatabase.com) with the purpose of improving the consistency of BMP monitoring information. The database aims to achieve efficient data entry, stored data and output information with a user friendly interface (Strecker, et al., 2001).

Chapter 3

METHODOLOGY

3.1 SITE DESCRIPTION AND SAMPLING PROTOCOL

3.1.1 Monitoring Location

The monitoring location for this project is Mt. Rainier, Maryland on U.S. Route 1. The site area is located at the intersection of Rhode Island Avenue (U.S. Rt. 1) and 33rd Street (Figures 3.1 and 3.2). The city of Mt. Rainier along Route 1 is highly urbanized with a mix of commercial, residential, and institutional (bus depot, municipal buildings, churches and offices) land uses. The monitoring project was divided into three phases: phase 1: Before Construction (Flint, 2004) (June 2002 - September 2003), phase 2: gutter filters only (November 2003 - September 2004) and phase 3: complete LID implementation (gutter filters + bioinlets) (October 2004 – November 2005). The study drainage area (Figure 3.3) is estimated to be 5580 m^2 (60069 ft^2) and flows to two inlets.

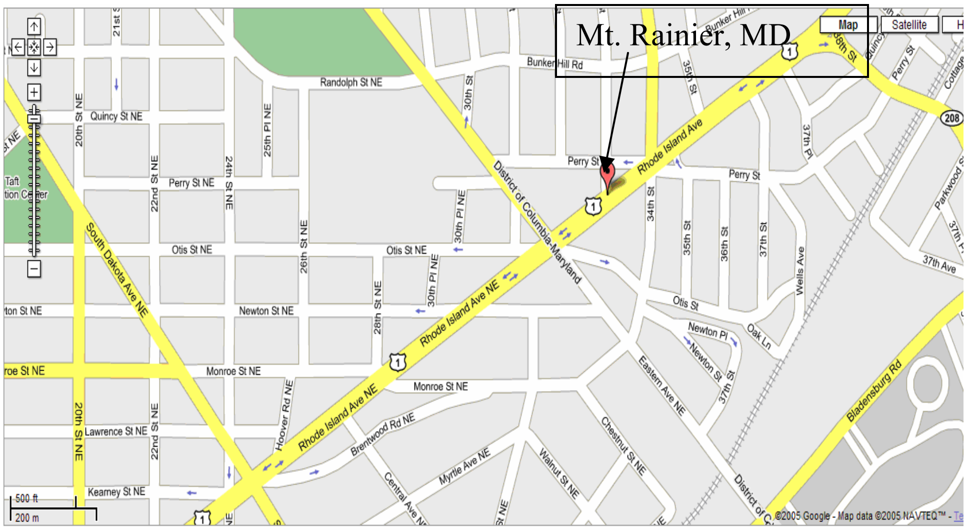


Figure 3.1. Site map of Mt. Rainier, MD (http://maps.google.com)

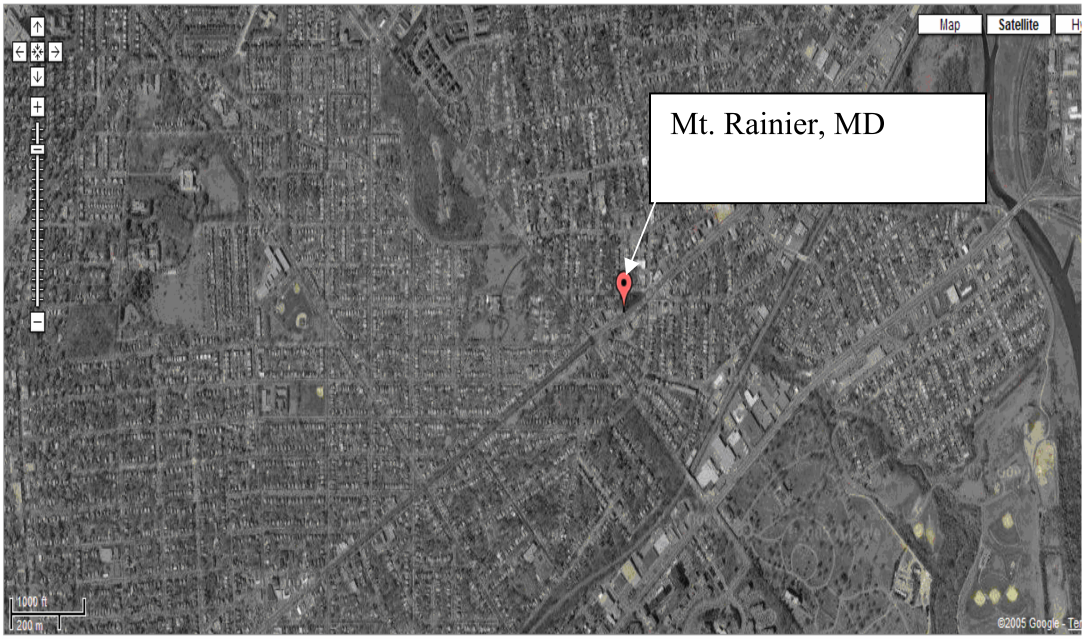


Figure 3.2. Satellite image of Mt. Rainier, MD (http://maps.google.com)

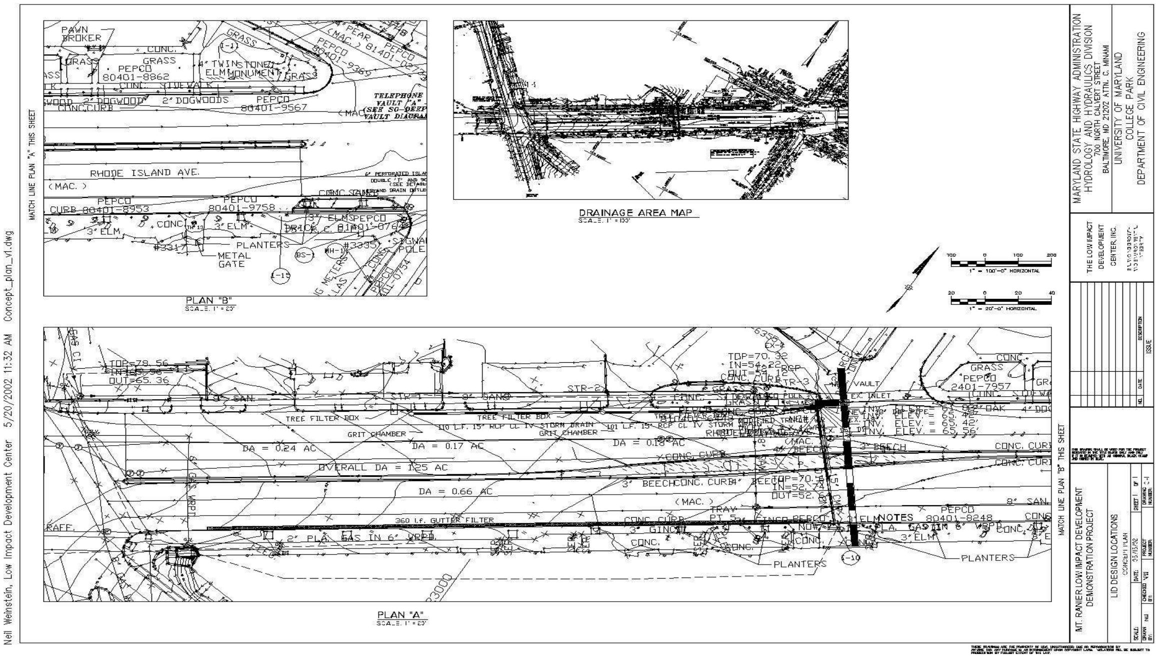


Figure 3.3. Mt. Rainier, MD Drainage Area Map.

One inlet is on the east side of Rt. 1 (Figure 3.4). Flow from this inlet is piped under Rt. 1 to the inlet on the west side (Figure 3.5). The combined flows are piped to the sampling point. System monitoring, at the storm drain level, is conducted in order to observe the contribution of non-point source roadway runoff to the Anacostia River.

Figure 3.4. East side inlet, looking south on Rhode Island Avenue before LID.

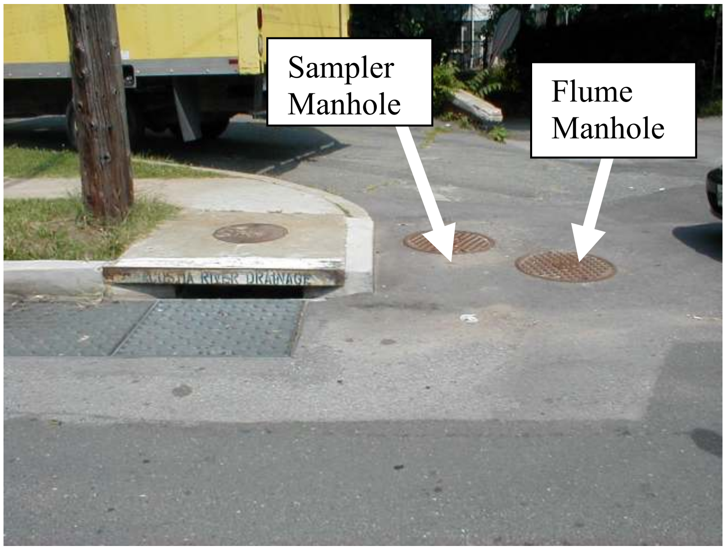


Figure 3.5. West side inlet and sampling area.

3.1.2 Monitoring Equipment and Protocol

Based on the design by the Low Impact Development Center, a Tracom 24-inch Palmer-Bowlus flume was installed below grade, just north of the inlet at the corner of Rt. 1 and 33rd St. (Figure 3.6). An ISCO Model 6712 Portable Sampler (Figure 3.7) with a polypropylene strainer was installed adjacent to the flume. The sampler has a bubble flow meter calibrated to monitor flow rates through the flume.

Figure 3.6. Palmer Bowlus Flume grade at Mt. Rainier, MD.

Figure 3.7. Mt. Rainer sampler.

The sampler contained twenty-four 300-mL glass bottles that were cleaned and acid washed before placing them in the sampler. The sampling program collected 12 samples per event (filling 2 bottles per sample, each of 280 mL to ensure adequate volume for all the water quality testing).

A sampling event triggered when the head in the flume reached 0.1 ft, which corresponds to a flow of about 0.004 m^3/s (0.135 cfs). This flow rate corresponds to a rainfall intensity of 0.25 cm/hr (0.1 in/hr), based on a drainage area of 5580 m^2 (60069 ft^2) and a rational method c of 0.9. Once enabled, the sampler stayed enabled. The first 8 samples were collected with a 20 minute interval for each sample, while the later 4 samples were collected with a 60 minute interval for each sample. The sample timing is presented in Table 3.1, with an emphasis on obtaining more samples in the early part of the precipitation event to capture the first flush phenomenon. A report summary is generated for every sampling event listing the details of the settings for the sampler and the time when the event was initiated. The data from the sampler is retrieved in the field using a Rapid Transfer Device (RTD). The data can be downloaded in the Environmental Engineering laboratory at the University of Maryland, College Park, by plugging the RTD to an attachment on a computer in the laboratory and using the Flowlink software. This provides the runoff hydrograph and gives the flow data and the level data in the flume.

Table 3.1. Sampling Times for Automated Collection During Storm Events at Mt. Rainier.

Sample Number	**Time**	**Sample Number**	**Time**
1	0 minutes	7	2 hours
2	20 minutes	8	2 hr, 20 min
3	40 minutes	9	2 hr, 40 min
4	1 hour	10	3 hr, 40 min
5	1 hr, 20 min	11	4 hr, 40 min
6	1 hr, 40 min	12	5 hr, 40 min

The background stormwater monitoring study began in June 2002 (Flint, 2004). Monitoring continued through construction and after installation of gutter filters (Figure 3.8) and bioinlets (Figures 3.9 and 3.10) and water quality data were obtained for the desired pollutants. The data sets were divided into three phases – Before Construction (Flint, 2004), gutter filters only, and gutter filters and bioinlets. The neighborhood has been stable and there haven't been many changes in the area. As a result water quality runoff in phase 1 can be assumed to be influent water quality into the LID practices. Comparisons among concentrations and the annual pollutant loads from these three phases allow an evaluation of the LID practices implemented at the site.

Figure 3.8. Gutter Filter on East side of Rt. 1.

Figure 3.9. Bioinlets on the West side of Rt. 1(facing west) (10/2004).

Figure 3.10. Bioinlets and the manhole for the inlet chamber (facing west) (04/2005).

3.1.3 Weather Station

In June 2002, a Wireless Vantage Pro weather station with remote data collection was installed on the roof of the Mt. Rainier Public Works building (Wells Avenue, Mt. Rainier, MD) approximately 1500 ft from the sampling site. This tipping bucket sampler logs rainfall depth in 2-minute increments. The complete Wireless Weather Station III (Davis Instruments) is comprised of an anemometer, wind cups, rain collector, weather station console, field case, radiation shield, transmitter and receiver. Data were transmitted from the outdoor sensors to an indoor receiver. Data were transferred to a desktop computer inside the Public Works building with the help of "Weatherlink" software. Weatherlink temporarily stored the weather condition data every five minutes to an archive. The computer automatically downloaded data twice a day. The weather station monitored the temperature, wind chill, wind direction, wind speed, and rainfall. The weather data were periodically retrieved from that computer using a Zip disk.

3.2 Low Impact Development Practices at Mt. Rainier, MD.

Gutter filters on the east side of U.S. Rt. 1 and bioinlets on the west side of U.S. Rt. 1 were constructed and monitoring of stormwater runoff was carried out in order to evaluate their ability to improve stormwater quality. Gutter filters (Figures 3.8 and 3.11-plan view) were installed along the curb on the east side of the site. The gutter filter treatment facility is composed of an under drain and the filter media. The filter media consists of pool filter sand, sand and the mixed media. The mixed media was made up of perlite, zeolite and granular activated carbon (GAC). The component materials of the gutter filters confirmed to the specifications stated in the provisions by the Maryland State Highway Administration. The pool filter sand layer of 12 inches was placed at the most upstream section of the filter, with a 12-inch layer of sand in the middle section, followed by a 12-inch layer of mixed media consisting of 4-inch layers each of perlite, zeolite and GAC placed consecutively in the most downstream section. Two detention/collection chambers located at the ends of the filter media completed the gutter filter on the west side of Rt. 1.

Perlite is a refined filter aid and has a high porosity of 80 – 90 % (Purchas and Sutherland, 2002). Perlite filter media removes suspended solids with attached pollutants (California stormwater quality association - BMP handbooks). Zeolites are used as the adsorbent beds and display a high cation exchange capacity. Their pores also assist in ion exchange mechanisms and therefore removal of lead, copper, cadmium and zinc (Magic mineral Zeolite, Laumontite landscape aquaculture applications). Zeolites act as subsurface barriers and prevent the spread of mobile pollutants in contaminated soils and thus protect downstream aquifers and filter the flow into groundwater (New Mexico institute of mining and technology). Granular activated carbon (GAC) provides in-depth adsorption resulting from its micro porous capillary structure, and its correspondingly very high internal surface area. GAC not only removes solid particles (or liquid droplets) but also assists in removal of odors or other gaseous impurities, color, chlorine and hydrocarbon vapors (Purchas and Sutherland, 2002).

The construction for the bioinlet facility (Figures 3.9, 3.10 and 3.12 – side view) was completed in September 2004. The Bioretention Soil Mixture (BSM) was a mixture of planting soil, mulch and sand and was in accordance with the pre-specified pH requirement (5.5-7.5) and soluble salts concentration (not to exceed 500 ppm) criteria. The BSM was a uniform mix free of stones, stumps, roots or other similar objects larger than 2-inches excluding mulch. The planting soil had to meet the textural classification requirements specified in the provisions. The USDA textural classification for planting soil was Loamy Sand or Sandy Loam. The planting soil contained some clay to adsorb pollutants like hydrocarbons, heavy metals and nutrients. The bioinlets were comprised of a pretreatment/ inlet chamber, biofilter chamber and an outlet/bypass chamber. Buttonbush was used as vegetation in the bioinlets. The data collection for this project was divided into phases with one phase comprising stormwater treatment from gutter filters only (November 2003- September 2004) and the other phase involving data obtained after treatment from gutter filters and bioinlets (October 2004 – November 2005).

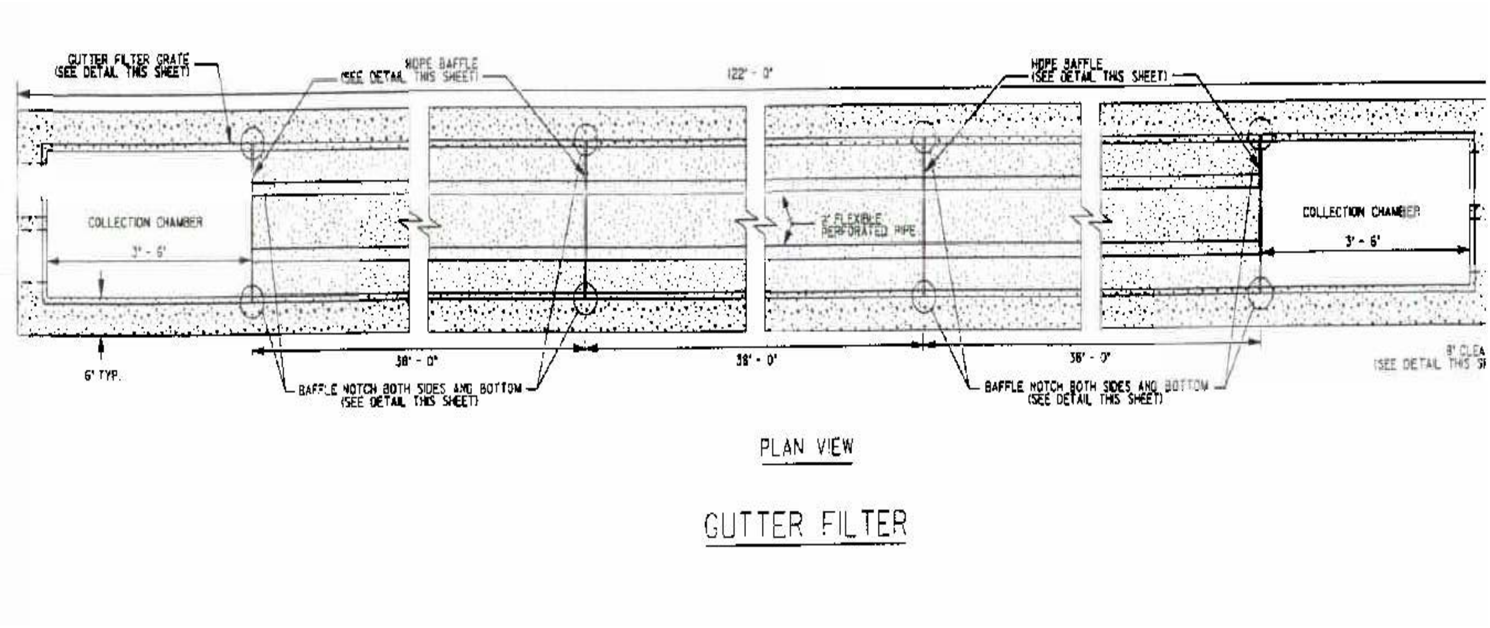


Figure 3.11. Plan view diagram of gutter filters at Mt. Rainier, MD.

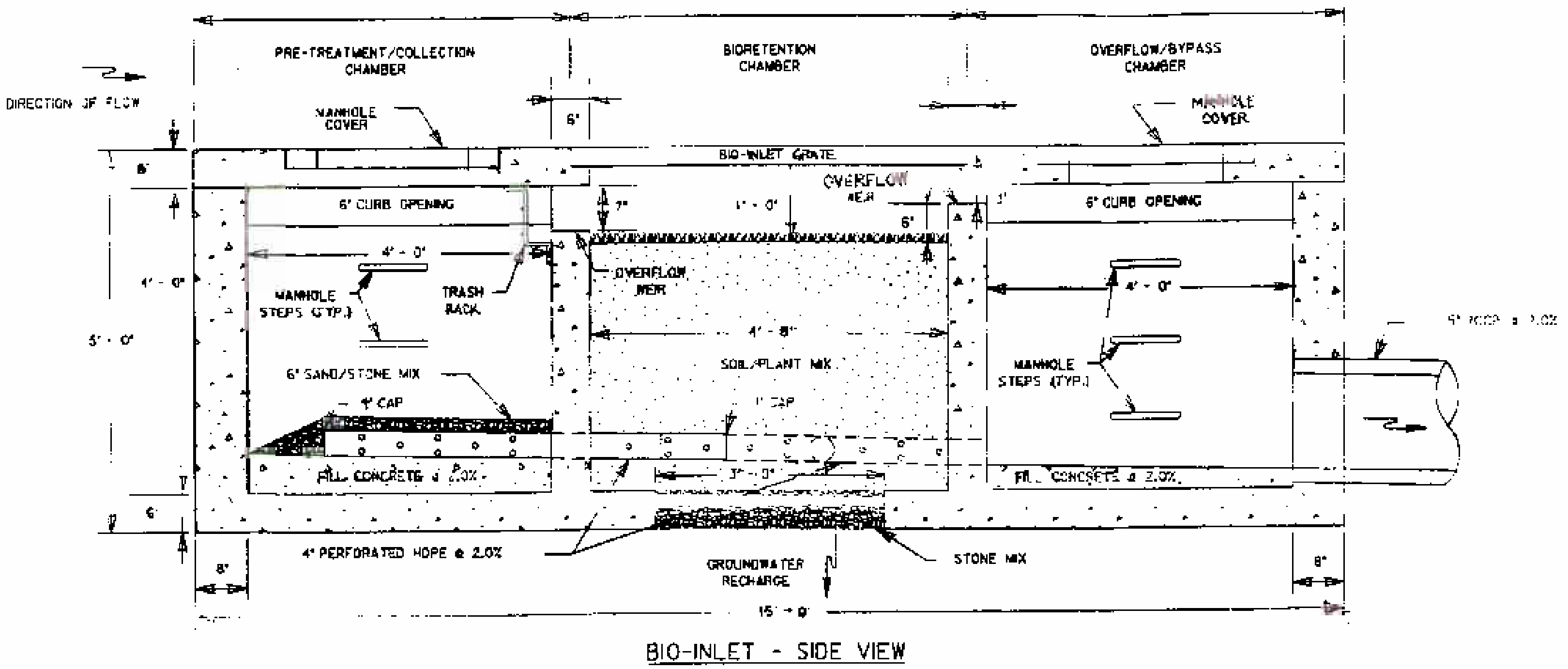


Figure 3.12. Side view diagram of bioinlet retrofit at Mt. Rainier, MD.

3.3 Sample Workup and Analytical Procedures

Samples were picked up within 24 hours of the storm onset and transported to the Environmental Engineering Laboratory at the University of Maryland in College Park, MD. At the lab, time-sensitive analyses were carried out on TP, NO_3^-, NO_2^-, Cl^- and TSS as described below. The remaining sample volume was preserved for later TKN and metal analyses. One bottle for each sample containing approximately 100 mL of stormwater was preserved for metal analyses using ten drops of concentrated HNO_3 (EMD Chemicals OmniTrace Grade or Fisher Scientific Metal Grade for Atomic Absorption). The second bottle of each sample was preserved by adding twenty drops of concentrated H_2SO_4 (Fisher Scientific) to approximately 200 mL of sample. Sample preservation lowers the pH of the sample to between 1 and 2. Metal and TKN digestion were completed within two weeks. Metal analyses were completed within six months. All analyses were in accordance with the methods (Table 3.2) detailed in *Standard Methods for the Examination of Water and Wastewater* (APHA, 1995). To minimize the potential for volatilization or biodegradation between sampling and analysis, samples were refrigerated without freezing. All filtration was completed using 0.2 μm pore size; 25-mm diameter membrane disk filters (Pall Corporation), 25-mm Easy Pressure syringe filter holders (Pall Corporation), and 60 mL Luer-Lok syringes (Becton Dickerson & Co.) to remove suspended solids.

The concentrations for various storm events varied over a range of values and the concentrations employment for analytical calibrations were therefore appropriately chosen. The smallest standard concentration did not correspond to the instrument detection limit for Cl^-, TP, NO_3^- and NO_2^-.

Table 3.2. Analytical methods for determination of pollutant concentrations in Mt. Rainier storm events.

Pollutant	Standard Method (APHA, 1995)	Detection Limit (mg/L)
Total Suspended Solids, TSS	2540D	1.3
Total Phosphorus	4500-P	0.24
Total Kjeldahl Nitrogen, TKN	4500-N_{org}	0.14
Copper	3030 E	0.002
Lead	3030 E	0.002
Zinc	3030 E	0.025
Nitrite	4500-NO_2^- B	0.01 as N
Nitrate	Dionex DX-100 ion chromatograph	0.1 as N

3.3.1 Total Suspended Solids Analysis

Total suspended solids were analyzed based on Section 2540D of Standard Methods (APHA et al., 1995). A pre-weighed standard glass-fiber filter with 47 mm diameter (Pall Corporation) filtered a portion of well-mixed sample. The filters were placed on an inert aluminum weighing dish. The retained residue was dried to a constant mass at 103 to 105°C for 24 hours. The filter and residue were weighed. The mass of the residue was determined by subtracting the mass of the pre-weighed filter from the mass of the filter and residue. Mass measurements were determined using a Mettler model AE240 scale with a precision of ± 0.1 mg. Therefore, TSS measurements were limited to 1.3 to 1.5 mg/L (sample volume 65 mL to 75 mL) by the scale precision as the least count.

3.3.2 Phosphorus Analysis

Phosphorus analysis was divided into two general procedural steps: (a) conversion of the various phosphorus forms to dissolved orthophosphate, and (b) colorimetric determination of dissolved orthophosphate. The different forms of phosphorus were converted to orthophosphate by persulfate digestion, following Section 4500-P B (APHA, et al., 1995). Fifty mL of sample, one mL of 30% H_2SO_4 that was prepared using concentrated H_2SO_4 (Fisher Scientific), and 0.5 g of $K_2O_8S_2$ (J. T. Baker) were boiled on a hot plate until approximately 10 - 20 mL of the solution remained. Then, the completely digested sample was cooled; a drop (0.05 mL) of phenolphthalein indicator aqueous solution was added, neutralized to a faint pink color with NaOH solution and diluted to 100 mL with distilled water. Stannous chloride color development, Section 4500-P D (APHA, et al., 1995), followed sample digestion. Color development occured by forming molybdophosphoric acid by addition of 4 mL of ammonium molybdate reagent to the prepared sample and reducing molybdophosphoric acid to colored molybdenum blue by addition of 10 drops (0.5 mL) of stannous chloride reagent. After 10 minutes, a Shimadzu model UV160U spectrophotometer was used to measure the sample absorbance at 690 nm. Samples were compared against standard concentrations of 0.24, 1.2, and 3 mg/L as P that were prepared using 1000 mg/L stock solution (Fisher Scientific).

3.3.3 Nitrate and Chloride Analyses

Samples were filtered with 0.2 μm filters for analysis of NO_3^- and Cl^- using ion chromatography. Nitrate and Cl^- analyses were performed by a Dionex ion chromatograph (model DX-100) via injection of five mL of sample into a 1.3 mM sodium carbonate/1.5 mM sodium bicarbonate eluent. Nitrate and Cl^- were separated and converted to their conductive acid forms with an AS-9-SC separator column and an AG-9-SC guard column. Detection is via conductivity measurement. Nitrate and Cl^- were differentiated by adjusting the flowrate to 1.4 mL/min. Nitrate was analyzed using the 10 μS scale. Chloride was measured separately, using the 30 μS scale. Samples were compared against standard concentrations of 0.2, 0.4, 1.0, 1.4 and 2.0 mg/L for NO_3^--N and 1, 2, 4, 10, and 20 mg/L for Cl^-. Nitrate and Cl^- standards were prepared using 0.1 M NO_3^- stock solution (Orion) and 1000 mg/L Cl^- stock solution (Labchem Inc.).

3.3.4 Nitrite Analysis

Nitrite analysis was carried out by the colorimetric method outlined in section 4500-NO_2^- B of Standard Methods (APHA, et al., 1995). Ten mL of the filtrate was diluted to 50 mL, after sample filtration. Portions of the filtrate were used for both NO_3^- and NO_2^- analyses. Therefore, 0.2 μm membrane filters were used rather than 0.45 μm pore size filters specified in the Standard Method. A reddish purple azo dye developed upon mixing of NO_2^- with diazotized sulfanilamide (J. T. Baker) and N-(1 naphthyl)-ethylenediamine dihydrochloride (NED dihydrochloride, Fisher Scientific, diazotized sulfanilamide + NED dihydrochloride + 85% phosphoric acid, diluted to 1L of distilled water give the coloring reagent). Photometric measurement of the reddish purple azo dye was completed using a UV-visible recording spectrophotometer, Shimadzu model UV160U with sample absorbance at 543 nm. Standards were prepared by diluting 1000 mg/L NO_2^--N stock solution (Fisher Chemicals) to concentrations of 0.02, 0.08, 0.12, and 0.24 mg/L as N. Final concentrations were obtained by multiplying the measured concentration by the dilution factor.

3.3.5 Total Kjeldahl Nitrogen Analysis

Total Kjeldahl Nitrogen analysis was according to 4500-N_{org}, Macro-Kjeldahl Method (APHA *et al.*1995) in three steps: (1) digestion of 200-220 mL of sample by evaporation after addition of 50 mL of digestion reagent, (2) distillation of digested sample, that was diluted to 300 mL and treated with 50 mL of $NaOH\text{-}Na_2S_2O_3\cdot 5H_2O$ reagent, into boric acid indicating solution, and (3) titration of distillate with standard 0.02 N H_2SO_4 titrant. The titrant pipette had 0.1 mL accuracy and 200-220 mL of sample was used for TKN analysis. Therefore, the smallest measurable concentration was 0.14 mg/L of NH_4^+-N as calculated following the standard method.

3.3.6 Cadmium, Copper, Lead and Zinc Analyses

Metal analyses were carried out in two stages. In the first stage (nitric acid digestion) 100 mL of acid-preserved sample was heated after addition of 5 mL of trace metal grade concentrated HNO_3 (Fisher Scientific Trace Metal Grade for Atomic Absorption). The digested samples were diluted to 100 mL and filtered with 0.2 μm filters (Pall Corporation). The second stage involved analysis of Cd, Cu and Pb on the furnace module of a Perkin Elmer Model 5100 ZL (Zeeman Furnace Module) PC Atomic

Absorption Spectrophotometer, Standard Method 3110, and Zn on the flame module, Standard Method 3111 (APHA et al., 1995) on the filtered and digested samples. Metals were determined against a range of standard concentrations (Table 3.3).

Table 3.3. Standard concentrations for the metals in AA analysis**.**

Metal	Units	AA Analysis Technique	Standard Concentrations Used
Cadmium (Cd)	(µg/L)	Furnace	10, 20, 30, 40
Copper (Cu)	(µg/L)	Furnace	10, 30, 50, 60, 70
Lead (Pb)	(µg/L)	Furnace	10, 30, 50, 70, 100, 200
Zinc (Zn)	(mg/L)	Flame	0.1, 0.4, 0.7, 1.0, 5.0

Standards for Cd, Cu, Pb, and Zn were prepared using 1000 mg/L stock solutions (Pb, VWR Scientific; Cd, Cu, Zn, Fisher Scientific). For all metal analyses, samples with concentrations outside the specified ranges were diluted by an amount appropriate to lower the concentration to within the ranges specified. The measured concentrations were multiplied by dilution factor to obtain final concentrations.

3.4 Quality Assurance/ Quality Control

All glassware was acid washed (HNO_3), rinsed with deionized water and allowed to dry before use. The bench top was covered with clean layer of absorbent paper and replaced every month. Field blanks and periodic standards checks were adopted as a part of quality assurance in data collection. Field blanks were obtained by placing 2 empty glass bottles on their sides at the base of the sampler while setting up with the other 24 empty glass bottles before a storm event. They were filled with deionized water at the time of collection of sample, capped and brought back to the lab along with the other glass bottles filled with stormwater. The exact same tests were run on field blanks for the pollutants of interest as in the case of the stormwater samples. Field blanks were analyzed once for every 2-3 storms. In the case of metal analyses by the Atomic Absorption Spectrophotometer a standards check was done after analyzing 5-7 samples for a particular storm and the readings were accepted if the error in measuring the standards was less than 10%. Field blank measurements were not taken into consideration in metal analyses. Cadmium was always found below detection limit. In the case of nitrite analyses, standard concentrations of 0.020 mg/L, 0.080 mg/L, 0.12 mg/L and 0.24 mg/L were analyzed with a blank sample once every month. Similarly for TP, standard concentrations of 0.24 mg/L, 1.2 mg/L and 3.0 mg/L along with a blank sample were run once every month. The TSS field blank on 07/07/05 was higher due to an unclean interior of the auto-sampler. The results of the field blanks at Mt. Rainer are presented in Table 3.4.

Table 3.4. Field Blank concentrations at Mt. Rainier, MD.

Storm Event	TSS mg/L	NO_2^- mg-N/L	NO_3^- mg-N/L	TKN mg/L	TP mg/L	Cd µg/L	Cu µg/L	Pb µg/L	Zn mg/L
DL*	(1.3)	(0.01)	(0.1)	(0.14)	(0.24)	(2)	(2)	(2)	(0.025)
12/11/03	3.7	0.027	ND	ND	<0.24	<2	5.1	5.2	<0.025
06/05/04	1.4	<0.02	ND	<0.14	<0.24	ND	ND	ND	ND
10/19/04	ND	0.031	ND	<0.14	0.27	<2	4.8	6.4	0.32
07/07/05	6.6	ND	0.12	<0.14	ND	<2	5.0	3.6	<0.25
09/26/05	4.1	<0.02	ND	ND	<0.24	ND	5.3	4.9	<0.25
11/16/05	2.6	<0.02	ND	ND	<0.24	ND	5.5	ND	ND

* = Detection Limit
ND = No Data

3.5 Data Handling

The sampling protocol is pre–programmed into the auto-sampler with information about the definition of enabling a sampling event (head in flume > 0.1 ft), equipment used in connection with the sampler (24 bottles) and pacing for sample collection (non-uniform) (Table 3.1). The sample bottle number and size and the length of the sampler line are entered into the program. The sample bottle number and size determines the distance that the distributor arm rotates between each bottle. Specification of the length of the sample line determines the purging duration before and after collection of each sample. The sample numbers 1-8 each have a period of 20 minutes each, while the remaining 4 samples have a period of an hour each. A period comprises of 2 minute intervals (10 intervals for samples 1-8 and 30 intervals for samples 9-12). The period volume for one particular sample equals the sum of the volumes calculated for each two minute interval. Each interval represents the time when the flowrate is recorded (every 2 minutes). Runoff volume passing through the flume for one interval was calculated by multiplying the flowrate (L/s) that was determined every two minutes, by 120 seconds, resulting in the volume amount that passed through the flume for each two minute interval.

The loading pollutant mass is calculated for each interval by multiplying the sample concentration (C) by the volume that was determined for each two minute interval. The sample mass equals the sum of the masses calculated for each two minute interval during the period for that particular sample. The Event Mean Concentration (EMC) for the entire event was determined by dividing the total pollutant mass by the total runoff volume. EMC thus equals the sum of the mass for all intervals divided by the sum of the volume for all intervals. The calculations for EMC from every interval are detailed in Flint (2004). Equation 2.1 gives the EMC ($\overline{C}$) for a storm event of duration t_r. In case the pollutant concentration for a particular interval fell below the detection limit, an EMC range was calculated using the detection limit/ smallest standard concentration as one extreme and zero as the other. For statistical analyses, a value of ½ of the detection limit was used. Event mean concentration, annual pollutant loads, and mass loadings with respect to runoff volume were calculated for 17 storms in phase 2 (after construction of gutter filters) and 14 storms in phase 3 (gutter filters + bioinlets).

Annual pollutant loads were determined by the Simple Method as described by Schueler (1987). It is determined by equation 2.2. For the site at Mt. Rainier, MD, Annual Precipitation (P) = 44 in/yr (http://www.weather.com), Dimensionless average runoff coefficient (R_v) = 0.95, Dimensionless correction factor that adjusts for storms runoff (P_j) = 0.9, Conversion factor for matching appropriate units (CF) = 0.254. The constants were adopted equal to those by Flint (2004), as the analyses involved comparison of phases 2 and 3 with phase 1 (Flint, 2004).

3.5.1 Statistical Analyses

The student's *t* test and the Mann-Whitney U test were employed to analyze the pollutant removal efficiency by comparing the data obtained from the drainage area with no treatment (Flint, 2004) with each of these two treatment phases. Application of parametric tests (student's *t* test) and non-parametric tests (Mann-Whitney *U* test) allow establishing the level of water quality improvement. The current study has tried to incorporate these tests in its objective to determine the impact of the Low Impact Development (LID) practices adopted at Mt. Rainier. The student's *t* test is employed on the event mean concentrations of the pollutants and is based on the *t* distribution. If the result of the *t* test is significant, then it can be concluded with high confidence that the samples represent populations with different mean values. However, the Mann-Whitney *U* test is employed with ordinal (rank-order) data in a hypothesis testing situation involving a design with two independent samples. If the result of the Mann-Whitney U test is significant, it indicates there is a significant difference between the two sample medians and, as a result of the latter, one can conclude that there is a high likelihood that the samples represent populations with different median values. It is assumed that the pollutant EMCs would decrease after the construction of a stormwater management treatment facility. The *t* test and the Mann-Whitney U test are employed to establish a certain degree of confidence in whether the reduction in concentration is due to chance or as a direct consequence of the treatment.

3.5.1.a Student's *t* Test

The *t* test, which is employed in a hypothesis testing situation involving two independent samples, is an inferential statistic test of the mean that is based on the *t* distribution. If the result of the *t* test is significant then it can be concluded with high confidence that the samples represent populations with different mean values (Handbook of parametric and non-parametric statistical procedures, Sheskin, 2003). The *t* test for two independent samples is employed with interval/ratio data, and is based on the following assumptions: a) Each sample has been randomly selected from the population it represents; b) The distribution of the data in the underlying population from which each of the samples is derived is normal; and c) The variance of the underlying population represented by Sample 1 is equal to the variance of the underlying population represented by Sample 2 ($\sigma_1^2 = \sigma_2^2$).

The following approach was adopted in the application of the *t* test to the data collected from Mt. Rainier. The data has been characterized into 3 sample groups – phase 1: before construction, phase 2: gutter filters only, and phase 3: gutter filters + bioinlets. Spreadsheets were used for performing the various calculations on the data set. The individual means, standard deviations and the corresponding variance were calculated. Knowing the number of elements in each group, the Degree of Freedom was determined for each pollutant. $\overline{X}_1$ and $\overline{X}_2$ are the two calculated sample means while μ_1 and μ_2 denote the population means from which the samples are derived.

Null Hypothesis: $\mu_1 = \mu_2$: This implies that the sample means for both the data sets are equal.

Alternative Hypothesis: In the current project, the following directional alternative hypothesis was considered: $\mu_1 > \mu_2$. It indicates that the sample mean from population 1 is greater than the sample mean from population 2.

The hypothesis is evaluated with a one-tailed *t* test and will be supported if the sign of the computed *t* is positive, and the absolute value of *t* is equal to or greater than the tabled critical one-tailed *t* value at the pre-specified level of significance (95%). It is obvious that if the null hypothesis is rejected, the alternative hypothesis that is selected is accepted.

For the current data set, there are a different number of elements for the three groups, i.e., there is an unequal number of subjects in each sample. The following equation was adopted to compute the *t* value:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{(n_1 - 1) * s_1{}^2 + (n_2 - 1) * s_2{}^2)}{(n_1 + n_2 - 2)} (\frac{1}{n_1} + \frac{1}{n_2})}} \tag{3.1}$$

where, n_1 and n_2 represent the sample sizes for each of the population groups, and s_1 and s_2 represent the sample standard deviation for the particular group. This computed value of *t* is evaluated with the tabled critical value for a one tailed distribution obtained from a Table of Student's *t* distribution. The particular tabled *t* value is obtained for a particular degree of freedom and the pre-specified level of significance. If the directional alternative hypothesis $\mu_1 > \mu_2$ is employed, the null hypothesis can be rejected if the sign of *t* is positive, and the value of *t* is equal to or greater than the tabled critical one-tailed value at the pre-specified level of significance.

This equation was used for each of the pollutant EMCs and each time a comparison was made between the computed *t* value and the tabled one-tailed critical *t* value. If the alternative hypothesis is supported then one can say at a 95% significance level that the treatment is working and the difference in the means is significant and not due to chance.

3.5.1.b Mann-Whitney U Test

The Mann-Whitney U Test is employed with ordinal (rank-order) data in a hypothesis testing situation involving a design with two independent samples. If the result of the Mann-Whitney U Test is significant, it indicates there is a significant difference between the two sample medians, and as a result of the latter the researcher can conclude that there is a high likelihood that the samples represent populations with different median values (Sheskin, 2003). It is a non parametric test employed with ordinal data. This test is employed when one does not want to violate the assumption of normal distribution of data or the assumption of homogeneity of variance. It should however be noted that when this test is applied, the raw data is sacrificed for ranks. The Mann-Whitney U test is based on the following assumptions: a) Each sample has been randomly selected from the population it represents; b) The two samples are independent of one another; c) The original variable observed (which is subsequently ranked) is a continuous random variable (although sometimes such tests are carried out for discrete random variables; and d) The underlying distributions from which the samples are derived are identical in shape. The shapes however need not be normal. A researcher is able to eliminate the effect of outliers, as the U test considers ranked data and therefore it scores over other tests where the outliers significantly influence the variability.

The following approach was adopted in the application of the Mann-Whitney U test to the data collected from Mt. Rainier. The data were characterized into 3 sample groups – phase 1: before construction, phase 2: gutter filters only, and phase 3: gutter filters and bioinlets. Spreadsheets were used for performing various calculations on the data set. The individual means, standard deviations and the corresponding variance were calculated. Knowing the number of elements in each group, the Degree of Freedom was determined for each pollutant. $\overline{X}_1$ and $\overline{X}_2$ are the two sample means while μ_1 and μ_2 denote the population means from which the samples are derived. The data from either of the groups to be compared were assimilated and ranked in their order of magnitude in such a way that the lowest value had a rank = 1 and the value just greater than that as 2 and so on. In case there are two or more data points with an equal score, the average of the ranks involved is assigned to all scores tied for a given rank. n_a and n_b denote the number of elements in each data set.

Null Hypothesis: $\mu_1 = \mu_2$: This implies that the sample means from the two populations are equal.

Alternative Hypothesis: In the current study, the following directional alternative hypothesis was considered: $\mu_1 > \mu_2$.

The hypothesis is evaluated with a Mann Whitney U test statistic. The null hypothesis can be rejected if the obtained absolute value of z is equal to or greater than the tabled critical one-tailed value at a pre-specified level of significance. The directional hypothesis which is supported is the one that is consistent with the data. In this case, if the sum of ranks of phase 1 (before construction) is greater than the sum of ranks (R_x) of phase 2 or 3 (after implementation of LID practices) then the directional hypothesis $\boldsymbol{\mu_1} > \boldsymbol{\mu_2}$ is supported. The U statistic is determined by using the formula:

$$U_a = n_a n_b + \frac{n_a(n_a+1)}{2} - R_1 \tag{3.2}$$

and

$$U_b = n_a n_b + \frac{n_b(n_b+1)}{2} - R_2 \tag{3.3}$$

The lower of these two U values is selected to obtain the computed z value. Calculation of a z value is the normal approximation of the Mann-Whitney U statistic for large sample sizes. The z value is calculated using the formula:

$$z = \frac{(U - \frac{n_a n_b}{2})}{\sqrt{\frac{(n_a n_b(n_a + n_b + 1))}{12}}} \tag{3.4}$$

This calculated z value will always be negative as we use the lower of the U values from U_a and U_b. Comparing this computed absolute z value with the tabled z value for one-tailed normal distribution table helps in deducing the result. These steps are adopted for each of the pollutant EMCs and each time a comparison is made between the computed absolute z value and the tabled one-tailed z value form the Table of Normal Distribution. If $|z|$ fromequation3.4 is greater than the tabled one-tailed value, the null hypothesis of equality is rejected. In case the alternative hypothesis is supported, then one can say at a 95% significance level that the treatment is working and the difference in the means is not due to chance.

3.5.1.c Rosner's Outlier Test

The wide data range in the EMC for the pollutants resulted in some outliers which were initially identified by visual inspection and later confirmed statistically. The Rosner's outlier test was adopted for determining outliers in all the pollutant data sets with sample size (n) greater than 25. It is an iterative approach for testing k outliers with m steps (m = 1, 2, … k). The null and alternative hypotheses are:

H_0: All values in the sample of size n-m+1 are from the same normal population**.**

H_a: The m most extreme events are unlikely to have come from the same normal population as the remainder of the sample of size n-m.

The data were ranked in an ascending order and the mean and the standard deviation were calculated. The test statistic R (Modeling Hydrological changes: Statistical study; Mccuen, 2003) is calculated as:

$$R_m = \frac{\left| X_{(m)} - \overline{X}_{(m)} \right|}{S_{(m)}} \tag{3.5}$$

where, $X_{(m)}$ = the extreme value (largest or smallest in the sample),

$\overline{X}_{(m)}$ = sample mean and

$S_{(m)}$ = standard deviation

The critical value (R_c) is determined by (Mccuen, 2003):

$$\begin{aligned} R_c &= 2.295 + 0.02734n - 0.0002175n^2 - 0.03786m + 0.0009356nm - 0.0000793m^2 \\ &- 0.00006973nm^2 + 0.000008374m^3 + 0.000003943nm^3 \text{ (for 25<n<50)} \end{aligned} \tag{3.6}$$

If the test statistic (R_m) is greater than the critical value (R_c), then the null hypothesis is rejected and the presence of k outliers is accepted**.**

3.5.1.d Dixon- Thompson Test

The Dixon-Thomson test was adopted for determining outliers on the higher end and lower end in case of pollutant EMC data sets with sample size (n) 25 or less. The data were ranked in an ascending order with the smallest denoted as X_1 and the largest denoted as X_n. The subscript represents the rank of the value from smallest to largest. The test statistic R and critical value R_c depend on the sample size. The null hypothesis that the data are drawn from the same population is rejected if R is greater than R_c. The equations used to compute the test statistic R depending on the sample size are tabulated in Table 3.5. The critical values are presented in Table 3.6. The R test statistic was compared with the critical value at 5% level of significance.

Table 3.5. Equations for calculating the Test Statistic for Dixon-Thompson Test (Mccuen, 2003).

Sample size	Low Outlier Test Statistic	High Outlier Test Statistic	Equation #
3 to 7	$R = \frac{X_2 - X_1}{X_n - X_1}$	$R = \frac{X_n - X_{n-1}}{X_n - X_1}$	(3.7)
8 to 10	$R = \frac{X_2 - X_1}{X_{n-1} - X_1}$	$R = \frac{X_n - X_{n-1}}{X_n - X_2}$	(3.8)
11 to 13	$R = \frac{X_3 - X_1}{X_{n-1} - X_1}$	$R = \frac{X_n - X_{n-2}}{X_n - X_2}$	(3.9)
14 to 25	$R = \frac{X_3 - X_1}{X_{n-2} - X_1}$	$R = \frac{X_n - X_{n-2}}{X_n - X_3}$	(3.10)

Table 3.6. Critical values for Dixon-Thompson Test depending on the sample size (Mccuen, 2003).

sample size (m)	Critical Value		
	5%	2.5%	1%
3	0.943	0.970	0.988
4	0.765	0.829	0.889
5	0.641	0.707	0.777
6	0.560	0.626	0.693
7	0.503	0.562	0.630
8	0.549	0.610	0.675
9	0.506	0.565	0.630
10	0.472	0.528	0.590
11	0.570	0.617	0.670
12	0.540	0.586	0.637
13	0.515	0.560	0.610
14	0.538	0.583	0.632
15	0.518	0.562	0.611
16	0.499	0.542	0.590
17	0.482	0.525	0.574
18	0.467	0.509	0.556
19	0.455	0.495	0.541
20	0.444	0.482	0.528
21	0.431	0.470	0.516
22	0.422	0.461	0.506
23	0.414	0.452	0.494
24	0.405	0.443	0.485
25	0.397	0.435	0.480

The outliers identified by either of the tests were eliminated and the calculations for the student's *t* test and the Mann-Whitney U test were carried out again. The student's t test uses raw data and its results and conclusions are affected by the presence of an outlier. The Mann-Whitney U test uses ranked data and therefore the inferences from the U test are not affected by the outliers, though a different z statistic is computed. The elimination of the outliers was used as a tool to avoid the inconsistency in the inferences reported by the student's *t* test and the Mann-Whitney U test for some of the pollutant EMC data sets.

3.5.1.e Probability Plots

Probability plots are important due to the limitations of the objective tests. The probability plots have all the information on the agreement between the sample and the theoretical distributions and their visual inspection leads to sound conclusions (Van Buren, et al., 1997). The plotting position in such probability plots is given by the formula by Blom (1958) in equations 2.8 and substituting the α value in 2.9 to obtain F_i. The exceedance probability for a particular pollutant EMC is obtained by plotting (1-F_i) on the x-axis on a probability scale and the log-concentration on the dependent axis. A wide range of EMCs was reported from the data analysis of all the 3 phases and a logarithmic scale also aids in preventing scatter while plotting on the y-axis. The linearity of the lognormal distribution in stormwater quality data aids in performance comparison across the different phases.

Chapter 4

RESULTS AND DISCUSSIONS

4.1 FIELD SAMPLING

The primary aim of the current study was to evaluate the pollutant removal efficiency of the Low Impact Development practices adopted at Mt. Rainier, MD. This study is an extension of characterizing the pollutants in highway runoff at Mt. Rainier, MD (Flint, 2004). Accordingly, monitoring water quality for Total Suspended Solids (TSS), Total Kjeldahl Nitrogen (TKN), nitrite (NO_2^-), nitrate (NO_3^-), Total Phosphorus (TP), chloride (Cl), cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn) was continued. The entire project was divided into three phases- Before Construction (June 2002-September 2003) (Flint, 2004), gutter filters (November 2003 – September 2004) and gutter filters and bioinlets (October 2004 – November 2005). Table 4.1 lists the number of events for which each of the pollutants was analyzed in each phase. The Dionex ion chromatograph (model DX-100) in the Environmental Engineering laboratory at the University of Maryland, College Park was not functioning accurately and as a result nitrate and chloride analysis could not be carried out in some storm events of phases 2 and 3.

There was some oil residue in the flume (Figure 4.1) from the greasing of a nearby utility pole during March 2005. The sampling process was on hold from April 2005 to June 2005 (during phase 3) due to a problem in the bioinlet caused by road construction. The alignment of the pipe responsible for the water flowing from the inlet chamber into the bioinlet and from the bioinlet to the outlet pond was disturbed. This led to accumulation of water in the inlet tank (Figure 4.2) and caused slow seepage of water into the flume (Figure 4.3). The ISCO auto-sampler could not distinguish between water during the rains and the seepage water and hence it would trigger without any rains. The bioinlet was restored in the month of June and monitoring was resumed starting July. Activities like road maintenance, deicing of roads, asphalting of roads, oil and seepage water bleeding at the sampling site led to some outlier concentrations in the pollutants in some storms.

Table 4.1. Summary of the data sets for water samples collected in each of the sampling phases.

Project Phase	Before Construction (Phase 1) (Flint, 2004)	Gutter Filters (Phase 2)	Gutter Filters + Bioinlets (Phase 3)
Total # of storm events analyzed	32	17	14
Pollutants			
Total Suspended Solids (TSS)	30	17	14
Total Kjeldahl Nitrogen (TKN)	31	16	14
Nitrate (NO_3^-)	25	3	6
Nitrite (NO_2^-)	32	17	14
Total Phosphorus (TP)	30	17	14
Cadmium (Cd)	10	16	12
Copper (Cu)	32	17	14
Lead (Pb)	32	17	12
Zinc (Zn)	30	17	12
Chloride (Cl)	3	5	7

Figure 4.1. Oil residue in the flume from greasing of a nearby utility pole (March 2005).

Figure 4.2. Disturbance in the pipe alignment between the inlet storage chamber and the bioinlet resulted in accumulation of water in the storage chamber (March 2005).

Figure 4.3. Residual water in the flume at the sampling point resulting from seepage water (March 2005).

4.2. MEASURED CONCENTRATIONS

A wide range of values were obtained from the sample analyses. The lowest measured concentration, the highest measured concentration and the mean values for the pollutants are given in Tables 4.2 and 4.3 for stormwater runoff analyzed after the construction of gutter filters only. The range of concentrations for each of the pollutants varied over an order of magnitude. In the cases of TKN, nitrite, nitrate, TP, Total Cd, Total Cu and Total Pb, the smallest concentration was found to be below the detection limit. In the case of TSS, the lowest concentration measured was 1.3 mg/L, while the highest was 7000 mg/L. This wide range skews the calculations for the mean and gave a high variance.

Chloride was analyzed for 5 events, with the lowest concentration equal to 2.1 mg/L and the highest concentration of 760 mg/L, which also gave a very high variance.

Table 4.2 Low, high and mean measured N, P, TSS and Cl concentrations for all samples analyzed in phase 2 (Gutter Filters)

	TKN (mg/L)	NO_2^- (mg-N/L)	NO_3^- (mg-N/L)	TP (mg-P/L)	TSS (mg/L)	Cl (mg/L)
# of events w/data	16	17	4	17	17	5
Low	<0.14	<0.01	<0.2	<0.24	1.3	2.1
High	17	1.8	5.7	3.7	7000	760
Mean	2.0	0.18	0.92	0.71	125	50

Table 4.3 Low, high and mean measured metal concentrations for all samples analyzed in phase 2 (Gutter Filters)

	Cd (µg/L)	Cu (µg/L)	Pb (µg/L)	Zn (mg/L)
# of events w/data	16	17	17	17
Low	<2	<2	<2	0.1
High	455	210	1200	1.2
Mean	21	50	67	0.33

Similarly, the lowest, highest and the mean of the measured concentrations of the pollutants from analyses of stormwater runoff after the construction of gutter filters and bioinlets are shown in Tables 4.4 and 4.5. The lowest concentrations for nitrite, TP, total Cd, and total Zn were below the detection limit. The storm event on 01/13/2005 gave very high concentrations of zinc, in the range of 130 to 350 mg/L. These values were greater by about three orders of magnitude than Zn concentrations in other storm events. The storm events on 11/20/04 and 01/13/05 had nitrate concentrations measuring up to 110 mg-N/L and 230 mg-N /L respectively, which were very high compared to nitrate concentrations in other storm events, which were lower by an order of magnitude. The storm event on 03/20/2005 had TSS concentrations upto 840 mg/L, which was again higher by an order of magnitude from the TSS concentrations in other storms. The highway was paved around February – March and this might have resulted in such high concentrations of TSS. Chloride data was obtained in 7 events with the lowest concentration of 1.2 mg/L and the highest concentration of 1150 mg/L. Consequently, the calculations of the mean were skewed assuming a symmetrical distribution. The outliers were a result of road maintenance activities, deicing of roads, asphalting of the pavement and greasing of the utility pole.

Table 4.4. Low, high and mean measured concentrations for all samples analyzed in Phase 3 (Gutter Filters + Bioinlets)

	TKN (mg/L)	NO_2^- (mg-N/L)	NO_3^- (mg-N/L)	TP (mg-P/L)	TSS (mg/L)	Cl (mg/L)
# of events w/data	14	14	6	14	13	7
Low	0.53	<0.01	0.31	<0.24	2.7	1.2
High	12	2.9	230	2.2	840	1150
Mean	3.3	0.23	22	0.78	51	135

Table 4.5. Low, high and mean measured concentrations for all samples analyzed in Phase 3 (Gutter Filters + Bioinlets)

	Cd (µg/L)	Cu (µg/L)	Pb (µg/L)	Zn (mg/L)
# of events w/data	12	14	12	12
Low	<2	16	7.3	<0.05
High	63	280	160	330
Mean	2.3	78	35	25

4.3. EVENT MEAN CONCETRATIONS

The event mean concentrations (EMC) were determined for each event as the total pollutant load over the total runoff volume for that event (Equation 2.1). A range of EMCs was obtained for each particular pollutant for each phase in the project. At the end of the project duration an arithmetic mean of the entire individual storm EMCs was calculated. The summary data for stormwater samples analyzed after treatment by gutter filters only is presented in Table 4.6. Similarly, the samples analyzed after complete implementation of LID practices (gutter filters + bioinlets) is presented in Table 4.7. The range of EMCs obtained for each phase is evident from Tables 4.6 and 4.7. The mean of the EMCs for a phase for a particular pollutant with the standard deviation is shown in the tables. The statistical analysis was carried out on the EMC for individual storms. The probability plots were also plotted from the EMC data. The mean EMC in phases 2 and 3 were used to determine the percentage removal or export with comparison to the mean EMC value in phase 1 (Flint, 2004).

Table 4.6. Summary of the EMC data for each storm event monitored in phase 2 for each pollutant.

STORM EVENT	TKN	NITRATE	NITRITE	TOTAL PHOSPHORUS	TSS	CADMIUM	COPPER	LEAD	ZINC	CHLORIDE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
11/12/2003	ND	0.10	0.69-0.74	0.69	4600	0.090	0.15	0.91	0.76	ND
11/19/2003	0.9	ND	0.01-0.02	0.32-0.12	530	0.040	0.07	0.22	0.56	ND
12/11/2003	2.1	ND	0.01-0.02	0.33-0.28	140	0.080	0.03	0.08	0.40	ND
12/24/2003	0.3	ND	0.049	0.24-0	90	0.040	0.14	0.07	0.76	ND
3/6/2004	0.5	0.37	0.03	0.25-0.01	91	<0.002	0.03	0.02	<0.05	ND
3/16/2004	0.7	0.83	0.05	0.87	65	<0.002	0.06	0.05	<0.05	ND
4/13/2004	0.7	3.5	3.7	0.53-0.41	98	<0.002	0.03	0.01	0.19	652
04/23/2004	7.0	ND	0.002-0.010	1.5-1.4	83	<0.002	0.04	0.02	0.45	ND
05/05/2004	1.5	ND	0.02	0.71	26	<0.002	0.05	0.02	0.20	ND
05/25/2004	4.0	ND	1.3	1.1	40	<0.002	0.11	0.01	0.28	ND
06/05/2004	0.66	ND	0.05	0.46	25	ND	0.04	0.02	0.18	ND
06/22/2004	2.6	ND	0.43	1.2	18	<0.002	0.079	0.06	0.41	ND
07/24/2004	1.1	ND	0.07	0.61	29	0.069-0.070	0.019	0.11	0.19	ND
08/02/2004	1.4	ND	0.17	0.59	7	0.004-0.005	0.089	0.06	0.30	11
08/12/2004	1.2	ND	0.02	0.20	14	<0.002	0.048	0.06	0.35	2.6
09/07/2004	0.91	ND	0.08	1.3	69	<0.002	0.060	0.06	0.40	19
09/17/2004	3.2	ND	0.19	1.4	45	0.004-0.005	0.10	0.06	0.46	9.6
Mean	**1.7**	**1.2**	**0.21**	**0.72-0.67**	**350**	**0.020**	**0.07**	**0.11**	**0.35-0.35**	**140**
Standard deviation	**1.7**	**1.6**	**0.33**	**0.43-0.47**	**1100**	**0.032**	**0.04**	**0.21**	**0.21-0.22**	**290**

ND = No Data.

Table 4.7 Summary of the EMC data for each storm event monitored in phase 3 for each pollutant.

STORM EVENT	TKN	NITRATE	NITRITE	TOTAL PHOSPHORUS	TSS	CADMIUM	COPPER	LEAD	ZINC	CHLORIDE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10/19/2004	1.9	1.1	0.18	0.61	ND	0.044	0.11	0.044	0.36	17
11/4/2004	2.0	1.9	0.04	0.89	26	0.002-0.003	0.09	0.058	0.67	5.6
11/20/2004	2.1	67	0.32	0.65	28	<0.002	0.05	0.016	0.13	220
12/9/2004	1.2	8.0	0.07	0.42	83	<0.002	0.05	0.038	0.16	29
1/13/2005	0.93	46	0.10	1.4	32	<0.002	0.04	0.051	210	29
3/20/2005	7.1	ND	0.02	0.73	360	<0.002	0.14	0.062	0.73	610
7/7/2005	1.1	0.73	0.10	0.44	9	<0.002	0.06	0.033	0.31	3
7/27/2005	2.9	ND	0.18	0.49	15	<0.002	0.075	0.013	0.59	ND
8/8/2005	4.6	ND	0.47	0.81	120	<0.002	0.12	0.034	0.56	ND
9/26/2005	7.6	ND	0.054	0.89	18	<0.002	0.12	0.02	0.50	ND
10/7/2005	1.5	ND	0.10	0.54	33	<0.002	0.039	0.04	1.3	ND
10/11/2005	3.0	ND	0.17	0.38	27	<0.002	0.059	0.02	0.29	ND
11/16/2005	4.5	ND	0.10	1.1	91	ND	0.093	ND	ND	ND
11/29/2005	2.0	ND	0.08	0.62	64	ND	0.043	ND	ND	ND
Mean	**3.0**	**21**	**0.14**	**0.71**	**70**	**0.004-0.005**	**0.078**	**0.04**	**18**	**130**
Standard deviation	**2.2**	**29**	**0.12**	**0.29**	**94**	**0.012-0.014**	**0.035**	**0.017**	**67**	**230**

ND = No Data.

Table 4.8 compares the mean EMC and the range of EMCs of the selected pollutants at the Mt. Rainier site before and after construction of the gutter filters. The results suggest that the gutter filters are working in the improvement of the quality of the stormwater runoff in case of some pollutants.

Table 4.8. Summary information for comparison of pollutant concentrations at Mt. Rainier, MD, before and after gutter filter construction.

Water Quality Parameter	Before Construction (June 2002-September 2003, Flint, 2004)			After Gutter Filter Construction (November 2003- September 2004)			Ratio of mean EMC $\frac{Phase2}{Phase1}$
	EMC Range	Mean EMC	Median EMC	EMC Range	Mean EMC	Median EMC	
TKN (mg/L-N)	0.81-10	3.4	2.5	0.32-7.1	1.7	1.1	0.50
Nitrite (mg/L-N)	0.014-4.2	0.24	0.048	0.01-1.3	0.21	0.054	0.88
Nitrate (mg /L-N)	0.14 – 4.3	0.85	0.51	0.1 – 3.5	1.2	0.60	1.4
TP (mg/L-P)	<0.24-1.9	0.52-0.57	0.59	<0.24-1.5	0.67-0.72	0.61	1.3
TSS (mg/L)	41-1600	420	380	7-4600	350	65	0.83
Cl (mg/L)	0.03-14	3.5	6.9	2.6-650	140	11	40
Zn (mg/L)	0.18-6.0	1.2	0.81	<0.025-0.76	0.35	0.35	0.29
Cu (µg/L)	24-290	110	89	20-150	66	60	0.60
Pb (µg/L)	15-1200	220	99	13-910	120	0.058	0.59
Cd (µg/L)	13-93	35	22	<2-90	20	0.001	0.57

The mean EMC of all the pollutants except for nitrate, phosphorus and chlorine has decreased. The mean EMC values for TKN and Zn has decreased by at least one half of those found before the construction of the filters. The EMCs of the other pollutants, nitrite, TSS, copper, lead and cadmium also decreased. Nitrite decreased by 12%, TSS decreased by 17%, Cu decreased by 40%, lead decreased by 41% and Cd decreased by 43% of the concentrations in phase 1 (Flint, 2004).

The comparison between the EMC ranges and the mean EMC before and after construction of gutter filters and bioinlets is listed in Table 4.9. The mean EMC of TKN, nitrite, TSS, Total Cd, Total Pb and Total Cu are less than the mean EMC before construction at the site, indicating that the treatment may be working. The mean EMC of Total Cd (11-14% of the EMC before construction) and TSS and Total Pb have decreased (17% and 16% of the EMC before construction respectively) significantly. The mean EMC of nitrite decreased to 50%, while Total Cu was reduced to 71% of the EMC before construction. The mean EMC of TKN after construction of the gutter filters and bioinlets reduced to 3.0 mg/L from earlier 3.4 mg/L, thus dropping by 12% from the initial value. An export was found in case of nitrate, TP, Cl and Total Zn EMCs after construction of the gutter filters and bioinlets. The EMC for these pollutants increased after implementing the LID practice. Nitrate concentration increased to 25 times of the EMC, TP increased 120 – 140% and total Zn increased to 15 times of the EMC before construction. In case of Zn, the event on 01/13/05 had a very high concentration. Ignoring the outlier in phase 3 gave a mean Zn EMC of 0.50 mg/L, which is less than the mean EMC in phase 1. In this case, the Zn mean EMC in phase 3 was reduced by 58% from phase 1.

Table 4.9. Summary information for comparison of pollutant concentrations at Mt. Rainier, MD, before and after gutter filters + bioinlets construction.

Water Quality Parameter	Before Construction (June 2002-September 2003, Flint, 2004)			Gutter Filters + Bioinlets (October 2004- November 2005)			Ratio of mean EMC $\frac{Phase3}{Phase1}$
	EMC Range	Mean EMC	Median EMC	EMC Range	Mean EMC	Median EMC	
TKN (mg/L-N)	0.81-10	3.4	2.5	0.93 – 7.6	3.0	2.1	0.88
Nitrite (mg/L-N)	0.014-4.2	0.24	0.048	0.02 – 0.47	0.12	0.098	0.50
Nitrate (mg /L-N)	0.14 – 4.3	0.85	0.51	0.73 – 67	21	5.0	25
TP (mg/L-P)	<0.24-1.9	0.52-0.57	0.59	0.38 – 1.4	0.71	0.63	1.2-1.4
TSS (mg/L)	41-1600	420	380	9 – 360	70	32	0.17
Cl (mg/L)	0.03-14	3.5	6.9	2.8-610	130	29	37
Zn (mg/L)	0.18-6.0	1.2	0.81	0.13 - 210	18	0.53	15
Zn* (mg/L)	0.18-6.0	1.2	0.81	0.13- 1.3	0.50	0.50	0.42
Cu (µg/L)	24-290	110	89	36 – 140	78	69	0.71
Pb (µg/L)	15-1200	220	99	13 – 62	36	36	0.16
Cd (µg/L)	13-93	35	22	<2 – 44	4 – 5	1	0.11 – 0.14

* = Pollutant analyses after ignoring the outlier on 01/13/05.

4.4. POLLUTANT LOADS

Table 4.10 compares the annual pollutant loadings at Mt. Rainier before and after construction of the gutter filters. The annual loadings after construction of gutter filters were estimated based on 17 storm events over a period of 11 months. The estimated annual pollutant loadings (L) have been calculated from the Simple Method as described by Schueler (1987) similar to before construction in equation 2.2. The flow weighted concentrations are determined by summing the entire pollutant mass over all the storms monitored over the total runoff volume of all the storms.

As with the EMC data, the annual loadings suggested an improvement in water quality after construction of the filters. It was also observed that although the EMC for nitrate and Total Phosphorus had increased post construction of filters, the annual loading after construction of gutter filters was less than before construction. This is because the annual loadings were calculated using a flow weighted concentration and not the individual EMCs.

Table 4.10. Comparison of the annual pollutant loads for pollutants in Mt. Rainier, MD, using the Simple Method, before and after construction of the gutter filters.

Water Quality Parameter	Mt. Rainier Annual Loading (Before Construction, Flint, 2004)		Estimated Annual Loading for Mt. Rainier after gutter filter construction		Ratio of Annual Loading
	(kg/ha-year)	(lb/ac-year)	(kg/ha-year)	(lb/ac-year)	
Nitrite (as N)	1.8	1.6	0.79	0.71	0.43
Nitrate (as N)	9.7	8.6	4.0	3.6	0.41
TKN	25	22	14	12	0.56
TP (as P)	4.6	4.1	4.3	3.8	0.94
TSS	3100	2800	1900	1700	0.60
Zn	8.5	7.6	3.2	2.9	0.38
Cd	0.24	0.22	0.20	0.18	0.84
Cu	0.84	0.74	0.49	0.43	0.58
Pb	1.72	1.53	0.86	0.76	0.50

The comparison between the annual pollutant loadings before and after construction of gutter filters and bioinlets is listed in Table 4.11. The annual pollutant loadings were obtained after monitoring the site after complete implementation of the LID practices from October 2004 to November 2005 for a total of 14 storm events. The annual pollutant loading decreased significantly in case of TSS, Total Pb and Total Cd and there was some reduction in case of TKN, nitrite and Total Cu. The annual pollutant loading for TSS decreased by 86%, Pb decreased by 82%, Cd decreased by 91% , TKN by 15%, nitrite by 5% and Cu decreased by 12% of the pollutant loadings before construction. The pollutant loading after the construction of gutter filters and bioinlets for TP increased by 13% from before construction. The pollutant loadings for nitrate increased 30 times of the loadings before construction, while zinc loadings increased 12 times of the loadings before construction. These high pollutant loads are mainly due to very high zinc concentration in the storm event of 01/13/05, and high nitrate concentrations in the storm events of 11/20/04 and 01/13/05. There was not much change in the annual loadings in phases 1 and 3 for nitrite (5%). Correspondingly, the EMC too had increased in the case of nitrate (25 times), TP (20 -40%) and Total Zn (15 times), while the TKN EMC had decreased by 12% and the nitrite EMC had decreased by 50% (Table 4.9). In the case of Zn, ignoring the event of 01/13/05, gave a reduction in the annual pollutant loading by 41%.

Table 4.11. Comparison of the annual pollutant loads for Pollutants in Mt. Rainier, MD, using the Simple Method, before and after construction of the gutter filters and bioinlets.

Water Quality Parameter	Mt. Rainier Annual Loading (Before Construction, Flint, 2004)		Estimated Annual Loading for Mt. Rainier after gutter filters and bioinlets construction		Ratio of Annual Loading
	(kg/ha-year)	(lb/ac-year)	(kg/ha-year)	(lb/ac-year)	
Nitrite (as N)	1.8	1.6	1.7	1.6	0.95
Nitrate (as N)	9.7	8.6	290	260	30
TKN	25	22	21	19	0.85
TP (as P)	4.6	4.1	5.2	4.6	1.1
TSS	3100	2800	430	380	0.14
Zn	8.5	7.6	104	93	12
Zn*	8.5	7.6	5.0	4.5	0.59
Cd	0.24	0.22	0.02	0.02	0.091
Cu	0.84	0.74	0.74	0.66	0.88
Pb	1.72	1.53	0.32	0.28	0.18

* = Pollutant analyses after ignoring the outlier for Zn on 01/13/05.

4.5. EVALUATION OF LID EFFICIENCY

4.5.1 *Student's t test and the Mann-Whitney U test*

The impact of the LID practices on water quality at Mt. Rainier, MD can be assessed by comparison of the data sets in the 3 phases: phase 1 - before construction, phase 2 – gutter filters only, and phase 3 – gutter filters + bioinlets. For the treatment to be successful, the pollutant EMCs in phases 2 and 3 had to be less than the EMCs when no treatment was employed at the site. The student's *t* test was selected as the parametric test and the Mann-Whitney U test was selected as the non-parametric test to determine whether the sample means before and after any sort of treatment were statistically different. These tests helped to establish with a 95% confidence that the decrease in the

EMC (increase in some cases) after any treatment was due to the treatment method itself and not due to randomness. The student's *t* test involved the comparison between the tabled critical *t* value and the absolute (modulus function) of the computed *t* value. The Mann-Whitney U test compared the z value from the Table of Normal Distribution with the computed z value. The pre-significance level in both the tests was set at 95%. The tests were based on the null hypothesis that the population mean before construction was equal to the population mean in either of the treatment phases. This implied that in order for the treatment to be successful, the null hypothesis had to be rejected and a directional alternative hypothesis (sample mean in phase 1 > sample mean in phase 2/3) has to be adopted. There were little data available on chloride and therefore neither the student's *t* test nor the Mann-Whitney U test was run on it in comparison of phase 1 with phases 2 and 3. The results of the tests are presented in Tables 4.12, 4.13 and 4.14.

It is evident from Table 4.12, that with a 95% confidence the *t* test concludes for the three pollutants: TKN, Total Cu and Total Zn, that the treatment was successful, while for the other five pollutants: nitrite, nitrate, Total Cd, Total Pb and Total Phosphorus, it was not possible to say with a 95% confidence that the treatment had been successful. In the case of TSS, the variance was high and therefore it was not applicable to run the *t* test on it.

However, in the case of the Mann-Whitney U Test, one can say with a 95% confidence level for all the pollutants except nitrite, nitrate and Total Phosphorus that the treatment was successful. In the case of TP and nitrate, there was an increase in the concentration in phases 2 and 3 when compared to phase 1, but the increase was not statistically significant. Thus, although the sample means for the 2 phases were different, an increase in the pollutant concentration was found after the treatment had been employed. This test considers ranks rather than the raw data itself, and therefore the question of a large variance as in case of TSS does not arise.

The outliers for all the pollutants except Cd in phase 1 were identified by the Rosner's outlier test, while Cd from phase 1 and all pollutants from phase 2 were evaluated by the Dixon-Thompson test. The Rosner's test is used for sample sets greater than 25, while the Dixon-Thompson test is used for data sets with sample sizes 25 or less. It was found that TSS had two outliers on the higher end in phase 1 and one higher outlier in phase 2. Pb had an outlier on the higher side as well in phases 1 and 2. The student's *t* test and the Mann-Whitney U test were employed on the data ignoring the outliers and the results are presented in Table 4.12. It was found that after eliminating the outliers, the student's *t* test established at a 95% pre-significance level that the mean EMCs for TSS and Pb

Table 4.12. Statistical summary of the results of the *t* test and the Mann-Whitney U Test comparing data sets for water samples for no treatment and after construction of gutter filters at Mt. Rainier, MD. The pre-significance level for both the tests is 95%.

Pollutant	Total # of elements*	Student's *t* test			Mann Whitney U test			Mean EMC ratio phase 2/ phase 1
		$t_{computed}$	$t_{dof,0.05}$	Significant difference in population means?	$z_{computed}$ (absolute)	$z_{0.05}$	Significant difference in population means?	
TKN	45	2.4	1.7	✓	3.1	1.65	✓	0.50
Nitrite	49	0.18	1.7	X	0.47	1.65	X	0.88
Nitrate	29	-0.62	1.7	X	0.0	1.65	X	1.4
TP	45	-0.4	1.7	X	0.48	1.65	X	1.3
TSS	45	NA	NA	——	3.5	1.65	✓	0.83
TSS**	42	3.8	1.7	✓	4.2	1.65	✓	0.24
Cd	24	1.2	2.1	X	1.8	1.65	✓	0.57
Cu	47	2.2	1.7	✓	2.5	1.65	✓	0.60
Pb	47	1.3	1.7	X	2.4	1.65	✓	0.59
Pb**	45	2.3	1.7	✓	2.8	1.65	✓	0.30
Zn	45	2.9	1.7	✓	4.0	1.65	✓	0.29

* = The total number of applicable samples in the combined data sets used for comparison.

** = Eliminating the outlier concentration in the pollutant data set.

NA = Not Applicable to run the student's *t* test due to high variance.

decreased after the gutter filters were constructed. The outliers mainly influence the results of the *t* test. The Mann- Whitney U test also established at a 95% pre-significance level that the gutter filters improved the water quality by decreasing the mean EMCs of TSS and Pb.

The statistical conclusions from comparison of mean EMCs in phase 1 and phase 3 are summarized in Table 4.13. It was possible to conclude with a 95 % confidence from the student's *t* test that the reduction in the mean EMC of TSS, Total Cd and Total Pb was due to the LID practice at the site. As per the student's *t* test, it was not possible to say with a 95% confidence that there were differences in the mean EMC of TKN, nitrite and Total Cu.

According to the Mann-Whitney U test, the reduction in the mean EMC for nitrite, TKN, TSS, Total Cd, Total Cu, and Total Pb was credited to the LID practice with a 95% confidence level. In case of nitrate, TP and Total Zn, it can be said with a 95 % confidence level that the increase in their respective mean EMCs was a result of the presence of gutter filters and bioinlets.

The Rosner's outlier test identified the outliers in all the pollutant EMC data sets except Cd from phase 1 and the Dixon-Thompson test was adopted for selecting the outliers from data for Cd in phase 1 and all the pollutants in phase 3. Outliers were obtained in data for TKN, nitrite, TP, TSS, Pb and Zn in phase 1, while nitrite, TSS, Zn and Cd EMC data sets gave outliers in phase 3. The student's *t* test and the Mann-Whitney U test were employed on the data ignoring the outliers. The outliers did not have any effect on the results from the *t* test and the U test for all the pollutants except Zn. Eliminating the outlier for Zn from the storm event on 02/03/2003 in phase 1, the student's *t* test concluded with 95% pre-significance level that the LID practice at the site improved the water quality by decreasing the mean EMC for Zn.

The Mann-Whitney U test concluded at a 95% significance level that the export in the concentration of nitrate was caused by the LID practices (gutter filters + bioinlets) at the site after ignoring the outlying high concentrations. The Mann-Whitney U test also established the reduction in the Zn concentration in the runoff treated by gutter filters and bioinlets from the runoff receiving no treatment at a 95% significance level after ignoring the outlier.

The summary in Table 4.13 does not include the results from the student's *t* test and the Mann-Whitney U test for TKN, nitrite, nitrate, TP, TSS, and Pb after eliminating the outliers as it did not have any effect on the conclusion and the interpretation of the results. Zn was included in the table, as prior to ignoring the outlier, the student's t test could not establish at a 95% presignificance level that the treatment was working. However on eliminating the outlier, it could be established at a 95% presignificance level that the gutter filters and bioinlets decreased the mean EMC of Zn.

The results of the statistical analyses for the comparison of water quality between phase 2 and phase 3 are tabulated in Table 4.14. The student's *t* test could not conclude that the water quality improved or deteriorated after the installation of the bioinlets for any of the pollutants at a 95% significance level.

Table 4.13. Statistical summary of the results of the t test and the Mann-Whitney U Test comparing data sets for water samples for No treatment and after construction of Gutter Filters and Bioinlets. The pre-significance level for both the tests is 95%.

Pollutant	Total* # of elements	Student's *t* test						Mean EMC ratio phase 3/ phase 1
		$t_{computed}$	$t_{dof,0.05}$	Significant difference in population means?	$z_{computed}$ (absolute)	$z_{0.05}$	Significant difference in population means?	
TKN	45	0.54	1.7	✗	2.8	1.65	✓	0.88
Nitrite	46	0.48	1.7	✗	5.7	1.65	✓	0.50
Nitrate	31	-3.7	1.7	✗	9.9	1.65	✓ export	25
TP	44	-1.4	1.7	✗	7.1	1.65	✓ export	1.2-1.4
TSS	43	3.3	1.7	✓	15	1.65	✓	0.17
Cd	22	3.6	1.7	✓	12	1.65	✓	0.11 - 0.14
Cu	46	1.6	1.7	✗	4.9	1.65	✓	0.71
Pb	44	2.3	1.7	✓	13	1.65	✓	0.16
Zn	42	-1.5	1.7	✗	7.4	1.65	✓ export	15
Zn**	40	2.4	1.7	✓	9.1	1.65	✓	0.42

* = The total number of applicable samples in the combined data sets used for comparison.

** = Pollutant analyses carried out by ignoring the outliers

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The Mann-Whitney U test established at a 95% significance level that the water quality improved for nitrite, TSS, Cd and Pb. The event mean concentration of these pollutants decreased after setting up the bioinlets in addition to the gutter filters. The Mann-Whitney U test concluded at a 95% significance level that the water quality deteriorated after the complete implementation of the LID practice (gutter filters + bioinlets) for TKN, nitrate, TP, Cu and Zn. The bioinlets seem to be a source of nitrogen, phosphorus, Cu and Zn. Vegetation in the bioinlets and application of fertilizers to the plants in the bioinlets may be the sources of nitrogen and phosphorus. Nitrification processes or washout of accumulated nitrate from evaporated water result in export of nitrate from bioretention areas (Davis et al., 2006). The organic rich bioinlet chamber support significant microbial populations which are responsible for aerobic metabolism of organic N resulting in the production of ammonium and, eventually, nitrate through ammonification and nitrification (Davis et al., 2006). The soil media may be responsible for the input of metals in the effluent from bioinlets.

The outliers for the pollutant data sets in phases 2 and 3 were identified by the Dixon-Thompson test. TKN, nitrate, nitrite, TSS and Pb EMC data sets in phase 2 had an outlier each. In phase 3, nitrite, TSS, Zn and Cd pollutant EMC data had an outlier each as well. The student's *t* test was also conducted after ignoring the outliers in the case of all these pollutants, yet it was not possible to establish at a 95% significance level that the samples were statistically different except in the case of Cd. The student's *t* test concluded at a 95% pre-significance level, that the water quality improved by decrease in the mean EMC of Cd after installation of bioinlets in addition to the gutter filters. The Mann-Whitney U test too was conducted after eliminating the outliers and the results obtained were exactly similar to those including the outliers. Only those cases in which the interpretations from the results of the student's *t* test and the Mann-Whitney U test changed after eliminating the outliers have been presented in Table 4.15.

Table 4.14. Statistical summary of the results of the student's *t* test and the Mann-Whitney U Test comparing data sets for water samples after treatment with gutter filters only, and after construction of gutter filters and bioinlets. The pre-significance level for both the tests is 95%.

Pollutant	Total* # of elements	Student's *t* test			Mann-Whitney U test			Mean EMC ratio phase 3/ phase 2
		$t_{computed}$	$t_{dof,0.05}$	Significant difference in population means?	$z_{computed}$ (absolute)	$z_{0.05}$	Significant difference in population means?	
TKN	30	-1.7	1.7	✗	7.8	1.65	✓ export	1.7
Nitrite	31	0.66	1.7	✗	3.6	1.65	✓	0.74
Nitrate	10	-1.3	1.8	✗	3.5	1.65	✓ export	17
TP	31	-0.13	1.7	✗	1.5	1.65	✓ export	1.0
TSS	30	0.92	1.7	✗	2.7	1.65	✓	0.24
Cd	28	1.68	1.7	✗	7.1	1.65	✓	0.22
Cd**	27	2.1	1.7	✓	5.1	1.65	✓	1.05
Cu	31	-0.78	1.7	✗	3.2	1.65	✓ export	1.2
Pb	29	1.2	1.7	✗	5.5	1.65	✓	0.33
Zn	29	-1.2	1.7	✗	5.1	1.65	✓ export	51
Zn**	24	-1.1	1.7	✗	3.5	1.65	export	1.3

* = The total number of applicable samples in the combined data sets used for comparison.

** = Pollutant analyses carried out by ignoring the outlier.

The comparisons among the data sets for each of the three phases throws light on the influence of the LID practices for treating highway runoff in an urban area. There has been a statistically significant removal for all the pollutants except TP and nitrate by either of the LID practices. The mean EMCs for nitrite, TSS, Cd and Pb decreased after treatment by gutter filters and there was further improvement in the water quality after the addition of the bioinlets. In the case of TKN, Zn and Cu, the gutter filters lowered the mean EMCs in comparison to phase 1. The addition of bioinlets slightly increased the mean EMCs in phase 3 when compared to phase 2. However, the mean EMCs in phase 3 were lower than the mean EMCs in phase 1. Nitrate and TP mean EMCs in phase 3 were greater than those in phase 2, which in turn were greater than in phase 1, clearly showing signs of export. The outliers in case of TSS and Pb in phase 1 and Cd and Zn in phase 3 were eliminated and comparisons were carried out. In the case of Zn**, eliminating the EMC on 01/13/05, it was observed that the mean EMC was lowered by the gutter filters, but there was a slight increase after the addition of bioinlets. The mean EMC in phase 3 though was less than that in phase 1. The outlier concentrations in TSS data from phase 1 were eliminated and it was established at a 95% confidence by the student's t test that the gutter filters improved the water quality by decreasing the mean EMC of TSS from phase 1. Similarly, purging the outlier concentration from the Pb data set in phase 1 resulted in establishing at a 95% significance level that the gutter filters decreased the mean EMC from phase 1. Thus eliminating the outliers in these three cases avoided any discrepancy with the conclusions of the Mann-Whitney U test for the same data set.

However, in some case there was still some inconsistency between the results of the student's *t* test and the Mann-Whitney U test when comparisons for water quality were made between the 3 phases of the project. This disagreement was due to the fact that the student's *t* test uses raw data to test the mean while, the Mann- Whitney U test uses ranked measures. As a result the Mann-Whitney U test counters the influence of the outliers at the expense of raw data. The student's *t* test does not compromise on the data, but is influenced by the outliers. The student's *t* test can be employed only on data that is normally distributed. Any departure from this distribution would make the student's *t* test inappropriate for that data set and therefore more emphasis should be placed on the Mann-Whitney U test.

4.5.2 *Probability Plots*

Figures 4.4 – 4.13 give a concise view of the relative difference in the EMCs of a particular pollutant in all the three phases of the project- Before construction, after construction of gutter filters, and after implementation of the complete LID practices (gutter filters + bioinlets). The concentrations have been plotted on a logarithmic scale on the dependent axis. The x-axis gives the value (probability) when a particular concentration will be exceeded. The plotting position for the probability value is given by Blom (1958) and given in equation 2.9. The plotting position has been discussed in detail earlier in Chapters 2 and 3 and the plotting position on the exceedance charts is given by

$$F_{ip} = 1 - \frac{(i - \frac{3}{8})}{(N + \frac{1}{4})} \tag{4.1}$$

The lognormal distribution is evident when a straight line is obtained for data for a particular pollutant in a phase. This linearity is visible in all the probability plots presented later (Figures 4.4 -4.13). It is this property which helps to distinguish between the 3 phases and presents a visual picture of the difference in concentrations between them.

In the case of TSS (Figure 4.4), the stormwater had a TSS concentration of 100 mg/L or more 85% of the time when no treatment was employed at the site. Stormwater analyzed after the construction of gutter filters had a TSS concentration of 100 mg/L or more only 40% of the time. Once the gutter filters and bioinlets were in place, TSS concentration of 100 mg/L was exceeded about 20% of the time. Thus, there was a definite decrease in the EMC of TSS after the employment of the LID practices. It is evident from Figure 4.4 that the EMC for TSS when no treatment is employed at the site was greater than the EMC when gutter filters were employed, which in turn was greater than the EMC when gutter filters and bioinlets were used at the site for stormwater runoff treatment (Figure 4.4).

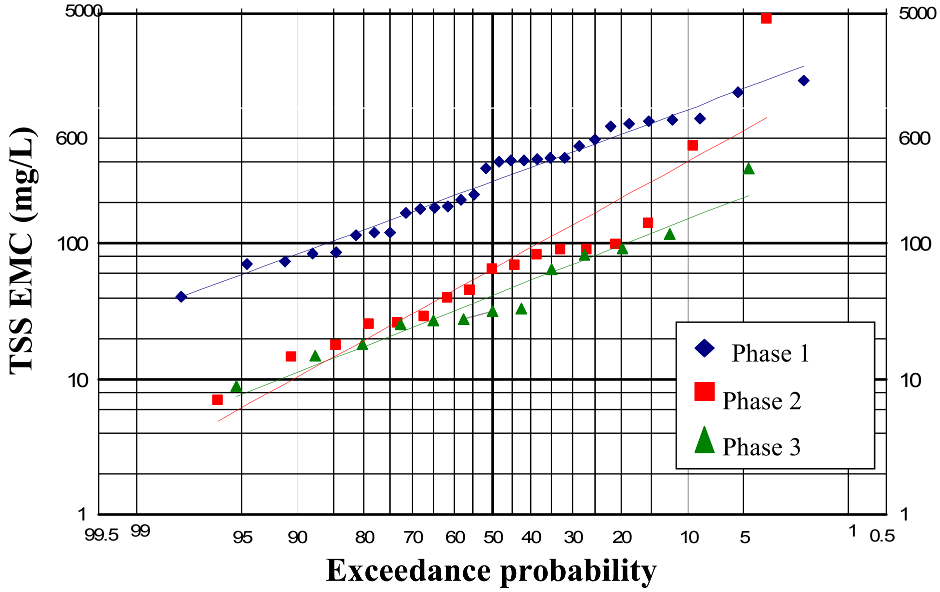


Figure 4.4. Comparison of the 3 phases of the project for TSS EMCs giving the exceedance probability for the range of concentrations.

The comparison of the EMCs for nitrite is shown in Figure 4.5. The LID treatment did not have a significant effect in the reduction of the EMC. The median EMC for nitrite when there is no treatment method employed at the site, after construction of gutter filters, and after gutter filters and bioinlets are in place is 0.055, 0.072, and 0.097 mg/L-N, respectively. The trend lines for all the three phases are closely spaced and intersect each other, indicating no real difference in the EMCs. A concentration of 0.1 mg/L-N was exceeded 40% of the time when the stormwater runoff received no treatment of any sort, 48% of the time after treatment by gutter filters and 42% of the time after treatment from gutter filters and bioinlets (Figure 4.5).

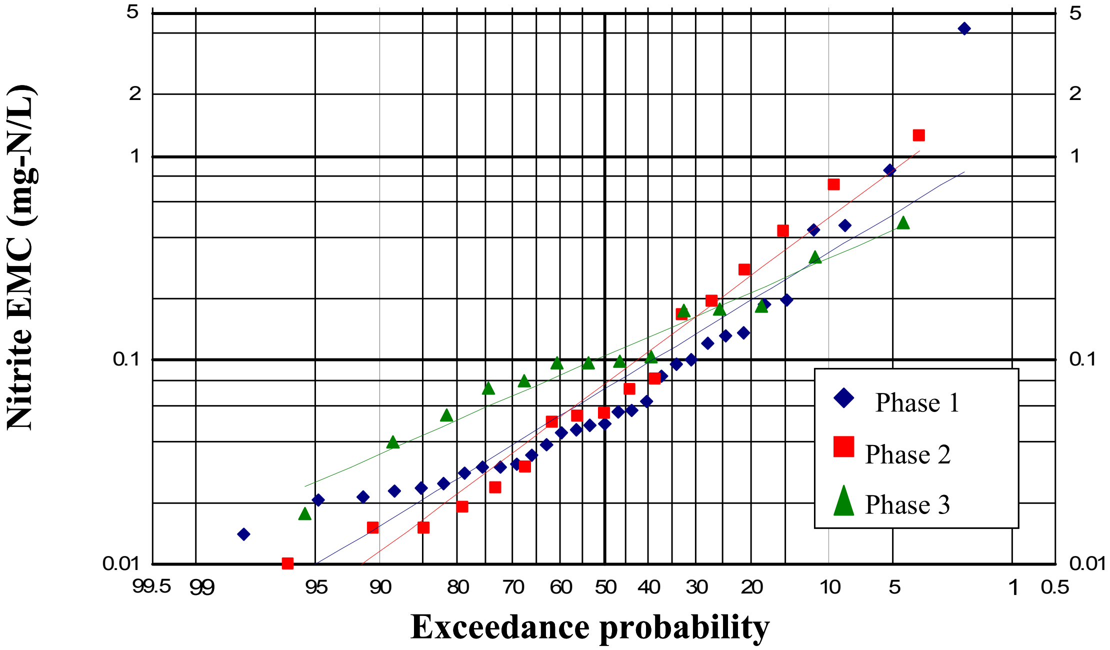


Figure 4.5. Comparison of the 3 phases of the project for nitrite EMCs giving the exceedance probability for the range of concentrations.

The nitrate analysis is useful to make suggestions for a trend, but no noteworthy conclusions can be drawn as few data are available. In the case of nitrate, the mean EMC after construction of gutter filters was greater than the mean EMC before construction. There was a significant increase in the mean EMC when gutter filters as well as bioinlets were used as treatment measures. The exceedance plot for nitrate concentrations for all the three phases is shown in Figure 4.6. There seems to be an export in the nitrate concentration after the LID practices are implemented. There are, however, very little nitrate data from phases 2 and 3 to confirm this observation.

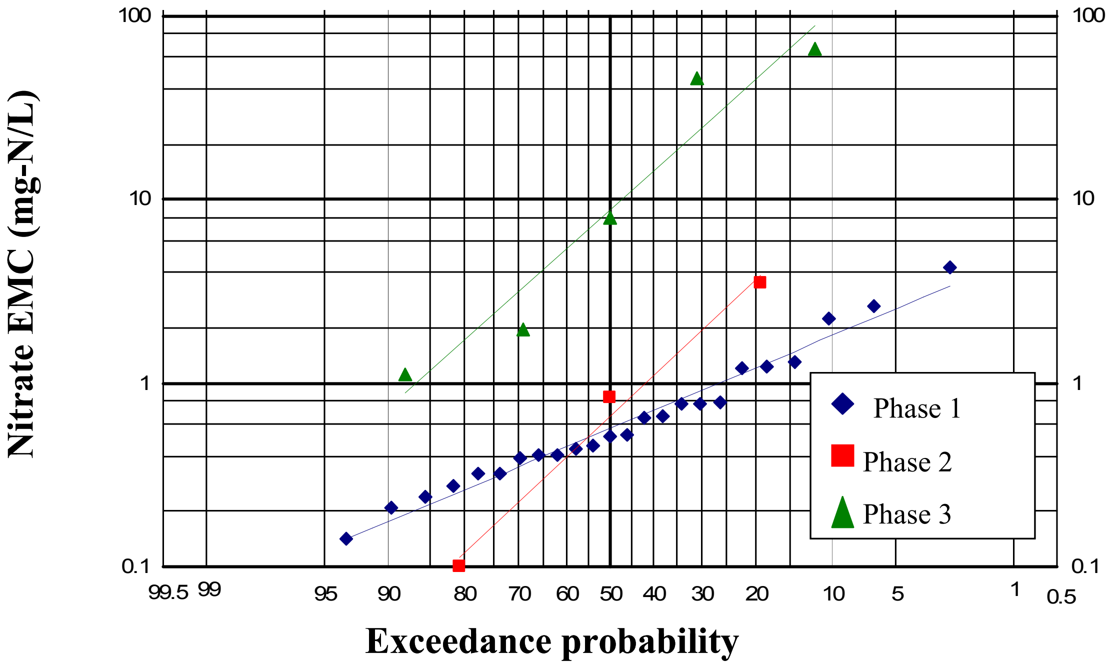


Figure 4.6. Comparison of the 3 phases of the project for nitrate EMCs giving the exceedance probability for the range of concentrations.

The relation between the EMCs for TKN in the three project phases is depicted in Figure 4.7. There was a definite decrease in the TKN EMCs after construction of the gutter filters as compared to the EMCs before construction. However, there was a subsequent increase in the EMCs after the installation of the bioinlets . The EMCs from phase three are still slightly less than the EMCs from phase one. A concentration of 2 mg/L was exceeded 70% of the time when no treatment was employed, 30% of the time after the gutter filters were installed, and 60% of the time after gutter filters and bioinlets were used to treat the runoff (Figure 4.7).

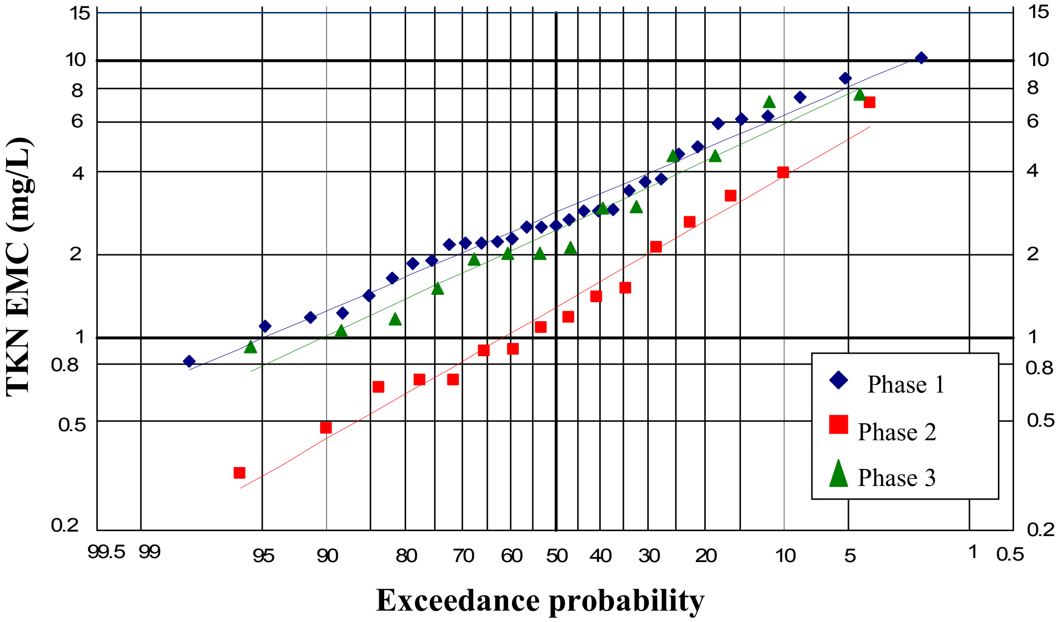


Figure 4.7. Comparison of the 3 phases of the project for TKN EMCs giving the exceedance probability for the range of concentrations.

The assessment of the treatment method for TP in the three phases of the project is shown in Figure 4.8. There was clearly an increase in the EMC of TP after the treatment methods were employed. The mean EMC in phase 3 was greater than that in phase 2, which in turn was greater than in phase 1. The bioinlets were introducing greater loads of TP into the stormwater. Considering a concentration of 0.6 mg/L, phase 1 exceeded it 30% of the time, phase 2 exceeded it 45% of the time, and phase 3 exceeded it 63% of the time (Figure 4.8).

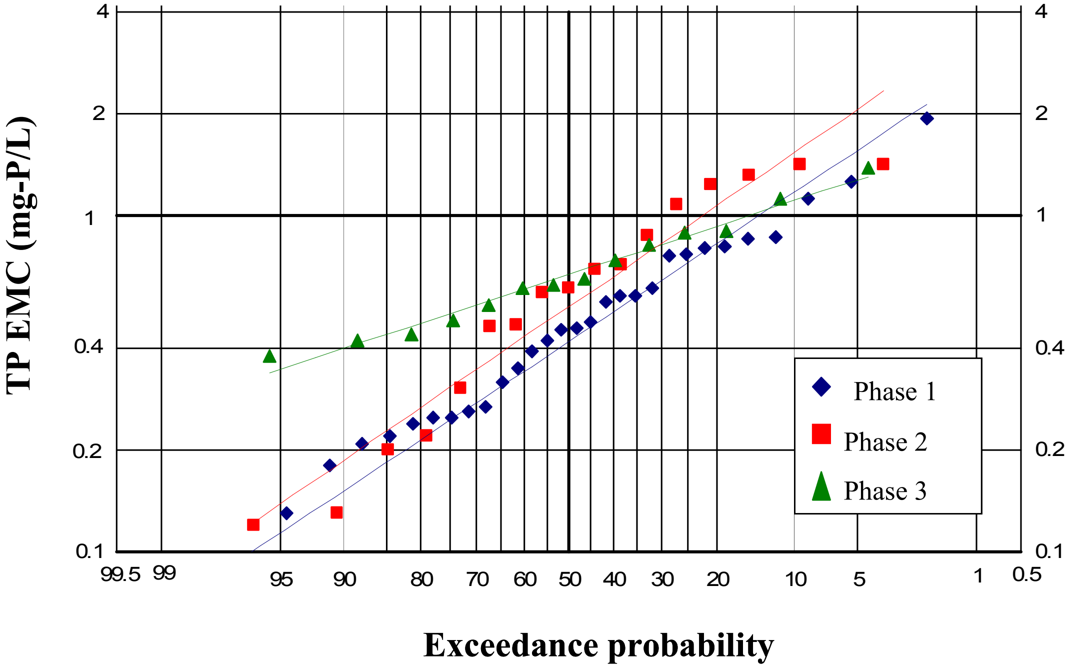


Figure 4.8. Comparison of the 3 phases of the project for TP EMCs giving the exceedance probability for the range of concentrations.

Adequate chloride data were not present to draw conclusions about the influence of the LID treatment on the pollutant concentration. From limited data, it is observed that the chloride concentration in stormwater analyzed after the construction of gutter filters was greater than the baseline concentration and the chloride concentrations after gutter filters and bioinlets were installed were slightly less than that from stormwater from gutter filters only. There was, however, a definite increase in the chloride loadings from phase 1. A concentration of 10 mg/L was exceeded 62% of the time when gutter filters were employed and 72% of the time when gutter filters as well as bioinlets were used (Figure 4.9). There was not enough data from phase 1 to draw any significant inference.

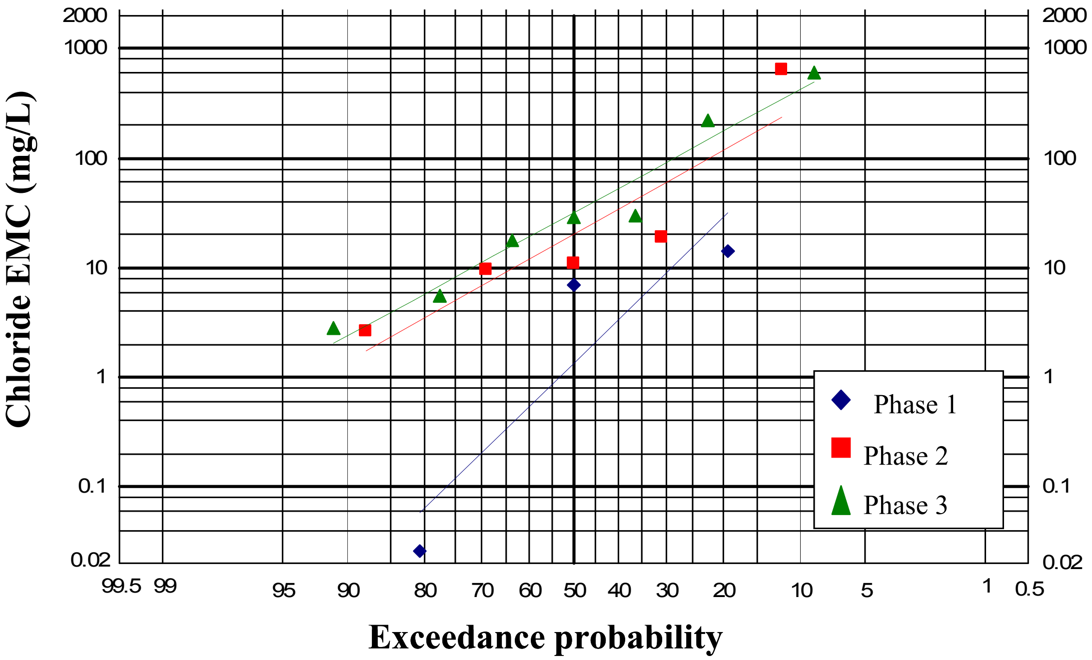


Figure 4.9. Comparison of the 3 phases of the project for Cl EMCs giving the exceedance probability for the range of concentrations.

Total lead concentrations decreased after the use of the LID practices. The Pb concentration before construction of any treatment was greater than that obtained from stormwater treated by gutter filters only. The lead concentration in stormwater treated by gutter filters and bioinlets was less than that treated by gutter filters only. This trend in decreasing concentrations is clearly shown in Figure 4.10. For a Pb concentration of 65 µg/L (fresh water acute criterion), stormwater receiving no treatment exceeded it 70% of the time, stormwater receiving treatment from gutter filters only exceeded it 40% of the time, and stormwater receiving treatment from gutter filters and bioinlets exceeded it only 10% of the time (Figure 4.10). At low concentrations in the range of 10 – 30 µg/L, there is a cross over in the trendlines for gutter filter treatment only and gutter filters and bioinlets treatment phases, with Pb in phase 2 exhibiting even lower concentrations than that in phase 3.

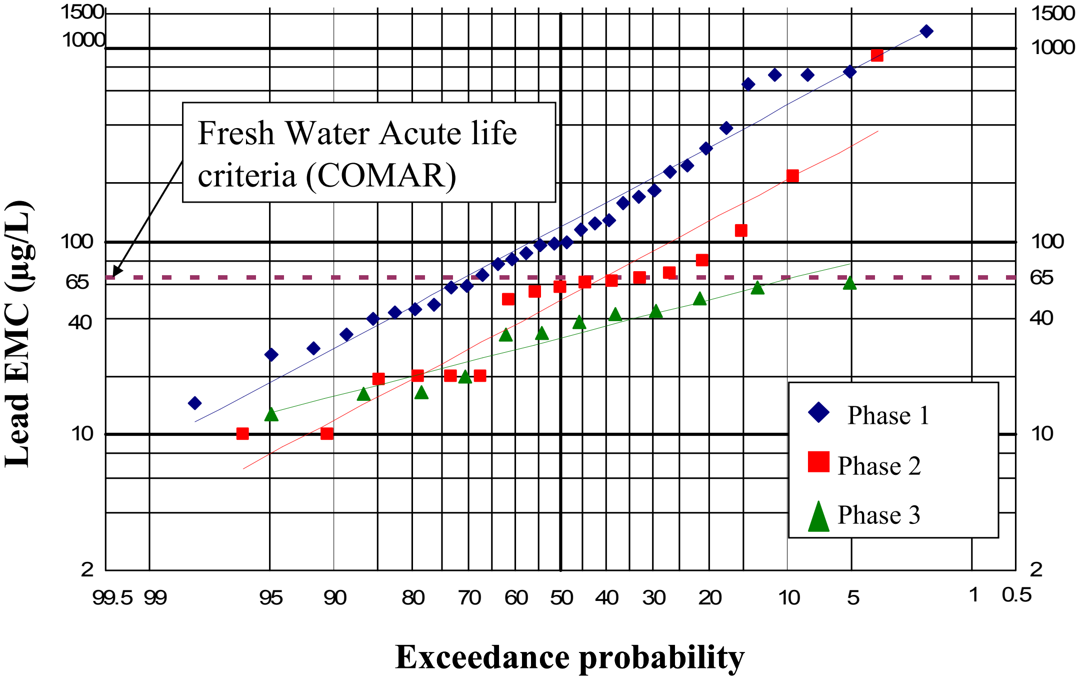
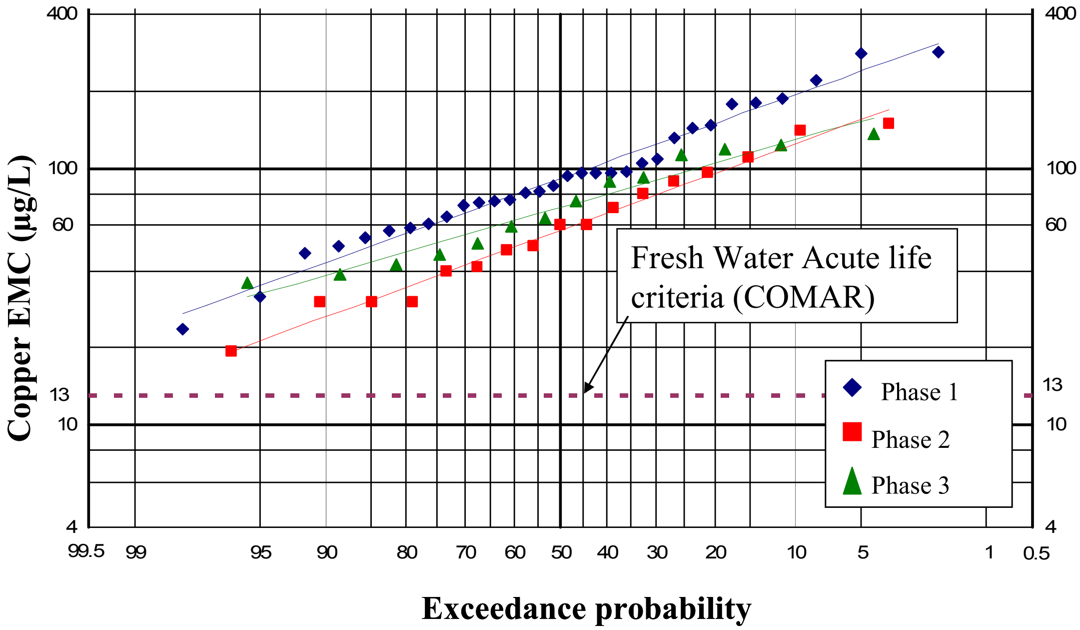


Figure 4.10. Comparison of the 3 phases of the project for Total Pb EMCs giving the exceedance probability for the range of concentrations.

The concentrations of Total Copper decreased from the baseline after the use of gutter filters. However, an increase in the EMCs was observed after gutter filters and bioinlets were used to treat the stormwater runoff. Figure 4.11 displays the trends in the Total Cu concentrations in the three phases. A concentration of 60 µg/L was exceeded 77% of the time when no treatment was employed, 43% of the time when only gutter filters were employed and 66% of the time when gutter filters and bioinlets both were employed. The trendlines for all the three phases are closely spaced.



Fresh Water Acute life criteria (COMAR)

Figure 4.11. Comparison of the 3 phases of the project for Total Cu EMCs giving the exceedance probability for the range of concentrations.

The Total Zinc concentrations in phase 3 are slightly greater than those in stage 2 after ignoring an outlier in phase 3. There is a very high concentration in one of the storm events in phase 3 (210 mg/L) which skews the results for the calculations of the mean. The Zn concentrations after treatment from the gutter filters are the lowest, followed by concentrations from gutter filters and bioinlets (ignoring the outlier in phase 3). The concentrations from the baseline are greater than each of the other two phases. When no treatment was adopted at Mt. Rainier, a concentration of 400 µg/L in stormwater was exceeded 85% of the time; when only gutter filters were employed for treatment, it was exceeded 31% of the time and when gutter filters as well as bioinlets were employed, it was exceeded 63% of the time (Figure 4.12). The trend line for Zn in phase 3 is drawn by ignoring outliers having concentrations in the range of 130,000 – 330,000 µg/L.

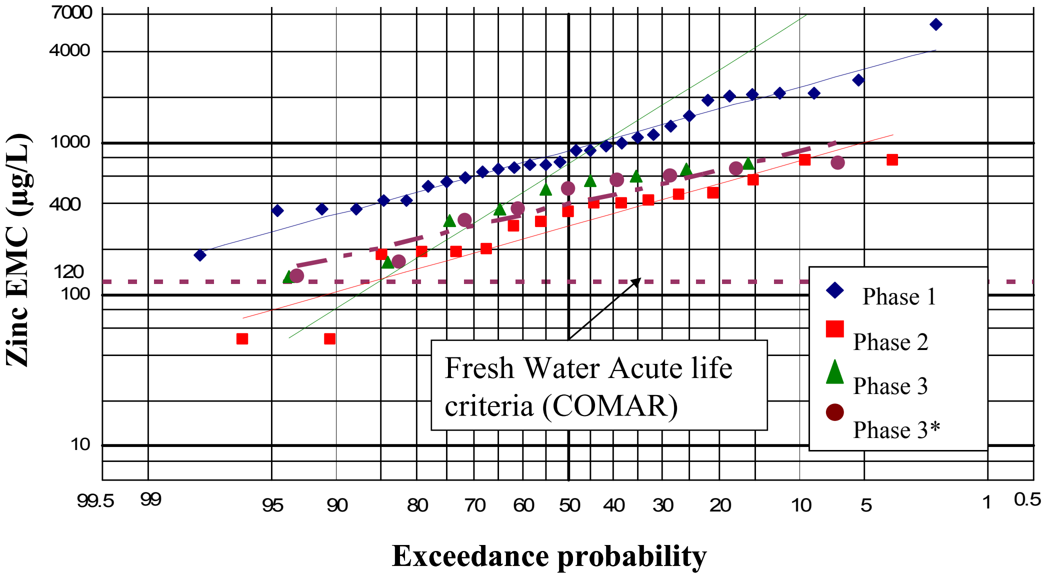


Figure 4.12. Comparison of the 3 phases of the project for Total Zn EMCs giving the exceedance probability for the range of concentrations. Phase 3* represents data ignoring the outlier concentration.

Figure 4.12 also presents the comparison between the Zn EMCs in the 3 phases after ignoring the outlier from the storm event on 01/13/05. It is observed from Figure 4.12 that the Zn EMCs are greater when no treatment is employed, followed by the EMCs in phase 3 and finally in phase 2. The trendlines for Zn EMCs in phases 2 and 3 are closely spaced. The gutter filters show the better results for Zn removal than gutter filters + bioinlets.

The concentration of Total Cd from the stormwater analyzed after treatment from gutter filters and bioinlets is less than that in untreated stormwater samples by an order of magnitude. The Total Cd from runoff treated by gutter filters only was slightly less than that from stormwater runoff with no treatment. The Cd concentrations in phase 3 were generally found to be below the detection limit of 2 µg/L. Figure 4.13 confirms that the treatment of stormwater is effective in reducing the concentration of Cd from stormwater runoff. For a concentration of 10 µg/L in stormwater at Mt. Rainier, when no treatment is employed that concentration is exceeded 93% of the time. When only gutter filters are used as a treatment, this concentration is exceeded 30% of the time, and when bioinlets are used together with gutter filters, the concentration is exceeded just 12% of the time (Figure 4.13). The data below the detection limit were not plotted, but their positions were used to derive the plotting positions and trendlines shown in Figure 4.13.

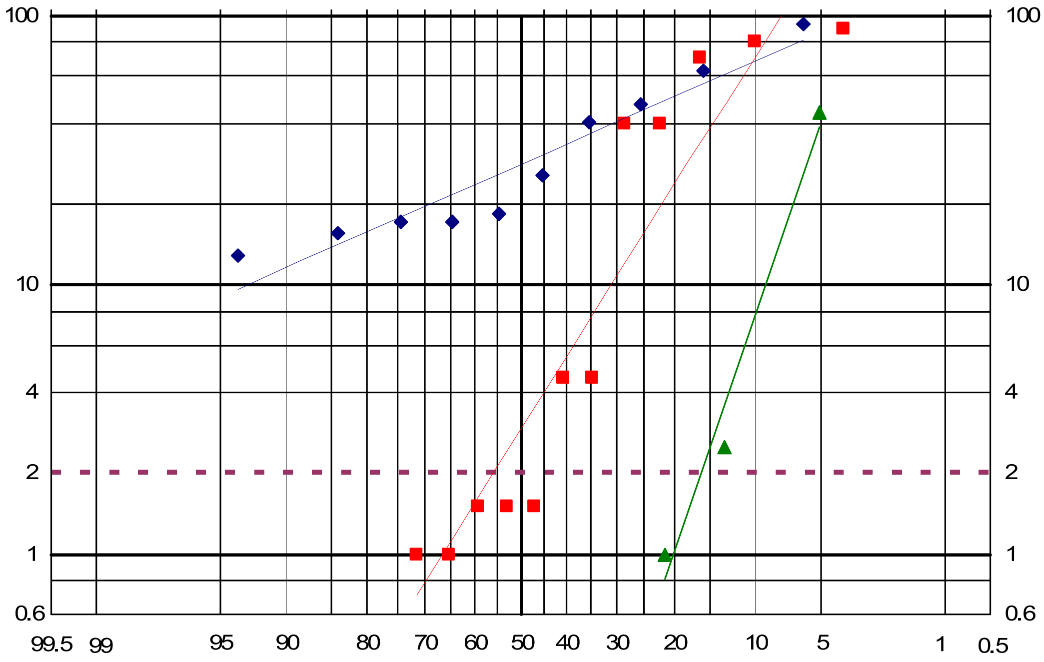


Figure 4.13. Comparison of the 3 phases of the project for Total Cd EMCs giving the exceedance probability for the range of concentrations.

The results obtained from the LID study at Mt. Rainier,MD were compared to other LID studies (Tables 4.15 and 4.16). Bioretention BMPs are similar to bioinlets and therefore comparison of results from phase 3 was carried out with other bioretention studies. The TSS and metal removal at Mt. Rainier, MD by gutter filters and bioinlets was in the same range of values in literature. Total Phosphorus at Mt. Rainier, MD showed export which was also found at a site monitored by Rushton (2001) in Tampa, Fl. However, TP removal of 70-85% in laboratory box studies and 65 ± 8% in Greenbelt, MD and 87 ± 2% in Largo, MD were reported by Davis et al., 2006. TKN removal at Mt. Rainier, MD after phase 3 was 12% while Davis et al., (2006) had obtained a TKN removal of 52 ± 7% at Greenbelt, MD and 67 ± 9% at Largo, MD in their field studies. Correspondingly, in the laboratory box studies, the TKN removal ranged from 74% to 83%. Pb reduction at Mt. Rainier, MD was comparable to that obtained by Davis et al., (2006), where a removal of 84% to >98% was obtained in laboratory box studies. Copper was poorly removed at Mt. Rainier after treatment by gutter filters and bioinlets, while the laboratory bioretention box studies carried out by Davis, et al., (2006) obtained a Cu removal of 89% – 99%. Zn removal at Mt. Rainier was 58% in comparison to a Zn removal of 88% - >98% in the box studies conducted by Davis et al., (2006).

Table 4.15. Comparison between pollutant concentration reduction at Mt. Rainier, MD with results obtained by Davis, et al. (2006).

Pollutant	Mt. Rainier, MD[a]	Davis et al., (2006)		
		Laboratory study	Field study	
			Greenbelt ,MD	Largo, MD
TKN	12%	23-95%	52 ± 7%	67 ± 9
TP	*20-40% increase*	1-85%	65 ± 8%	87 ± 2%
Nitrate	*25 times increase*	*13-26% increase* and 19-79% removal	16 ± 6%	15 ± 12%
Cu	29%	89-99%	97 ± 2	43 ± 11
Pb	84%	84->98%	>95	70 ± 23
Zn	58%	88->98%	>95	64 ± 42

a = Gutter filters + bioinlets.

Several differences in vegetation characteristics, soil mulch layer between the Largo, Greenbelt and Mt. Rainier facilities could be responsible for difference in the metal uptake. The bioretention media provide adsorption sites and provide opportunity for metal and phosphorus removal via vegetative uptake and harvesting. The organic rich bioretention layers support significant microbial populations which enhance ammonification and nitrification.

Table 4.16. Summary information on the removal efficiency between Mt. Rainier, MD compared to results from sites in MD (Hsieh and Davis, 2005) and Tampa, Florida (Rushton et al., 2001). Typical efficiencies reported by FHWA, 1999 for Bioretention areas are also presented.

Pollutant	Mt. Rainier, MD[a]	Mt. Rainier, MD[b]	Bioretention studies (FHWA, 1999)	Hsieh and Davis, 2005[c]	Tampa, Florida (Rushton et al., 2001)[d]
TSS	*75%	83%	75%	29 - >96%	91-92%
TP	-----	*20 - 40% increase*	59%	4 - 99%	94% increase to 76% removal
Cd	-----	86-89%	-----	-----	-----
Pb	*69%	84%	-----	66 - >98%	88-93%
Cu	40%	29%	-----	-----	81-94%
Zn	71%	*58%	-----	------	75-89%

* = Eliminating outlier concentrations.
a = Gutter filters; b = Gutter filters + bioinlets; c = Bioretention area; d = Porous pavements and swales were used in a parking lot.

Barrett (2003), determined that TSS removal from sand filters was independent of the influent concentration and a constant average effluent concentration of 7.8 ± 1.2 mg/L (as compared to 86 mg/L TSS effluent from gutter filters after ignoring the outlier concentration at Mt. Rainier, MD) was obtained by linear regression at 90% confidence level.

4.6. FIRST FLUSH

The concentrations of the pollutants were expected to be greater in the initial part of the storm and decrease with storm duration. Wanielista and Yousef (1993) defined first flush as 50% of the total pollutant mass in the initial 25% of total runoff volume. This criterion of first flush had been adopted by Flint (2004) and was therefore used in phases 2 and 3 as well. In the case of stormwater runoff analyzed after construction of gutter filters, the first flush phenomenon as defined by Wanielista and Yousef (1993) was found sparingly for the pollutants. Total Cd in 1 out of 15 events and total Zn and TP in 1 out of 16 events exhibited first flush. The first flush effect was seen in 2 out of 16 events for nitrite. Total Pb and Total Cu exhibited a first flush effect in 3 out of 16 events. TSS showed evidence of the first flush effect 4 times in 16 events and TKN demonstrated it in 5 out of 15 events. Nitrate and Chloride did not display any first flush occurrences. The percentage of mass in the first 25% of runoff volume at Mt. Rainier after construction of gutter filters is detailed in Table 4.17.

First flush can also be defined qualitatively from dimensionless parameters: normalized mass and normalized volume. Normalized mass is the ratio of the instantaneous mass to that of the total mass for a particular pollutant at the end of an event. Similarly, normalized volume is obtained by dividing the instantaneous runoff volume by the total runoff volume for a storm event (Equations 2.3 and 2.4). The normalized pollutant mass loading and runoff volume for metals is plotted in Figure 4.14 for stormwater analyzed after the construction of gutter filters. All the pollutants which have 50% or greater mass in the initial 25% runoff volume exhibit first flush. Similarly, Figure 4.15 indicates the nutrient and the TSS pollutants following the first flush phenomena. The events lying above the 45^{o} line are assumed to exhibit first flush (Geiger, et al., 1987). Only those events for particular pollutants with 50% or greater mass in 25% runoff volume from the Table 4.17 were chosen for these dimensionless parameter plots.

Table 4.17. Percentage of pollutant mass in the initial 25% runoff volume for stormwater analyzed after construction of gutter filters.

	Event										
Pollutant		Cd	Pb	Cu	Zn	TKN	TP	Nitrite	Nitrate	TSS	Cl
	11/12/2003	11	33	27	25	ND	32	26	26	39	ND
	11/19/2003	36	60	45	40	66	44	36	ND	77	ND
	12/11/2003	19	29	60	36	13	25	27	ND	19	ND
	12/24/2003	48	34	38	40	76	25	28	ND	42	ND
	3/6/2004	31	56	55	25	63	27	81	43	31	ND
	3/16/2004	27	27	19	25	47	18	32	27	44	ND
	4/13/2004	6	25	17	26	10	39	23	41	13	ND
	04/23/2004	21	42	24	39	58	51	26	ND	52	ND
	05/05/2004	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	05/25/2004	21	39	34	35	45	28	20	ND	46	ND
	06/05/2004	ND	56	47	61	54	40	50	ND	64	ND
	06/22/2004	25	15	28	30	28	29	30	ND	24	ND
	07/24/2004	1	37	82	33	28	20	30	ND	68	ND
	08/02/2004	57	29	31	33	9	29	34	ND	35	34
	08/12/2004	37	36	26	32	41	6	47	ND	22	41
	09/07/2004	24	36	39	46	11	28	34	ND	25	37
	09/17/2004	43	41	35	39	34	36	1	ND	38	24

ND = No Data

Wanielista and Yousef (1993) defined first flush as 50% or greater mass in the initial 25% stormwater runoff volume. Events exhibiting first flush using this criterion are in red color.

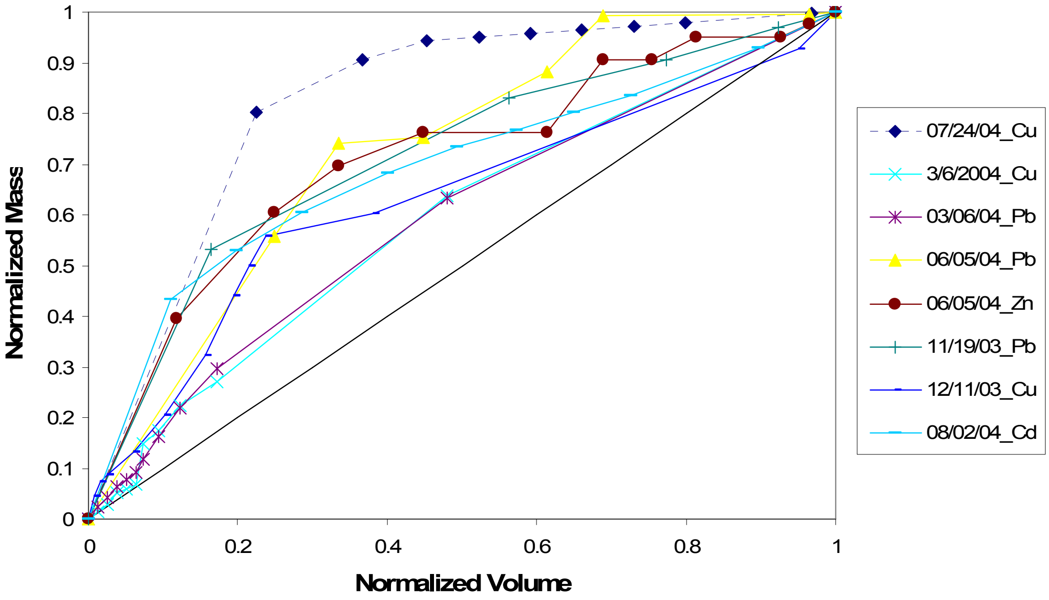


Figure 4.14. Normalized mass and volume chart for pollutants (metals) indicating first flush effect in particular storm events (gutter filters only) (as defined by Geiger et al., 1987).

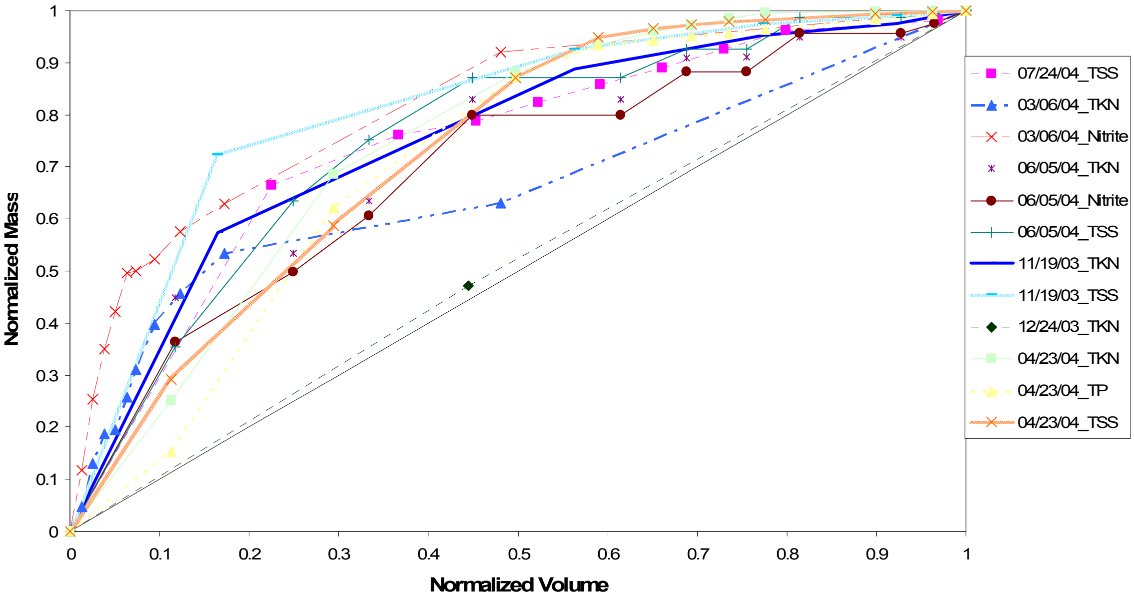


Figure 4.15. Normalized mass and volume chart for pollutants (nutrients and TSS) indicating first flush effect in particular storm events (gutter filters only) (as defined by Geiger et al., 1987).

In the analyses of stormwater runoff after construction of gutter filters and bioinlets, nitrate, TP and Cd did not show any first flush based on the definition of 50% or more pollutant mass and initial 25% runoff volume (Wanielista and Yousef, 1993). First flush was observed for TSS in 4 out of 13 events, chloride in 3 out of 7 events, nitrite and Cu in 2 out of 14 events, Zn in 2 out of 12 events, TKN in 1 out of 13 events and Pb in 1 out of 12 events. The percentage pollutant mass in 25% of the total runoff volume at Mt. Rainier after construction of gutter filters and bioinlets is listed in Table 4.18. The normalized mass and runoff volume plots are shown in Figure 4.16 for metals and Figure 4.17 for nutrients and TSS. Figures 4.14- 4.17 only indicate the events which show evidence of the first flush phenomena according to the 50% pollutant mass in the initial 25% runoff volume criterion defined by Wanielista and Yousef (1993) (Tables 4.17 and 4.18).

Table 4.18. Percentage of pollutant mass in the initial 25% runoff volume for stormwater analyzed after construction of gutter filters and bioinlets.

	Event										
Pollutant		Cd	Pb	Cu	Zn	TKN	TP	Nitrite	Nitrate	TSS	Cl
	10/19/2004	36	36	38	35	17	18	30	7	ND	33
	11/4/2004	35	28	31	24	40	29	56	33	22	50
	11/20/2004	24	37	33	32	35	39	20	39	28	44
	12/9/2004	25	27	28	31	34	27	40	11	36	79
	1/13/2005	19	24	36	34	38	20	50	38	47	10
	**3/20/2005	25	3	51	59	27	39	24	ND	58	41
	7/7/2005	23	22	24	21	44	29	49	32	42	55
	7/27/2005	25	41	39	28	38	37	26	ND	64	ND
	8/8/2005	28	54	42	56	40	39	31	ND	31	ND
	9/26/2005	25	36	39	26	35	35	30	ND	65	ND
	10/7/2005	25	37	55	36	43	37	24	ND	65	ND
	10/11/2005	25	27	23	23	22	32	26	ND	23	ND
	11/16/2005	ND	ND	26	ND	31	33	26	ND	19	ND
	11/29/2005	ND	ND	49	ND	51	40	37	ND	44	ND

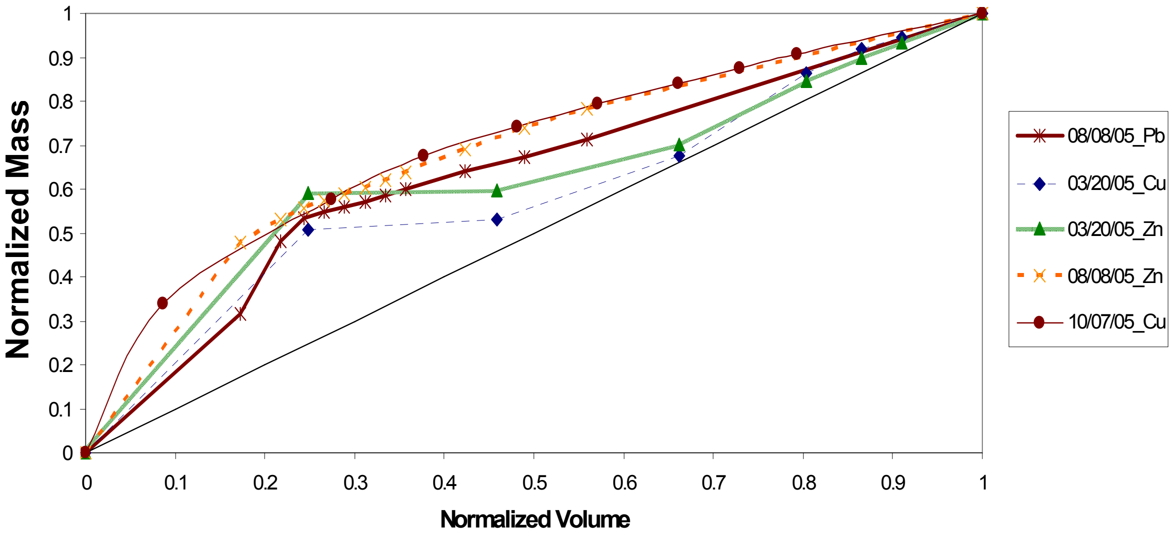


Figure 4.16. Normalized mass and volume chart for pollutants (metals) indicating first flush effect in particular storm events (gutter filters + bioinlets) (as defined by Geiger et al., 1987).

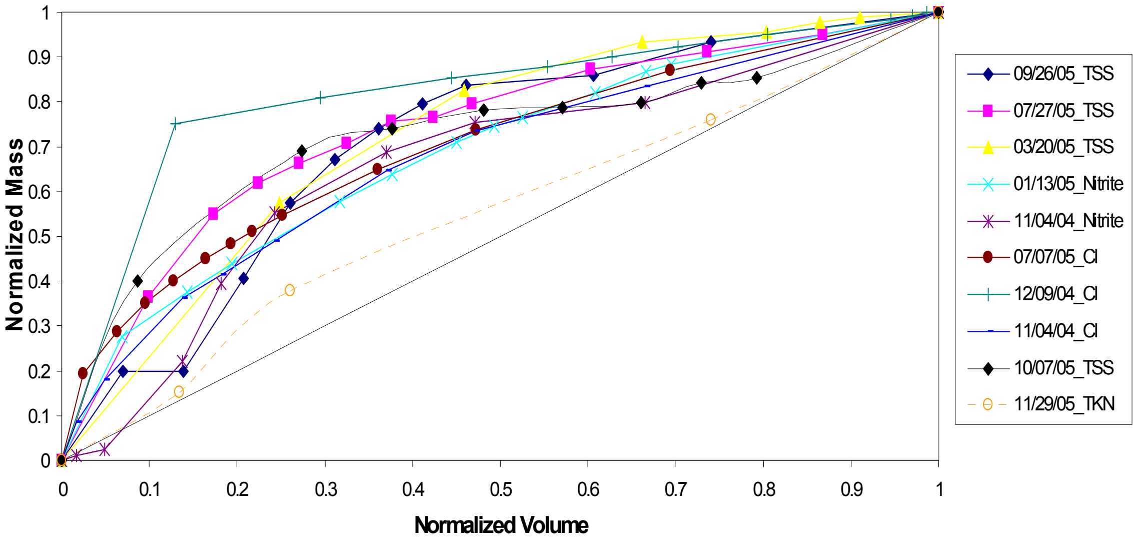


Figure 4.17 Normalized mass and volume chart for pollutants (nutrients and TSS) indicating first flush effect in particular storm events (gutter filters + bioinlets) (as defined by Geiger et al., 1987).

First Flush criteria have been extensively used for designing of Best Management Practices (BMPs) over the years. The first flush for storm events was calculated from stormwater runoff after passing through the gutter filters and bioinlets. The implementation of the BMPs did not change the first flush characteristics at the site. The current research shows that the first flush criteria were not found frequently in case of the LID practices at Mt. Rainier. The occurrence of first flush for each of the pollutants in each phase is listed in Table 4.19. It is evident that first flush does not occur predominantly in any of the project phases at Mt. Rainier, MD. Therefore using the first flush as a governing concept for designing BMPs at Mt. Rainier, MD is not practical.

Table 4.19. Comparison between first flush occurrences for each pollutant in each phase of the project. First flush criterion as defined by Wanielista and Yousef (1993).

Pollutants	Before Construction (Flint, 2004)	Gutter Filters	Gutter filters + bioinlets
TSS	13%	25%	33%
TKN	16%	33%	0
NO_3^-	16%	0	0
NO_2^-	25%	13%	20%
TP	20%	6%	0
Cd	0	7%	0
Cu	16%	19%	11%
Pb	9%	19%	10%
Zn	10%	6%	20%
Cl	ND	0	43%

ND = No Data

4.7. COMPARISON OF METAL POLLUTANTS WITH SURFACE WATER QUALITY CRITERIA

It is evident from Table 4.20, that the mean EMC in case of all the metal pollutants except lead is greater than the fresh water aquatic life criteria as per the Code of Maryland Regulations (COMAR). Table 4.20 gives the mean EMC for the metal pollutants, along with the standard deviation. Lead concentration from stormwater analyzed after treatment from gutter filters and bioinlets is less than the acute fresh water aquatic life criteria. The mean EMC in case of Total Cd has decreased after the construction of LID practices and is approaching the regulatory concentrations. Ignoring the outlier EMC of 210 mg/l for Zn does not bring the EMC low enough to meet the water quality criteria.

Table 4.20. Assessment of water quality at Mt. Rainier, MD with respect to regulatory standards for heavy metals.

Pollutant	Event Mean Concentration at Mt. Rainier, MD						Fresh Water Aquatic Life[a]	
	Before Construction		Gutter Filters		Gutter Filters + Bioinlets		Acute (µg/L)	Chronic (µg/L)
	# events	mean EMC	# events	mean EMC	# events	mean EMC		
Cd (µg/L)	10	**35 ± 26**	16	**20 ± 32**	12	**4 - 5± 13**	2.0	0.25
Cu (µg/L)	32	**110 ± 66**	17	**67 ± 39**	14	**78 ± 35**	13	9
Pb (µg/L)	32	**220 ± 290**	17	**350 ± 210**	12	**36 ± 17**	65	2.5
Zn (mg/L)	30	**1.2 ± 1.1**	17	**0.35 ± 0.22**	12	**18 ± 61**	120	120
Zn ** (mg/L)	30	**1.2 ± 1.1**	17	**0.35 ± 0.22**	11	**0.50 ± 0.31**	120	120

** = Ignoring an outlier concentration of storm-event 01/13/05

a = COMAR water quality standards – 2005

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

The escalating concern of urban stormwater runoff polluting the receiving surface waters has led to the current research. The main objective of the research was to evaluate the effectiveness of two Low Impact Development practices (gutter filters and bioinlets) in treating highway runoff in an ultra urban area in Mt. Rainier, MD. Preceding work by Flint (2004) characterized the water quality from highway stormwater runoff in this ultra urban area. The current work was an extension of the project and determined the water quality after the gutter filters and the bioinlets were in place for treatment purposes. The entire project was divided into three phases- before construction (June 2002- September 2003) (Flint, 2004) (32 events), gutter filters (November 2003 – September 2004) (17 events) and gutter filters and bioinlets (October 2004 – November 2005) (14 events). The pollutants analyzed for water quality were Total Suspended Solids (TSS), Total Kjeldahl Nitrogen (TKN), nitrite (NO_2^-), nitrate (NO_3^-), total phosphorus (TP), chloride (Cl), zinc (Zn), copper (Cu), lead (Pb) and cadmium (Cd). Statistical analyses in the form of the student's *t* test and the Mann-Whitney U test allowed establishing with a 95% confidence level whether any reduction in the concentration of the pollutants could be attributed to the treatment measures. The plots for each pollutant on a probability scale provided a graphical representation of the exceedance probability for any concentration. An outlier analysis was carried out on all the pollutants except Cl in each sample phase as little data were available for it. The Rosner's outlier test was used for determining outliers if any for all pollutant EMC data sets (sample size > 25) except Cd in phase 1. The Dixon-

Thompson test was adopted to identify outliers for pollutant data sets in phases 2 and 3 and Cd from phase 1 (sample size $\leq$ 25). The student's *t* test and the Mann-Whitney U test were employed on the data sets after ignoring the outliers and results were obtained.

The concentrations and the annual pollutant loads in phases 2 and 3 were compared with phase 1 and appropriate inferences were drawn. The mean EMC (mg/L) and pollutant loadings (kg/ha/yr) for TSS, TKN, nitrite, nitrate, TP, Zn, Cd, Cu and Pb were found to be 350 and 1900, 1.7 and 14, 0.20 and 0.79, 1.2 and 4.0, 0.60 and 4.3, 0.34 and 3.2, 0.02 and 0.20, 0.07 and 0.49, and finally, 0.11 and 0.86, respectively after analyses of the stormwater runoff when treated by the gutter filters only. The mean EMC (mg/L) and pollutant loadings (kg/ha/yr) for TSS, TKN, nitrite, nitrate, TP, Zn, Cd, Cu and Pb were found to be 70 and 430, 3.0 and 21, 0.14 and 1.7, 21 and 290, 0.71 and 5.2, 18 and 104, 0.004-0.005 and 0.02, 0.078 and 0.74, and finally, 0.036 and 0.32, respectively, after installation of gutter filters and bioinlets. The storm event on 01/13/05 gave a particularly very high concentration of Zn and ignoring that outlier, the EMC (mg/L) and the annual pollutant loading (kg/ha/yr) was 0.50 and 5.0 (in comparison to 18 and 104, respectively).

Tables 5.1 to 5.3 provide a summary of the statistical conclusions for water quality after treatment by gutter filters only. Based on the results of the student's *t* test, it was concluded with a 95% confidence level that the gutter filter treatment method was effective in the case of TKN, Cu and Zn while it could not be established at 95% confidence that the gutter filters significantly changed levels of nitrite, nitrate, TP, Cd and Pb. The student's *t* test was not applicable to TSS due to the high variance. However, when outlying mean EMCs for TSS and Pb data sets were excluded, the student's *t* test established that the gutter filters resulted in a statistically significant removal of these pollutants. The Mann-Whitney U test concluded that the gutter filters were working in reducing the concentrations of TSS, TKN, Zn, Cd, Cu and Pb. Nitrite, nitrate and TP did not show a statistically significant difference in the mean EMC.

Table 5.1. Summary information for pollutants exhibiting statistically significant reduction in concentration after treatment by gutter filters only.

Pollutant	Mean EMC		Reduction	Statistically (95%) Significant Difference	
	Loading			*t* test	U test
	Phase 1	Phase 2			
TKN (mg/L)	3.4	1.7	50%	✓	✓
(kg/ha/yr)	25	14	44%		
**TSS (mg/L)	350	90	75%	✓	✓
(kg/ha/yr)	2800	1300	53%		
Cu (µg/L)	110	66	40%	✓	✓
(kg/ha/yr)	0.84	0.49	42%		
Zn (mg/L)	1.2	0.35	71%	✓	✓
(kg/ha/yr)	8.5	3.2	62%		
***Pb (µg/L)	190	58	69%	✓	✓
(kg/ha/yr)	1.6	0.75	53%		

** = Ignoring the TSS outlier concentrations from storm events on 07/26/02 and 03/06/03.
***= Ignoring the Pb outlier concentrations from storm events on 02/03/03 and 11/12/03.

Table 5.2. Summary information for statistically identical pollutants after treatment by gutter filters only.

Pollutant	Mean EMC		Ratio	Statistically (95%) Significant Difference	
	Loading			*t* test	U test
	Phase 1	Phase 2			
NO_2^- (mg/L-N)	0.24	0.21	0.88	X	X
kg/ha/yr	1.8	0.79	0.43		
NO_3^- (mg/L-N)	0.85	1.2	1.4	X	X
kg/ha/yr	9.7	4.0	0.41		
TP (mg/L-P)	0.52-0.57	0.67-0.72	1.3	X	X
kg/ha/yr	4.6	4.3	0.94		

Table 5.3. Summary information for statistically significantly different pollutants (only by the Mann-Whitney U test) after treatment by gutter filters only.

Pollutant	Mean EMC		Removal	Statistically (95%) Significant Difference	
	Loading			*t* test	U test
	Phase 1	Phase 2			
Cd (µg/L)	35	20	43%	X	✓
(kg/ha/yr)	0.24	0.20	16%		

The mean EMCs for the pollutants in phases 2 and 3 were less than those when the stormwater received no treatment (phase 1) but there were some exceptions. The mean EMC for TP in phase 1 was less than the mean EMC in phase 2, which, was less than in phase 3. Similarly, the mean EMC for nitrate in phase 1 was less than in phase 2, which was less than phase 3. In cases of TKN and Cu, phase 1 was the highest, followed by phase 3 and phase 2 was the lowest. Disregarding the Zn outlier in phase 3, it was observed that the mean EMC in phase 1 was the highest followed by phase 3, with phase 2 slightly less.

Tables 5.4 to 5.6 present the statistical conclusions for water quality after treatment from gutter filters and bioinlets. For the comparison between phase 1 and phase 3 of the project, the student's *t* test concluded at a 95% confidence level that the treatment was working in reducing the concentrations only for TSS, Cd, Pb and *Zn (with one point sequestered). The Mann –Whitney U test established at 95% confidence level that the means were different and the concentrations for TSS, TKN, nitrite, Cd, Cu and Pb decreased due to the gutter filters and bioinlets. With the Mann-Whitney U test, at a 95% confidence level it can be said that the means were different and the concentrations of nitrate and TP *increased* due to the gutter filters and bioinlets.

Table 5.4. Summary information for statistically significantly different pollutants after treatment by gutter filters and bioinlets.

Pollutant	Mean EMC		Reduction	Statistically (95%) Significant Difference	
	Loading				
	Phase 1	Phase 3		*t* test	U test
TSS (mg/L)	420	70	83%	✓	✓
(kg/ha/yr)	3100	430	86%		
Cd (µg/L)	35	4-5	86-89%	✓	✓
(kg/ha/yr)	0.24	0.02	91%		
Pb (µg/L)	220	36	84%	✓	✓
(kg/ha/yr)	1.7	0.32	81%		
*Zn (mg/L)	1.2	0.50	58%	✓	✓
(kg/ha/yr)	8.5	5.0	41%		

* = Ignoring the outlier of storm-event on 01/13/05.

Table 5.5. Summary information for statistically significantly different pollutants (only by the Mann-Whitney U test) after treatment by gutter filters and bioinlets.

Pollutant	Mean EMC		Ratio	Statistically (95%) Significant Difference	
	Loading			*t* test	U test
	Phase 1	Phase 3			
TKN (mg/L)	3.4	3.0	0.88	X	✓
kg/ha/yr	25	21	0.84		
NO_2^- (mg/L-N)	0.24	0.14	0.58	X	✓
kg/ha/yr	1.8	1.7	0.94		
Cu (µg/L)	110	78	0.71	X	✓
kg/ha/yr	0.84	0.74	0.88		

Table 5.6. Summary information for statistically significantly different pollutants exported (only by the Mann-Whitney U test) after treatment by gutter filters and bioinlets.

Pollutant	Mean EMC		Ratio	Statistically (95%) Significant Difference	
	Loading			*t* test	U test
	Phase 1	Phase 3			
NO_3^- (mg/L-N)	0.85	21	25	X	✓
kg/ha/yr	9.7	290	30		
TP (mg/L-P)	0.52-0.57	0.71	1.2-1.4	X	✓
kg/ha/yr	4.6	5.2	1.1		

There have been some instances where the results of the student's *t* test and the Mann-Whitney U test do not match (Tables 5.3, 5.6, 5.7 and 5.8). This is mainly because the *t* test uses raw data, while the U test uses ranked measures. The U test is appropriate for analyzing data with a large variance as it eliminates the effects of the outliers. The *t* test has to be run on the same sample sets regardless of the outliers. Discrepancy was observed in the results from the *t* test and the U test when the raw data was scattered. The student's *t* test is appropriate for a data set if the underlying distribution is normal. These characteristics of the *t* test lead to inconsistency in the results from the student's *t* test and Mann-Whitney U test. Emphasis was laid on the results from the Mann-Whitney U test as the assumption of normally distributed data for applying student's *t* test was violated..

The data suggest that the gutter filters lowered the concentrations for all the pollutants except nitrate and TP. The statistical significant removal percentages as a function of the influent concentrations in stormwater analyzed after treatment from gutter filters only were 75% (**TSS), 50% (TKN), 71% (Zn), 40% (Cu) and 69% (**Pb). Giving priority to the Mann-Whitney U test, the concentration of Cd decreased by 43%. The water quality from the gutter filters with respect to nitrite, nitrate and TP was statistically identical to before construction.

The comparison between phase 1 and phase 3 indicated reductions of TSS (83%), Cd (86-89%), Pb (84%) and *Zn (58%). The student's *t* test failed, but the Mann-Whitney U test established with 95% confidence that there was a statistically significant reduction of TKN (12%), nitrite (42%) and Cu (29%). The Mann-Whitney U test established at a 95% significance level that the water quality deteriorated for nitrate and TP with ratios with respect to phase 1 in the order of 25 and 1.3 respectively.

The comparison of EMC pollutant data between phase 2 and 3 did not give statistically significant differences in any of the pollutants by the student's *t* test. The only exception to this was Cd on ignoring the outlier concentration (**Cd - 95% removal) from the storm on 10/19/04. The Mann-Whitney U test established at 95%

significance that the water quality improved after the addition of bioinlets (Table 5.7) with TSS (80%), nitrite (29%), Cd (75-80%) and Pb (67%). The Mann-Whitney U test established at a 95% significance level that the water quality deteriorated for TKN, nitrate, Cu and Zn with ratios with respect to phase 2 as 1.8, 17, 1.2 and 51, respectively (Table 5.8). When the outlier concentrations for nitrate (storm event on 04/13/04) and Zn (01/13/05) were ignored, it was concluded by the Mann-Whitney U test at a 95% presignificance level that the water quality deteriorated giving ratios as 48 and 1.44, respectively. Neither test could establish any statistical difference in the mean EMC of TP between phases 2 and 3 (Table 5.9).

Table 5.7. Summary information for statistically significantly different pollutants (reduction) (only by the Mann-Whitney U test except **Cd) after treatment by gutter filters and bioinlets in comparison to runoff treated with gutter filters only.

Pollutant	Mean EMC		Reduction	Statistically (95%) Significant Difference	
	Loading			t test	U test
	Phase 2	Phase 3			
TSS(mg/L)	350	70	80%	X	✓
(kg/ha/yr)	1900	430	77%		
NO_2^- (mg/L-N)	0.21	0.14	29%	X	✓
(kg/ha/yr)	0.79	1.7	2.2*		
**Cd (µg/L)	20	1.1	95%	✓	✓
(kg/ha/yr)	0.20	0.02	90%		
Pb (µg/L)	110	36	67%	X	✓
(kg/ha/yr)	0.85	0.32	62%		

* = expressed as ratio

Table 5.8. Summary information for statistically significantly different pollutants exported (only by the Mann-Whitney U test) after treatment by gutter filters and bioinlets in comparison to runoff treated with gutter filters only.

Pollutant	Mean EMC		Ratio	Statistically (95%) Significant Difference	
	Loading			t test	U test
	Phase 2	Phase 3			
TKN (mg/L)	1.7	3.0	1.8	✗	✓
(kg/ha/yr)	14	21	1.5		
NO_3^- (mg/L-N)	1.2	21	17	✗	✓
kg/ha/yr	4.0	290	73		
Cu (µg/L)	66	78	1.2	✗	✓
kg/ha/yr	0.49	0.74	1.5		
Zn (mg/L)	0.35	18	51	✗	✓
(kg/ha/yr)	3.2	100	32		

Table 5.9. Summary information for statistically identical pollutants after treatment by gutter filters and bioinlets when compared to treatment by gutter filters only.

Pollutant	Mean EMC		Ratio	Statistically (95%) Significant Difference	
	Loading			*t* test	U test
	Phase 2	Phase 3			
TP (mg/L-P)	0.67-0.72	0.71	0.99-1.0	✗	✗
kg/ha/yr	4.3	5.2	1.2		

The first flush effect, defined as more than 50% of pollutant mass in the initial 25% runoff volume (Wanielista and Yousef, 1993) was not observed in many pollutants. TSS in 4 out of 17, TKN in 5 out of 17, nitrite in 2 out of 17, TP and Zn in 1 out of 17 events, Cd in 1 out of 16 events, and Cu and Pb in 3 out of 17 events exhibited first flush in stormwater runoff analyzed after the construction of gutter filters only. Nitrate did not exhibit first flush in the 4 events for which data was available. In the case of runoff analyses after complete LID implementation (gutter filters + bioinlets), first flush was observed for TSS in 4 out of 13 events, chloride in 3 out of 7 events, nitrite and Cu in 2 out of 14 events, Zn in 2 out of 12 events, TKN in 1 out of 13 events and Pb in 1 out of 12 events. Nitrate, TP and Cd did not exhibit first flush in any of the events. The first flush calculations were carried out on the effluent from the BMPs. The bioinlets have an inlet chamber which retains runoff and therefore it reduces a chance of first flush occurrence.

The main scope of the project was to determine the extent to which the gutter filters and bioinlets would lower the concentrations of the target pollutants. The observations made in this project and the interpretations drawn from them will help the Maryland State Highway administration to provide cost efficient stormwater management systems that not only meet transportation requirements, but also are environmentally sound. The LID practices would serve to protect surface and ground waters, wetlands and other sensitive habitats. The outcomes of the current study garner support for BMPs in stormwater management in urban areas and highways. The findings underline the need to move away from conventional end-of-pipe solutions and highlighting the importance of urban planning. The gutter filters and bioinlets can be used in the future at sites where the target pollutants are TSS and metals.

Further research in this aspect should be directed in evaluation of different types of BMPs and their efficiency in pollutant removal. A relatively accurate assessment would incorporate other factors like traffic characteristics (Average Daily Traffic), drainage area characteristics (land use and soil structure) and rainfall characteristics. Consistent data reporting from studies at different sites with all such parameters would help in performance comparisons. Such a study would throw light on the appropriate BMP to be implemented for a site. A performance comparison study of different BMPs would aid in making an astute choice of a BMP for a particular site. Statistical characterization is an appropriate tool to determine the effectiveness of stormwater BMPs. Benefit-cost analyses would also help in promoting the ideology of LID practices. Modeling studies can be directed at predicting stormwater quality from the BMPs. The models, though, generally are site specific and the need is for a universal model.

Investigations could be focused on various facets of stormwater management such as analysis on dependence on particulate size fractions, impact of traffic density, land use, soil studies and seasonal variations on pollutants in stormwater runoff. The choice and the design of BMPs depend on a number of factors with the site in consideration being a primary feature. The results from research from a pilot study at a particular site would help in the astute judgment of selection of a BMP. Thus monitoring studies, progressive research and making conscientious decisions to incorporate LID practices in land development would usher in, an environmentally sound society.

APPENDIX

Photos


Figure A.1. Mt. Rainier Monitoring Area, east side, looking south.

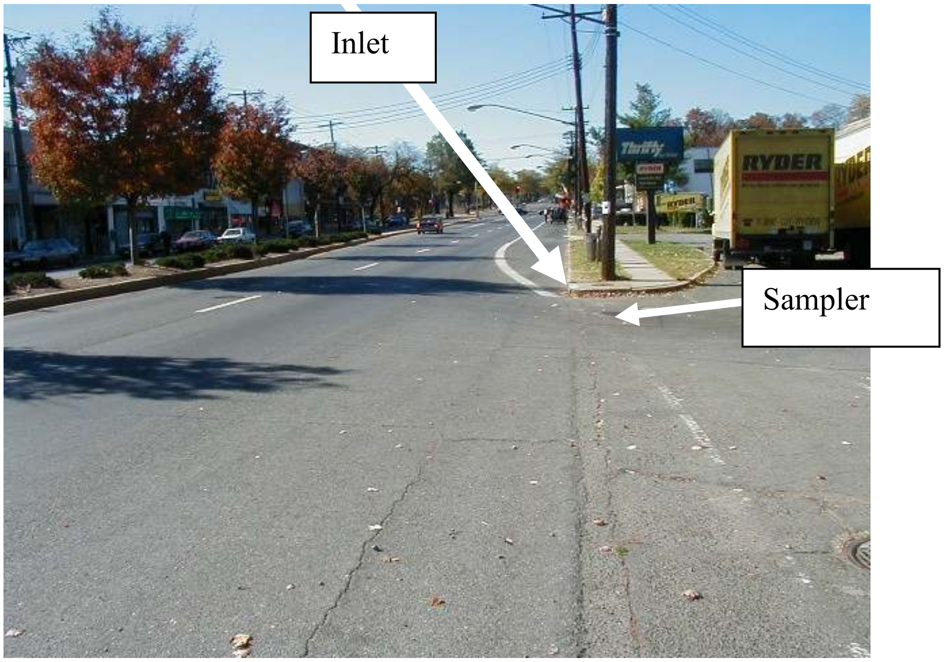


Figure A.2. Mt. Rainier monitoring area, west side, looking south.


Figure A.3. East side inlet before installation of gutter filters.


Figure A.4. East side inlet, looking west across U.S. Rt. 1 to other inlet.

Figure A.5. Gutter filters on the east side of Rt. 1 at Mt. Rainier, MD.

Figure A.6. Gutter Filters on the east side due south at Mt.Rainier, MD.

Figure A.7. West side inlet looking south.

Figure A.8. West side inlet.

Figure A.9. Bioinlet area due south on the West side at Mt. Rainier, MD.

Figure A.10. Bioinlet treatment cell on West of Rt. 1(from top).

Data Spreadsheets

Blue color indicates the average of the preceding and following value.

Total Volume (L)	**123720**
Storm Duration (min)	**80**

11/29/2005

			Average Flow	**Cu**		**Nitrite**		**TKN**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	20:08	0	13.8	42.88	0.710093	0.080	1.33	2.29	37.94
3, 4	20:28	20	13.1	80.90	1.271748	0.070	1.10	3.55	55.82517
5, 6	20:48	40	49.5	33.00	1.9602	0.082	4.86	1.60	95.04
7,8	21:08	60	26.7	41.13	1.3178	0.080	2.57	1.87	59.81
Total Loadings (g)					**5.26**		**9.86**		**248.61**
EMC (mg/L)					**0.043**		**0.080**		**2.01**

		Phosphorous		Solids	
		TP		**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	20:08	0.65	10.77	69	1148.2
3, 4	20:28	0.64	10.07	84	1327.0
5, 6	20:48	0.57	33.67	51	3009.6
7,8	21:08	0.68	21.77	76	2435.0
Total Loadings (g)			**76.28**		**7919.81**
EMC (mg/L)			**0.62**		**64**

Total Volume (L)	**100560**
Storm Duration (min)	**220**

11/16/2005

Bottle #	Sampling Time	Time (min)	Average Flow (L/s)	**Cu** Conc. (ug/L)	Mass (g)	**Nitrite** Conc. (mg/L)	Mass (g)	**TKN** Conc. (mg/L)	Mass (g)
1, 2	16:46	0	7.5	149.93	1.3494	0.112	1.00	5.33	48.00
3, 4	17:06	20	6.3	52.50	0.3969	0.118	0.89	5.46	41.30
5, 6	17:26	40	4.9	78.64	0.4624	0.082	0.48	5.99	35.23
7,8	17:46	60	4.0	78.13	0.3750	0.086	0.41	5.86	28.14
9,10	18:06	80	4.0	77.62	0.3726	0.090	0.43	5.73	27.52
11,12	18:26	100	4.0	88.97	0.4271	0.098	0.47	5.73	27.52
13,14	18:46	120	4.0	100.32	0.4815	0.105	0.50	5.73	27.52
15,16	19:06	140	8.2	96.44	0.9490	0.101	0.99	4.65	45.74
17,18	19:26	160	13.6	92.56	4.5428	0.097	4.75	3.56	174.90
Total Loadings (g)					**9.36**		**9.94**		**455.87**
EMC (mg/L)					**0.093**		**0.099**		**4.53**

Bottle #	Sampling Time	**TP** Conc. (mg/L)	Mass (g)	**TSS** Conc. (mg/L)	Mass (g)
1, 2	16:46		0.81	7.33	117
3, 4	17:06	1.59	12.03	51	383.2
5, 6	17:26	2.22	13.04	34	201.2
7,8	17:46	1.85	8.89	33	160.0
9,10	18:06	1.49	7.15	24	116.8
11,12	18:26	1.29	6.19	32	155.7
13,14	18:46	1.09	5.23	49	233.5
15,16	19:06	0.98	9.67	52	511.7
17,18	19:26	0.88	42.95	130	6374.0
Total Loadings (g)			**112.49**		**9190.27**
EMC (mg/L)			**1.12**		**91**

Total Volume (L)	**11880**
Storm Duration (min)	**80**

10/11/2005

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	11:12	0	2.5	21.50	0.06	0.26	0.79	55.04	0.16512
3, 4	11:32	20	3.0	21.75	0.08	0.26	0.95	64.24	0.231264
5, 6	11:52	40	2.4	20.28	0.06	0.39	1.14	62.52	0.1801
7,8	12:12	60	2.0	16.18	0.04	0.23	0.55	53.27	0.1278
Total Loadings (g)					**0.24**		**3.43**		**0.70**
EMC (mg/L)					**0.020**		**0.29**		**0.059**

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	11:12	2.00	0.006	0.00	0	0.181	0.54	2.60	7.79
3, 4	11:32	2.00	0.0072	0.00	0	0.148	0.53	3.00	10.81756
5, 6	11:52	2.00	0.00576	0.00	0	0.193	0.55	3.47	9.98
7,8	12:12	2.00	0.0048	0.00	0	0.183	0.44	2.80	6.72
Total Loadings (g)			**0.02**		**0.00**		**2.07**		**35.31**
EMC (mg/L)			**0.002**		**0.000**		**0.174**		**2.97**

		TP		**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	11:12	0.49	1.46	24	73.1
3, 4	11:32	0.36	1.29	29	104.2
5, 6	11:52	0.33	0.95	30	87.2
7,8	12:12	0.35	0.83	23	56.1
Total Loadings (g)			**4.53**		**320.55**
EMC (mg/L)			**0.38**		**27**

10/7/2005

Total Volume (L)	**229708**
Storm Duration (min)	**220**

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	10:34	0	16.5	51.74	1.02	4.11	81.12	153.89	3.038106
3, 4	10:54	20	36.0	68.71	2.97	0.58	24.94	49.20	2.126575
5, 6	11:14	40	19.7	53.85	1.27	0.42	10.05	37.17	0.8790
7,8	11:34	60	19.9	38.99	0.93	0.27	6.50	25.13	0.5995
9,10	11:54	80	17.2	32.31	0.67	0.67	13.79	22.48	0.4637
11,12	12:14	100	17.3	25.62	0.53	1.07	22.08	19.83	0.4110
13,14	12:34	120	13.1	26.19	0.41	3.01	47.19	19.65	0.3078
15,16	12:54	140	12.2	26.76	0.39	4.96	72.64	19.47	0.2851
23,24	16:14	340	13.2	31.76	1.51	0.20	9.35	17.61	0.8379
Total Loadings (g)					**9.71**		**287.66**		**8.95**
EMC (mg/L)					**0.042**		**1.25**		**0.039**
		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	10:34	2.00	0.039485225	0.00	0	0.055	1.09	3.30	65.19
3, 4	10:54	2.00	0.086446138	0.00	0	0.120	5.18	2.25	97.05
5, 6	11:14	2.00	0.047300717	0.00	0	0.123	2.91	1.66	39.16
7,8	11:34	2.00	0.047708482	0.00	0	0.126	3.02	1.07	25.44
9,10	11:54	2.00	0.041252206	0.00	0	0.115	2.37	1.07	22.00
11,12	12:14	2.00	0.041456088	0.00	0	0.103	2.14	1.07	22.11
13,14	12:34	2.00	0.031329929	0.00	0	0.104	1.63	0.80	12.49
15,16	12:54	2.00	0.029291105	0.00	0	0.105	1.54	0.53	7.74
23,24	16:14	2.00	0.09514512	0.00	0.000	0.080	3.81	1.12	53.28
Total Loadings (g)			**0.46**		**0.00**		**23.70**		**344.47**
EMC (mg/L)			**0.002**		**0.000**		**0.103**		**1.50**

10/7/2005

		Phosphorous **TP**		Solids **TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	10:34	1.38	27.23	154	3037.3
3, 4	10:54	0.51	22.01	51	2218.0
5, 6	11:14	0.52	12.23	16	368.6
7,8	11:34	0.53	12.53	13	318.1
9,10	11:54	0.45	9.31	3	55.0
11,12	12:14	0.38	7.82	4	85.2
13,14	12:34	0.43	6.79	21	334.2
15,16	12:54	0.49	7.17	5	77.1
23,24	16:14	0.40	19.03	23	1112.1
Total Loadings (g)			**124.12**		**7605.52**
EMC (mg/L)			**0.54**		**33**

Total Volume (L)	**101431**
Storm Duration (min)	**400**

9/26/2005

Metals

Bottle #	Sampling Time	Time (min)	Average Flow (L/s)	**Pb** Conc. (ug/L)	**Pb** Mass (g)	**Zn** Conc. (mg/L)	**Zn** Mass (g)	**Cu** Conc. (ug/L)	**Cu** Mass (g)
1, 2	18:40	0	5.9	27.41	0.20	0.62	4.46	141.60	1.010441
3, 4	19:00	20	5.7	23.12	0.16	0.57	3.96	230.96	1.593167
5, 6	19:20	40	5.8	22.32	0.16	0.47	3.29	202.68	1.4119
7,8	19:40	60	4.6	21.52	0.12	0.37	2.03	174.40	0.9541
9,10	20:00	80	4.2	19.02	0.10	0.33	1.69	145.38	0.7410
11,12	20:20	100	4.2	16.51	0.08	0.29	1.49	116.36	0.5931
13,14	20:40	120	4.2	16.31	0.08	0.40	2.00	107.32	0.5434
15,16	21:00	140	4.2	16.11	0.08	0.50	2.53	98.28	0.5009
17,18	21:20	160	4.1	14.68	0.22	0.55	8.05	92.56	1.3587
19,20	22:20	220	3.8	13.24	0.18	0.60	8.14	86.83	1.1802
21,22	23:20	280	3.7	12.28	0.16	0.52	6.93	85.08	1.1274
23,24	0:20	340	3.6	11.32	0.15	0.45	5.84	83.32	1.0900
Total Loadings (g)					**1.68**		**50.40**		**12.10**
EMC (mg/L)					**0.017**		**0.50**		**0.119**

09/26/2005

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	18:40	2.00	0.014271768	0.00	0	0.074	0.52	11.58	82.65
3, 4	19:00	2.00	0.013796042	0.00	0	0.069	0.47	11.51	79.42395
5, 6	19:20	2.00	0.013931964	0.00	0	0.060	0.42	9.79	68.16
7,8	19:40	2.00	0.010941689	0.00	0	0.052	0.28	8.06	44.08
9,10	20:00	2.00	0.01019412	0.00	0	0.046	0.24	8.06	41.06
11,12	20:20	2.00	0.01019412	0.00	0	0.040	0.21	8.06	41.06
13,14	20:40	2.00	0.010126159	0.00	0	0.045	0.23	7.63	38.61
15,16	21:00	2.00	0.01019412	0.00	0	0.049	0.25	7.20	36.68
17,18	21:20	2.00	0.029359066	0.00	0	0.050	0.73	6.51	95.63
19,20	22:20	2.00	0.02718432	0.00	0	0.050	0.69	5.83	79.29
21,22	23:20	2.00	0.026504712	0.00	0.000	0.053	0.70	5.98	79.29
23,24	0:20	2.00	0.026164908	0.00	0.000	0.055	0.72	6.13	80.24
Total Loadings (g)			**0.20**		**0.00**		**5.46**		**766.19**
EMC (mg/L)			**0.002**		**0.000**		**0.054**		**7.55**

09/26/2005

		Phosphorous		Solids	
		TP		**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	18:40	1.51	10.81	51	367.0
3, 4	19:00	1.25	8.61	56	388.6
5, 6	19:20	1.09	7.60	44	309.6
7,8	19:40	0.93	5.10	33	179.9
9,10	20:00	1.08	5.50	25	125.7
11,12	20:20	1.23	6.25	20	103.3
13,14	20:40	0.94	4.75	16	78.9
15,16	21:00	0.65	3.32	8	39.7
17,18	21:20	0.67	9.88	9	137.0
19,20	22:20	0.70	9.45	9	125.2
21,22	23:20	0.70	9.32	ND	
23,24	0:20	0.71	9.31	ND	
Total Loadings (g)			**89.88**		**1854.89**
EMC (mg/L)			**0.89**		**18**

Total Volume (L)	**226479**
Storm Duration (min)	**400**

8/8/2005

Metals

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	12:44	0	32.5	62.11	2.42	1.55	60.48	261.40	10.1882
3, 4	13:04	20	8.6	121.21	1.26	0.65	6.68	92.74	0.961159
5, 6	13:24	40	4.8	69.72	0.40	0.53	3.05	81.15	0.4660
7,8	13:44	60	4.3	18.23	0.09	0.42	2.16	69.56	0.3593
9,10	14:04	80	4.3	17.97	0.09	0.40	2.06	85.97	0.4470
11,12	14:26	100	4.3	17.71	0.09	0.38	1.94	102.38	0.5288
13,14	14:46	120	4.3	20.64	0.11	0.41	2.10	126.93	0.6513
15,16	15:06	140	4.2	23.56	0.12	0.44	2.21	151.48	0.7567
17,18	15:26	160	4.2	20.25	0.30	0.43	6.49	130.42	1.9633
19,20	16:26	220	4.2	16.93	0.26	0.42	6.34	109.36	1.6574
21,22	17:26	280	4.3	19.42	0.30	0.35	5.42	97.42	1.5228
23,24	18:26	340	27.8	21.90	2.19	0.28	27.47	85.48	8.5397
Total Loadings (g)					**7.63**		**126.42**		**28.04**
EMC (mg/L)					**0.034**		**0.56**		**0.124**

8/8/2005

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	12:44	2.54	0.098997818	2.54	0.098998	0.12	4.61	8.86	345.42
3, 4	13:04	2.00	0.020728044	0.00	0	1.16	12.07	4.19	43.39329
5, 6	13:24	2.00	0.011485375	0.00	0	2.05	11.76	3.97	22.82
7,8	13:44	2.00	0.010330042	0.00	0	2.93	15.15	3.76	19.42
9,10	14:04	2.00	0.010398002	0.00	0	2.76	14.34	3.76	19.54
11,12	14:26	2.00	0.010330042	0.00	0	2.59	13.35	3.76	19.42
13,14	14:46	2.00	0.010262081	0.00	0	1.97	10.08	3.96	20.32
15,16	15:06	2.00	0.009990238	0.00	0	1.35	6.72	4.16	20.79
17,18	15:26	2.00	0.030106634	0.00	0	0.72	10.78	4.23	63.60
19,20	16:26	2.00	0.030310517	0.00	0	0.09	1.32	4.29	64.99
21,22	17:26	2.00	0.031261968	0.00	0.000	0.07	1.16	3.81	59.57
23,24	18:26	2.00	0.199804752	0.00	0.000	0.06	6.19	3.33	333.01
Total Loadings (g)			**0.47**		**0.10**		**107.54**		**1032.28**
EMC (mg/L)			**0.002**		**0.000**		**0.475**		**4.56**

8/8/2005

		Phosphorous		Solids	
		TP		**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	12:44	1.38	53.89	177	6916.8
3, 4	13:04	1.06	10.93	132	1372.1
5, 6	13:24	0.92	5.30	13	73.8
7,8	13:44	0.79	4.09	ND	
9,10	14:04	0.75	3.88	ND	
11,12	14:26	0.70	3.62	3	14.2
13,14	14:46	0.69	3.53	16	149.7
15,16	15:06	0.68	3.38	ND	
17,18	15:26	0.72	10.81	ND	
19,20	16:26	0.76	11.51	4	62.3
21,22	17:26	0.69	10.79	ND	
23,24	18:26	0.71	62.09	184	18338.2
Total Loadings (g)			**183.83**		**26927.09**
EMC (mg/L)			**0.81**		**119**

Total Volume (L)	**108431**
Storm Duration (min)	**400**

7/27/2005

				Metals					
			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	19:44	0	8.9	23.05	0.25	0.71	7.63	174.68	1.869744
3, 4	20:04	20	6.7	25.01	0.20	0.81	6.55	89.80	0.726243
5, 6	20:24	40	4.6	16.94	0.09	0.56	3.07	73.41	0.4016
7,8	20:44	60	4.2	8.87	0.05	0.31	1.59	57.02	0.2906
9,10	21:04	80	4.9	10.23	0.06	0.45	2.66	62.59	0.3679
11,12	21:24	100	4.6	11.59	0.06	0.59	3.28	68.16	0.3775
13,14	21:44	120	4.2	10.50	0.05	0.46	2.37	64.08	0.3266
15,16	22:04	140	4.0	9.41	0.05	0.34	1.63	60.00	0.2895
17,18	22:24	160	4.1	9.75	0.14	0.49	7.24	60.81	0.8947
19,20	23:24	220	4.0	10.09	0.15	0.65	9.33	61.62	0.8878
21,22	0:24	280	4.0	10.20	0.15	0.66	9.45	59.29	0.8462
23,24	1:24	340	4.0	10.30	0.15	0.68	9.71	56.96	0.8168
Total Loadings (g)					**1.39**		**64.51**		**8.10**
EMC (mg/L)					**0.013**		**0.59**		**0.075**

7/27/2005

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	19:44	2.00	0.021407652	0.00	0	0.05	0.49	6.75	72.25
3, 4	20:04	2.00	0.01617467	0.00	0	0.06	0.47	3.31	26.76
5, 6	20:24	2.00	0.010941689	0.00	0	0.40	2.20	2.93	16.01
7,8	20:44	2.00	0.01019412	0.00	0	0.75	3.09	2.55	12.97
9,10	21:04	2.00	0.011757218	0.00	0	0.40	2.32	2.55	14.96
11,12	21:24	2.00	0.01107761	0.00	0	0.04	0.24	2.55	14.10
13,14	21:44	2.00	0.01019412	0.00	0	0.06	0.32	2.55	12.97
15,16	22:04	2.00	0.009650434	0.00	0	0.08	0.40	2.55	12.28
17,18	22:24	2.00	0.029427026	0.00	0	0.10	1.40	2.59	38.04
19,20	23:24	2.00	0.028815379	0.00	0	0.11	1.54	2.63	37.82
21,22	0:24	2.00	0.028543536	0.00	0.000	0.21	3.00	2.27	32.35
23,24	1:24	2.00	0.028679458	0.00	0.000	0.31	4.49	1.91	27.38
Total Loadings (g)			**0.22**		**0.00**		**19.97**		**317.91**
EMC (mg/L)			**0.002**		**0.000**		**0.184**		**2.93**

7/27/2005

		Phosphorous		Solids	
		TP		TSS	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	19:44	1.00	10.71	54	581.1
3, 4	20:04	0.53	4.33	37	296.2
5, 6	20:24	0.56	3.05	20	107.9
7,8	20:44	0.58	2.96	14	72.8
9,10	21:04	0.53	3.09	11	67.2
11,12	21:24	0.47	2.61	14	79.1
13,14	21:44	0.24	1.20	3	14.4
15,16	22:04	0.00	0.00	10	48.3
17,18	22:24	0.24	3.58	8	122.6
19,20	23:24	0.49	7.01	4	61.7
21,22	0:24	0.49	7.01	4	61.2
23,24	1:24	0.50	7.12	6	80.8
Total Loadings (g)			**52.65**		**1593.14**
EMC (mg/L)			**0.49**		**15**

Total Volume (L)	**243673**
Storm Duration (min)	**400**

7/7/2005

Metals

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	19:44	0	4.9	49.36	0.29	0.33	1.91	118.02	0.689783
3, 4	20:04	20	7.9	34.79	0.33	0.26	2.50	77.94	0.738913
5, 6	20:24	40	6.5	27.38	0.21	0.28	2.19	66.60	0.5182
7,8	20:44	60	6.6	19.97	0.16	0.30	2.39	55.26	0.4394
9,10	21:04	80	7.4	18.15	0.16	0.25	2.16	49.28	0.4354
11,12	21:24	100	5.9	16.32	0.12	0.19	1.34	43.30	0.3060
13,14	21:44	120	5.1	31.44	0.19	0.22	1.36	44.34	0.2697
15,16	22:04	140	6.8	46.55	0.38	0.26	2.09	45.38	0.3701
17,18	22:24	160	7.4	44.61	1.19	0.44	11.67	65.05	1.7352
19,20	23:24	220	7.6	42.67	1.16	0.62	16.83	84.72	2.3031
21,22	0:24	280	15.0	35.13	1.90	0.38	20.29	69.63	3.7620
23,24	1:24	340	20.7	27.59	2.06	0.13	9.85	54.54	4.0680
Total Loadings (g)					**8.14**		**74.58**		**15.64**
EMC (mg/L)					**0.033**		**0.31**		**0.064**

								7/7/2005	
		Cd				**Nitrite**		**Nitrate**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	19:44	2.00	0.011689258	0.00	0	0.04	0.21	0.8	4.4
3, 4	20:04	2.00	0.018961063	0.00	0	0.46	4.33	0.3	3.2
5, 6	20:24	2.00	0.015563023	0.00	0	0.32	2.51	1.1	8.3
7,8	20:44	2.00	0.015902827	0.00	0	0.19	1.49	1.8	14.2
9,10	21:04	2.00	0.017669808	0.00	0	0.14	1.22	1.3	11.6
11,12	21:24	2.00	0.014135846	0.00	0	0.09	0.63	0.8	5.9
13,14	21:44	2.00	0.012164983	1.00	0.006082	0.09	0.53	0.8	4.7
15,16	22:04	2.00	0.016310592	0.00	0	0.09	0.71	0.7	5.7
17,18	22:24	2.27	0.06067141	1.27	0.033997	0.08	2.07	0.8	20.3
19,20	23:24	2.55	0.069292832	2.55	0.069293	0.07	1.86	0.8	22.3
21,22	0:24	2.27	0.122888587	1.27	0.069	0.06	3.48	0.7	37.0
23,24	1:24	2.00	0.149173956	0.00	0.000	0.06	4.50	0.6	41.0
Total Loadings (g)			**0.52**		**0.18**		**23.55**		**178.67**
EMC (mg/L)			**0.002**		**0.001**		**0.097**		**0.73**

7/7/2005

				Phosphorous		Solids			
		TKN		**TP**		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	19:44	3.47	20.26	0.79	4.61	34	200.4	22.7	132.6
3, 4	20:04	2.67	25.28	0.58	5.47	26	250.2	6.7	63.5
5, 6	20:24	2.07	16.08	0.52	4.05	11	87.7	5.5	43.0
7,8	20:44	1.47	11.66	0.46	3.69	13	102.2	4.3	34.5
9,10	21:04	1.47	12.96	0.45	4.00	11	99.5	3.8	33.4
11,12	21:24	1.47	10.37	0.44	3.12	7	49.8	3.2	22.7
13,14	21:44	1.33	8.11	0.42	2.57	9	52.1	3.1	18.9
15,16	22:04	1.20	9.79	0.40	3.29	8	68.9	3.0	24.6
17,18	22:24	1.06	28.39	0.41	10.88	10	266.7	2.6	69.4
19,20	23:24	0.93	25.25	0.41	11.22	9	257.1	2.2	59.3
21,22	0:24	0.78	42.28	0.42	22.73	6	304.4	1.7	91.0
23,24	1:24	0.64	47.46	0.43	31.98	6	426.2	1.2	88.8
Total Loadings (g)			**257.90**		**107.62**		**2165.35**		**681.57**
EMC (mg/L)			**1.06**		**0.44**		**9**		**3**

Total Volume (L)	**4521**
Storm Duration (min)	**140**

3/20/2005

Metals

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	5:02	0	0.9	8.02	0.01	1.73	1.94	278.10	0.311848
3, 4	5:32	20	0.8	7.25	0.01	0.02	0.02	15.75	0.014985
5, 6	6:02	40	0.8	82.58	0.08	0.38	0.34	97.05	0.0890
7,8	6:32	60	0.5	157.90	0.10	0.73	0.47	178.35	0.1151
9,10	7:02	80	0.2	122.19	0.03	0.64	0.18	129.33	0.0353
11,12	7:32	100	0.2	86.48	0.02	0.56	0.11	80.30	0.0164
13,14	8:02	120	0.3	83.33	0.03	0.54	0.22	81.10	0.0331
Total Loadings (g)					**0.28**		**3.29**		**0.62**
EMC (mg/L)					**0.062**		**0.73**		**0.136**

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	5:02	2.00	0.002242706	0.00	0	0.02	0.02	7.60	8.52
3, 4	5:32	2.00	0.001902902	0.00	0	0.01	0.01	5.70	5.42
5, 6	6:02	2.00	0.001834942	0.00	0	0.02	0.02	6.81	6.25
7,8	6:32	2.00	0.001291255	0.00	0	0.02	0.01	7.92	5.12
9,10	7:02	2.00	0.000546086	0.00	0	0.02	0.01	7.92	2.16
11,12	7:32	2.00	0.000407765	0.00	0	0.02	0.00	7.92	1.62
13,14	8:02	2.00	0.00081553	0.00	0	0.02	0.01	7.89	3.22
Total Loadings (g)			**0.01**		**0.00**		**0.08**		**32.31**
EMC (mg/L)			**0.002**		**0.000**		**0.018**		**7.15**

		3/20/2005					
		TP		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	5:02	1.16	1.30	837	938.9	995.5	1116.3
3, 4	5:32	0.49	0.47	432	411.3	549.0	522.3
5, 6	6:02	0.53	0.48	191	175.2	480.0	440.4
7,8	6:32	0.56	0.36	56	36.0	411.0	265.4
9,10	7:02	0.68	0.19	127	34.8	454.5	124.1
11,12	7:32	0.80	0.16	87	17.7	498.0	101.5
13,14	8:02	0.84	0.34	45	18.5	485.3	197.9
Total Loadings (g)			**3.31**		**1632.37**		**2767.89**
EMC (mg/L)			**0.73**		**361**		**612.3**

Total Volume (L)	**93446**
Storm Duration (min)	**400**

1/13/2005

				Metals					
			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	21:36	0	5.4	44.03	0.28	326.50	2107.97	46.33	0.299141
3, 4	21:56	20	5.7	40.98	0.28	246.30	1698.98	49.29	0.339996
5, 6	22:16	40	4.0	50.25	0.24	278.05	1322.76	53.66	0.2553
7,8	22:36	60	9.6	59.53	0.69	309.80	3579.22	58.02	0.6704
9,10	22:56	80	4.6	43.40	0.24	267.05	1488.21	44.87	0.2500
11,12	23:16	100	5.7	27.28	0.19	224.30	1524.36	31.71	0.2155
13,14	23:36	120	3.4	21.64	0.09	178.40	721.39	28.74	0.1162
15,16	23:56	140	2.5	16.00	0.05	132.50	405.22	25.78	0.0788
17,18	0:16	160	2.1	15.01	0.12	150.90	1163.97	24.66	0.1902
19,20	1:16	220	1.5	14.03	0.08	169.30	908.96	23.53	0.1263
21,22	2:16	280	0.8	48.10	0.13	161.85	439.98	25.02	0.0680
23,24	3:16	340	7.9	82.18	2.34	154.40	4401.88	26.51	0.7558
Total Loadings (g)					**4.72**		**19762.90**		**3.37**
EMC (mg/L)					**0.051**		**211.49**		**0.036**

1/13/2005

		Cd				**Nitrite**		**Nitrate**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	21:36	2.00	0.012912552	0.00	0	0.39	2.50	227.0	1465.6
3, 4	21:56	2.00	0.013796042	0.00	0	0.13	0.91	8.5	58.6
5, 6	22:16	2.00	0.009514512	0.00	0	0.12	0.57	8.5	40.4
7,8	22:36	2.00	0.023106672	0.00	0	0.11	1.25	8.5	98.2
9,10	22:56	2.00	0.011145571	0.00	0	0.10	0.57	10.5	58.5
11,12	23:16	2.00	0.01359216	0.00	0	0.10	0.65	12.5	85.0
13,14	23:36	2.00	0.008087335	0.00	0	0.08	0.31	10.5	42.5
15,16	23:56	2.00	0.006116472	0.00	0	0.06	0.18	8.5	26.0
17,18	0:16	2.00	0.015427102	0.00	0	0.07	0.52	82.3	634.4
19,20	1:16	2.00	0.010737806	0.00	0	0.08	0.40	156.0	837.5
21,22	2:16	3.00	0.008141704	2.00	0.005	0.06	0.15	90.3	245.3
23,24	3:16	3.99	0.113753127	3.99	0.114	0.04	1.06	24.5	698.5
Total Loadings (g)			**0.25**		**0.12**		**9.07**		**4290.58**
EMC (mg/L)			**0.003**		**0.001**		**0.097**		**45.91**

1/13/2005

				Phosphorous		Solids			
		TKN		**TP**		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	21:36	1.78	11.50	1.14	7.35	78	504.1	81.0	523.0
3, 4	21:56	1.53	10.54	0.91	6.30	55	382.2	33.5	231.1
5, 6	22:16	1.24	5.92	1.09	5.19	25	118.9	33.5	159.4
7,8	22:36	0.96	11.10	1.27	14.64	77	893.5	33.5	387.0
9,10	22:56	0.96	5.35	1.25	6.97	21	114.5	38.3	213.2
11,12	23:16	0.96	6.53	1.23	8.39	33	223.9	43.0	292.2
13,14	23:36	0.87	3.52	1.25	5.04	25	101.1	ND	
15,16	23:56	0.78	2.39	1.26	3.85	12	36.7	ND	
17,18	0:16	0.74	5.67	1.49	11.46	9	71.0	ND	
19,20	1:16	0.69	3.70	1.71	9.20	15	78.3	1149.0	6168.9
21,22	2:16	0.67	1.82	1.67	4.54	7	19.4	595.3	1618.1
23,24	3:16	0.65	18.48	1.62	46.28	15	427.6	41.5	1183.1
Total Loadings (g)			**86.53**		**129.20**		**2971.27**		**10776.00**
EMC (mg/L)			**0.93**		**1.38**		**32**		**29.5**

Total Volume (L)	**53090**
Storm Duration (min)	**340**

12/9/2004

Metals

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	14:10	0	5.7	31.10	0.21	0.18	1.25	47.40	0.32677
3, 4	14:30	20	7.3	53.36	0.47	0.23	2.01	56.96	0.499365
5, 6	14:50	40	6.6	46.44	0.37	0.19	1.52	49.27	0.3901
7,8	15:10	60	4.9	39.52	0.23	0.15	0.90	41.58	0.2430
9,10	15:30	80	3.2	32.33	0.13	0.10	0.38	33.57	0.1300
11,12	15:50	100	3.3	25.14	0.10	0.04	0.17	25.56	0.1025
13,14	16:10	120	4.5	30.29	0.16	0.12	0.68	42.09	0.2288
15,16	16:30	140	6.2	35.44	0.27	0.21	1.54	58.62	0.4387
17,18	16:50	160	0.4	37.03	0.05	0.12	0.16	43.43	0.0563
19,20	17:50	220	0.2	38.62	0.03	0.04	0.04	28.24	0.0237
21,22	18:50	280	0.2	22.08	0.02	0.06	0.04	25.08	0.0182
Total Loadings (g)					**2.03**		**8.68**		**2.46**
EMC (mg/L)					**0.038**		**0.16**		**0.046**

12/9/2004

		Cd		**Nitrite**		**Nitrate**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	14:10	2.00	0.01378776	0.14	0.97	1.7	11.7	1.91	13.16
3, 4	14:30	2.00	0.017533886	0.09	0.79	5.7	50.0	1.25	10.96
5, 6	14:50	2.00	0.015834866	0.07	0.59	12.5	98.6	1.03	8.19
7,8	15:10	2.00	0.011689258	0.06	0.34	19.2	112.2	0.82	4.79
9,10	15:30	2.00	0.007747531	0.06	0.21	12.1	46.7	0.82	3.17
11,12	15:50	2.00	0.008019374	0.05	0.21	4.9	19.6	0.82	3.29
13,14	16:10	2.00	0.010873728	0.05	0.28	4.2	22.8	1.08	5.85
15,16	16:30	2.00	0.014969054	0.05	0.38	3.5	26.2	1.33	9.98
17,18	16:50	2.00	0.0025944	0.04	0.05	12.5	16.2	1.00	1.30
19,20	17:50	2.00	0.0016752	0.02	0.02	21.4	17.9	0.67	0.56
21,22	18:50	2.00	0.0014544	0.03	0.02	4.6	3.3	0.86	0.62
Total Loadings (g)			**0.11**		**3.86**		**425.26**		**61.87**
EMC (mg/L)			**0.002**		**0.073**		**8.01**		**1.17**

12/9/2004

		Phosphorous		Solids			
		TP		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	14:10	0.31	2.16	113	778.0	168.7	1163.0
3, 4	14:30	0.61	5.31	129	1134.5	10.1	88.5
5, 6	14:50	0.49	3.88	48	382.2	8.6	68.1
7,8	15:10	0.37	2.19	99	578.0	7.1	41.5
9,10	15:30	0.37	1.45	42	162.3	8.0	31.0
11,12	15:50	0.37	1.50	58	232.3	8.9	35.7
13,14	16:10	0.37	2.02	40	215.9	7.9	43.0
15,16	16:30	0.37	2.75	99	740.1	6.9	51.6
17,18	16:50	0.38	0.49	76	98.3	10.6	13.7
19,20	17:50	0.38	0.32	55	46.3	14.2	11.9
21,22	18:50	0.58	0.42	48	35.0	0.0	0.0
Total Loadings (g)			**22.48**		**4403**		**1548**
EMC (mg/L)			**0.42**		**83**		**29.2**

Total Volume (L)	**326400**
Storm Duration (min)	**100**

11/20/2004

Metals

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	19:32	0	65.0	25.26	1.97	0.17	13.57	71.48	5.57544
3, 4	19:52	20	81.0	18.94	1.84	0.24	22.84	56.80	5.52096
5, 6	20:12	40	74.0	10.80	0.96	0.05	4.26	40.84	3.6266
7,8	20:32	60	47.0	9.63	0.54	0.03	1.41	32.50	1.8330
9,10	20:52	80	5.0	8.27	0.05	0.07	0.39	29.44	0.1766
Total Loadings (g)					**5.363**		**42.476**		**16.733**
EMC (mg/L)					**0.016**		**0.13**		**0.051**

		Cd				**Nitrite**		**Nitrate**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	19:32	2.00	0.156	0.00	0	0.27	21.21	110	8580
3, 4	19:52	2.00	0.1944	0.00	0	0.48	46.53	44	4277
5, 6	20:12	2.00	0.1776	0.00	0	0.29	25.62	60	5328
7,8	20:32	2.00	0.1128	0.00	0	0.17	9.74	58	3271
9,10	20:52	2.00	0.012	0.00	0	0.16	0.95	70	420
Total Loadings (g)			**0.653**		**0.000**		**104.053**		**21876**
EMC (mg/L)			**0.002**		**0.000**		**0.319**		**67.022**

11/20/2004

				Phosphorous		Solids			
		TKN		**TP**		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	19:32	3.10	241.59	1.05	82.043	32.39	2527	412	32136
3, 4	19:52	2.23	216.76	0.54	52.294	29.58	2875	170	16524
5, 6	20:12	1.74	154.12	0.52	45.779	28.57	2537	156	13852.8
7,8	20:32	1.25	70.50	0.51	28.713	17.39	981	156	8798.4
9,10	20:52	1.26	7.57	0.51	3.035	17.14	103	158	948
Total Loadings (g)			**690.541**		**211.865**		**9023**		**72259**
EMC (mg/L)			**2.12**		**0.649**		**27.6**		**221.4**

Total Volume (L)	**173280**
Storm Duration (min)	**220**

11/4/2004

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	9:06	0	2.4	55.43	0.16	0.74	2.1312	158.68	0.456998
3, 4	9:26	20	4.6	30.13	0.17	0.32	1.7388	88.00	0.48576
5, 6	9:46	40	12.9	61.15	0.95	0.63	9.78	108.08	1.6731
7,8	10:06	60	6.3	92.18	0.70	0.95	7.17	128.16	0.9689
9,10	10:26	80	8.9	68.86	0.74	0.59	6.35	100.68	1.0753
11,12	10:46	100	18.4	45.55	1.01	0.24	5.32	73.20	1.6163
13,14	11:06	120	14.6	61.55	1.08	0.43	7.57	98.38	1.7236
15,16	11:26	140	27.9	77.55	2.60	0.62	20.86	123.56	4.1368
17,18	11:46	160	16.1	45.03	2.62	0.94	54.54	57.80	3.3570
Total Loadings (g)					**10.000**		**115.447**		**15.494**
EMC (mg/L)					**0.058**		**0.67**		**0.089**

		Cd				**Nitrite**		**Nitrate**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	9:06	2.25	0.00648576	2.25	0.006486	0.02	0.07	0.46	1.325
3, 4	9:26	2.00	0.01104	0.00	0	0.02	0.10	2.02	11.150
5, 6	9:46	4.03	0.06239214	3.03	0.046912	0.09	1.36	2.56	39.629
7,8	10:06	6.06	0.04582116	6.06	0.045821	0.16	1.19	3.1	23.436
9,10	10:26	4.03	0.04304574	3.03	0.032366	0.10	1.07	3.13	33.428
11,12	10:46	2.00	0.04416	0.00	0	0.04	0.93	3.16	69.773
13,14	11:06	2.71	0.04754928	1.71	0.030029	0.03	0.45	2.3	40.296
15,16	11:26	3.43	0.11476944	3.43	0.114769	0.01	0.30	1.44	48.211
17,18	11:46	2.00	0.11616	0.00	0	0.02	1.39	1.22	70.858
Total Loadings (g)			**0.491**		**0.276**		**6.857**		**338.106**
EMC (mg/L)			**0.003**		**0.002**		**0.040**		**1.95**

11/4/2004

				Phosphorous		Solids			
		TKN		**TP**		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	9:06	6.91	19.89	1.30	3.732	19.72	56.789	28.65	82.512
3, 4	9:26	3.82	21.08	1.32	7.277	7.04	38.873	16.44	90.7488
5, 6	9:46	3.32	51.42	1.04	16.158	19.95	308.821	11.565	179.0262
7,8	10:06	2.83	21.36	0.77	5.815	32.86	248.400	6.69	50.5764
9,10	10:26	2.17	23.17	0.96	10.205	27.14	289.886	6.78	72.4104
11,12	10:46	1.51	33.42	1.14	25.210	21.43	473.143	6.87	151.6896
13,14	11:06	1.75	30.62	1.01	17.669	27.14	475.543	4.89	85.6728
15,16	11:26	1.98	66.37	0.88	29.302	32.86	1100.057	2.91	97.4268
17,18	11:46	1.39	80.58	0.68	39.268	24.66	1432.110	2.76	160.3008
Total Loadings (g)			**347.911**		**154.635**		**4423.6**		**970.364**
EMC (mg/L)			**2.01**		**0.89**		**25.53**		**5.6**

Total Volume (L)	**9120**
Storm Duration (min)	**60**

10/19/2004

				Metals					
			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	21:00	0	3.7	62.73	0.28	0.51	2.2688	171.47	0.761312
3, 4	21:20	20	2.9	26.16	0.09	0.23	0.8039	59.00	0.20532
5, 6	21:40	40	1.0	25.79	0.03	0.19	0.23	54.56	0.0655
Total Loadings (g)					**0.401**		**3.301**		**1.032**
EMC (mg/L)					**0.044**		**0.362**		**0.113**

		Cd		**Nitrite**		**Nitrate**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	21:00	62.73	0.278536	0.21	0.94	0.31	1.376	1.27	5.65
3, 4	21:20	26.16	0.0910252	0.12	0.43	1.86	6.473	2.57	8.94
5, 6	21:40	25.79	0.030944	0.22	0.26	1.89	2.268	2.44	2.93
Total Loadings (g)			**0.401**		**1.625**		**10.117**		**17.519**
EMC (mg/L)			**0.044**		**0.178**		**1.109**		**1.921**

		Phosphorous		Solids			
		TP		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	21:00	0.43	1.918	ND		23.37	103.7628
3, 4	21:20	0.80	2.800	ND		13.05	45.414
5, 6	21:40	0.68	0.819	ND		10.95	13.14
Total Loadings (g)			**5.537**		**0.0**		**162.317**
EMC (mg/L)			**0.607**		**0.000**		**17.798**

Total Volume (L)	**13800**
Storm Duration (min)	**86**

9/17/2004

Metals

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	13:14	0	5.3	104.60	0.67	0.72	4.5856	134.52	0.855547
3, 4	13:34	20	2.2	35.58	0.09	0.26	0.6811	67.96	0.179414
5, 6	13:54	40	1.4	34.95	0.06	0.25	0.41	67.78	0.1139
7, 8	14:14	60	0.9	34.31	0.04	0.24	0.2538	67.60	0.073008
23,24	18:54	340	0.6	16.52	0.03	0.23	0.4712	49.92	0.101837
Total Loadings (g)					**0.889**		**6.406**		**1.324**
EMC (mg/L)					**0.064**		**0.464**		**0.096**

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	13:14	9.37	0.05956776	9.37	0.059568	0.01	0.06	4.44	28.21
3, 4	13:34	2.00	0.00528	0.00	0	0.18	0.48	2.75	7.25
5, 6	13:54	2.00	0.00336	0.00	0	0.35	0.58	2.22	3.73
7, 8	14:14	2.00	0.00216	0.00	0	0.51	0.55	1.70	1.84
23,24	18:54	2.00	0.00408	0.00	0	0.48	0.98	1.78	3.64
Total Loadings (g)			**0.074**		**0.060**		**2.656**		**44.669**
EMC (mg/L)			**0.005**		**0.004**		**0.192**		**3.237**

9/17/2004

		TP		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	13:14	2.03	12.919	67.90	431.852	9.03	57.431
3, 4	13:34	1.20	3.167	8.97	23.692	9.33	24.631
5, 6	13:54	0.94	1.584	8.86	14.886	9.78	16.430
7, 8	14:14	0.69	0.741	2.67	2.880	10.23	11.048
23,24	18:54	0.55	1.130	71.43	145.714	11.04	22.522
Total Loadings (g)			**19.540**		**619.0**		**132.062**
EMC (mg/L)			**1.416**		**44.857**		**9.57**

Total Volume (L)	**38760**
Storm Duration (min)	**130**

9/7/2004

Metals

Bottle #	Sampling Time	Time (min)	Average Flow (L/s)	**Pb** Conc. (ug/L)	**Pb** Mass (g)	**Zn** Conc. (mg/L)	**Zn** Mass (g)	**Cu** Conc. (ug/L)	**Cu** Mass (g)
1, 2	13:36	0	12.5	78.33	1.18	0.73	10.9050	94.32	1.4148
3, 4	13:56	20	6.1	70.67	0.52	0.30	2.2033	53.28	0.39001
5, 6	14:16	40	4.4	54.05	0.29	0.26	1.36	54.30	0.2867
7, 8	14:36	60	3.5	37.43	0.16	0.21	0.8988	55.32	0.232344
9,10	14:56	80	3.1	22.18	0.08	0.18	0.6510	58.68	0.21829
11,12	15:16	100	2.2	6.92	0.02	0.14	0.3590	62.04	0.163786
13,14	15:36	120	0.5	10.84	0.01	0.29	0.1719	63.34	0.038004
15,16	15:56	140	0.0	14.76	0.00	0.44	0.0000	64.64	0
Total Loadings (g)					**2.135**		**15.367**		**2.324**
EMC (mg/L)					**0.055**		**0.396**		**0.060**

Bottle #	Sampling Time	**Cd** Conc. (ug/L)	**Cd** Mass (g)	Conc. (ug/L)	Mass (g)	**Nitrite** Conc. (mg/L)	**Nitrite** Mass (g)	**TKN** Conc. (mg/L)	**TKN** Mass (g)
1, 2	13:36	2.00	0.03	0.00	0	0.11	1.67	0.40	5.94
3, 4	13:56	2.00	0.01464	0.00	0	0.10	0.76	1.45	10.63
5, 6	14:16	3.26	0.0171864	2.26	0.011906	0.08	0.44	1.80	9.52
7, 8	14:36	4.51	0.018942	4.51	0.018942	0.06	0.27	2.15	9.05
9,10	14:56	3.26	0.0121086	2.26	0.008389	0.05	0.20	1.89	7.03
11,12	15:16	2.00	0.00528	0.00	0	0.05	0.12	1.63	4.30
13,14	15:36	2.55	0.0015276	1.55	0.000928	0.05	0.03	1.91	1.14
15,16	15:56	3.09	0	3.09	0	0.06	0.00	2.19	0.00
Total Loadings (g)			**0.081**		**0.031**		**3.138**		**35.146**
EMC (mg/L)			**0.002**		**0.001**		**0.081**		**0.907**

Total Volume (L)	**444720**
Storm Duration (min)	**140**

8/12/2004

Metals

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	17:04	0	59.2	104.37	7.41	0.41	29.0554	46.80	3.324672
3, 4	17:24	20	94.4	60.23	6.82	0.51	57.3197	57.70	6.536256
5, 6	17:44	40	56.8	80.06	5.46	0.46	31.49	52.13	3.5528
7, 8	18:04	60	79.3	57.14	5.44	0.23	21.8868	60.93	5.797623
9, 10	18:24	80	21.3	48.74	1.25	0.19	4.86	45.84	1.1717
13, 14	19:04	120	22.9	41.37	1.14	0.35	9.54	36.45	1.0016
Total Loadings (g)					**27.514**		**154.144**		**21.385**
EMC (mg/L)					**0.062**		**0.347**		**0.048**

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	17:04	3.73	0.26483712	3.73	0.264837	0.06	4.05	2.40	170.24
3, 4	17:24	2.24	0.25352064	2.24	0.253521	0.02	2.53	1.12	126.31
5, 6	17:44	2.00	0.13632	0.00	0	0.01	0.62	1.24	84.45
7, 8	18:04	2.00	0.19032	0.00	0	0.03	3.22	0.98	93.49
9, 10	18:24	2.00	0.05112	0.00	0	0.00	0.02	1.13	28.76
13, 14	19:04	2.00	0.05496	0.00	0	0.00	0.11	0.87	23.83
Total Loadings (g)			**0.951**		**0.518**		**10.550**		**527.076**
EMC (mg/L)			**0.002**		**0.001**		**0.024**		**1.185**

8/12/2004

		TP		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	17:04	0.06	4.294	10.77	765.046	5.25	372.96
3, 4	17:24	0.03	3.938	16.92	1917.046	2.7	305.856
5, 6	17:44	0.41	27.915	16.92	1153.477	2.43	165.6288
7, 8	18:04	0.39	37.139	18.46	1756.800	2.22	211.2552
9, 10	18:24	0.41	10.550	15.38	393.231	2.49	63.6444
13, 14	19:04	0.18	4.989	16.18	444.529	2.1	57.708
Total Loadings (g)			**88.825**		**6430.129**		**1177.052**
EMC (mg/L)			**0.200**		**14.459**		**2.647**

Total Volume (L)	**31440**
Storm Duration (min)	**280**

8/2/2004

Metals

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	17:38	0	2.9	71.67	0.25	0.54	1.8618	162.92	0.566962
3, 4	17:58	20	2.3	69.51	0.19	0.30	0.8280	55.15	0.152214
5, 6	18:18	40	2.3	69.23	0.19	0.27	0.75	91.68	0.2530
7, 8	18:38	60	3.0	68.94	0.25	0.24	0.8784	128.20	0.46152
9, 10	18:58	80	2.4	61.09	0.18	0.33	0.94	107.68	0.3101
11, 12	19:18	100	2.1	53.23	0.13	0.41	1.0256	87.15	0.219618
13, 14	19:38	120	2.0	45.27	0.11	0.30	0.71	71.09	0.1706
15, 16	19:58	140	2.0	37.31	0.09	0.18	0.4392	55.03	0.13208
17, 18	20:18	160	1.5	54.57	0.29	0.22	1.19	60.83	0.3285
19,20	21:18	220	0.9	71.83	0.23	0.26	0.8294	66.63	0.215892
21,22	22:18	280	0.0	47.60	0.00	0.45	0.0000	59.77	0
23,24	23:18	340	0.0	23.37	0.00	0.64	0.0000	52.91	0
Total Loadings (g)					**1.916**		**9.444**		**2.811**
EMC (mg/L)					**0.061**		**0.300**		**0.089**

8/2/2004

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	17:38	17.97	0.0625356	17.97	0.062536	0.01	0.05	0.00	0.00
3, 4	17:58	5.00	0.01379448	5.00	0.013794	0.44	1.22	0.57	1.56
5, 6	18:18	4.04	0.01116006	4.04	0.01116	0.31	0.85	1.52	4.19
7, 8	18:38	3.09	0.0111204	3.09	0.01112	0.17	0.62	2.47	8.89
9, 10	18:58	2.54	0.00732816	2.54	0.007328	0.22	0.64	2.00	5.75
11, 12	19:18	2.00	0.00504	0.00	0	0.27	0.68	1.52	3.84
13, 14	19:38	2.00	0.0048	0.00	0	0.18	0.44	1.52	3.66
15, 16	19:58	2.00	0.0048	0.00	0	0.10	0.23	1.52	3.66
17, 18	20:18	2.56	0.0138024	2.56	0.013802	0.07	0.37	1.46	7.86
19,20	21:18	3.11	0.01008288	3.11	0.010083	0.04	0.14	1.39	4.49
21,22	22:18	5.38	0	5.38	0	0.04	0.00	1.59	0.00
23,24	23:18	7.65	0	7.65	0	0.04	0.00	1.79	0.00
Total Loadings (g)			**0.144**		**0.130**		**5.225**		**43.910**
EMC (mg/L)			**0.005**		**0.004**		**0.166**		**1.397**

8/2/2004

		TP		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	17:38	0.67	2.319	14.52	50.529	17.28	60.1344
3, 4	17:58	0.66	1.831	6.45	17.803	14.13	38.9988
5, 6	18:18	0.76	2.088	5.00	13.800	13.05	36.018
7, 8	18:38	0.85	3.058	1.67	6.000	11.97	43.092
9, 10	18:58	0.60	1.739	9.09	26.182	10.14	29.2032
11, 12	19:18	0.36	0.903	6.45	16.258	8.31	20.9412
13, 14	19:38	0.38	0.921	6.67	16.000	8.54	20.484
15, 16	19:58	0.41	0.983	1.67	4.000	8.76	21.024
17, 18	20:18	0.50	2.714	6.25	33.750	9.12	49.248
19,20	21:18	0.60	1.930	11.29	36.581	9.48	30.7152
21,22	22:18	0.70	0.000	11.48	0.000	10.10	0
23,24	23:18	0.81	0.000	12.90	0.000	10.71	0
Total Loadings (g)			**18.486**		**220.902**		**349.859**
EMC (mg/L)			**0.588**		**7.0**		**11.1**

Total Volume (L)	**34680**
Storm Duration (min)	**280**

7/24/2004

			Average Flow	**Pb**		**Zn**		**Cu**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	7:56	0	6.5	168.07	1.31	0.26	2.0358	69.08	0.538824
3, 4	8:16	20	4.1	164.13	0.81	0.16	0.7872	14.41	0.070897
5, 6	8:36	40	2.5	122.83	0.37	0.14	0.43	8.21	0.0246
7, 8	8:56	60	2.0	81.53	0.20	0.13	0.3024	2	0.0048
9, 10	9:16	80	2.0	83.90	0.20	0.17	0.42	2.00	0.0048
11, 12	9:36	100	2.0	86.27	0.21	0.22	0.5352	2	0.0048
13, 14	9:56	120	2.0	77.38	0.19	0.22	0.52	2.00	0.0048
15, 16	10:16	140	2.0	68.50	0.16	0.21	0.4992	2	0.0048
17, 18	10:36	160	1.6	65.85	0.39	0.16	0.93	2.00	0.0118
19,20	11:36	220	0.3	63.20	0.07	0.11	0.1156	2	0.00216
Total Loadings (g)					**3.90**		**6.57**		**0.67**
EMC (mg/L)					**0.112**		**0.189**		**0.019**

7/24/04

Bottle #	Sampling Time	**Cu** Conc. (ug/L)	Mass (g)	**Cd** Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	**Nitrite** Conc. (mg/L)	Mass (g)
1, 2	7:56	69.08	0.5388	2	0.0156	0	0	0.08	0.65
3, 4	8:16	14.41	0.0709	6.616	0.032551	6.616	0.032551	0.10	0.48
5, 6	8:36	7.21	0.0216	230.708	0.692124	230.708	0.692124	0.09	0.27
7, 8	8:56	0	0.0000	454.8	1.09152	454.8	1.09152	0.08	0.20
9, 10	9:16	0	0.0000	228.4	0.54816	227.4	0.54576	0.06	0.15
11, 12	9:36	0	0.0000	2	0.0048	0	0	0.05	0.11
13, 14	9:56	0	0.0000	2	0.0048	0	0	0.05	0.12
15, 16	10:16	0	0.0000	2	0.0048	0	0	0.05	0.13
17, 18	10:36	0	0.0000	2.542	0.014947	2.542	0.014947	0.05	0.32
19,20	11:36	0	0.0000	3.084	0.003331	3.084	0.003331	0.06	0.06
Total Loadings (g)			**0.63**		**2.412632**		**2.380232**		**2.5**
EMC (mg/L)			**0.018**		**0.070**		**0.069**		**0.072**

Bottle #	Sampling Time	**TKN**		Phosphorous **TP**		Solids **TSS**	
		Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	7:56	1.24	9.64	0.46	3.570	85.47	666.667
3, 4	8:16	1.15	5.68	0.85	4.164	20.00	98.400
5, 6	8:36	1.43	0.43	0.87	2.616	8.70	26.087
7, 8	8:56	1.70	4.07	0.90	2.154	15.00	36.000
9, 10	9:16	1.63	3.90	0.92	2.205	14.04	33.684
11, 12	9:36	1.56	3.73	0.94	2.255	13.79	33.103
13, 14	9:56	1.20	2.87	0.61	1.465	14.75	35.410
15, 16	10:16	0.84	2.02	0.28	0.675	15.00	36.000
17, 18	10:36	0.76	4.45	0.28	1.662	3.39	19.932
19,20	11:36	0.67	0.73	0.28	0.307	16.98	18.340
Total Loadings (g)			**37.52**		**21.072**		**1003.623**
EMC (mg/L)			**1.08**		**0.61**		**28.94**

Total Volume (L)	**81120**
Storm Duration (min)	**40**

6/22/2004

				Metals					
			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	15:56	0	47.7	34.69	1.99	90.35	5.17	0.49	28.1620
3, 4	16:16	20	19.9	114.84	2.74	52.7	1.26	0.23	5.4208
Total Loadings (g)					**4.73**		**6.43**		**33.58**
EMC (mg/L)					**0.0583**		**0.08**		**0.41**

		Cd				**Nitrite**		**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	15:56	2.045	0.117	2.045	0.117	0.52	29.95	2.95	168.71
3, 4	16:16	2	0.048	0	0	0.21	4.95	1.77	42.23
Total Loadings (g)			**0.165**		**0.117**		**34.9**		**210.94**
EMC (mg/L)			**0.002**		**0.001**		**0.430**		**2.60**

		Phosphorous		Solids	
		TP		**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	15:56	1.42	81.346	16.63	796.05
3, 4	16:16	0.75	17.909	66.25	632.1
Total Loadings (g)			**99.255**		**1428.15**
EMC (mg/L)			**1.22**		**17.61**

Total Volume (L)	**89040**
Storm Duration (min)	**400**

6/5/2004

			Metals						
			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	2:44	0	8.7	ND	ND	103.26	1.08	0.61	6.3997
3, 4	3:04	20	9.8	81.88	0.96	54.03	0.64	0.29	3.3634
5, 6	3:24	40	6.3	41.94	0.32	50.44	0.38	0.20	1.4780
7, 8	3:44	60	8.5	2	0.02	45.94	0.47	0.11	1.0710
9, 10	4:04	80	0.0	15.316	0.23	32.42	0.00	0.23	0.0034
11, 12	4:24	100	5.5	28.632	0.19	18.89	1.06	0.35	2.3034
13, 14	4:44	120	0.0	ND	ND	9.45	0.00	0.24	0.0014
15, 16	5:04	140	4.4	ND	ND	0.00	0.00	0.14	0.7181
17, 18	5:24	160	0.0	ND	ND	2.84	0.00	0.13	0.0013
19,20	6:24	220	0.9	2	0.01	5.68	0.02	0.13	0.4267
21, 22	7:24	280	0.0	2	0	8.38	0.000	0.12	0
23,24	8:24	340	0.9	2	0.00624	11.07	0.035	0.12	0.37752
Total Loadings (g)					**1.73**		**3.68**		**16.14**
EMC (mg/L)					**0.0194**		**0.04**		**0.18**

6/5/2004

						Phosphorous	Solids		
		Nitrite		**TKN**		**TP**			**TSS**
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	2:44	0.17	1.77	2.52	26.31	1.03	10.780	76.25	796.05
3, 4	3:04	0.06	0.65	0.43	5.07	0.49	5.760	53.75	632.1
5, 6	3:24	0.07	0.53	0.78	5.89	0.45	3.400	35	264.6
7, 8	3:44	0.09	0.94	1.12	11.42	0.4	4.112	26.25	267.75
9, 10	4:04	0.08	0.00	0.92	0.01	0.65	0.010	30	0.4428
11, 12	4:24	0.06	0.41	0.72	4.74	0.89	14.213	18.75	123.75
13, 14	4:44	0.06	0.00	0.57	0.00	0.57	0.003	15	0.0882
15, 16	5:04	0.07	0.35	0.43	2.26	0.26	1.349	26.25	138.6
17, 18	5:24	0.05	0.00	0.46	0.00	0.26	0.002	11.25	0.108
19,20	6:24	0.03	0.10	0.49	1.65	0.26	0.880	5	16.8
21, 22	7:24	0.03	0.00	0.46	0.00	0.27	0.000	5	0
23,24	8:24	0.04	0.12	0.44	1.37	0.28	0.867	3.7	11.55556
Total Loadings (g)			**4.9**		**58.73**		**41.376**		**2251.845**
EMC (mg/L)			**0.055**		**0.66**		**0.46**		**25.29**

Total Volume (L)	**31200**
Storm Duration (min)	**280**

5/25/2004

Metals

			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	20:44	0	6.7	20.21	0.16	146.33	1.18	0.396	3.1838
3, 4	21:04	20	4.5	14.26	0.08	81.22	0.44	0.331	1.7874
5, 6	21:24	40	4.5	14.77	0.08	56.06	0.30	0.221	1.1934
7, 8	21:44	60	2.0	14.18	0.03	43.13	0.10	0.146	0.3504
9, 10	22:04	80	1.8	8.285	0.02	41.68	0.09	0.14	0.3024
11, 12	22:24	100	1.2	2.394	0.00	35.59	1.00	0.101	0.1454
13, 14	22:44	120	1.0	1.5	0.00	34.06	0.04	0.987	1.1844
15, 16	23:04	140	1.0	8.219	0.01	33.59	0.04	0.151	0.1812
17, 18	23:24	160	1.0	5.247	0.02	34.81	0.12	0.136	0.4733
19,20	0:24	220	0.1	2.043	0.00	23.19	0.01	0.156	0.0562
21, 22	1:24	280	0.0	2.703	0	29.05	0.000	0.115	0
Total Loadings (g)					**0.41**		**3.32**		**8.86**
EMC (mg/L)					**0.0130**		**0.11**		**0.28**

5/25/2004

Phosphorous

		Cd		**Nitrite**		**TKN**		**TP**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	20:44	2	0.02832	1.03	8.25	7.11	57.16	1.19	9.5928
3, 4	21:04	2	0.0108	1.72	9.27	3.46	18.70	0.79	4.2579
5, 6	21:24	2	0.0108	1.52	8.22	3.28	17.69	0.68	3.6856
7, 8	21:44	2	0.0048	1.75	4.19	2.74	6.57	0.5	1.2064
9, 10	22:04	2	0.00432	1.22	2.63	2.47	5.34	0.5	1.0858
11, 12	22:24	2	0.0028	1	1.44	1.82	2.62	0.38	11.9711
13, 14	22:44	2	0.0024	0.94	1.13	2.28	2.74	0.31	0.3681
15, 16	23:04	2	0.0024	0.79	0.95	2.49	2.99	0.23	0.2718
17, 18	23:24	2	0.0072	0.85	2.95	2.57	8.96	0.25	0.8664
19,20	0:24	2	0.00072	0.85	0.31	2.12	0.76	0.15	0.0538
21, 22	1:24	2	0.000	0.91	0.00	2.89	0.00	0.19	0
Total Loadings (g)			**0.07456**		**39.3**		**123.54**		**33.3597**
EMC (mg/L)			**0.002**		**1.261**		**3.96**		**1.07**

5/25/2004

Bottle #	Sampling Time	Solids **TSS** Conc. (mg/L)	Mass (g)
1, 2	20:44	73.42	590.2785
3, 4	21:04	61.25	330.75
5, 6	21:24	41.18	222.353
7, 8	21:44	2.5	6
9, 10	22:04	14.81	32
11, 12	22:24	12.5	18
13, 14	22:44	11.39	13.671
15, 16	23:04	2.5	3
17, 18	23:24	7.5	26.1
19,20	0:24	6.25	2.25
21, 22	1:24	7.5	0
Total Loadings (g)			**1244.403**
EMC (mg/L)			**39.88**

Total Volume (L)	**14520**
Storm Duration (min)	**280**

5/5/2004

Metals

			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	17:38	0	1.9	29.39	0.07	43.34	0.10	0.26	0.58
3, 4	17:58	20	1.0	20.15	0.02	42.10	0.05	0.23	0.27
5, 6	18:18	40	1.0	15.20	0.02	40.29	0.05	0.18	0.22
7, 8	18:38	60	1.0	10.25	0.01	38.47	0.05	0.14	0.17
9, 10	18:58	80	1.0	11.15	0.01	35.92	0.04	0.17	0.20
11, 12	19:18	100	1.0	12.04	0.01	33.37	0.31	0.20	0.24
13, 14	19:38	120	1.0	12.59	0.02	26.92	0.03	0.16	0.19
15, 16	19:58	140	1.0	13.14	0.02	20.47	0.02	0.12	0.14
17, 18	20:18	160	1.0	12.65	0.04	20.05	0.07	0.23	0.76
19,20	21:18	220	0.1	12.15	0.00	19.63	0.01	0.33	0.12
Total Loadings (g)					**0.23**		**0.73**		**2.90**
EMC (mg/L)					**0.02**		**0.05**		**0.20**

5/5/2004

		Cd		**Nitrite**				**TKN**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	17:38	10.15	0.00	0.03	0.06	0.03	0.06	0.87	1.97
3, 4	17:58	4.43	0.00	0.01	0.01	0.00	0.00	4.59	5.51
5, 6	18:18	3.49	0.00	0.01	0.01	0.01	0.01	3.61	4.33
7, 8	18:38	2.55	0.00	0.02	0.03	0.02	0.03	0.14	0.17
9, 10	18:58	2.98	0.00	0.03	0.03	0.03	0.03	1.70	2.04
11, 12	19:18	3.41	0.01	0.03	0.04	0.03	0.04	2.44	2.93
13, 14	19:38	2.95	0.00	0.02	0.03	0.02	0.03	2.00	2.40
15, 16	19:58	2.48	0.00	0.01	0.02	0.01	0.02	2.00	2.40
17, 18	20:18	2.80	0.00	0.01	0.05	0.01	0.05	0.14	0.47
19,20	21:18	3.11	0.00	0.01	0.00	0.01	0.00	0.14	0.05
Total Loadings (g)			**0.0167987**		**0.3**		**0.3**		**22.2726**
EMC (mg/L)			**0.001**		**0.019**		**0.019**		**1.53**

		TSS	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)
1, 2	17:38	85.00	193.80
3, 4	17:58	60.00	72.00
5, 6	18:18	40.00	48.00
7, 8	18:38	25.00	30.00
9, 10	18:58	10.00	12.00
11, 12	19:18	10.00	12.00
13, 14	19:38	1.25	1.50
15, 16	19:58	1.25	1.50
17, 18	20:18	1.25	4.20
19,20	21:18	1.25	0.45
Total Loadings (g)			**375.45**
EMC (mg/L)			**25.86**

Total Volume (L)	**58440**
Storm Duration (min)	**340**

4/23/2004

Metals

			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	18:38	0	5.5	38.97	0.26	44.51	0.29	0.74	4.90
3, 4	18:58	20	8.8	35.77	0.38	40.49	0.43	0.65	6.87
5, 6	19:18	40	9.9	12.50	0.15	24.30	0.29	0.58	6.88
7, 8	19:38	60	4.5	39.00	0.21	20.20	0.11	0.50	2.71
9, 10	19:58	80	3.0	13.80	0.05	20.00	0.07	0.14	0.52
11, 12	20:18	100	2.1	12.60	0.03	20.00	0.95	0.23	0.59
13, 14	20:38	120	2.0	10.40	0.02	19.50	0.05	0.36	0.85
15, 16	20:58	140	2.0	11.30	0.03	22.00	0.05	0.12	0.29
17, 18	21:18	160	2.0	11.40	0.08	24.30	0.17	0.17	1.21
19,20	22:18	220	1.0	11.34	0.04	26.15	0.10	0.18	0.67
21, 22	23:18	280	0.6	23.87	0.05	52.50	0.11	0.27	0.58
Total Loadings (g)					**1.30**		**2.63**		**26.07**
EMC (mg/L)					**0.02**		**0.04**		**0.45**

4/23/2004

		Cd				**Nitrite**			
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	18:38	6.22	0.0022	6.22	0.0022	0.01	0.07	0.00	0.00
3, 4	18:58	2.00	0.0007	0.00	0.0000	0.01	0.11	0.00	0.00
5, 6	19:18	2.00	0.0011	0.00	0.0000	0.01	0.12	0.00	0.00
7, 8	19:38	2.00	0.0004	0.00	0.0000	0.01	0.05	0.00	0.00
9, 10	19:58	2.00	0.0004	0.00	0.0000	0.01	0.04	0.00	0.00
11, 12	20:18	2.00	0.0041	0.00	0.0000	0.01	0.03	0.00	0.00
13, 14	20:38	2.00	0.0008	0.00	0.0000	0.01	0.02	0.00	0.00
15, 16	20:58	2.00	0.0011	0.00	0.0000	0.01	0.02	0.00	0.00
17, 18	21:18	2.00	0.0019	0.00	0.0000	0.01	0.02	0.00	0.00
19,20	22:18	2.00	0.0022	0.00	0.0000	0.01	0.05	0.01	0.05
21, 22	23:18	2.00	0.0013	0.00	0.0000	0.02	0.04	0.02	0.04
Total Loadings (g)			**0.016116168**		**0.002223**		**0.6**		**0.1**
EMC (mg/L)			**0.000276**		**0.00**		**0.010**		**0.002**

4/23/2004

				Phosphorous				Solids	
		TKN		**TP**				**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	18:38	15.80	104.28	1.99	13.11	1.99	13.11	214.00	1412.40
3, 4	18:58	16.90	178.46	3.77	39.83	3.77	39.83	135.00	1425.60
5, 6	19:18	6.80	80.78	1.80	21.35	1.80	21.35	116.00	1378.08
7, 8	19:38	4.00	21.60	0.95	5.14	0.95	5.14	69.00	372.60
9, 10	19:58	3.10	11.16	0.24	0.86	0.00	0.00	23.00	82.80
11, 12	20:18	2.00	5.04	0.24	0.60	0.00	0.00	16.00	40.32
13, 14	20:38	2.00	4.80	0.24	0.58	0.00	0.00	9.00	21.60
15, 16	20:58	2.00	4.80	0.24	0.58	0.00	0.00	9.00	21.60
17, 18	21:18	0.00	0.00	0.24	1.67	0.00	0.00	8.00	55.68
19,20	22:18	0.00	0.00	0.24	0.89	0.00	0.00	5.00	18.60
21, 22	23:18	0.00	0.00	0.24	0.52	0.00	0.00	3.00	6.48
Total Loadings (g)			**410.928**		**85.13259**		**79.43019**		**4835.76**
EMC (mg/L)			**7.03**		**1.46**		**1.36**		**82.75**

Total Volume (L)	**4800**
Storm Duration	**40 min**

4/13/2004

Metals

			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	15:54	0	2.0	14.09	0.03	17.59	0.04	0.20	0.47
3, 4	16:14	20	2.0	14.01	0.03	32.88	0.08	0.19	0.45
Total Loadings (g)					**0.07**		**0.12**		**0.92**
EMC (mg/L)					**0.01**		**0.03**		**0.19**

		Cd				**Nitrate**		**Nitrite**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	15:54	2.00	0.00	0.00	0.00	5.66	13.59	0.26	0.61
3, 4	16:14	6.24	0.00	6.24	0.00	1.32	3.17	0.29	0.71
Total Loadings (g)			**0.002765227**		**0.002053**		**16.75225**		**1.320737**
EMC (mg/L)			**0.00**		**0.00**		**3.49**		**0.275**

4/13/2004

				Phosphorous				Solids	
		TKN		**TP**				**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	15:54	0.28	0.67	0.82	1.96	0.82	1.96	52.00	124.80
3, 4	16:14	1.12	2.69	0.24	0.58	0.00	0.00	144.00	345.60
Total Loadings (g)			**3.36**		**2.537756**		**1.961756**		**470.4**
EMC (mg/L)			**0.70**		**0.53**		**0.41**		**98.00**

		Cl	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)
1, 2	15:54	759	1821.6
3, 4	16:14	545	1308
Total Loadings (g)			**3129.6**
EMC (mg/L)			**652.00**

Total Volume (L)	**48804**
Storm Duration (min)	**220**

3/16/2004

Metals

			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	12:36	0	4.9	23.87	0.14	49.66	0.29	0.05	0.2940
3, 4	12:56	20	7.7	26.09	0.24	45.49	0.42	0.05	0.4620
5, 6	13:16	40	5.2	12.42	0.08	29.24	0.18	0.05	0.3120
7, 8	13:36	60	3.8	12.4	0.06	25.18	0.11	0.05	0.2280
9, 10	13:56	80	3.0	17	0.06	25	0.09	0.05	0.1800
11, 12	14:16	100	2.7	18	0.06	25	0.08	0.05	0.1620
13, 14	14:36	120	3.8	23.19	0.11	24.9	0.11	0.05	0.2280
15, 16	14:56	140	2.8	35.93	0.12	49.56	0.17	0.05	0.1680
17, 18	15:16	160	2.0	36	0.27	50	1.65	0.05	0.3720
Total Loadings (g)					**1.13**		**3.11**		**2.41**
EMC (mg/L)					**0.02**		**0.06**		**0.05**

		Cd				**Nitrite**		**Nitrate**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	12:36	6.613	0.03888444	6.613	0.038884	0.1115915	0.7	0.93	5.468
3, 4	12:56	2	0.01848	0	0	0.023687	0.2	0.85	7.854
5, 6	13:16	2.14	0.0133536	2.14	0.013354	0.01597067	0.1	0.82	5.117
7, 8	13:36	2	0.00912	0	0	0.02148233	0.1	0.84	3.830
9, 10	13:56	2	0.0072	0	0	0.02644283	0.1	0.84	3.024
11, 12	14:16	2	0.00648	0	0	0.02644283	0.7	0.82	2.657
13, 14	14:36	2	0.00912	0	0	0.03140333	0.1	0.93	4.241
15, 16	14:56	21.22	0.0712992	21.22	0.071299	0.04573367	0.2	0.84	2.822
17, 18	15:16	2	0.01488	0	0	0.060064	0.4	0.74	5.328
Total Loadings (g)			**0.18881724**		**0.123537**		**2.559361**		**40.3416**
EMC (mg/L)			**0.00**		**0.00**		**0.052**		**0.827**

3/16/2004

				Phosphorous		Solids			
		TKN		**TP**		**TSS**		**Cl**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	12:36	1.69	9.9372	0.7306904	4.29646	88	517.44	19.8	116.424
3, 4	12:56	0.98	9.0552	0.5476406	5.060199	136	1256.64	21.8	201.432
5, 6	13:16	0.98	6.1152	0.5412178	3.377199	77	480.48	22.4	139.776
7, 8	13:36	0.14	0.6384	0.9972366	9.972366	29	132.24	23	104.88
9, 10	13:56	0.35	1.26	0.9330086	3.358831	27	97.2	23.3	83.88
11, 12	14:16	0.35	1.134	0.9330086	3.022948	10	32.4	23.6	76.464
13, 14	14:36	0.56	2.5536	0.8366666	3.8152	48	218.88	39	177.84
15, 16	14:56	0.43	1.4448	0.8816262	2.962264	29	97.44	32.8	110.208
17, 18	15:16	0.3	2.16	0.9265858	6.671418	44	316.8	26.6	197.904
Total Loadings (g)			**34.2984**		**42.53688**		**3149.52**		**1208.808**
EMC (mg/L)			**0.70**		**0.87**		**64.53**		**24.77**

Total Volume (L)	**280080**
Storm Duration (min)	**340**

3/6/2004

Metals

			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	1:16	0	3.0	29.4	0.11	35.61	0.128	0.05	0.18
3, 4	1:36	20	3.0	26	0.09	32.88	0.128	0.05	0.18
5, 6	1:56	40	3.0	23.8	0.09	54.76	0.197	0.05	0.18
7, 8	2:16	60	2.8	21.3	0.07	19.14	0.064	0.05	0.168
9, 10	2:36	80	3.0	18.8	0.07	18.82	0.068	0.05	0.18
11, 12	2:56	100	2.4	38.7	0.11	26.26	0.708	0.05	0.144
13, 14	3:16	120	4.9	36.1	0.21	40	0.235	0.05	0.294
15, 16	3:36	140	6.5	32.9	0.26	53.85	0.420	0.05	0.39
17, 18	3:56	160	3.8	25.5	0.36	32	0.422	0.05	0.66
19, 20	4:56	220	24.0	18.1	1.56	37	3.197	0.05	4.32
21, 22	5:56	280	39.1	11.7	1.7	21.72	3.162	0.05	7.278
Total Loadings (g)					**4.63**		**8.73**		**13.974**
EMC (mg/L)					**0.02**		**0.03**		**0.05**

03/06/2004

		Cd				**Nitrate**		**Nitrite**	
Bottle #	Sampling Time	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	1:16	2	0.007	0	0.000	0.790	2.844	0.240	0.864
3, 4	1:36	2	0.007	0	0.000	0.610	2.196	0.280	1.008
5, 6	1:56	14.33	0.052	14.33	0.052	0.780	2.808	0.200	0.720
7, 8	2:16	2	0.007	0	0.000	1.080	3.629	0.160	0.538
9, 10	2:36	2	0.007	0	0.000	0.880	3.168	0.150	0.540
11, 12	2:56	2	0.006	0	0.000	0.950	2.736	0.010	0.029
13, 14	3:16	2	0.012	0	0.000	0.830	4.880	0.030	0.176
15, 16	3:36	2.472	0.019	2.472	0.019	0.710	5.538	0.050	0.390
17, 18	3:56	2	0.026	0	0.000	0.470	6.204	0.030	0.396
19, 20	4:56	2	0.173	0	0.000	0.450	38.880	0.025	2.160
21, 22	5:56	2	0.291	0	0.000	0.210	30.568	0.004	0.582
Total Loadings (g)			**0.61**		**0.07**		**103.4508**		**7.40304**
EMC (mg/L)			**0.00**		**0.00**		**0.37**		**0.03**

03/06/2004

				Phosphorous				Solids	
		TKN		**TP**				**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	1:16	2.24	8.1	0.73	2.60	0.73	2.6	20	72
3, 4	1:36	3.92	14.1	0.24	0.86	0	0	75	270
5, 6	1:56	2.6	9.4	0.29	1.04	0.29	0.3	51	183.6
7, 8	2:16	0.42	1.4112	0.24	0.81	0	0	177	594.7
9, 10	2:36	2.9	10.44	0.24	0.86	0	0	43	154.8
11, 12	2:56	3.08	8.8704	0.24	0.69	0	0	78	226.4
13, 14	3:16	2.5	14.7	0.24	1.41	0	0	128	752.6
15, 16	3:36	1.26	9.828	0.24	1.87	0	0	177	1380.6
17, 18	3:56	0.96	13.248	0.24	3.17	0	0	120	1584
19, 20	4:56	0.72	16.4	0.24	20.74	0	0	118	10195.2
21, 22	5:56	0.56	62.208	0.24	34.93	0	0	61	9979.2
Total Loadings (g)			**168.7056**		**68.99**		**2.9**		**25393.1**
EMC (mg/L)			**0.60**		**0.25**		**0.01**		**90.66**

Total Volume (L)	**6480**
Storm Duration (min)	**30**

12/24/2003

			Average Flow	**Pb**		**Cu**		**Cd**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	1:19	0	4.8	92	0.26	210	0.6	77	0.2
3, 4	1:29	20	2.7	49	0.18	74	0.3	18	0.06
Total Loadings (g)					**0.44**		**0.9**		**0.26**
EMC (mg/L)					**0.07**		**0.14**		**0.04**

		Zn		**Nitrite**		**TKN**		**TP**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	1:19	1.2	3.5	0.056	0.16	2.8	0.98	0.24	0.69
3, 4	1:29	0.38	1.4	0.044	0.16	4	1.1	0.24	0.86
Total Loadings (g)			**4.9**		**0.32**		**2.08**		**1.55**
EMC (mg/L)			**0.76**		**0.05**		**0.32**		**0.24**

		TSS	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)
1, 2	1:19	150	430
3, 4	1:29	43	150
Total Loadings (g)			**580**
EMC (mg/L)			**89.51**

Total Volume (L)	**227760**
Storm Duration (min)	**370**

12/11/2003

			Average Flow	**Pb**		**Cu**		**Zn**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	0:21	0	3.0	650	1.17	183	0.3	1.1	1
3, 4	0:41	20	1.6	120	0.23	110	0.2	0.52	1
5, 6	1:01	40	1.7	116	0.2	61	0.1	0.47	1
7, 8	1:21	60	6.6	104	0.8	42	0.3	0.34	2.7
9, 10	1:41	80	7.9	98	0.9	50	0.5	0.53	5
11, 12	2:01	100	11.0	89	1.1	63	0.8	0.44	5.5
13, 14	2:21	120	7.2	21	0.18	96	0.8	0.87	7.5
15, 16	2:41	140	4.0	33	0.16	89	0.4	0.86	4.1
17, 18	3:01	160	2.0	32	0.15	75	0.4	0.54	2.6
19, 20	4:01	220	9.1	19	0.6	68	0.3	0.46	15
21, 22	5:01	280	36.0	88	11.4	55	2.2	0.32	42
23, 24	6:01	340	3.0	35	0.4	43	0.5	0.31	3.5
Total Loadings (g)					**17.29**		**6.8**		**90.9**
EMC (mg/L)					**0.08**		**0.03**		**0.40**

12/11/2003

		Cd		**Nitrite**				**TKN**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	0:21	92	0.17	0.037	0.067	0.05	0.170	4.8	8.6
3, 4	0:41	70	0.11	0.07	0.130	0	0.000	0.7	1.3
5, 6	1:01	44	0.08	0.021	0.043	0.23	1.400	0.56	1.1
7, 8	1:21	28	0.17	0.02	0.160	0	0.000	0.35	2.8
9, 10	1:41	33	0.31	0.02	0.190	0	0.000	0.14	1.3
11, 12	2:01	36	0.45	0.02	0.250	0	0.000	1.1	14
13, 14	2:21	44	0.38	0.02	0.170	0	0.000	0.98	8.5
15, 16	2:41	50	0.24	0.02	0.096	0	0.000	1.8	8.6
17, 18	3:01	78	0.4	0.02	0.096	0	0.000	1.8	8.6
19, 20	4:01	84	2.7	0.02	0.650	0	0.000	1.8	59
21, 22	5:01	92	12	0.02	2.600	0	0.000	2.7	350
23, 24	6:01	36	0.4	0.02	0.220	0	0.000	1.4	16
Total Loadings (g)			**17.41**		**4.672**		**1.57**		**479.8**
EMC (mg/L)			**0.08**		**0.021**		**0.007**		**2.11**

12/11/2003

		TP		**TP**		**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	0:21	0.48	0.86	0.48	0.86	210	380
3, 4	0:41	0.5	0.96	0.5	0.96	80	150
5, 6	1:01	0.55	1.1	0.55	1.1	76	160
7, 8	1:21	0.6	4.8	0.6	4.8	76	600
9, 10	1:41	0.24	2.3	0	0	59	560
11, 12	2:01	0.24	3	0	0	140	1800
13, 14	2:21	0.25	2.2	0	0	100	860
15, 16	2:41	0.29	1.4	0.29	1.4	100	480
17, 18	3:01	0.32	1.5	0.32	1.5	93	450
19, 20	4:01	0.32	10	0.32	10	86	2800
21, 22	5:01	0.34	44	0.34	44	160	21000
23, 24	6:01	0.24	2.7	0	0	80	890
Total Loadings (g)			**74.82**		**64.62**		**30130**
EMC (mg/L)			**0.33**		**0.28**		**132.29**

Total Volume (L)	**292680**
Storm Duration (min)	**90**

11/20/2003

Metals

			Average Flow	**Pb**		**Cu**		**Cd**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	14:19	0	80.0	710	34	150	7.2	55	2.6
3, 4	14:39	20	97.0	160	19	66	7.7	43	5
5, 6	14:59	40	51.0	78	4.8	41	2.5	20	1.2
7, 8	15:19	60	36.0	93	4.1	39	1.7	23	1
9, 10	15:39	80	17.0	84	1.9	33	0.7	22	0.5
Total Loadings (g)					**63.8**		**19.8**		**10.3**
EMC (mg/L)					**0.22**		**0.07**		**0.04**

		Zn		**Nitrite**				**TKN**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	14:19	1.1	52.9	0.04	1.9	0.04	1.9	3.2	150
3, 4	14:39	0.55	64.2	0.02	2.3	0	0	0.7	82
5, 6	14:59	0.43	26.5	0.02	1.2	0	0	0.28	17
7, 8	15:19	0.37	16.2	0.02	0.87	0	0	0.14	6.1
9, 10	15:39	0.23	5.2	0.02	0.45	0	0	0.28	6.3
Total Loadings (g)			**165**		**6.72**		**1.9**		**261.4**
EMC (mg/L)			**0.56**		**0.02**		**0.01**		**0.89**

11/20/2003

		Phosphorous				Solids	
		TP				**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)			Conc. (mg/L)	Mass (g)
1, 2	14:19	0.73	35	0.73	35	2300	111000
3, 4	14:39	0.24	28	0	0	270	31000
5, 6	14:59	0.24	15	0	0	120	7400
7, 8	15:19	0.24	10	0	0	57	2500
9, 10	15:39	0.24	5.4	0	0	62	1400
Total Loadings (g)			**93.4**		**35**		**153300**
EMC (mg/L)			**0.32**		**0.12**		**523.78**

Total Volume (L)	**21960**
Storm Duration (min)	**60**

11/12/2003

Metals

			Average Flow	**Pb**		**Cu**		**Cd**	
Bottle #	Sampling Time	Time (min)	(L/s)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)	Conc. (ug/L)	Mass (g)
1, 2	5:44	0	23.0	1200	16	160	2.2	42	0.6
3, 4	6:04	20	6.2	520	3.9	140	1	18	1.4
5, 6	6:24	40	0.7	76	0.06	100	0.08	10	0.008
Total Loadings (g)					**19.96**		**3.28**		**2.008**
EMC (mg/L)					**0.91**		**0.15**		**0.09**

Nitrogen

		Zn		**Nitrate**		**Nitrate**		**Nitrite**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	5:44	0.77	10.5	0.16	2.2	0.16	2.2	0.72	9.8
3, 4	6:04	0.75	5.6	0.14	1	0	0	0.64	4.8
5, 6	6:24	0.64	0.54	0.14	0.12	0	0	0.55	0.46
Total Loadings (g)			**16.64**		**3.32**		**2.2**		**15.06**
EMC (mg/L)			**0.76**		**0.15**		**0.10**		**0.69**

		Phosphorous		Solids	
		TP		**TSS**	
Bottle #	Sampling Time	Conc. (mg/L)	Mass (g)	Conc. (mg/L)	Mass (g)
1, 2	5:44	0.89	12	7000	96000
3, 4	6:04	0.33	2.5	480	3600
5, 6	6:24	0.65	0.55	100	84
Total Loadings (g)			**15.05**		**99684**
EMC (mg/L)			**0.69**		**4539.34**

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